Ultra-Lightweight Cement

Summary Report

July 8, 2005

Fred Sabins

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Submitted by
CSI Technologies
2202 Oil Center Court
Houston, TX 77073

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement. Focus during the project has been on use of ultra-lightweight hollow glass spheres (ULHS) as well as other, more traditional lightweight cement additives to create candidate compositions. These candidate compositions were evaluated in the laboratory through a series of design and performance tests. Field applications of promising ULHS compositions were conducted. This report includes a summary of all results obtained throughout the project.

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Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, to isolate various formations from one another, and to control fluid movement within the well.

Typical cement fluid density ranges from 14 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitates application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections: surface casings and intermediate casings. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are relatively low.

The minimum practical density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength. Lower temperature further delays strength development. Achieving density requirements lower than this or strength requirements greater than minimum necessitate use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are a candidate material for producing ultra-lightweight cements. These small, hollow, glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

Foamed cement is a technique employed in the industry to achieve low density slurry designs by the use of injecting nitrogen into the cement slurry.

Sodium silicate is another technique employed in the industry to achieve low density. Sodium silicate is an additive which will flocculate in a cement slurry and enable increased amounts of water to be incorporated into the design, thus enabling lightweight systems to be designed.

Project Objectives

The primary objective of this project was to develop an improved ultra-lightweight cement for well application. Techniques for creating cements with density less than 11.0 lb/gal were evaluated as well as performance properties of ultra-lightweight cements. The following list of tasks was assigned to this project by the Department of Energy sponsor.

TASK 1. ***Assess Ultra-Lightweight Cementing Problems***
The contractor shall assess the problems associated with ultra-lightweight conventional and nitrified cements including surface mixing problems, high costs for compressors and other equipment, variations in cement density due to the effects of temperature and pressure, fluid loss, lost circulation, gas migration, and potentially high set permeabilities. The contractor shall hold meetings with engineers from service companies and operators to determine their experience with lightweight cements. Costs and other economic issues will also be investigated as part of this assessment. The contractor shall identify the existing problems that need to be addressed by the new ULHS cements, as well as the geographic producing areas in which lightweight cements are most commonly used.

TASK 2. ***Review Russian Ultra-Lightweight Cement Literature***
The contractor shall review and summarize the literature concerning the development and use of ultra-lightweight nitrified cements as well as the benefits and/or problems that these systems present. Because the Russians have been the leaders in using ultralight spheres to reduce the density of drilling muds and cements, the contract shall also review the Russian literature on lightweight cements and correspond with Russian drilling engineers to thoroughly review and identify any problems that they may have encountered and how they overcame them while using UHLS drilling fluids and cements.

TASK 3. ***Test Ultra-Lightweight Cements***
The contractor shall perform laboratory tests to measure the strength and bonding characteristics of ultra-lightweight cements (7 to 13 lb/gal) made with ULHS and compare them to the strengths of gasified cements and conventional cements. The following standard laboratory cement tests that will be conducted on ULHS cements include:

1. Compressive Strength
2. Rheology
3. Fluid Loss
4. Free Water
5. Thickening Time

After the standard tests are conducted and comparative slurries are generated, a detailed investigation will be performed with no-standard cement slurries. The contractor shall also conduct the following non-standard tests:

6. Fluid Migration
7. Cement-to-Casing Bonding
8. Durability
    a. Tensile Strength
    b. Flexural Strength
9. Permeability
4. Thermal Conductivity
10. Gel Strength

The contractor shall compare the data from these tests to data from lightweight gasified and conventional cements.

TASK 4. ***Computer Modeling of Friction Pressures and Gas Migration***

The contractor shall use the rheology data from Task 3 to conduct a dynamic design of ULHS slurries to ensure proper placement and circulation control for a variety of cementing scenarios. These dynamic designs will be compared to those for gasified and conventional cements. MEI's Cementing Hydraulics Model CEMENT will be used to calculate pressure drops and ECDs for lightweight cements for a range of field cases. MEI's Fluid Migration Simulator FLUIDMIG will be used to determine the ability of ULHS cement slurries to control gas or fluid migration for a variety of cementing scenarios.

TASK 5. ***Develop Cementing Economics Model***

The contractor shall develop a cementing economics model CEMCON that will allow users to compare the cost of cementing wells with gasified and ULHS cements. Risk factors will be included to cover problems encountered with ultra-lightweight cements (e.g., gas migration, lost circulation and squeezing). This is an important task because nitrified cements require specialized equipment such as compressors and foam generators, whereas ULHS cements require the cost of hollow glass spheres, making it difficult to compare costs with these different cements.

TASK 6. ***Develop ULHS Slurry Design Computer Program***

The contractor shall develop a computer program SLURRYDESIGN that will utilize an expert system to design ULHS cement slurries for different applications. Users will input slurry density, bottom-hole temperature and pressure, well profile, casing programs and other information. The program will optimize slurry design for each specific wellsite. SLURRYDESIGN will be based on data from Task 3 tests and will be updated as new data become available.

TASK 7. ***Measure Correlations for Ultrasonic Prediction of Compressive Strength***

The contractor shall correlate base slurry compressive strengths versus ULHS loading so that the Ultrasonic Compressive Strength Machine can be used to determine compressive strengths. This will facilitate development of improved slurry designs that are easier to run in the field and that provide better cement jobs.

TASK 8. ***Develop Field ULHS Cement Blending and Mixing Techniques***
The contractor shall developed special field blending and mixing techniques for the ULHS cement due to its low density. On an earlier DOE project, MEI successfully mixed ULHS into drilling muds on two Mobil field wells in California. The contractor shall use information gained on the earlier DOE project in which MEI successfully mixed ULHS into drilling muds on two Mobil field wells, along with technical input from 3M (the ULHS manufacturer) to develop the cement-mixing techniques. These techniques will be tested prior to conducting full-scale field tests.

TASK 9. ***Conduct Field Tests***
The contractor shall field test the ULHS cement in one or more wells where lost circulation problems prevent the use of conventional cements. Shell Oil Company will provide one test well for this ULHS cement in either West Virginia or Ohio.

TASK 10. ***Technology Transfer***
The contractor shall transfer the results of this project through workshops, publications in leading technical forums, and in conjunction with the Petroleum Technology Transfer Council (PTTC). The results will also be presented in our cementing training classes presented around the world. The contractor shall actively promote the use of this technology, coordinating its efforts with the industry leaders, and focus on the geographic areas identified in the study.

TASK 11. ***Assess Occurrence of Alkali-Silica Reaction***
The contractor shall evaluate the extent to which ULHS in cement reacts with alkali when cement is contacted by high pH water. Contractor will determine ASR test procedures and methods from the construction industry that are applicable to oilwell cements and conduct long-term tests to verify whether ASR is occurring and when and how it manifests itself.

TASK 12. ***Test ULHS Cement Under Specifications of JIP Entitled "Long Term Integrity of Deepwater Cement Systems Under Stress/Compaction Conditions."***
The DOE shall join the joint industry project studying low-density cements for deep water application. The main focus of this JIP is the determination of mechanical properties of cement required to maintain durability under down-hole stress conditions.

Observations and Conclusions

The following conclusions and observations are based on the results of this project. Note that the reader is referred to specific quarterly reports, attached as Appendices 1 through 13 to this final summary report for detailed discussion of results leading to and supporting each conclusion or observation. Reference page numbers or appendices refer to the actual page numbers or appendices of the referenced Quarterly Report.

- Laboratory procedures for cement design tests to establish mixability, slurry stability and separation, effects of pressure, and mixing were established. (Quarterly Report 2, Appendix A)

- Satisfactory quality-control procedures for raw materials and sample preparation were established. (Quarterly Report 1, Section 7.3 and Table 7.4)

- Typical design parameters derived from USA historical data were established to evaluate field application of candidate materials under realistic conditions. Historical lightweight cement performance data analysis has given a density range to incorporate in evaluating the candidate systems. (Quarterly Report 1, Table 7.1 and Appendix 11.2.)

- Physical performance properties of candidate ULHS materials measured over a wide range of application pressures indicate that the materials are functional as light weight additives for typical oilwell cementing conditions. (Quarterly Report 2, Appendix B.)

- Review of literature covering ULHS research conducted by Russian investigators including compositions, raw material physical properties, sources, properties of cement formulated with ULHS, and application conditions indicated that sodium glass is susceptible to attack by alkaline media. It also provided solutions for combating the attack with the use of protective materials such as boron and aluminum silicates. The most commonly used hollow microspheres used in Russia had limited hydrostatic collapse strength no greater than three thousand pounds per square inch. (Russian report is contained in Appendix 3 of Quarterly Report 1. Review of the Russian work is presented on Page 6 of Quarterly Report 3.)

- An evaluation between UCA strengths and crush test strengths was conducted. While the UCA strengths are acceptable for showing the general trends of strength development, actual compressive strength measurements should be gathered from crush tests. (Quarterly Report 2, pages 16 through 23)

- Laboratory-designed test procedures for ULHS and foamed cements were established. An evaluation between field mixing and laboratory mixing of ULHS was conducted and performance testing gave matching results within acceptable limits. (Laboratory test procedures for Foam and ULHS cements are presented in

Quarterly Report 2, Appendix A. Field mixing procedure evaluation is presented in Quarterly Report 5, pages 31 and 32.)

- Testing protocols for Young's modulus, tensile strength, drillout testing, expansion and shear bond were established. (Quarterly Report 6 contains Young's Modulus, shear bond, and tensile strength protocols and results. Drill out testing is described in Quarterly Report 7. Expansion testing and results are reported in Quarterly Report 13.)

- ASTM C190 ("dog bone" tensile strength) tests produced a notable amount of deviation between results. In comparison, ASTM C496 (splitting tensile strength) tests had less variability. Tensile strengths of the sodium silicate cements were lower than the foamed and ULHS cements. (Quarterly Report 4, pages 30 and 31 and Quarterly Report 5, pages 13 and 14.)

- From the Young's modulus testing, there was no noticeable difference between the effective compressive strengths at the different confining pressures. (Quarterly Report 6, pages 13 and 14.)

- Poisson's Ratio testing with lightweight cements yielded unexpected results. Extremely low or negative values were obtained for several compositions. It is theorized that this behavior was a result of increased porosity of ultra-low-density cements tested. (From MMS test data presented in Quarterly Report 9, Appendix B.)

- A field job using ULHS was successfully performed in November of 2001. This field job was conducted to test the slurry's performance in actual formations. The slurry was designed to ensure ease of blending, mixing, and pumping on location in actual wells. (Quarterly Report 5, pages 31 through 33.)

- Both foam and ULHS systems tested favorably with the drillout testing model which was conducted to evaluate the resilience of the systems after drillout procedures. (Quarterly Report 7, pages 11 through 15.)

- Pressure cycling did not detrimentally affect the shear bond strength of the lightweight cement systems cured in a pipe-in-pipe configuration. (Quarterly Report 7, pages 9 through 11.)

- Temperature cycling detrimentally affected the shear bond strength of the lightweight cement systems. (Quarterly Report 7, pages 9 through 11.)

- Expansion testing provided evidence of a reaction known as alkali-silica reactivity (ASR) in some of the systems. Testing protocols were established to evaluate whether or not this phenomenon was occurring in the systems. Long term testing revealed no adverse effects from the caustic curing medium to compressive strength development for all systems. (Quarterly Report 13, pages 4 and 6.)

- ASR testing performed on TXI Lightweight cement showed expansion occurred in all systems designed and an increase in tensile strength occurred with the TXI Lightweight system designed with ULHS. (Quarterly Report 13, pages 5 and 6.)

- A second field job using ULHS was performed successfully in July of 2002. This field job was conducted to test the slurry's performance in a land-based well that closely resembled deepwater operations. Ultrasonic and sonic logs performed on the well after the cement operation showed good cement bond to pipe, good cement bond to formation, and high compressive strengths.

- Nine members, representing Chandler Engineering, ExxonMobil, Halliburton, Schlumberger, 3M, and TXI comprised an advisory board which offered critical guidance throughout this JIP research project. The combined expertise of these operators, manufacturers, and service companies provided invaluable perspectives and objective evaluations to successfully develop an improved, ultra lightweight cement product.

- A computer program (Decision Support System) was developed to assist in slurry design of ultra-lightweight cement systems. (Quarterly Report 8, pages 8 -10.)

Discussion

All tasks assigned to the project were completed and outcome of each task is summarized below. The results covered by each report are also summarized below. Note that the reader is referred to specific quarterly reports, attached as Appendices 1 through 13 to this final summary report for detailed discussion of results leading to and supporting each conclusion or observation. Reference page numbers or appendices refer to the actual page numbers or appendices of the referenced Quarterly Report.

TASK 1. ***Assess Ultra-Lightweight Cementing Problems***
Minimum practical density limit for conventional cements was found to be 11.0 lb/gal. Literature review presented in Appendix E of Quarterly Report 2 and discussed in Quarterly Report 3 dealt with potential problems of lightweight cement systems susceptibility to alkali-silica reactivity (ASR). Based on this literature review, the steering committee elected to conduct a long term study of ASR for ULHS cements. Historical service company data presented in Quarterly Report 4 confirmed conventional ultra-lightweight cement uses, limitations, and application ranges.

TASK 2. ***Review Russian Ultra-Lightweight Cement Literature***
The literature indicated that ULHS of various origins and compositions were used in oilwell cementing compositions. Most of these materials had collapse strengths lower than the current material under investigation. The report noted that sodium based glass was susceptible to attack by alkaline media. (Russian report is contained in Appendix 3 of Quarterly Report 1. Review of the Russian work is presented on Page 6 of Quarterly Report 3.)

TASK 3. ***Test Ultra-Lightweight Cements***

Design, performance, and mechanical property testing was performed in the laboratory with ULHS cements. Special lab test procedures are reported in Quarterly Report 2. Test results are contained in all 13 Quarterly Reports attached hereto.

TASK 4. ***Computer Modeling of Friction Pressures and Gas Migration***
This task was not performed. Rheological properties of ULHS cements obtained during application scenario testing indicated the slurries would exhibit fluid mechanics similar to regular cement compositions. Design calculations and modeling by service companies for field applications confirmed this. The trend was extended to fluid migration properties: ULHS seem to behave as normal cements from rheology and static gel strength development perspectives. Therefore, this modeling was not performed directly.

TASK 5. ***Develop Cementing Economics Model***
A design algorithm encompassing economics, material performance, and well conditions was developed under this project. The program, Smart Cement, employs this algorithm. This development was not presented in any of the Quarterly reports. The program is accessible through 3M Corporation. A description of the program is presented as Appendix 14 of this report.

TASK 6. ***Develop ULHS Slurry Design Computer Program***
The program to assist in designing cements with ULHS was developed to calculate the amount of ULHS required for specific slurry density. The program does not simulate fluid dynamics. Instead, it focuses on static final placement pressure of the slurry and calculates slurry composition, yield and, density. The software was distributed to all members of the steering committee and is described in Quarterly Report 8. Discussion of this software appears on pages 20 through 26 of Quarterly Report 6 and pages 8 through 10 of Quarterly Report 8.

TASK 7. ***Measure Correlations for Ultrasonic Prediction of Compressive Strength***
Comparison of strength values measured by UCA actual crush strength values indicated satisfactory correlation between the 2 methods for Type I cements (Quarterly Report 2). Unsatisfactory correlation existed for TXI Lightweight cement with ULHS. No improved correlation was developed for this special cement subclass.

TASK 8. ***Develop Field ULHS Cement Blending and Mixing Techniques***
Effects of mixing energy imparted by centrifugal pumps were found to be negligible for the 6K ULHS (Quarterly Report 4). Applicability of field blending and mixing procedures was confirmed in the first field trial (Quarterly Report 5).

TASK 9. ***Conduct Field Tests***
The first field trial with ULHS, described in Quarterly Report 5, was conducted for Conoco in south Texas in November, 2001. The ULHS was mixed to density and pumped successfully. No meaningful evaluation testing was performed to determine the effectiveness of the material in place.

The second field trial, described in Quarterly Report 8, was performed on a RMOTC well in Wyoming. This 5000 ft well was drilled in an area known for lost circulation problems. Previous wells in the area were cemented with foam cement.

Results of this trial were excellent. Cement was blended, mixed, and pumped without problems. No lost circulation occurred during or after placement. Cement tops were as designed. Logs indicated excellent cement bond to pipe and formation.

TASK 10. ***Technology Transfer***
The results of this project were presented at the Midcontinent CBM Forum in Tulsa, OK in Fall, 2003. Title of the presentation was, "Improved Performance of Ultra-Lightweight Cement Compositions".

The Smart Cement design program was featured in the 3M exhibit of the 2004 SPE Annual Technical Conference.

Information from the ULHS research program has been included in 6 operator training schools presented by CSI Technologies in 2004 and 2005.

Task 11. ***Assess Occurrence of Alkali-Silica Reaction***
Results of evaluation of the potential for Alkali Silica Reaction to occur between ULHS and cement were presented in Quarterly Report 7. This analysis, presented on pages 18 through 20 of the Quarterly Report, indicated sufficient soluble alkali present for reaction to occur. Test method to evaluate the occurrence or effects of ASR with ULHS was presented in Quarterly Report 9, Appendix A. Quarterly Report 9 is presented in Appendix 9 of this report. Results of expansion and strength testing to assess the detrimental effects of ASR were presented in Quarterly Reports 10, 11, 12, and 13. Testing was re-initiated midway through the cycle due to discovery of several test procedures that produced erroneous results. All final results with modified procedures were presented in Quarterly Report 13

TASK 12. ***Test ULHS Cement under Specifications of JIP Entitled "Long Term Integrity of Deepwater Cement Systems Under Stress/Compaction Conditions."***
DOE joined the JIP being conducted by contractor. ULHS cements were evaluated in this JIP. Additional performance data including ULHS cement durability with pressure and temperature cycling were determined in this JIP. Results are presented in Appendix B of Quarterly Report 9.

A summary of information contained in each Quarterly Report is presented below. Each report is presented in its entirety herein in Appendices 1 through 13.

QUARTERLY REPORT 1 (Appendix 1, page 15 of this report)
Work conducted during this first quarter was aimed at establishment of test parameters and quality control procedures. Application conditions of ULHS cements (depth, temperature, and pressure) gathered from historical data were averaged to develop a set of standard realistic application design conditions to be used for the project. Application

design conditions dictate simulated placement times, downhole pressure, and temperature that cements will see in field application. These results are summarized in Table 7.1 of the Quarterly Report. Complete analysis of the data is presented in Appendix 2 of the Quarterly report.

The quality control program for cement to be used during this long-duration project was developed and initiated. QC criteria and results of tests for initial cement supply are presented on pages 10 through 12 of the Quarterly Report.

Special laboratory test procedures required for testing ULHS cement were developed and presented. These tests account for the fact that ULHS can undergo breakage from laboratory mixing or application of hydraulic pressure. Test methods for mixing without subjecting ULHS to high shear as well as a method of exposing ULHS cement slurry to hydraulic pressure after mixing were developed. These procedures are presented in Appendix 1 of the Quarterly Report.

Initial laboratory testing with ULHS to determine concentration limits, water requirements, rheology, and slurry stability was presented on pages 13 through 28 of Quarterly Report 1. These data indicate that optimum ULHS concentrations, dispersant concentrations and water requirements were determined for formulating cements with density less than 10 lb/gal.

The technical report, **Russian Hollow Microsphere Cements**, by Dr. Vladimir Sledkov was under review at time of writing Quarterly Report 1. This report is included as Appendix 1 of Quarterly Report 1.

QUARTERLY REPORT 2 (Appendix 2, page 81 of this report.)
Laboratory testing during this quarter focused on evaluation of ULHS materials and finalizing nonstandard test procedures for ULHS and foam cement. All ULHS test data were presented in Appendix B of Quarterly Report 2. Test procedures for ULHS and foam cement were presented in Appendix A of Quarterly Report 2.

Comparison of UCA measured strength vs. compressive strength determined by crushing indicated the lightweight correlation programmed into the UCA device is adequate for Type I cement with ULHS. TXI Lightweight cement containing ULHS had unacceptable variation in UCA vs. crush strength. This analysis is presented in pages 16 through 23 of Quarterly Report 2.

Steering Committee members BJ Services and Halliburton provided historical lightweight cement application data from their field job archives primarily. These results, including type of low density cement, density, performance parameters and general well conditions, provided a historical perspective of the use of low density cements. Preliminary analysis of the data is presented on pages 7 through 14 of Quarterly Report 2 while raw data provided by the companies is contained on Appendix C of Quarterly Report 2.

Appendix E of Quarterly Report 2 presents a review of low-density cementing literature. Details of the review support the need for a cement with density limits lower than 11.0 lb/gal.

QUARTERLY REPORT 3 (Appendix 3, page 227 of this report.)
Laboratory work conducted during this quarter was aimed at comparison of ULHS cements vs. foam cement and sodium silicate cement. These compositions were tested under two application scenarios: deepwater conductor pipe and land-based surface pipe. Test procedure variations for ULHS and foam cements were presented. Foam cement mixing and test procedures for this project were presented in Appendix B of Quarterly Report 3. Compositions of each cement for each application were presented in Table 5 of the Quarterly Report, page 14. Test results were presented in Tables 6 and 7 of the Quarterly Report, pages 15 and 16. ULHS and foam cement performed comparably and better than sodium silicate cement in the short-term testing. Further long-term mechanical property testing will be conducted to further assess the durability of each cement.

ULHS breakage with laboratory mixing shear was also further evaluated. These results, presented in Table 3, page 11 of the report, indicated that the 6K bead suffered least from shear. 3K, 4K, and 5K beads all sustained significant breakage from mixing with a blender.

Preliminary design for the first field application was conducted and reported in Table 10, page 19 of Quarterly Report 3.

Continuing lab materials quality control testing conducted during the third quarter were presented in Appendix A of Quarterly Report 3.

Literature review dealing with problems of ultra-lightweight cements revealed that alkali-silica reactivity was a potential problem. This problem was confirmed via review of the Russian report presented in Quarterly Report 1. Also revealed by analysis of the Russian work, presented on page 8 of Quarterly Report 3 was the fact that ULHS used in Russia was more susceptible to breakage than the ULHS used in this investigation.

QUARTERLY REPORT 4 (Appendix 4, page 261 of this report)
Laboratory testing during this quarter involved performance comparison between ULHS cements and other low-density cements in three different application scenarios. Results, presented on pages 23 through 30, compared performance for cements at 11.5 lb/gal and 10 lb/gal. The comparison of results indicates that viable ultra-lightweight cements can be formulated in the lab with ULHS or foam.

Mechanical property testing of cements designed for the application scenarios was initiated and preliminary results reported during this quarter on pages 30 through 32 of Quarterly Report 4.

Data received from project Steering Committee member Schlumberger was added to that received previously from other member service companies: BJ and Halliburton. This historical data revealed trends in use of lightweight cements including conditions and density ranges. Schlumberger data is presented in Appendix C of Quarterly Report 4. Corresponding data from the other service companies was presented in Quarterly Report 2. Analysis of all three data sets is presented on pages 10 through 15 of Quarterly Report 4. These data confirm application conditions for ultra-lightweight cements as well as practical limits of conventional lightweight compositions and foam cement.

The effects of centrifugal pump circulation on ULHS breakage were evaluated and presented in Quarterly Report 4. Results, presented on pages 18 through 20 of Quarterly Report 4, reveal that the 6K ULHS demonstrates very little damage from continuous circulation. The 3K material exhibited more significant damage with repeated circulation.

QUARTERLY REPORT 5 (Appendix 5, page 414 of this report.)
Laboratory testing during Quarter 5 dealt with mechanical properties of the ultra-low density cements designed for the Application Scenarios. Testing included tensile strength (pages 13 and 14 of Quarterly Report 5), Young's Modulus (pages 15 and 16 of Quarterly Report 5) and permeability (pages 17 through 21 of Quarterly Report 5). Interim shear bond testing under three different confining force conditions was also reported.

Large scale laboratory mixing tests were documented in this report. Effects of shear energy on integrity of ULHS were monitored by changes in slurry density. These results, presented in 25 through 28 of Quarterly Report 5, revealed that the 6K ULHS was not subject to damage from mixing or recirculation pump forces.

Initial ASR testing is presented in Quarterly Report 5, pages 28 to 31. Potentially deleterious expansion was noted in these tests necessitating a comprehensive test suite.

The first field application of ULHS was documented in Quarterly Report 5, pages 31 and 32. This trial confirmed that the ULHS could be mixed and pumped with standard field equipment.

QUARTERLY REPORT 6 (Appendix 6, page 461 of this report)
Testing this quarter focused on Young's modulus testing and thermal cycling. Young's modulus data are presented on pages 13 through 15 of Quarterly Report 6. Effects of thermal cycling on tensile and compressive strength were tested and found to be negligible. These results are presented in 10 through 13 of Quarterly Report 6.

Shear bond measurements with various external confining forces were performed and reported on pages 15 through 19 of Quarterly Report 6.

The design and operation of the software for ULHS cements was described and illustrated on pages 20 through 26 of Quarterly Report 6.

QUARTERLY REPORT 7 (Appendix 7, page 502 of this report)
Laboratory data generated during this quarter included shear bond data with temperature and pressure cycling. Results, presented on pages 9 through 11, indicated pressure cycling did not affect shear bond while thermal cycling did.

Drill out testing measured the resistance of ULHS, sodium silicate, or foam cement to stresses induced during drill out-drill ahead. These results, presented in pages 11 through 15, indicated that both foam and ULHS maintained annular seal after large-scale drill-out testing.

QUARTERLY REPORT 8 (Appendix 8, page 540 of this report)
Laboratory work conducted during this quarter focused on shear bond strength after pressure cycling. The second field trial with ULHS was designed, performed, and evaluated during this quarter. Results presented here indicate the test was successful.

The software developed to calculate cement designs incorporating ULHS was also described. This software was distributed to project participants. The program does not simulate cement placement, fluid dynamics, or pumping hydraulics. Instead, the program focuses on final placement conditions for the cement. Using inputted water requirements, the program calculates amount of ULHS needed to achieve a specified density for a particular cement formulation.

Results of ongoing QA/QC testing were presented as well as a test protocol for Alkali-Silica Reactivity evaluation.

QUARTERLY REPORT 9 (Appendix 9, page 574 of this report)
Progress reported in the ninth quarter focused on ASR testing and reporting of results from the MMS Joint industry Project. ASR testing initiated previously was restarted with modified specimen curing procedure. Modified test procedure is presented in Appendix A of Quarterly Report 9.

Data collected from the MMS JIP is presented in Appendix B of Quarterly Report 9. This data expands the Lightweight Cement project's database for light weight cement performance. Additional rock property testing and expanded annular seal testing are presented. Additionally, a study of measurement of Poisson's Ratio of lightweight cement and the effects of low or negative Poisson's Ratio on the durability of cement adjacent to soft formations is presented.

QUARTERLY REPORT 10 (Appendix 10, page 697 of this report)
Testing conducted in this quarter focused on ASR evaluation. Initial test procedures that produced unsatisfactory test specimens were modified further with encouraging results. Testing was ongoing.

QUARTERLY REPORT 11 (Appendix 11, page 715 of this report)
Testing reported in this quarter focused on ASR. Several additional test artifacts were noted in expansion testing with TXI Lightweight cement. This difficulty necessitated a

further change in test procedure for TXI Lightweight cements. This procedure change produced meaningful data, and expansion testing was reinitiated under the new test protocol

QUARTERLY REPORT 12 (Appendix 12, page 736 of this report)
This report summarizes interim ASR test results under the final test protocol.

QUARTERLY REPORT 13 (Appendix 13, page 757 of this report)
The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction (ASR) in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile and compressive strengths of eight different cement formulations are being tested.

ASR is a potentially damaging phenomenon that occurs in cement materials containing certain types of silica-containing materials when they are exposed to alkali in high-pH environments. The ASR reaction produces alkali-silicate gel, which swells and disrupts the cement's crystalline lattice. This reaction can cause expansion and microcracking of the cement and reduced strength.

All results of the entire ASR study are summarized in this report. Results indicate no adverse effects created by ASR. Cements (especially TXI Lightweight cement compositions) did expand, but no detrimental strength loss accompanied the expansion.

Appendix 1

Quarterly Report 1

Ultra-Lightweight Cement

Quarterly Report

October 1 to December 31, 2000

Fred Sabins

Issued January 15, 2001

DOE Award Number
DE-FC26-00NT40919, Tasks 1, 2, and 3

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

1.0 Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultralight hollow glass spheres (ULHS). Work reported herein addresses Task 1: Assess Ultra-Lightweight Cementing Problems, Task 2: Review Russian Ultra-Lightweight Cement Literature, and Task 3: Test Ultra-Lightweight Cements. Results reported this quarter include a review and summary surface pipe and intermediate casing cementing conditions historically encountered in the United States and establishment of average design conditions for ULHS cements. Russian literature concerning development and use of ultra-lightweight cements employing either nitrogen or ULHS was reviewed, and a summary is presented. Quality control testing of materials used to formulate ULHS cements in the laboratory was conducted to establish baseline material performance standards. A testing protocol was developed employing standard procedures as well as procedures tailored to evaluate ULHS. This protocol is presented and discussed. Finally, results of initial testing of ULHS cements is presented along with analysis to establish cement performance design criteria to be used during the remainder of the project.

2.0 Table of Contents

3.0 List of Graphical Materials

3.1 Tables

3.2 Figures

4.0 Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a well bore. The slurry is pumped into the annular space between the bore-hole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, isolate various formations from one another, and to control fluid movement within the well.

Normal cement fluid density ranges from 14 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitate application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the well bore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, named lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections: surface casings and intermediate casings. Since formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are relatively low.

The minimum density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength. Lower temperature further decreases strength development. Achieving density requirements lower than this threshold or strength requirements greater than minimum necessitate use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent as candidate material for producing ultra-lightweight cements. These small, hollow, glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS. The development will be achieved through a carefully designed program of modeling, design, laboratory testing, and field testing.

This phase of the project involves evaluation of conditions requiring ultra-lightweight cement, review of previous investigations conducted in Russia, and preliminary laboratory design testing.

5.0 Executive Summary

The initial laboratory phase of this investigation focused on establishment of test parameters and quality-control procedures. Standard test procedures employed for oilwell cement testing will not always work for ULHS cements. For instance, the high shear delivered by a Waring Blender can physically damage a portion of the spheres, thereby altering the density from the design requirement. Additionally, the ULHS are subject to failure with application of hydraulic pressure. Therefore, the density of a cement slurry containing ULHS will vary with pressure application. Therefore, test procedures must be modified to avoid or account for this breakage.

Testing methods for mixing without subjecting the ULHS to high shear were developed and evaluated. Additionally, a method of exposing the cement slurries to hydraulic pressure was developed in order to establish specific gravity vs. pressure correlations for the various grades of ULHS.

A project of this magnitude and duration requires a large volume of cement and additives to complete. During the course of the project, several batches of material will probably be utilized in the testing. This requires an extensive material classification and quality control process. Such a process has been established for this project.

Appropriate test criteria for testing ULHS cements under realistic design conditions were developed from historical United States data. These criteria will be used to evaluate appropriate cements throughout the project. Additionally, appropriate criteria for slurry stability and mixability were developed and used to establish ULHS water requirement ranges.

Evaluation of applications of ULHS cements has been initiated. A synopsis of investigations conducted in Russia has been completed. This report reveals that several successful applications have been achieved. Review and analysis of this synopsis is under way.

Problems necessitating use of ULHS are being summarized to establish test and performance evaluation criteria.

6.0 Experimental

Experimental methods employed in this investigation are based on generally-accepted laboratory test procedures for oil well cements. Where applicable, standard methods presented in the API RP 10 B,[1] These tests include: thickening time, compressive strength, rheology, and free fluid.

Non-standard test procedures were necessitated because of the unique nature of the ULHS. The spheres are brittle and can break when mixed in a slurry and subjected to differential pressure or shear. Additionally, the sphere's specific gravity is less than water, so the spheres can float, resulting in solids segregation. These non-standard laboratory methods include slurry mixing, density vs. pressure, and slurry stability.

Non-standard testing procedures are outlined in detail in Appendix 1, Section 11.

7.0 Results and Discussion

7.1 Summary of Casing Conditions in USA

The application of ULHS cements will primarily be in surface and intermediate casing cementation. Average conditions under which these casings are installed were assessed in order to establish representative testing conditions. First, historical review of casing sizes, hole depths, bottomhole static temperature (BHST), and bottomhole circulating temperature (BHCT) was conducted using **Worldwide Cementing Practices**.[2] The data were tabulated and are presented in Appendix 11.2. Data were then averaged and summarized in Table 7.1. This analysis indicates that the average surface casing size in the US is 8 5/8 inches. Average intermediate casing size is 9 5/8 inches. These average sizes along with average depths and temperatures will be used to calculate representative cement placement times, test temperatures, and volumes.

Table 7.1—Summary of Casing Conditions in USA

Number of Data Samplings						Avg. Depth (ft)	Avg. BHST (°F)	Avg. BHCT (°F)
Casing	**8 5/8 (in.)**	**9 5/8 (in.)**	**13 3/8 (in.)**	**Other**	**Total**			
Surface	64[a]	37	29	24	182	1,660	96	78
Intermediate	17	34[b]	—	26	77	8,300	174	128

[a]The average weight was 24 lb/ft

[b]The average weight was 53.5 lb/ft

7.2 Review of Russian Lightweight Cement Literature

A review of literature covering ULHS research conducted by Russian investigators is presented in Appendix 11.3. This review includes compositions of ULHS investigated, physical properties, sources, properties of cement formulated with ULHS, and application conditions. Results of these investigations and applications were generally favorable, indicating both economic and technical benefits of the systems.

Additional evaluation and analysis of the information will be performed and reported in subsequent reports.

7.3 Cement Quality Control Program

An extensive quality-control program was initiated because of the large quantity of cement to be used over the length of this project. Each bucket of cement is labeled with a materials log number and date upon receipt. When a bucket is first opened for use, the date of opening is also being recorded into the materials log. This log number will be referenced on the lab sheets for each test performed. Where applicable, tests according to the API Specification 10A[3] are conducted. Additionally, several other tests tailored specifically for the test conditions and materials (rheology and low-temperature compressive strength development) are included in this QC Program.

The Class A and Class H cement performance requirements are presented in API Specification 10. The lightweight cement testing, as it is not referenced in the API Specifications, is conducted according to QC procedures developed by the manufacturer.

This quality-control program is necessary because of the large volume of cement to be used during this DOE project. Initially, the testing lab has received five 5-gallon buckets of API Class A cement (analogous to ASTM Type I cement), ten 5-gallon buckets of API Class H cement, and nineteen 3-gallon buckets of Lightweight Oilwell cement from TXI. Both API Specification tests and Advisory–Board- Member-recommended testing are being performed for the cement quality control program. The physical requirements used for testing each of the cements are those listed in Table 7.2. To accelerate the rate of compressive strength development at low temperature, calcium chloride ($CaCl_2$) is being used according to Table 7.3 with both classes of cement. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 7.2—Cement Physical Requirements for Quality-Control Testing Program

Cement	Mix Water (%)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Type 1	46	15.7	772	355	API
Lightweight	75	13.2	541	406	TT and CS
Lightweight	105	12.1	426	447	FW
Class H	38	16.5	860	327	API

Table 7.3—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (%)
80	0.0
60	1.0
45	2.0

All of these tests have been run to provide a baseline for each type of cement. This data will provide a comparison when examining other data for this project. The complete set of tests will be conducted periodically throughout the length of DOE Project. Table 7.4 shows the first set of data conducted by the testing lab on the three cements received.

Table 7.4—Quality Control Testing of Cements

Cement Compositions Specified in Table 7.2

	Lightweight	Class A	Class H
Free Water (% by vol.)	0.8	0	1.2
Initial Viscosity (Bc)	6	9	12
Spec 5 Thickening Time (hr:min to 100 Bc)	2:20	2:21	1:54
Atmospheric Pressure (psi)			
Compressive Strength (24 hr)			
45°F (2% $CaCl_2$)	106	471	
60°F (1% $CaCl_2$)	162	763	
80°F (24 hr)	334	1079	
100°F (8 hr)		482	307
120°F (24 hr)	1009		
Viscometer Readings[a] (rpm)			
300	57	80	85
200	50	65	70
100	42	49	53
60	38	40	45
30	33	34	38
6	22	17	14
3	12	10	8

[a]After 20 minutes conditioning on atmospheric viscometer

7.4 –Design of Cement Slurries Containing Glass Beads

7.4.1 Glass Bead Specifications

The 3M Scotchlite Glass Bubbles K&S Series Product Information sheet provides all of the specifications on this material. The ULHS are hollow, spherical-shaped glass microspheres composed of soda-lime borosilicate. They can be provided in a crush strength range from 250 psi to 10,000 psi. The 3M Scotchlite Glass Bubbles K&S Series Product Information sheet is also the source for Table 7.5.

Table 7.5—Glass Bead Specifications

True Density				Particle Size Distribution (microns, by volume			Effective Top Size
Bead Application Pressure Rating (psi)	**Minimum S.G. (g/cc)**	**Maximum S.G. (g/cc)**	**Average S.G. (g/cc)**	**10th%**	**50th%**	**90th%**	**95th%**
3,000	0.34	0.40	0.37	20	40	80	85
6,000	0.43	0.49	0.46	15	40	70	80
10,000	0.57	0.63	0.60	15	30	55	65

Additional specific information can be obtained by calling the 3M Specialty Materials Group at 1-800-367-8905.

7.4.2 Mixing and Settling Data

The next series of tests was designed to determine mixing water requirements for formulating mixable and stable ULHS slurries. Slurry rheology and segregation tests were the basis for this determination. Testing was conducted with a variety of cement compositions with varying 3,000 psi ULHS concentrations.

Rheology testing was analyzed in several different ways and presented in the following figures. The first chart type, *Glass Beads Comparison Rheology Chart*, illustrates the entire viscometer range of results from different concentrations of mix water, with varying concentrations of the ULHS, maintaining constant density. A slurry formulated with normal mix water for base cement has also been included as a baseline reference.

The second chart type, *300 rpm and 200 rpm Glass Beads Comparison Rheology Chart*, illustrates the same information as the chart above it but only of the two rpm results.

The third chart type, *Percent Density Change Charts*, shows the percent change of slurry density with various concentrations of mix water and ULHS. The change in density indicates the extent of separation of the spheres. Procedure is specified in Table 11.1.3.

The mixability limit of a rheology reading less than 300 at 300 rpm and a percent density change less than 5% was used as a standard for analysis of data.

Table 7.6—3000-psi UHLS with Class A Cement at 13.0 lb/gal

Mix Water (gal/sk)	ULHS (% by weight)
4.8	8.26
5.2	7.65
5.4	7.34
5.8	6.72
6	6.42
7	4.87
5.2	Baseline

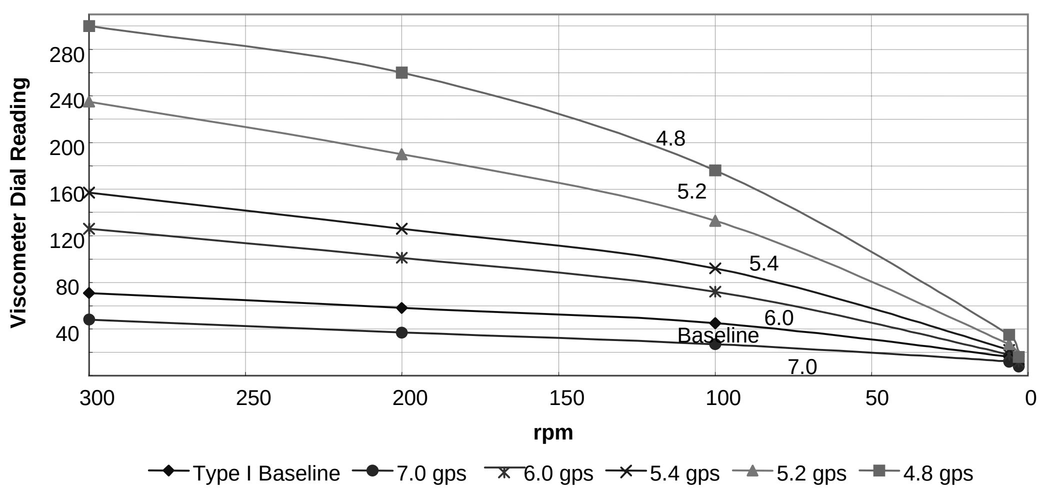


Figure 1–Rheology of cements outlined in Table 7.6. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

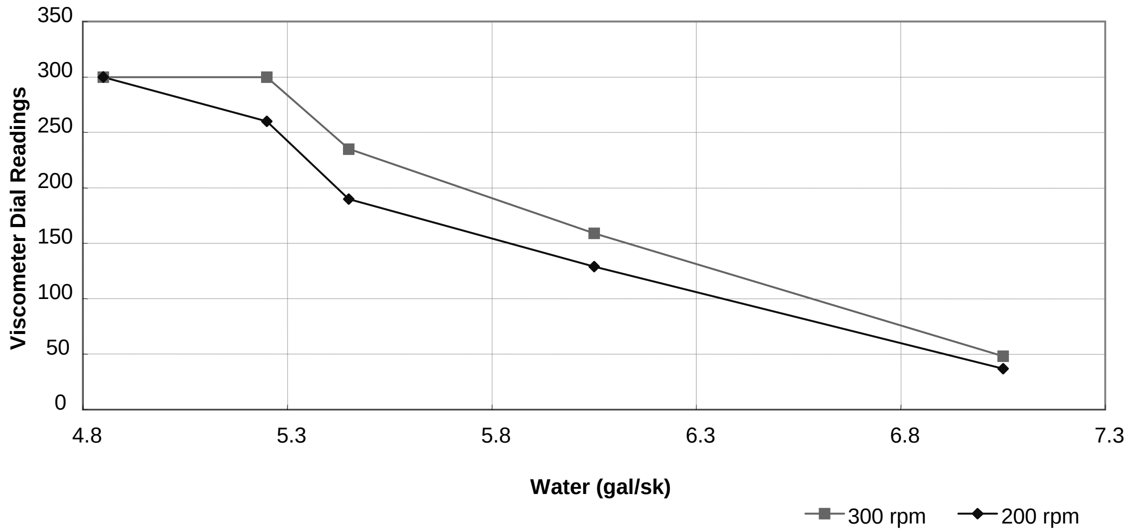


Figure 2–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.6. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

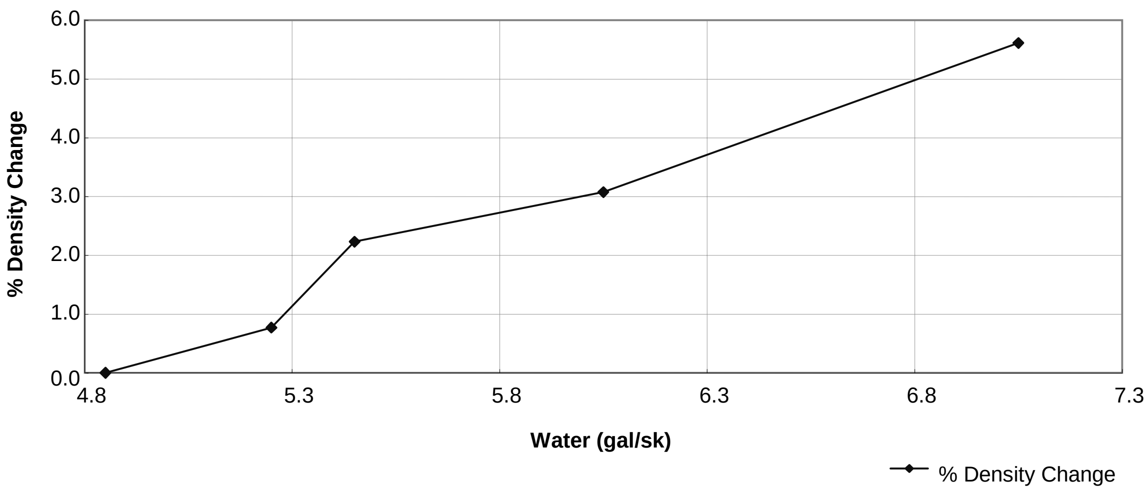


Figure 3–Density changes of cements outlined in Table 7.6

Table 7.6 presents mix water and ULHS requirements for 13.0 lb/gal slurries formulated with Class A cement. Figures 1, 2, and 3 present rheology and settling test data. Using a water requirement of 5.2 gal/sk for the Class A cement, the additional water for the ULHS was in a range of 0.03 gal H_20/lb to 0.31 gal H_20/lb.

Table 7.7—3,000-psi ULHS with Class A Cement at 10.0 lb/gal

Mix Water (gal/sk)	ULHS (%)
7.2	21.91
7.6	21.60
8.0	21.27
8.2	21.12
9.0	20.94
9.5	20.10
10.0	19.70
10.5	19.31
11.0	18.92

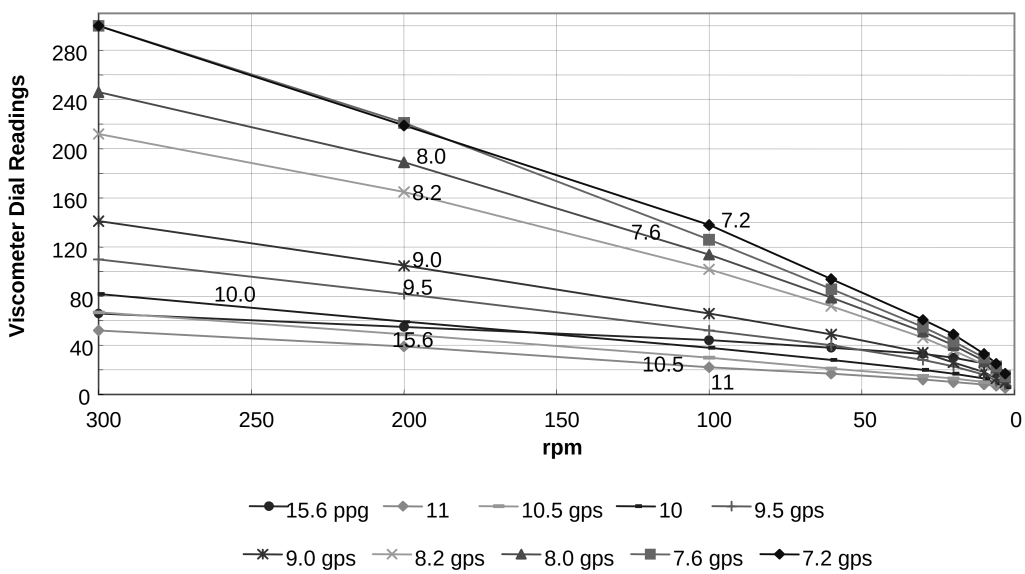


Figure 4– Rheology of cements outlined in Table 7.7. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

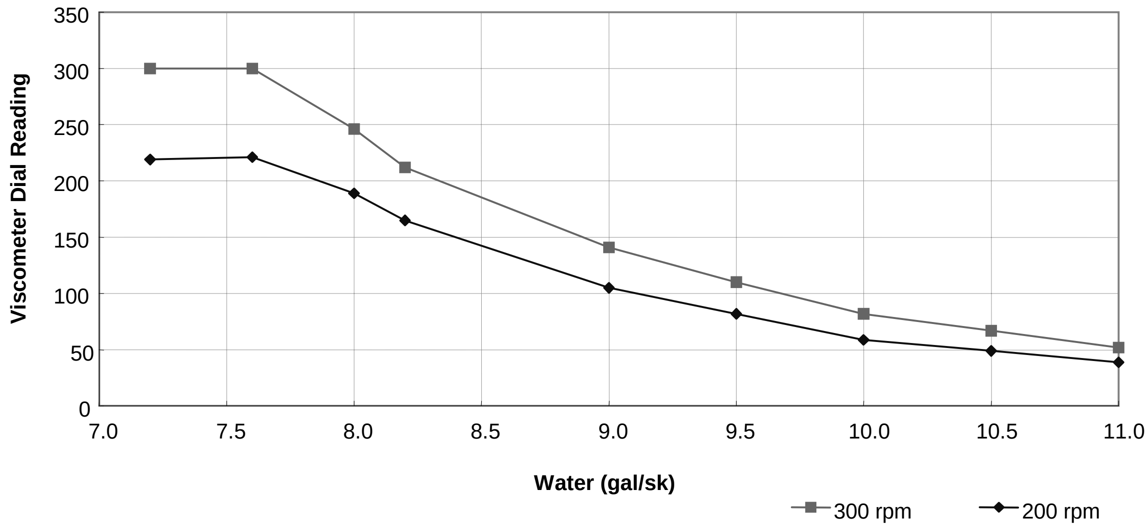


Figure 5–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.7. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

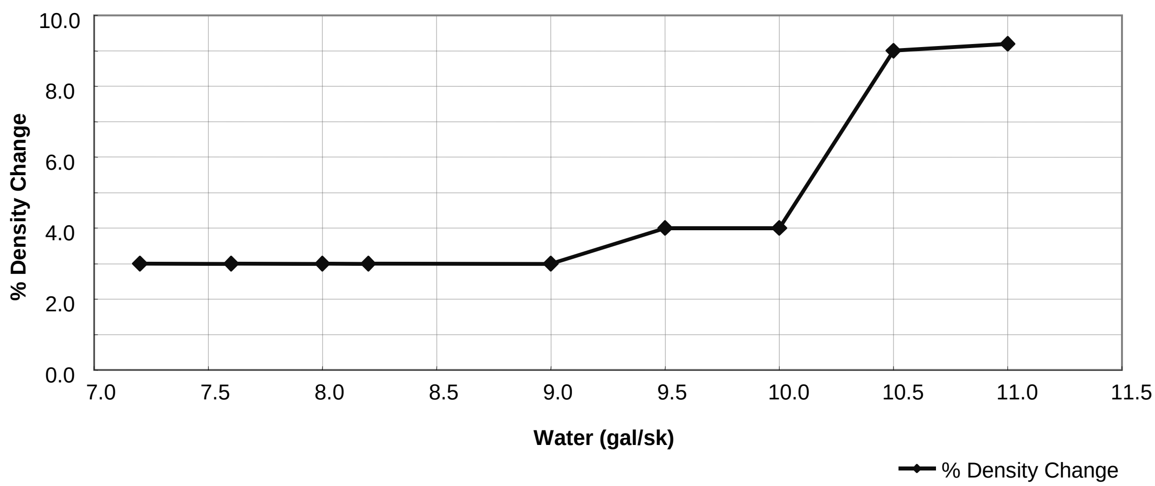


Figure 6–Density changes of cements outlined in Table 7.7

Table 7.7 and Figures 4, 5, and 6 present similar data for 10.0 lb/gal cement slurries formulated with Class A cement. Using a water requirement of 5.2 gal/sk for Class A cement, the additional water for the ULHS was in a range of 0.14 gal H_20/lb to 0.33 gal H_20/lb.

Table 7.8—3,000-psi ULHS with Lightweight Cement at 11.5 lb/gal

Mix Water (gal/sk)	ULHS (%)
5.5	9.98
6.0	9.21
7.0	7.67
8.0	6.12
9.0	4.58

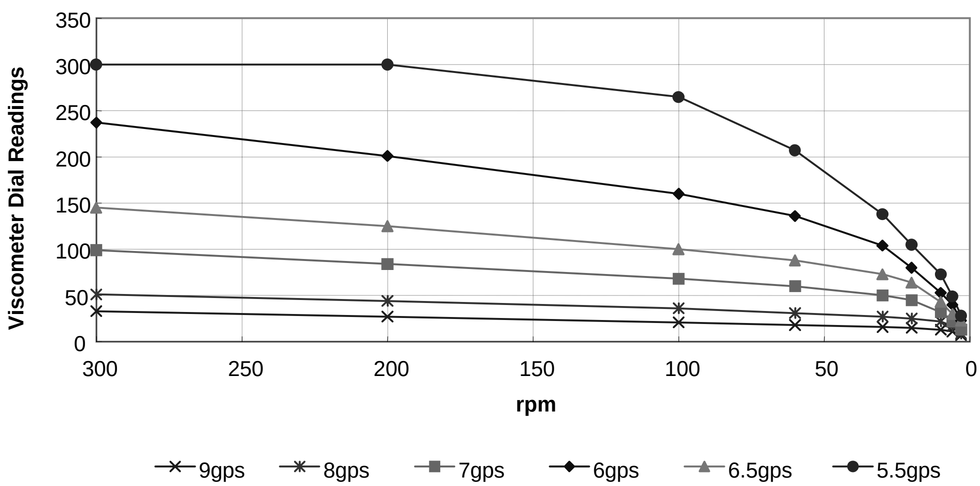


Figure 7–Rheology of cements outlined in Table 7.8. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

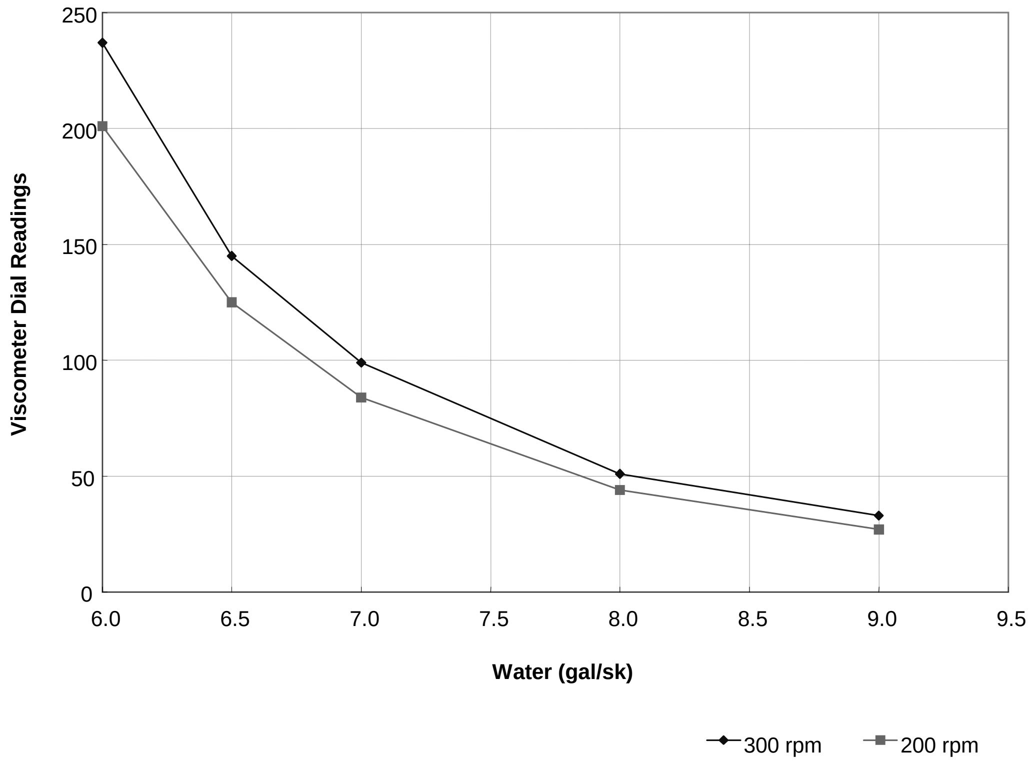


Figure 8–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.8

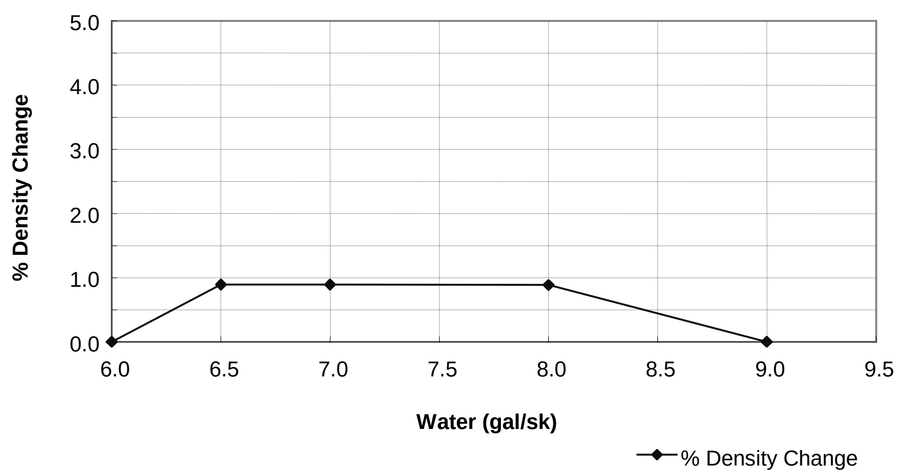


Figure 9–Density changes of cements outlined in Table 7.8

Table 7.8 and Figures 7, 8, and 9 present data for 11.5 lb/gal cements formulated with lightweight cement. Using a water requirement of 7.0 gal/sk for the lightweight cement, the additional water for the 3000-psi glass beads was in a range of 0.14 gal H_20/lb to 0.58 gal H_20/lb.

Table 7.9—3,000-psi ULHS with Lightweight Cement at 10.0 lb/gal

Mix Water (gal/sk)	ULHS (%)
6.5	18.96
7	18.46
7.5	17.97
8	17.48
10	15.5
11	14.52

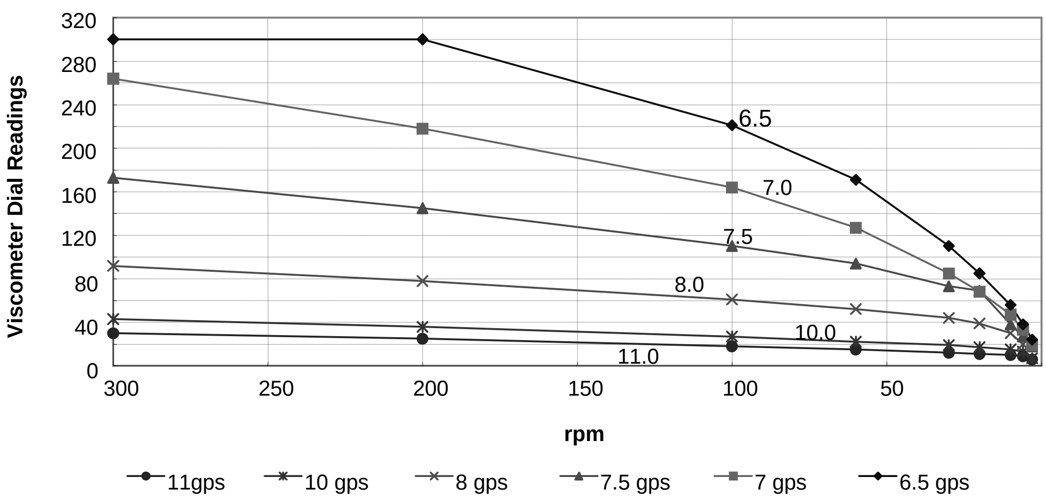


Figure 10–Rheology of cements outlined in Table 7.9. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

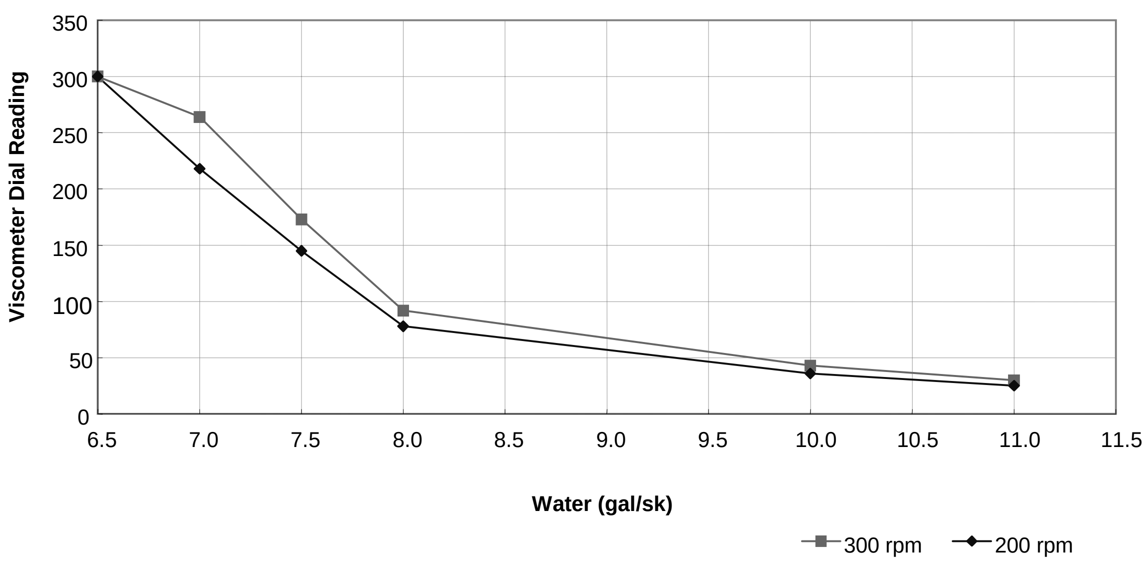


Figure 11–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.9. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

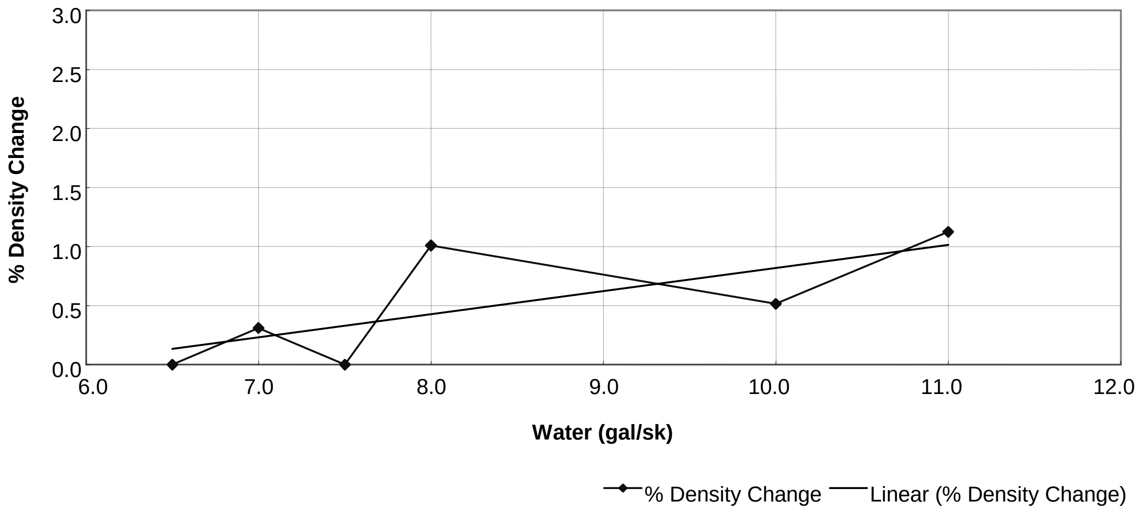


Figure 12–Density changes of cements outlined in Table 7.9

Table 7.9 and Figures 10, 11, and 12 present data for 10.0 lb/gal cements formulated with lightweight cement. Using a water requirement of 7.0 gal/sk for the lightweight cement, the additional water for the 3000-psi ULHS was in a range of 0.14 gal H_20/lb to 0.58 gal H_20/lb.

Table 7.10—3,000-psi ULHS with Class A Cement Plus 1% Dispersant (bwoc) at 13.0 lb/gal

Mix Water (gal/sk)	ULHS (%)
4.0	9.00
4.4	8.39
4.8	7.77

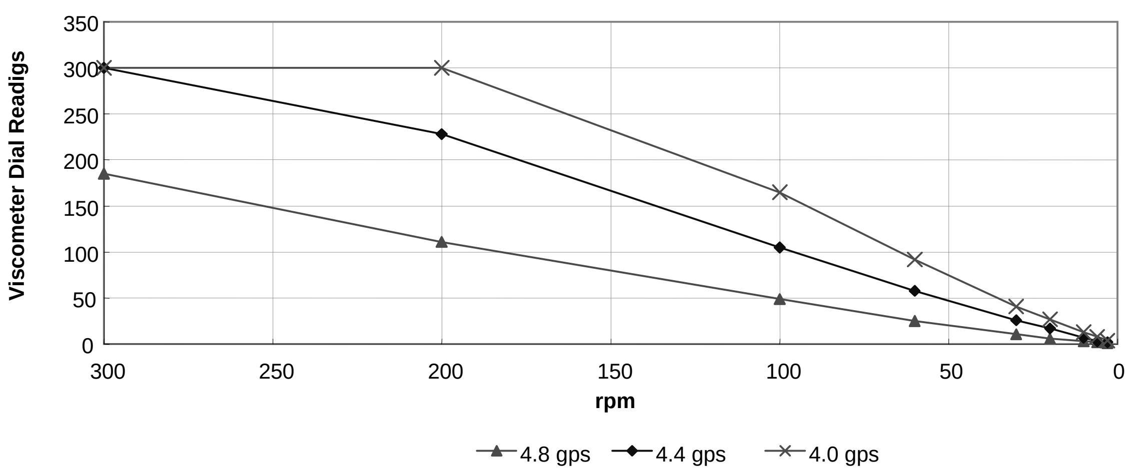


Figure 13–Rheology of cements outlined in Table 7.10. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

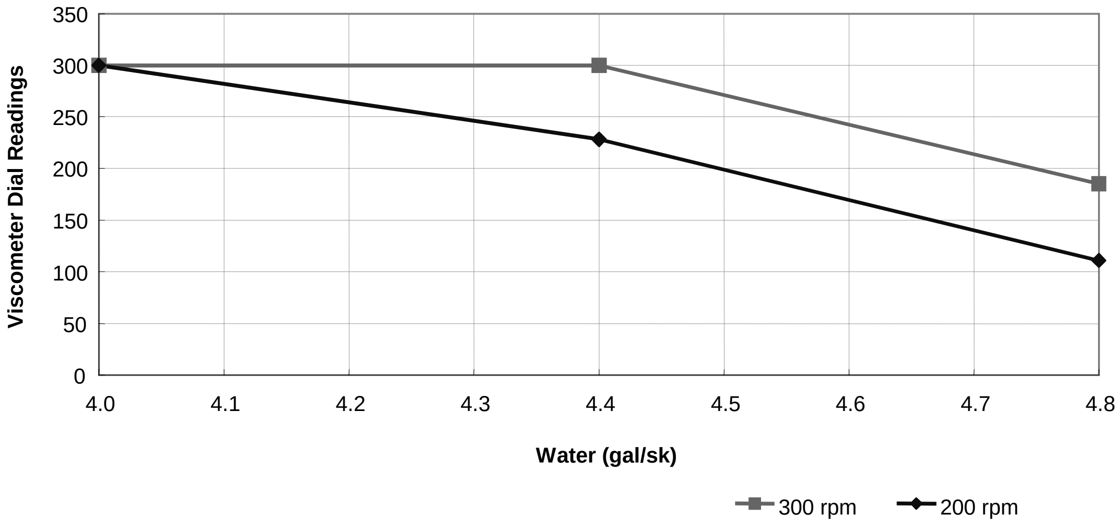


Figure 14–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.10. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

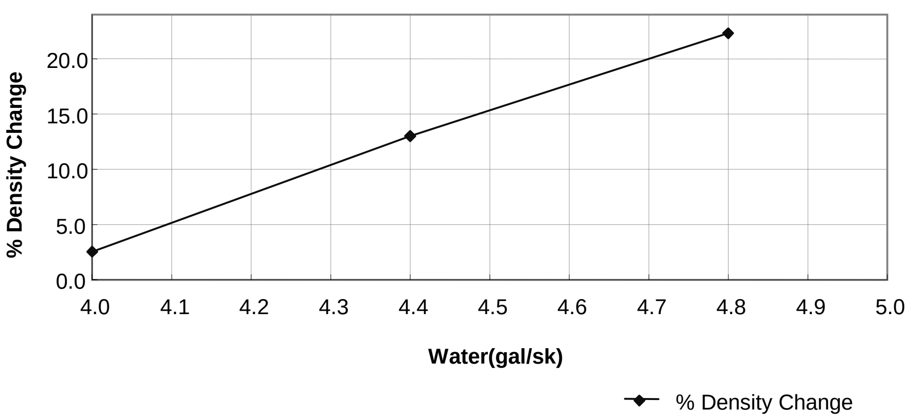


Figure 15–Density changes of cements outlined in Table 7.10

Table 7.10 and Figures 13, 14, and 15 present data for 13.0 lb/gal Class A cement containing a cement dispersant. Using a water requirement of 5.2 gal/sk for the Class A cement, the additional water for the 3000-psi ULHS with dispersant 0.32 gal H_20/lb.

Table 7.11—3,000-psi ULHS with Class A Cement Plus 1% Dispersant at 10.0 lb/gal

Mix Water (gal/sk)	ULHS (%)
6	22.41
6.5	22.49
7.2	21.94
7.5	21.43

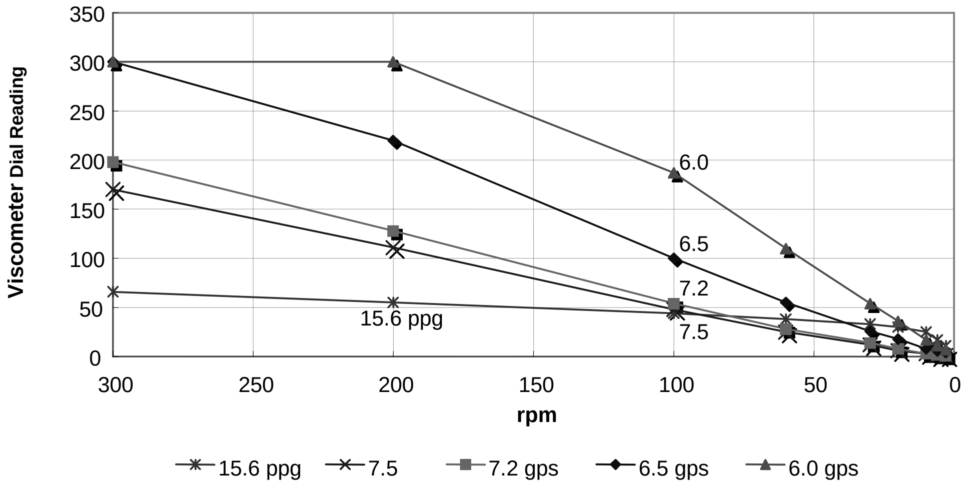


Figure 16–Rheology of cements outlined in Table 7.11. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

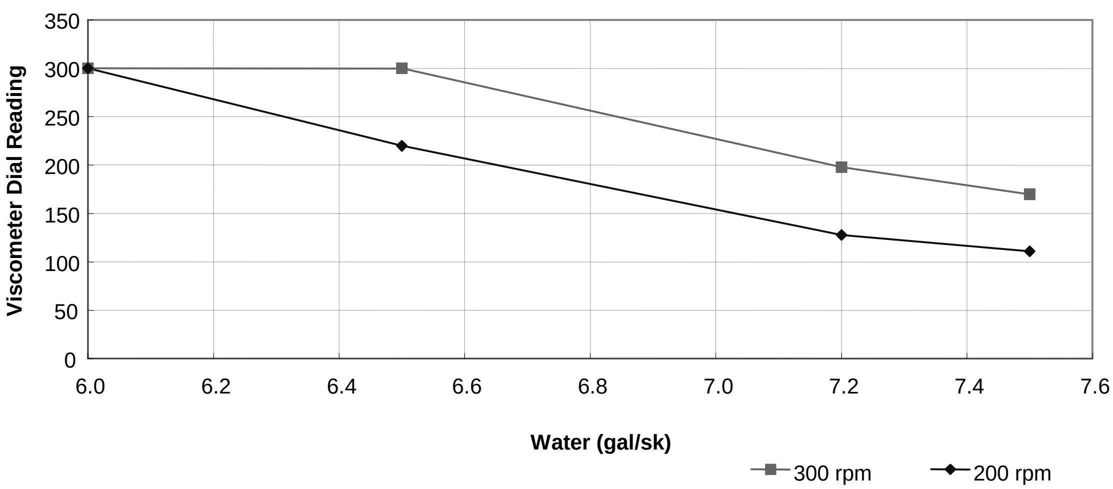


Figure 17–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.11. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

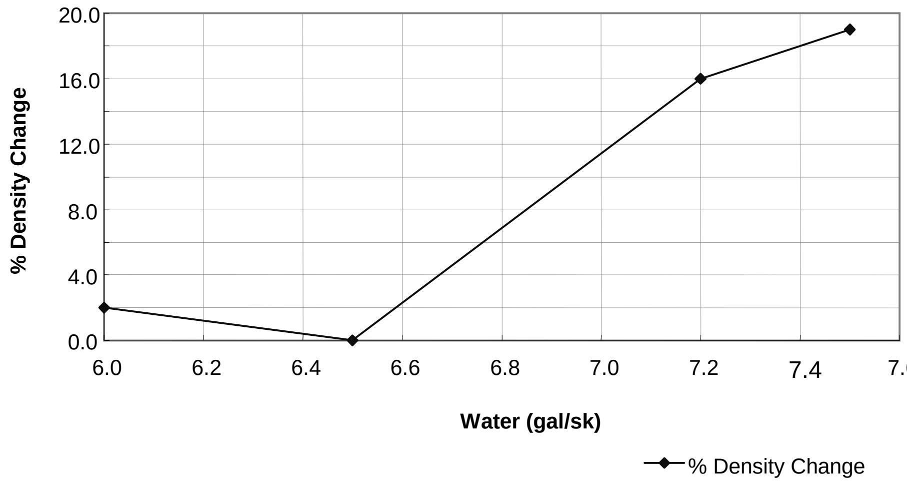


Figure 18–Density changes of cements outlined in Table 7.11

Test data for 10.0 lb/gal Class A cement containing a dispersant is presented in Table 7.14 and Figures 19, 20, and 21. Using a water requirement of 5.2 gal/sk for the Class A cement, the additional water for the ULHS with dispersant was in a range of 0.067 gal H_20/lb to 0.073 gal H_20/lb.

Table 7.12—3,000-psi ULHS with Lightweight Cement Plus 1% Dispersant at 10.0 lb/gal

Mix Water (gal/sk)	ULHS (%)
6	19.01
6.5	18.51
7	18.02
7.5	17.53

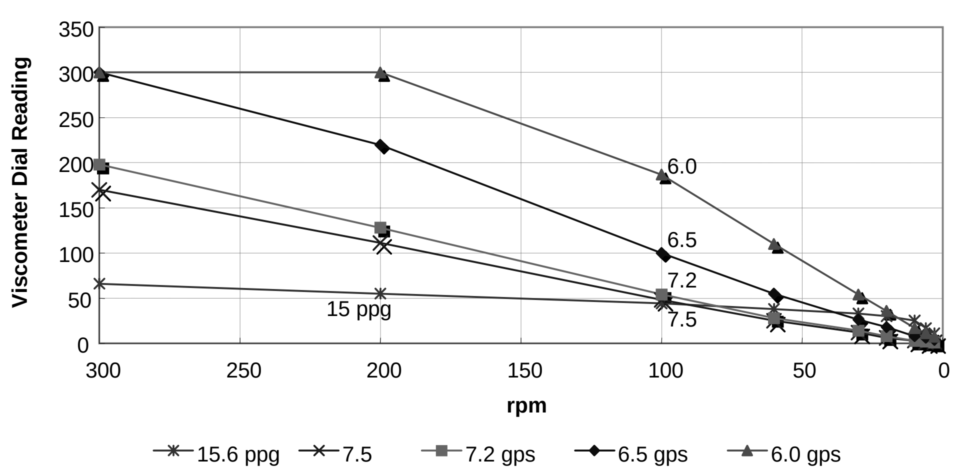


Figure 19–Rheology of cements outlined in Table 7.12. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

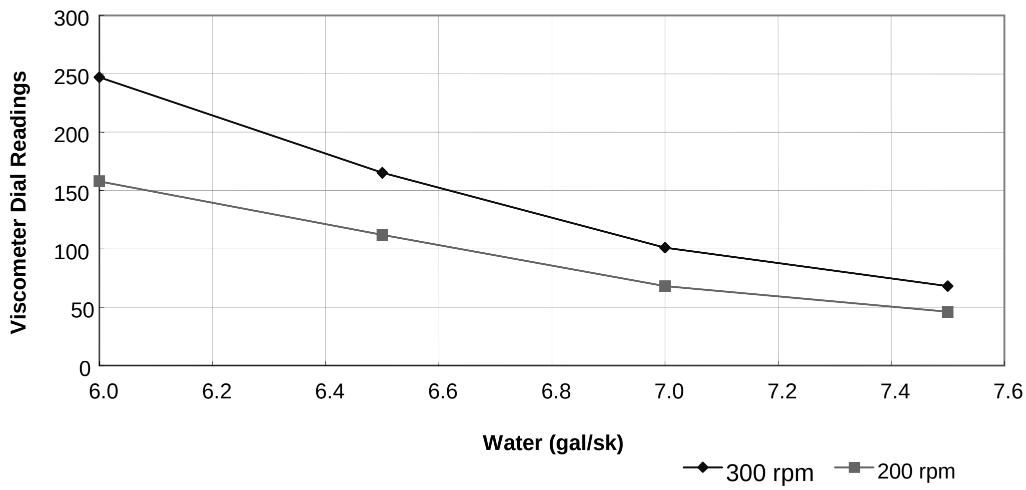


Figure 20–300 rpm and 200 rpm rheology measurements of cements outlined in Table 7.12. Note that the 300 dial reading on the chart is actually a 300 plus (300+) dial reading.

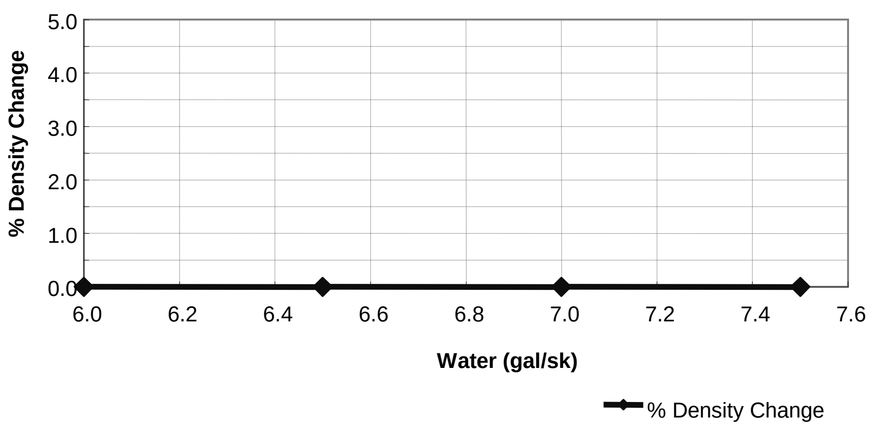


Figure 21–Density changes of cements outlined in Table 7.12

Table 7.11 and Figures 19, 20, and 21 present data for a 10.0 lb/gal lightweight cement containing dispersant. Using a water requirement of 7.0 gal/sk for the lightweight cement, the additional water for the ULHD was in a range of 0.07 gal H_20/lb to 0.03 gal H_20/lb. No density change was found throughout the entire test.

The dispersant concentration of 1% was arbitrarily chosen from past experience. However, rheology of the dispersant-containing cements demonstrates erratic behavior that may be indicative of sub-optimum dispersant concentration. The effect of the ULHS on dispersant activity must be further evaluated to resolve this.

Table 7.13—Descending and Ascending Viscometer Readings of Lightweight Cement at 11.5 lb/gal

Rheology (rpm)	5.5	Reverse	6.0	Reverse	6.5	Reverse	7.0	Reverse
300	300	300	237	220	145	146	99	94
200	300	300	201	187	125	126	84	83
100	265	256	160	150	100	101	68	67
60	207	207	136	130	88	85	60	58
30	138	132	104	102	73	69	50	50
20	105	107	80	81	64	63	45	45
10	73	72	53	50	43	43	32	31
6	49	43	40	38	30	28	22	21
3	28	28	23	23	23	23	13	13

The effects of running the viscometer in descending and ascending order are shown in Table 7.13 with three different ULHS and mix water concentrations. This testing was conducted to evaluate the centrifugal effects of the rotational viscometer on the stability of the slurries.

The data indicate that little effect results from testing in descending rotational speed. However, the maximum centrifugal effect would come from running the tests in ascending then descending order. Therefore, the testing will be repeated this way.

7.4.3 Shear Effect on Slurry Density with 3M 3K Glass Beads

Mixing of ULHS with a Waring Blender causes breakage of some spheres due to shearing of the blender blade. This breakage alters the slurry design density. An example of this occurrence, as shown in Figure 22, which presents data on a Class A cement slurry mixed with 3000 psi ULHS mixed with a Waring Blender. The cement and water were first mixed in a Waring Blender The ULHS were then added while continuously mixing by hand with a spatula. The slurry density was then measured using a pycnometer as outlined in Table 11.1.4. The same slurry was returned to the Waring Blender for 35, 105, 210 seconds to ascertain shearing effect on slurry density from breakage of glass beads.

These data indicate the occurrence of air entrainment since the measured density was 0.4 lb/gal lower than calculated. The data must be repeated with a pressurized mud balance. Additionally, it is proposed to use slurry defoamer in all cements to alleviate the problem.

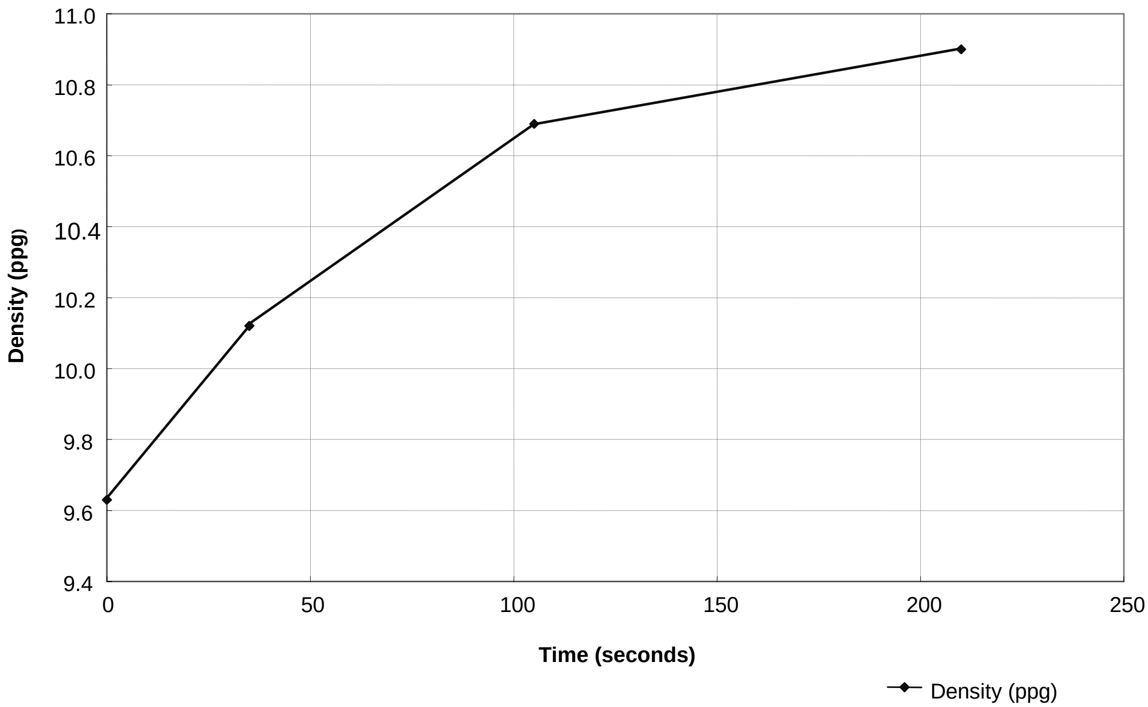


Figure 22–Effect of high-shear mixing on ULHS cement density

7.4.4 Glass Beads Specific Gravity versus Applied Pressure

The following three charts (Figures 26,-27, and 28) are results of slurries with 3,000, 6,000, and 10,000 psi ULHS after being pressurized at several predetermined pressures. These data will be used to calculate effective density lowering capacity of the ULHS vs. pressure.

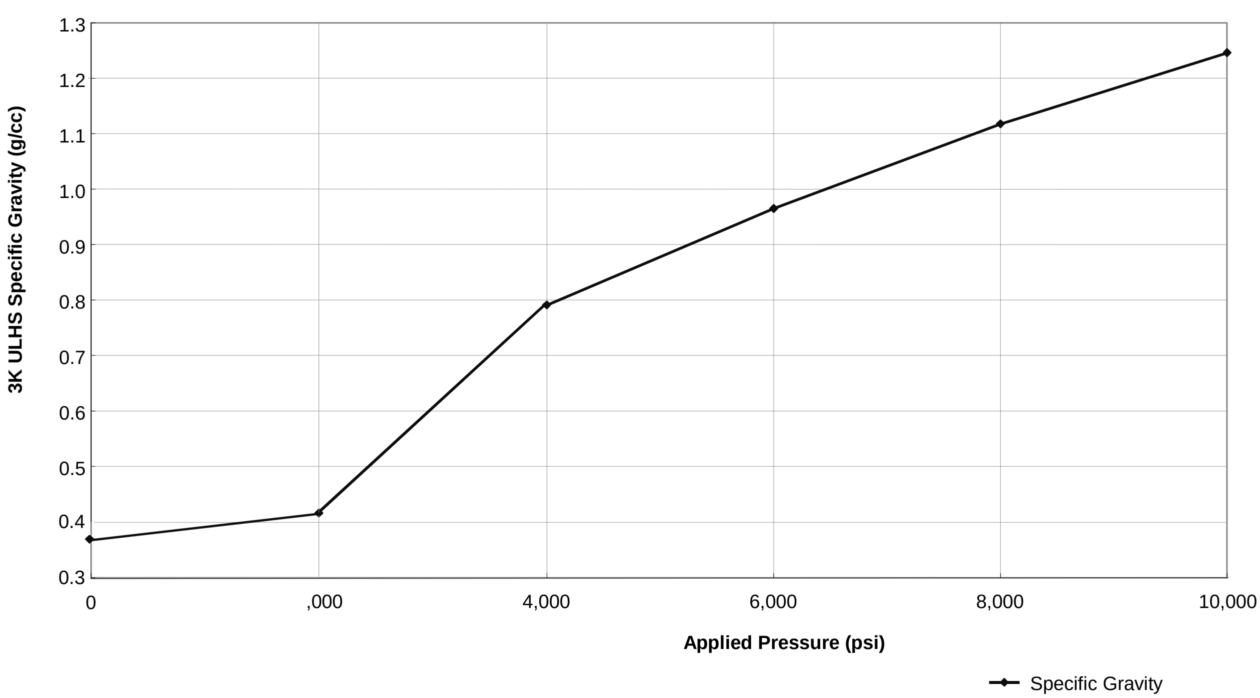


Figure 23–3000 psi ULHS specific gravity vs. pressure

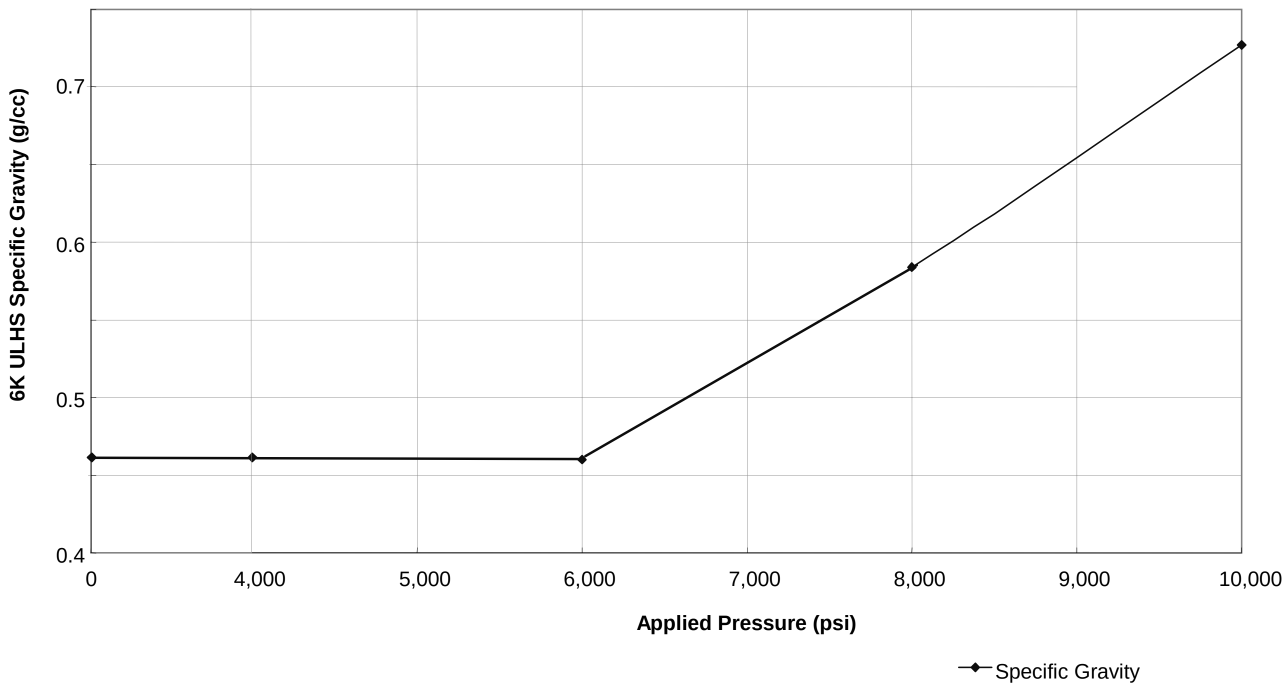


Figure 24–6000 psi ULHS specific gravity vs. pressure

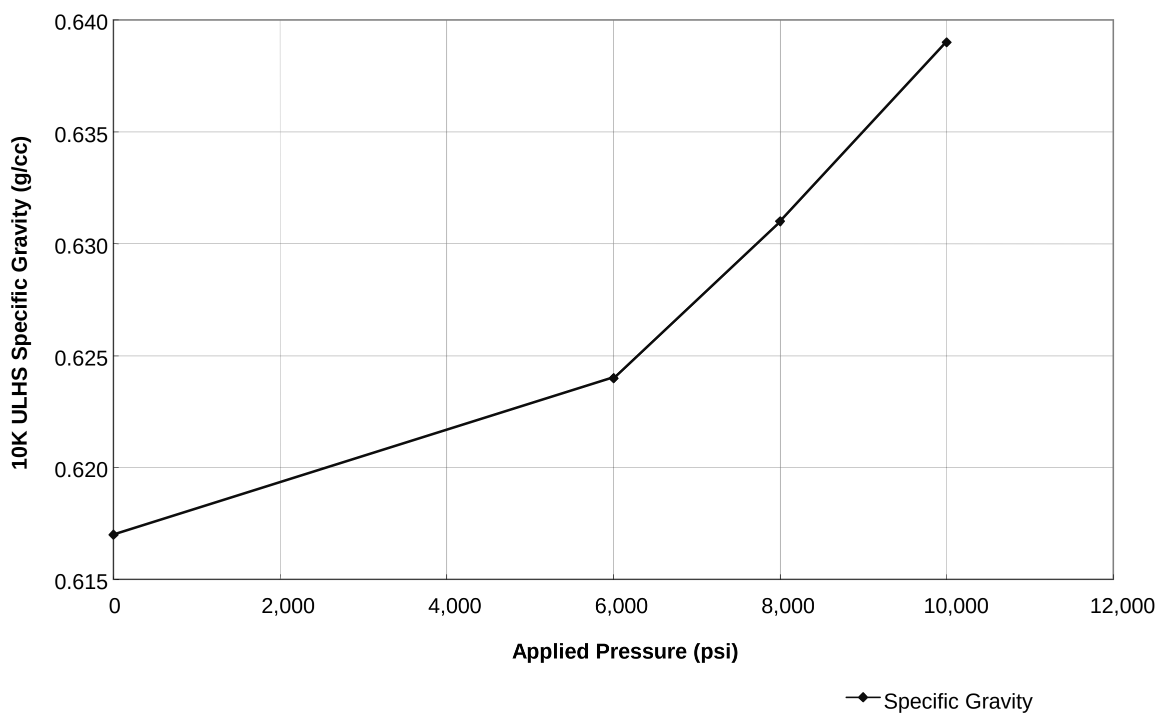


Figure 25–10,000 psi ULHS specific gravity vs. pressure

8.0 Conclusions

Based on initial results presented herein, the following conclusions can be drawn:

Laboratory procedures for cement design tests to establish mixability, slurry stability and separation, effects of pressure, and mixing are established.

Satisfactory quality-control procedures have been established.

Typical design parameters derived from USA historical data were established to evaluate field application of ULHS under realistic conditions.

Physical performance properties of ULHS materials measured over a wide range of application pressures indicate that the materials are functional as light weight additives for typical oilwell cementing conditions.

Air entrainment affects atmospheric density measurement techniques, and a cement defoamer must be employed in laboratory mixing methods.

9.0 References

1. API Recommended Practice 10 B, 22nd Edition, December 1997: 22nd Edition, December 1997: “Recommended Practice for Testing Well Cements,” American Petroleum Institute

2. Worldwide Cementing Practices First Edition, American Petroleum Institute, January 1991.

3. API Specification 10 A, 22nd Edition, January 1, 1995: “Specification for Cements and Materials for Well Cementing,” American Petroleum Institute.

10.0 List of Acronyms and Abbreviations

lb/gal — pound(s) per gallon
lb/ft — pound(s) per foot
rpm —revolutions per minute
gal/sk — gallon(s) per sack
H_2O/lb — water per pound
gps — gallon(s) per second
g/cc — grams per cubic centimeter
g — gram
cc — cubic centimeter
psi — pound(s) per square inch
UHLS —ultralight hollow glass spheres
API — American Petroleum Institute
avg. — average
BHCT — bottomhole circulating temperature
BHST — bottomhole static temperature
TXI — a cement supplier
CSI — Cementing Solutions, Inc.
QC — quality control
Bc — Bearden units of consistency
AT — atmospheric
3M — Minnesota Mining and Manufacturing
3K — 3,000-psi designation
TT—thickening time test
CS—compressive strength test
FW—free water test

11.0 Appendices

Appendix 11.1

Non-standard Test Procedures Developed for ULHS Cements

Table 11.1.1 Mixing Procedures of Cement and Glass Beads

Procedure 1: Mixing beads without high shear

(Mixing glass beads into a cement slurry using a Waring Blender can break beads, thereby altering the slurry density.)

1. Weigh out the appropriate amounts of the cement sample and additives, water, and glass beads into separate containers.

2. Mix the cement slurry according to Section 5.3.5 of the American Petroleum Instituted (API) Recommended Practice for Testing Well Cements, Twenty-Second Edition, December 1997.

3. Pour the slurry into a metal mixing bowl and slowly add the glass beads while continuously mixing by hand with a spatula.

Procedure 2: Mixing beads with high shear

Mix slurry including beads according to API Specification 10. Measure density with pressurized mud balance to assess degree of density change due to breakage.

Table 11.1.2 Procedures for Performing Stability Test

1. Prepare the cement and bead slurry as described in the *Mixing of Cement and 3M Scotchlite Beads* instructions above.

2. Pour 250 mL of the thoroughly mixed slurry into a 250 mL graduated cylinder and seal to prevent evaporation.

3. Stand the graduated cylinder upright in an 80°F water bath with water level equal to height of cement in graduated cylinder for 1 hour.

4. Mark the 250 mL graduated cylinder into three sections (Top, Middle, Bottom).

   Top 1/3 Section: 170 mL– 50 mL
   Middle 1/3 Section: 80 mL – 170 mL
   Bottom 1/3 Section: 0 mL – 80 mL

5 Fill a (30mL) syringe with 1 to 5 mL of the cement and bead mixture to remove any air trapped in the tip of the syringe; then eject slurry leaving the tip filled. Wipe any residue from the outside of the syringe.

6. Tare the washed syringe on a balance.

7. Refill the syringe with a least 10 mL of the cement and bead mixture from the top 1/3 section of the graduated cylinder.

8. Weigh and record the weight and volume of the syringe plus mixture.

9. Calculate the specific gravity of the mixture by dividing the recorded weight of the cement and bead mixture by the volume of mixture measured into the syringe. Compute density by multiplying by the density of water (8.33 lb/gal).

Example:

Syringe plus Cement & Beads – 38.14 g
Volume of Cement & Beads – 30 cc

38.14 g / 30 cc = 1.271 g/cc
1.271 g/cc x 8.33 = 10.59 lb/gal

10. Repeat steps 6 – 9 with the other two (middle, bottom) 1/3 sections of the graduated cylinder. Use a length of tubing attached to the syringe tip to access the lower portions of the cylinder.

TABLE 11.1.3

Calculations for Determining Density Difference Due to Separation

1. Using the data obtained in the *Procedure for Performing Stability Test* Subtract the top density from the bottom density.

2. Divide this value by the bottom density and multiply by 100.

3. The resulting value is the percent density difference due to glass bubble separation.

Example:
Top Density - 15.0 lb/gal
Bottom Density - 15.5 lb/gal

15.5 – 15.0 = 0.5
(0.5 / 15.5) x 100 = 3.23% density difference

Table 11.1.4 Density Determination using a Pycnometer

1. Assemble and weigh the empty pycnometer.
2. Remove the cap and lid.
3. Fill the cup with distilled or deionized water.
4. Lay the lid on top of the cap. Screw down the cap. Water should run out the hole in the center of the lid. This must occur to assure that the pycnometer is completely filled. With a soft, lint free cloth or wiper, wipe the pycnometer dry. Be careful to avoid touching the wiper directly to the hole in the center of the lid. If water is wicked up, the pycnometer will no longer be completely filled.
5. Re-weigh the assembled pycnometer. Subtract the weight of the empty pycnometer from the weight of the filled pycnometer. The resulting value is the net weight of the water.
6. Disassemble the pycnometer. Pour out the water and completely dry all parts.
7. Fill the pycnometer with the cement and bead mixture. Take care to fill the cup completely to eliminate air pockets by gently tapping the cup on a flat surface. Screw down the cap. The mixture should run out of the hole in the center of the lid. With a lint free cloth or wiper, wipe the pycnometer clean and dry. Avoid touching the wiper directly to the hole in the center of the lid.
8. Weigh the filled and clean pycnometer. Subtract the weight of the empty pycnometer from the weight of the mixture filled pycnometer. This is the net weight of the cement and bead mixture.
9. Divide the net weight of the cement and bead mixture by the net weight of the water. The result is the specific gravity of the sample.
10. Multiply the specific gravity by the density of water (8.33 lb/gal) to determine the density of the mixture. Report the temperature at which the measurements are made in case accounting for thermal expansion is necessary.
11. Thoroughly clean and dry all parts of the pycnometer.

Example:

Pycnometer – 52.0 g
Water – 63.6 g
Cement & Beads – 68.0 g
63.6 g – 52 g = 11.6 g
68.0 g – 52 g = 16.0 g
16.0 g ÷ 11.6 g = 1.38
1.38 x 8.33 lb/gal =11.49 lb/gal

[a]Notes:
A pycnometer can yield greater accuracy than other methods described herein.
Since the volume of the pycnometer is constant, determinations made are based only on weight.

Since density varies with temperature, it is important to make the determination of the mixture and water at the same temperature.

[a]Excerpts taken from Fisher Scientific Catalog No 03-247 – Instructions # 103234 First Issue: 03/98.

Table 11.1.5 Procedures for Determining Effects of Pressure on Collapse of Glass Beads

1. Weigh out the appropriate amounts of the cement sample, water, and glass beads into separate containers.

1. Mix slurry according to procedure outlined in Appendix 1.
4. Pour slurry into a 1-gallon plastic bag.

5. Close bag airtight, without air in slurry; use heavy-duty tape to seal bag.

6. Place bag into pressurized consistometer (API RP 10 B, Section 9).

7. Pressurize unit to desired pressure and maintain for 10 minutes.

9 Depressurize unit and remove slurry bag.

10. Ascertain that no cement leaked from bag or oil leaked into the bag.

11. Wipe oil from exterior of bag.

.

14. Open bag and pour slurry to the fill line in an atmospheric consistometer cup.
15. Condition slurry for 20 minutes at room temperature.
16. Record initial and final slurry consistency.

.

18 Determine density using a pressurized mud balance.

11.2 Appendix 2

Surface and Intermediate casing Analysis

A review of the *Worldwide Cementing Practices;* First Edition, January 1991 was conducted. All the United States of America surface and intermediate casing jobs were tabulated into a list, shown in Tables 11.2.1 and 11.2.2. Analysis of this list provides insight into the application prospect for lightweight slurries.

Table 11.2.1—Surface Casing

Field No.	Csg Size (in.)	Csg. Wt. (lb/ft)	Depth (ft)	BHST (°F)	BHCT (°F)
1	9 5/8	39	140	70	70
2	8 5/8	24	350	75	70
3	9 5/8	39	3,500	120	90
4	20	94	1,135	93	70
5	13 3/8	46	8,750	192	140
6	8 5/8	24	350	75	70
7	13 3/8	72	2,700	40	32
8	13 3/8	72	2,700	40	32
9	13 3/8	72	2,700	40	40
10	9 5/8	47	2,600	40	32
11	9 5/8	39	600	80	80
12	11 3/4	50	1,500	100	90
13	8 5/8	22	825	100	80
14	8 5/8	24	650	87	70
15	8 5/8	24	1,000	85	70
16	7	23	1,353	85	70
17	13 3/8	68	80	80	60
18	13 3/8	68	800	90	70
19	8 5/8	30	2,000	100	80
20	10 3/4	40.5	300	80	70
21	20	94	300	100	80
22	22	92.5	250	95	70
23	13 3/8	54.5	350	85	70
24	9 5/8	36	300	245	175
25	10 3/4	40.5	3,250	150	100
26	8 5/8	24	300	90	70
27	8 5/8	26.5	400	85	70
28	8 5/8	36	800	90	70
29	10 3/4	40.5	1,000	92	70
30	9 5/8	36	400	190	
31	9 5/8	32	550	80	70
32	13 3/8	72	4,500	143	105
33	10 3/4	45.5	2,500	120	85
34	13 3/8	68	1,700	80	70
35	13 3/8	61	40	65	65
36	9 5/8	35.25	300	80	70
37	8 5/8	30	175	70	70
38	9 5/8	39	3,500	120	90
39	13 3/8	46	8,750	192	140
40	8 5/8	24	400	65	65

41	8 5/8	24	375	65	65
42	9 5/8	32	425	60	60
43	8 5/8	22	1,100	110	80
44	8 5/8	22	1,100	110	90
45	9 5/8	38	1,800	120	90
46	10 3/4	40.5	2,500	110	80
47	8 5/8	22	375	90	80
48	8 5/8	22	475	90	70
49	9 5/8	40	2,500	112	80
50	13 3/8	40.5	4,000	124	90
51	13 3/8	68	4,487	125	90
52	13 3/8	46	3,000	115	85
53	8 5/8	22	1,200	115	80
54	16	84	3,500	118	95
55	16	84	1,150	92	70
56	13 3/8	68	1,932	103	80
57	16	84	3,300	100	70
58	13 3/8	68	4,600	140	100
59	13 3/8	72	11,000	220	140
60	10 3/4	40.5	3,000	116	90
61	10 3/4	40.5	2,000	104	80
62	13 3/8	72	3,500	120	90
63	16	84	3,300	125	90
64	13 3/8	72	3,000	116	90
65	20	133	7,400	70	70
66	13 3/8	72	4,000	128	95
67	16	72	4,500	134	95
68	10 3/4	40.5	3,000	116	90
69	11 3/4	40	950	70	70
70	16	75	800	70	70
71	11 3/4	40	325	70	70
72	8 5/8	22	600	80	80
73	9 5/8	38	2,750	120	90
74	8 5/8	24	550	85	70
75	9 5/8	39	3,050	120	90
76	9 5/8	39	3,700	125	95
77	10 3/4	45.75	4,000	130	90
78	9 5/8	39	140	70	70
79	8 5/8	24	350	75	70
80	8 5/8	24	350	75	70
81	8 5/8	36	2,000	90	80
82	8 5/8	40	150	100	80

83	8 5/8	24	950	85	70
84	11 3/4	42	500	75	70
85	13 3/8	48	350	70	70
86	8 5/8	24	90	80	70
87	13 3/8	48	450	80	70
88	9 5/8	38	325	80	70
89	13 3/8	48	350	75	70
90	20	94	625	75	60
91	13 3/8	56	650	75	70
92	8 5/8	24	500	70	70
93	9 5/8	40	3,000	120	90
94	8 5/8	24	200	65	65
95	8 5/8	24	800	70	70
96	8 5/8	22	450	70	70
97	8 5/8	24	850	80	80
98	8 5/8	24	550	75	75
99	13 3/8	68	250	75	75
100	10 3/4	40.5	2,000	90	80
101	8 5/8	22	500	80	80
102	8 5/8	24	900	80	80
103	8 5/8	22	200	65	65
104	8 5/8	22	125	65	65
105	8 5/8	24	1,200	70	70
106	8 5/8	24	105	70	70
107	10 3/4	43	5,300	110	90
108	8 5/8	24	1,000	70	70
109	11 3/4	54	750	80	80
110	9 5/8	36	2,000	90	85
111	9 5/8	36	1,000	80	80
112	9 5/8	36	400	80	70
113	8 5/8	24	600	70	70
114	9 5/8	36	1,900	114	80
115	13 3/8	54.5	350	80	70
116	9 5/8	36	2,000	110	90
117	8 5/8	22	250	90	70
118	13 3/8	68	2,980	116	80
119	8 5/8	24	250	85	70
120	8 5/8	24	400	80	70
121	13 3/8	68	3,250	136	100
122	8 5/8	32	1,500	90	70
123	8 5/8	32	110	80	70
124	8 5/8	24	1,350	100	80

125	8 5/8	24	500	88	70
126	8 5/8	20	150	100	80
127	8 5/8	24	3,000	120	95
128	9 5/8	36	500	85	70
129	8 5/8	24	250	85	70
130	9 5/8	36	2,700	92	85
131	9 5/8	36	2,700	92	85
132	9 5/8	36	800	95	80
133	10 3/4	40.5	2,300	115	80
134	10 3/4	60.7	2,080	105	80
135	8 5/8	28	3,600	142	110
136	13 3/8	72	5,200	90	70
137	11 3/4	42	975	80	70
138	9 5/8	36	500	103	80
139	8 5/8	24	160	95	80
140	8 5/8	24	475	85	70
141	8 5/8	24	400	90	80
142	8 5/8	24	120	80	70
143	13 3/8	68	3,000	125	95
144	10 3/4	45.75	2,000	115	90
145	10 3/	60.7	3,250	100	80
146	8 5/8	24	600	85	70
147	8 5/8	20	320	70	70
148	13 3/8	72	980	70	70
149	9 5/8	40	1,500	103	80
150	9 5/8	36	1,800	95	70
151	8 5/8	24	200	85	70
152	8 5/8	24	150	85	70
153	9 5/8	36	600	80	60
154	8 5/8	32	950	100	80
155	13 3/8	72	4,900	141	100
156	13 3/8	72	4,500	132	95
157	13 3/8	68	4,000	135	105
158	8 5/8	28	1,900	85	70
159	13 3/8	54.5	450	70	60
160	13 3/8	68	3,000	125	90
161	10 3/4	40.5	2,000	110	80
162	9 5/8	43.5	2,000	95	80
163	20	94	2,000	110	90
164	8 5/8	24	3,300	120	90
165	10 3/4	40.5	1,900	105	80
166	13 3/8	72	5,000	120	90

167	13 3/8	68	3,000	125	95
168	13 3/8	54.5	450	69	60
169	8 5/8	24	600	90	80
170	13 3/8	68	6,100	160	120
171	13 3/8	61	40	65	65
172	11 3/4	38	250	70	70
173	8 5/8	24	1,500	70	60
174	9 5/8	36	800	77.5	65
175	10 3/4	40.5	550	75	70
176	9 5/8	36	500	110	90
177	9 5/8	38	500	100	90
178	13 3/8	61	600	110	90
179	12 1/2	36	80	80	80
180	9 5/8	36	1,300	80	80
181	9 5/8	38	500	110	90
182	8 5/8	30	1,000	90	90

Table 11.2.2—Intermediate Casing

Field No.	Csg. Size (in.)	Csg. Wt. (lb/ft)	Depth (ft)	BHST (°F)	BHCT (°F)
1	13 3/8	72	10,500	250	180
2	9 5/8	42.5	17,500	330	265
3	9 5/8	47	9,500	190	120
4	9 5/8	47	9,000	185	120
5	9 5/8	47	8,500	180	120
6	8 5/8	28	3,200	115	90
7	8 5/8	37	1,000	100	80
8	9 5/8	36	1,300	80	60
9	9 5/8	47	7,200	175	130
10	13 3/8	68	3,000	120	95
11	16	75	2,000	110	90
12	9 5/8	36	3,000	120	90
13	9 5/8	53	11,600	230	155
14	7 5/8	31.7	12,400	260	185
15	9 5/8	53.5	5,000	145	100
16	8 5/8	22	2,000	110	80
17	7	24.7	4,700	140	100
18	9 5/8	41.5	17,500	330	255
19	7	20	2,000	80	70
20	9 5/8	53.5	13,400	240	180
21	9 5/8	53.5	11,700	210	140
22	9 5/8	43.5	13,200	242	160
23	11 3/4	65	11,750	206	140
24	10 3/4	45.5	2,500	110	90
25	9 5/8	47	4,751	126	95
26	13 3/8	72	5,650	120	90
27	9 5/8	53.5	7,500	205	140
28	9 5/8	53.5	19,000	315	240
29	9 5/8	53.5	11,950	212	140
30	11 3/4	65	11,500	230	160
31	9 5/8	53.5	13,000	180	125
32	9 5/8	53.5	14,500	254	180
33	9 5/8	53	15,500	280	205
34	8 5/8	28	37,500	85	80
35	10 3/4	51	6,500	120	95
36	8 5/8	28	1,600	70	70
37	7 5/8	35	14,400	297.5	235
38	8 5/8	32	3,000	90	70
39	8 5/8	28	3,050	95	80
40	8 5/8	28	3,000	110	80

41	8 5/8	24	2,200	110	80
42	13 3/8	61	2,900	95	70
43	9 5/8	40	4,300	113	80
44	5 1/2	17	8,000	155	110
45	8 5/8	24	1,000	90	85
46	7 5/8	39	16,000	195	140
47	7 5/8	39	16,500	220	155
48	8 5/8	32	3,000	120	100
49	8 5/8	28	6,000	130	95
50	9 5/8	47	9,207	209	155
51	9 5/8	53.5	10,750	256	195
52	7	24.5	10,850	190	130
53	7	24.5	10,850	190	130
54	7 5/8	29.7	6,500	185	125
55	7 5/8	33.7	11,000	250	190
56	10 3/4	45.75	12,800	160	110
57	8 5/8	32	4,900	110	80
58	9 5/8	53.5	9,500	232	170
59	7 5/8	39	10,425	236	180
60	8 5/8	32	4,500	85	70
61	9 5/8	53.5	9,280	176	125
62	9 5/8	53.5	8,300	185	130
63	9 5/8	43.5	9,700	210	145
64	8 5/8	32	5,000	110	90
65	9 5/8	47	7,200	195	130
66	7 5/8	29.7	8,300	220	165
67	7	35	9,100	220	170
68	13 3/8	68	8,100	200	130
69	7 5/8	26.4	8,400	220	155
70	9 5/8	47	15,000	260	175
71	9 5/8	53.5	10,300	245	190
72	9 5/8	43.5	9,600	250	190
73	8 5/8	22	2,000	110	80
74	8 5/8	24	1,400	70	70
75	7	72	2,300	85	85
76	7	23	3,875	90	80
77	9 5/8	38	4,800	160	115

11.3 Appendix 3

TR00-1 Russian Hollow Microsphere Cements

Russian Hollow Microsphere Cements

TR00-1

By

Dr. Vladimir V. Sledkov
LUKOIL
Sretensky Boulevard, 11
Moscow, Russia 101000

1. The Light-Duty Cements and Materials Used for Their Preparation

The traditional components for the light cements are: expanded clay aggregate, expanded pearlite sand, filter pearlite, burnt diatomite sand, petroleum coke, coal dust, Gilsonite, plaster, asbestos, Kerogen, and clay.

All of these components have large water requirements, and do not allow cement weights less then 1.45 g/cm^3 without changing other cement properties. Some of them (e.g., expanded pearlite and sand) fail under pressure and form new surfaces, intensively linking water to the concrete mix, increasing cement density, and increasing circulation loss problems.

The addition of high strength hollow microspheres increases crack resistance, and reduces density and cement strength. The Russians have used hollow spheres made from phenol-formaldehyde and carbamide formaldehyde tars, which have a trademark Plaminol [1, 2].

The hydrophobic microspheres are filled with nitrogen to withstand pressures up to 15 MPa and allow cement weights of 1.20 g/cm^3. Plaminol limitations are limited hydrostatic collapse strength, reduced cement strength, and high cost. Plaminol microsphere characteristics are shown in Table 1.

TABLE 1. Plaminol Microsphere Characteristics

Plaminol	Trademark (grade) FFP	Trademark (grade) MFP
1. Weight, g/cm^3		
- bulk	0.22-0.27	0.08-0.16
- mean	0.35-0.42	0.04-0.12
2. Dimensions, μm	50-400	50-300
3. Volumetric Compression Strength, MPa	20.0	15.0

The use of glass and ceramic microspheres made in the USA, Japan, Finland, Russia, and France have more potential. The hollow microspheres are produced from a mixture of liquid sodium silicate glass and a foaming agent. Carbonates, bicarbonates, sulphates, nitrates, and acids are used as foaming agents. The mass is dried and crushed after a foaming agent is added. The crushed powder is simultaneously melted and filled with gas bubbles (more often CO_2) during a high-temperature blending and blowing process. There are also other technologies, for example [3].

The glass microspheres have low density, high specific volumetric compression strength, low dielectric permeability in a broad band of frequencies, and good thermal insulation characteristics. There

is no irregular stress distribution around the microspheres as with other irregular fillers such as expanded pearlite.

Silicate, carbon, ceramic, and natural crystalline phase volcanic glass microspheres are produced also. The Russian hollow glass microsphere performance is shown in Table 2.

TABLE 2. Russian Hollow Glass Microsphere Characteristics

Grade	Group	Weight		Dimensions			Min 10% destr. Strength	Max Appl. Temp.	Dielectric Properties	
		True G/cm³	Volumetric g/cm³	μm *	μm *	μm *	MPa	°C	ε	tgδ
MC	A1	0.24-0.32	0.13-0.20	156	77	35	2.0	700	-	-
	A2	0.26-0.32	0.14-0.21	119	51	39	2.8			
MC-A9	A1	0.24-0.32	0.14-0.21	148	79	38	3.0	150	1.4-1.6	0.008
	A2	0.26--0.32	0.16-0.21	104	48	27	4.5			
	B1	0.33-0.40	0.20-0.26	102	50	28	4.5			
	B2	0.31-0.36	0.19-0.24	110	59	29	5.0			
MC	B	0.15-0.30	0.08-0.20	159	83	33	0.8	650	1.4	0.002
	1L	0.20-0.24	0.12-0.16	116	64	40	4.5			
MC-VP	2	0.25-0.32	0.13-0.21	122	68	33	6.0	-	1.4	0.006
	1L	0.20-0.24	0.13-0.16	111	63	41	4.5			
MC-VP	2	0.25-0.31	0.16-0.20	128	67	34	6.5	150	1.6	0.006
	3	0.27-0.31	0.17-0.20	105	64	42	9.0			
BK	-	0.25-0.30	0.13-0.18	158	78	39	4.5	1100	1.2	0.0005

* – Typical values
** – Max. diameter for fractions with 90, 50, and 10% microsphere mass on the integral distribution line
*** – For frequency interval 0.1-10 Hz.

Microspheres are delivered in the polyethylene sacks, stacked in cardboard boxes. The boxes can be delivered in piles.

TABLE 2a. Domestic Aluminum Sodium Borosilicate Glass Hollow Microsphere Properties (Manufacturer: "Fiber Glass," Novgorod, "Glass Fibre Plastics," Moscow Area)

Parameter	Microspheres Grade			
	O Group A	O Group B	MCO-O A9 Group A	MCO-O A9 Group B
Weight, g/cm³: – bulk – mean	0.12-0.16 0.24-0.30	0.16-0.20 0.31-0.40	0.12-0.16 0.24-0.30	0.15-0.20 0.31-0.40
Wall Thickness, μm	1-2	2-3	1-2	2-3
Thermal Conduction, W/(m°C)	0.06	-	-	0.067
Volumetric Compression Strength MPa	10.0-15.0	12.0-18.0	12.0-15.0	15.0-20.0

Notes: Diameter – up to 200 microns, Volume Space Factor – 0.6

The properties of hollow microspheres made in countries outside of Russia are shown in Tables 3 to 10.

TABLE 3. Hollow Glass Microsphere Properties
Manufacturer: "Emerson and Cuming Inc." (USA)

Parameter	Grade					
	Sodium borosilicate glass				SI (Silica – 95%)	VT (Silica with finishing agent)
	IG101	IG101D	IG25	R		
Weight, g/cm^3: – bulk – mean	 0.19 0.31	 0.19 0.30	 0.14 0.24	 0.17 0.36	 0.15 0.25	 0.16 0.27
Dimensions, μm	<200	<150	<175	<200	<175	<175
Volume Space Factor	0.62	0.65	0.61	0.46	0.56	0.60
Wall Thickness, μm	2	1.5	1.5	2	1.5	1.7
Initial Softening Temperature, °C	480	480	480	480	1000	315
Thermal conduction, W/(m °C)	0.06	-	-	-	-	-

TABLE 4. Hollow Glass Microsphere Properties
Manufacturer: "Minnesota Mining Manufacturing Co." (USA)

Parameter	GRADE							
	B15/ /250*	B20/ /350*	B23/ /500*	B28/ /750*	D35/ /1000*	B38/ /2000*	FT-102	FTD-202
Weight, g/cm^3: – bulk – mean	0.12-0.18 -	0.17-0.23 -	0.2-0.26 -	0.2-0.3 -	0.35 -	0.38 -	0.16 0.26	0.15 0.24
Volumetric Compression Strength, MPa	25.0	35.0	50.0	75.0	100.0	200.0	-	-
Dimensions, μm	-	-	-	-	-	-	<200	<200
Volume Space factor	-	-	-	-	-	-	0.62	0.62
Wall thickness, μm	-	-	-	-	-	-	1.5	1.2
Initial Softening Temperature, °C	-	-	-	-	-	-	1093	1093

* Close to ordinary leaf glass composition and structure

TABLE 5. Ceramic, Corundum, and Rock Hollow Microsphere Properties

Parameter	Manufacturer, Country		
	Seva Denco Norton Co., Japan, USA (Ceramic)	Carborundum Co., USA (Corundum)	Sirasy, Japan (Volcanic Glass, Feldspar and Quartz)
Weight, g/cm^3: – bulk – mean	0.6-0.9 -	0.25-0.4 -	0.14-0.32 0.39-0.69
Dimensions, μm	100-8000	40-500	30-6000
Volume Space factor			
Wall Thickness, μm	-	2.3-4.0	6-14
Initial Softening Temperature, °C	-		900-1000
Thermal Conduction, W/(m °C)			0.08
Volumetric Compression Strength, MPa	8.6	-	1.5-2.0

TABLE 6. Pearlite, Silicate, and Carbon Hollow Microsphere Properties

Parameter	Grade, Country – Manufacturer		
	Pearlite USA, France	Q-Cel, Silicate USA, Finland	Carbospheres, Carbon USA
Weight, g/cm^3: – bulk – mean	0.062-0.099 0.17-0.41	0.1 0.2	0.12-0.14 0.20-0.22
Dimensions, μm	75-145	20-200	5-150
Wall Thickness, μm	0.7-1.5	-	1-2
Thermal conduction, W/(m °C)		0.043	
Volumetric compression strength, MPa	-	-	-

TABLE 7. Carbon Hollow Microsphere (Krecaspheres) Properties
Manufacturer: "Kurecha Karaku" (Japan)

Parameter	Grade			
	A-50	A-100	A-200	A-300
Weight, g/cm^3: – bulk – mean	0.1-0.3 0.15-0.4	0.1-0.3 0.15-0.40	0.07-0.20 0.15-0.35	0.05-0.20 0.10-0.30
Dimensions, μm	45-75	75-150	150-250	250-420
Wall Thickness, μm	1-2	2-3	3-8	6-12

TABLE 8. Hollow and Polymeric Microsphere Properties

Parameter	Ceramic (Aluminum Silicate) "Drilling Fluids Service" Poland	Polymeric (**Phenol**-Formaldehyde) "PolymerSyntez" Vladimir, Russia
Weight, g/cm^3: – bulk – mean	 0.32-0.45 0.65-0.8	 0.35-0.45 0.7-0.9
Dimensions, μm	<500	-
Wall Thickness, μm	1400	-
Thermal Conduction, W/(m °C)	0.06	0.05
Volumetric Compression Strength, MPa	<5	<4

Note: Volume Space factor - 0.6

Ceramic, glass and polymer microsphere chemical compositions are shown in Table 9 [4].

TABLE 9. Hollow Microsphere Typical Chemical Structure

Components	Microsphere Structure %		
	Glass	Ceramic	Polymer
SiO_2	60-80	55-59	-
Al_2O_3	4-10	27-31	-
Fe_2O_3	-	4.6-5.5	-
K_2O	5-16	3.2-3.7	-
CaO	5-25	1.1-1.8	-
MgO	0-15	1.3-1.7	-
SO_2/SO_3	-	0.05-0.1	-
Cl	-	<0.1	-
Na_2O	5-16	1.0-2.0	-
MnO_2	0-10	-	-
B_2O_5	10-20	-	-
P_2O_5	0-5	-	-
Phenol-formaldehyde	-	-	100

Fractional components of Portland cement made with polymer (PM) and ceramic microspheres (CM) are shown in the Table 10 and X-ray patterns (Fig. 1 and Fig. 2).

TABLE 10. Microspheres and Portland Cement Fractional Structure

Particle Dimension µm	Contents, %				
	Cement Grade			Ceramic CMS	Polymeric PMS
	PC	GMS	AGMS		
0-15				-	-
16-30	12.8	22.3	23	-	-
31-45	32.6	40.5	40.6	-	5
46-60	28.1	27.2	25.7	5	10
61-80	15	10	10.7	5	5
81-250	8.8	-	-	78	60
251-500	2.7	-	-	12	20
Mean	2.7	-	-	140.2	110.3
	35.9	25.45	24.98		

AGMS denotes finished MCO-A9 Group B microspheres. Finish agent is a silicone fluid: γ - aminopropylsilane $NH_2(CH_2)_3 \cdot Si(OC_2H_5)_3$. Finished agent required quantity is 0.3% from a microsphere mass.

We can see the peaks (3.52; 3.22; 4.04)$\cdot 10^{-10}$ m on the X-ray pattern (Fig. 1), stipulated probably by a sodium borosilicate glass and boroaluminate glass peak (2.81; 4.29; 3.80)$\cdot 10^{-10}$ m. These components add glass corrosion resistance.

Microspheres with metal cover on external and internal surfaces are developed in the USA also as well as sodium borosilicate glass and boroaluminate glass microspheres [5, 6, 7].

The use of microspheres requires the enlarged contents of water, as a rule, with the purpose of a sliding stratum creation [8, 9]. Waterless sodium metasilicate (3%) have to be added for preservation of microspheres wholeness during intermixing.

It is known, the sodium glass has stability to acids, but is liable to attack by alkaline medium, which is present in cement systems.

Under the judgement of the contributors majority, the cement matrix aggression in the relation to the glass with the $Ca(OH)_2$ content increase [10]. It is recommended to enter: ashes – ablation, puzzolana, pumice, slag, ashes, expanded clay aggregate sand, and expanded clay, i.e., components to bind lime, for reduction of the cement matrix aggression [11,12, 13, 14].

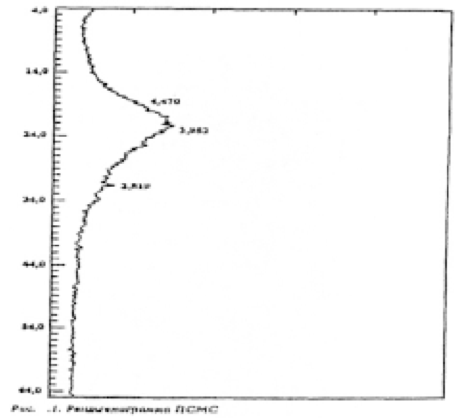


Fig. 1. GMS X-Ray Pattern

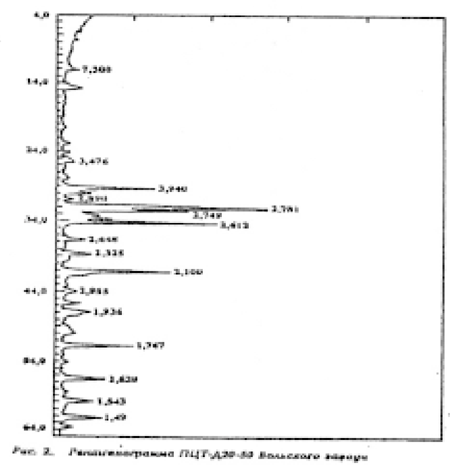


Fig. 2. PC X-Ray Pattern (Manufacturer: Volsky works, Russia)

Leaching takes place on a glass surface during the first stage of cementing. A protective calcium hydrosilicate diffuse layer together with silicon acid forms during the second stage. During the third stage, leaching of surface imperfections takes place along with crystalline hydrate crystallization and growth. This shows that surface protection of the glass microspheres is a necessity.

Silicones or other silicone liquids are used to produce a good cement adhesion with matrix and protect the glass surfaces.

Boron and aluminum silicates are the most chemical strong materials [15]. Difficult-to-dissolve hydroxides and water silicates are generated in protective films on glass surfaces by alkaline earth oxide hydrolysis. Silicon acid gels remain on the surface and slow down silicate glass destruction [15].

Ten years Russian experience has shown that microsphere corrosion does not occur with cements.

The properties of Portland cements (PC) made with polymeric (PMS) and ceramic (CMS) microspheres are shown in Tables 11 and 12.

TABLE 11. Light Cement Parameters

Seq. #	Cement Mix % (by mass)		Mean Weight g/cm^3	Fluidity Sm	Circulation P_m^{100}, h-min	Setting Period h-min	
						Start	End
1	PC, Water	100 50	1.825	17	1-30	1-55	2-35
2	PC, CMS, Water	100 10 80	1.470	23	2-10	2-30	3-20
3	PC CMS, Water	100 15 90	1.400	25	2-2	2-45	3-40
4	PC, CMS, Water	100 20 105	1.330	25	2-30	3-10	4-15
5	PC, CMS, Water	100 25 115	1.280	25	2-45	3-45	5-15
6	PC, PMS, Water	100 10 75	1.340	24	1-4	2-05	2-55
7	PC, PMS, Water	100 15 85	1.230	24	1-35	2-05	3-20
8	PC, PMS, Water	100 20 95	1.170	24	1-35	1-55	3-35

Notes: Temperature 75°C, atmospheric pressure

TABLE 12. Polymeric and Ceramic Microsphere Cement Properties

Seq. No.	Cement Mix (% by Mass)	Stone Strength, MPa			Body Adhesion Strength MPa
		Bending Strength	Compressive Strength		
			Top	Bottom	
1	PC 100 Water 50	5.25/2.1 –	24.93/13.2 –	24.93/13.2 –	2.96/1.5 –
2	PC 100 Water 90 CMS 15	4.46/2.3 5.34/2.7	9.90/5.0 10.20/5.2	13.20/6.8 16.50/8.4	-
3	PC 100 CMS 20 Water 105	2.38/1.2 –	6.93/3.5 –	12.54/6.29 –	-
4	PC 100 CMS 25 Water 115	1.25/0.6 –	3.66/1.9 –	3.96/2.0 –	0.92/0.5 –
5	PC 100 PMS 10 Water 75	3.86/2.0 3.86/2.0	6.60/3.4 7.26/3.7	6.60/3.4 10,56/5,3	-
6	PC 100 PMS 15 Water 85	1.19/0.6 –	6.27/3.1 –	6.6/3.4 –	-
7	PC 100 PMS 20 Water 95	0.47/0.25 –	2.31/1.3 –	2.77/1.9 –	1.26/0.6 –

Note: 1. Temperature 75°C/22°C, atmospheric pressure. 2. Numerator – grouting mortar is not treated by pressure, denominator – grouting mortar is treated by pressure 30 MPa.

The effect of pressure on cement weight is shown in Figs. 3 and 4 for light cements containing polymeric and ceramic microspheres.

Fig.3

Рис. 3 . Изменение плотности облегченных цементных тампонажных растворов в зависимости от давления обработки:
1 — 100 % ПЦТ-Д20-100 + + 15 % КМС + 90 % воды;
2 — 100 % ПЦТ-Д20-100 + + 10 % ПМС + 75 % воды
1

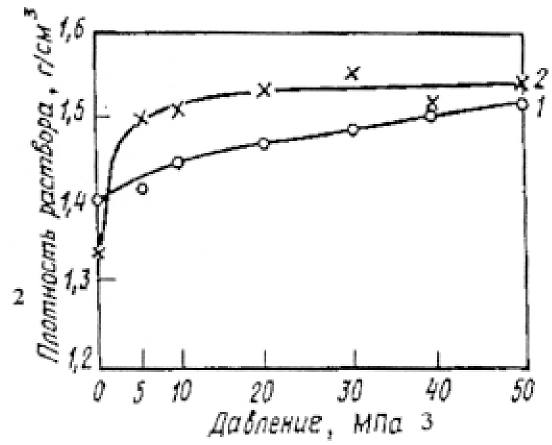


Fig.4

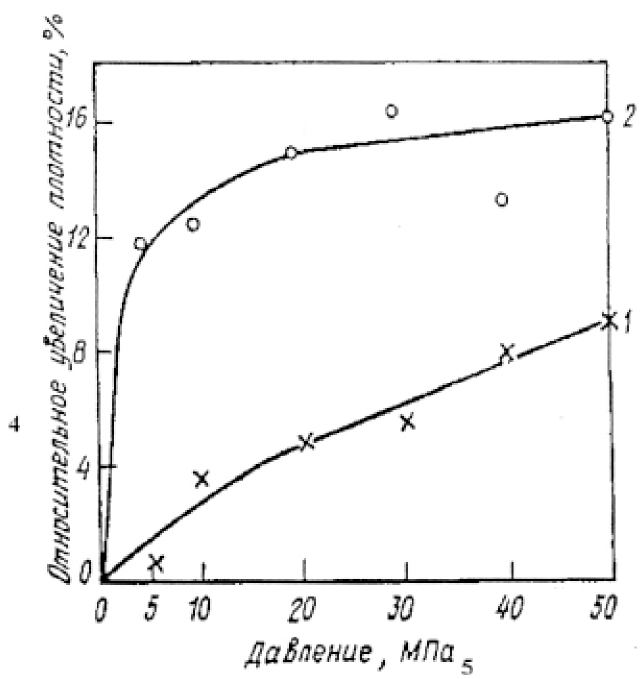


Рис. 4 Влияние величины давления на относительное увеличение плотности облегченных тампонажных растворов (разрушение микросфер) при одинаковой средней плотности, % (по массе). 6
Условные обозначения см. рис. 4.2

Figs. 3 and 4 captions in English are as follows:

1. Light oil-well cement weight vs. treatment pressure
   1) 100% PC-D20-100 + 15% CMS + 10% Water
   2) 100%PC-D20-100 + 10% PMS + 75% Water
2. Weight, g/cm^3
3. Pressure, MPa
4. Relative weight magnification, %
5. Pressure, MPa
6. Oil-well light relative weight (microspheres failure) magnification vs. pressure

TABLE 13. Cement and Stone Mixture with the Glass Microspheres Components

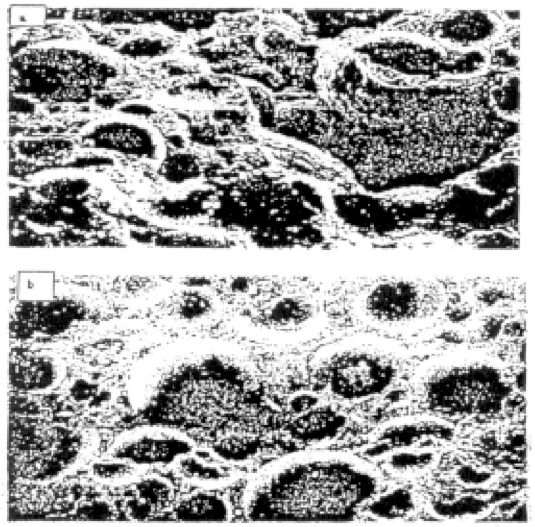
Composition, %	Setting Period h-min		W/C**	Strength MPa		Dry Mean Weight	Humidity %	Dry Water Absorption %		Cement Martix Volume Fraction
	Start	End		Compres.	Bending	g/cm^3	Mass	Mass	Volume	
				GMS Doping						
GMS,10	3-05	5-50	0.45	14.4	2.68	1.042	8.79	26.52	27.63	0.529
PC, 100										
GMS,20	3-05	6-10	0.645	7.38	2.147	0.762	9.29	35.41	26.27	0.451
PC,100										
GMS,30	3-05	6-30	0.925	5.12	1.317	0.603	9.01	42.26	25.49	0.391
PC,100										
PC from Sebriakovsk Works	3-05	5-50	0.22	51.93	8.833	1.829	7.28	15.47	28.29	1
				AGMS Doping						
AGMS,10	3-20	5-20	0.364	16.58	3.82	1.052	7.24	14.31	15.05	0.577
PC,100										
AGMS, 20	3-25	5-40	0.562	10.16	2.65	0.725	7.13	20.84	15.11	0.438
PC,100										
AGMS, 30	3-30	6-10	0.730	6.08	1.84	0.601	8.04	28.14	16.91	0.366
PC, 100										

** Cone spread 115 mm, W/C – Water/Cement Ratio
Note: PC – Portland Cement, GMS – Glass Microspheres, AGMS – Glass Microspheres with aminopropylsilane

The microstructure of cement made with GMS and AGMS microspheres shown in Fig. 5 was obtained using a scanning electronic microscope CAMSKAN (UK).

The cement weight as a function of glass microspheres mass fraction is shown in Fig. 6 and as a function of water/cement ratio (W/C) in Fig. 7. The impact of microspheres fraction on the cement strength is shown in Fig. 8.

The permeability and adhesive bond strength of cements containing glass microspheres are shown in Table 14, and the rheological properties are shown in the Fig. 9.



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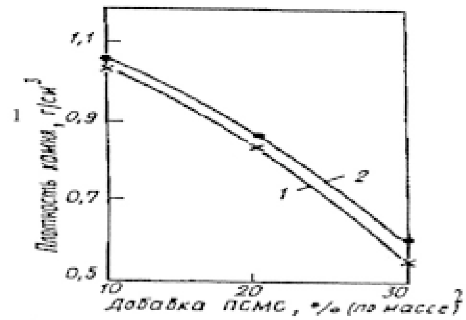
[illegible]

Fig 5

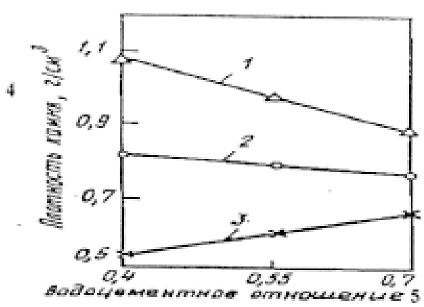
Fig. 5 caption:

1. Fig. 5. Plugging cement microstructure: (a) – with GMS, (b) – with AGMS x 400



3
Рис. 6. Зависимость средней плотности облегченного цементного тампонажного камня от содержания микросфер:
1, 2 — в возрасте 28 и 180 сут соответственно

Fig.6



6 Рис.7 Зависимость средней плотности облегченного цементного тампонажного камня от В/Ц:
1, 2, 3 — с добавкой ПСМС в количестве 10, 20 и 30 % (по массе) соответственно

Fig.7

Fig. 6 and Fig. 7 captions (English):

1. Plugging cement weight
2. GMS mass fraction, %
3. Mean plugging cement weight vs. microspheres mass fraction
    1) – 28 days cement age
    2) – 180 days cement age
4. Plugging cement mean weight
5. Water/cement ratio
6. Mean plugging cement weight vs. water/cement ratio
    1) – 10% GMS mass fraction
    2) – 20% GMS mass fraction
    3) – 30% GMS mass fraction

Fig.8

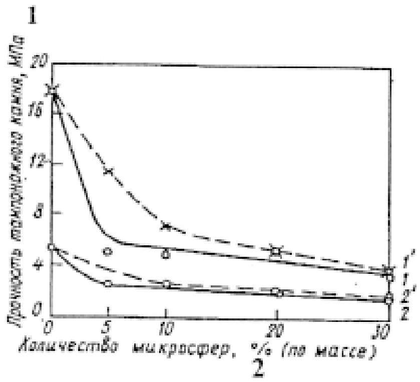


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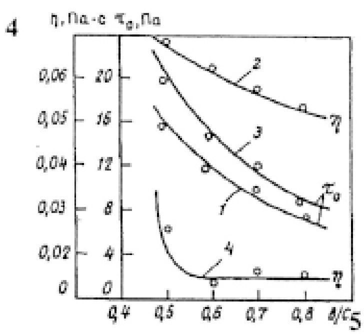
Рис. 8. Зависимость прочности облегченного цементного камня от расхода микросфер:
1, 1' — прочность при сжатии; 2, 2' — прочность при изгибе; 1, 2 — с ПСМС; 1', 2' — с АПСМС

Fig.9



6 *Рис. 9 Зависимость реологических свойств различных растворов от водосмесевого отношения:* 1, 2 — облегченные растворы с добавкой микросфер; 3, 4 — раствор из портландцемента; τ_0 — динамическое напряжение сдвига; η — пластическая вязкость

Fig. 8 and Fig. 9 captions (English):

1. Oil-well cement strength
2. Microspheres mass fraction, %
3. Light oil-well cement strength vs MS mass fraction
   - 1,1' – compression strength
   - 2,2' – bending strength
   - 1,2 – GMS cement
   - 1',2' – AGMS cement
4. η, Pa•Sec., τ_0, Pa
5. W/C – water/cement ratio
6. Rheological characteristics vs. water/cement ratio
   - 1,2 – light cement with microspheres
   - 3,4 – cement mix
   - τ_0 – yield point
   - η – plastic viscosity

TABLE 14. Adhesive Bond Between Plugging Cement and Glass or String Metal. (Plugging Cement Permeability)

Mix #	Mass Fractions, %			W/C	Permeability	Bond Strength MPa	
	PCT	GMS	AGMS		10^{-3} μm^2	Glass	Metal
1	100	-	10	0.44	0.0023/0.0038	0.43/0.22	1.71/0.88
2	100	10	-	0.75	0.029/0.05	0.57/0.3	1.25/0.65
3	100	-	-	0.50	0.0041/0.008	0.40/0.25	2.38/1.25

Notes: 1. Conditions of plugging cement setting: temperature 75°C/22°C, atmospheric pressure.
2. Numerator – parameters at the temperature of 75°C

As stated above, one of the lightweight fillers is filter pearlite. VolgogradNIPINeft (Lukoil Oil Research Institute) found that filter pearlite collapsed at pressures of 30 MPa. Filter pearlite is a waste of expanded pearlite production technology and has low cost.

Filter pearlite's specific surface is 3000 cm^2/g, average size of particles is 29.22 μm, and the density is 2.19 g/cm^3.

Chemical composition:

component	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	PPP
fraction, %	74	13	0.8	3.5	4	3/4

Caustic magnesite (CMA) and superplasticizer (SP) are used as additives to improve cement characteristics. Mathematical planning matrixes and filter pearlite cement characteristics are presented in Tables 15 and 16.

The component CMA ensures a volume increase during the solidification and improves bond strength with the casing and borehole walls. Superplasticizer (SP) reduces cement water requirements by 20-25% and ensures low porosity decrease.

TABLE 15. Mathematical Planning Matrix, Cement, and Stone Properties

Mix #	Factors (cement mass fraction, %)		Efficiency functions									
	FP	SP	W/C	P_p g/cm³	p100 h '	Humidity, % mass	Humidity, % vol.	R, MPa bend	R, MPa comp	R_{bs} MPa	P_0, g/cm³	B_m %
1.	30	1.5	1.25	1.33	1.25	4.92	5.42	2.55	7.14	0.85	0.93	32.8
2.	30	0	1.6	1.32	0.85	2.83	4.33	1.4	2.31	0.12	0.72	59.0
3.	0	1.5	0.26	2.86	0.75	0.93	1.92	9.2	43.3	3.1	1.93	9.16
4.	0	0	0.5	1.81	1.0	1.83	2.92	5.9	17.9	1.54	1.54	20.6
5.	30	0.75	1.25	1.38	1.25	5.25	6.0	2.9	6.18	0.81	1.04	21.9
6.	0	0.75	0.26	2.09	0.75	1.17	2.0	11.0	46.0	3.4	2.01	5.0
7.	15	1.5	0.72	1.56	0.92	3.33	6.25	4.4	11.0	2.02	1.11	15.7
8.	15	0	1.0	1.45	0.65	2.92	3.75	2.7	2.56	0.65	1.20	18.6
9.	15	0.75	0.73	1.57	0.75	3.33	6.25	3.8	7.1	1.94	1.33	11.4
10.	15	0.75	0.73	1.56	0.74	3.3	6.15	3.7	7.0	1.9	1.32	11.2
11.	15	0.75	0.73	1.56	0.75	3.32	6.2	3.8	7.1	1.92	1.32	11.3

Convention: $\frac{p100}{m}$ – circulation; R – strength, R_{bs} – bond strength between steel casing and cement stone; P_0 – means dry stone density; P_p – cement solution density; B_M – water requirements (% of dry stone mass), FP – filter pearlite; SP – superplasticizer

Table 16. Mathematical Planning Matrix, Additive Cement Solution and Cement Stone Properties (Additions: Filter Pearlite and Caustic Magnesite)

Mix	Factors (Cement Mass Fraction, %)			Efficiency functions									
				W/C	P_p	p_m^{100},	Humidity, %		R, MPa		R_b,	P_0,	B_m
#	FP	SP	CMA		g/cm³	h	Mass	vol	bend	Comp	MPa	g/cm³	%
1'	30	1.5	15	1.3	1.35	1.75	3.08	4.83	2.1	4.72	1.04	1.03	62.3
2'	0	1.5	15	0.41	1.92	0.75	2.16	2.75	5.4	19.9	3.71	1.85	21.1
3'	30	0	15	1.55	1.38	1.33	2.67	3.75	1.9	3.25	0.52	0.94	62.5
4'	0	0	15	0.56	1.83	0.75	1.92	2.58	3.5	11.2	1.68	1.63	27.0
5'	30	1.5	5	1.25	1.38	1.0	2.25	3.68	2.[illegible]	5.88	0.52	0.98	63.6
6'	0	1.5	5	0.34	1.88	0.75	1.68	3.68	4.5	11.3	2.55	1.8	20.3
7'	30	0	5	1.6	1.33	0.75	1.25	4.08	1.5	2.88	0.23	0.95	78.2
8'	0	0	5	0.5	1.84	0.7	1.0	2.0	5.1	14.1	1.6	1.58	26.6
9'	30	0.75	10	1.35	1.37	0.75	1.25	4.68	2.3	3.99	0.75	1.06	65.9
10'	0	0.75	10	0.42	1.84	1.0	1.75	2.75	5.0	13.6	2.66	1.87	22.4
11'	15	1.5	10	0.9	1.49	1.1	1.5	3.5	3.4	10.1	1.42	1.16	17.8
12'	15	0	10	1.0	1.5	0.68	1.5	2.5	2.25	4.77	0.72	1.3	47.8
13'	15	0.75	15	0.95	1.55	1.0	1.68	4.0	2.2	5.04	1.18	1.4	43.3
14'	15	0.75	5	0.87	1.44	1.68	2.0	3.68	2.25	6.93	1.62	1.3	44.4
15'	15	0.75	10	0.88	1.48	1.16	1.92	3.68	2.5	6.82	1.04	1.37	42.4
16'	15	0.75	10	0.88	1.49	1.16	1.9	3.65	2.6	6.83	1.1	1.35	42.6
17'	15	0.75	10	0.88	1.48	1.2	01.93	3.68	2.6	6.8	1.05	1.35	42.7
Please see Table 15 convention													

These light cements were first field tested in the JSC "LUKOIL" branch "Nizhnevolzhskneft" oilfields (Volgograd region) where there were used to overcome low formation pressures and lost circulation problems. The tests were conducted in the permafrost zones of the Yamal peninsula mainly by Tumenburgas, a branch of the RAO "GAZPROM."

Wells and cement weights are listed in Table 17.

TABLE 17. Oil-Well Light Cement Industrial Oilfield Introduction

Well number, oilfield	Casing MD m	TOC m	Mean Cement Weight g/cm³
EPS – Expanded Pearlite Sand, Nizhnia Volga			
9 Pamiatnaj	2627	wellhead	1.39
10 Pamiatnaj	2633	"	1.40
11 Pamiatnaj	2477	"	1.40
135 Pamiatnaj	2663	"	1.40
137 Pamiatnaj	2592	"	1.38
139 Pamiatnaj	2563	"	1.39
195 Sasovskaj	2556	"	1.40
67 Dobrinskaj	2611	"	1.40
68 Dobrinskaj	2738	"	1.42
136 Pamiatnaj	2688	"	1.40
6 Chernuschinskaj	3017	"	1.40
9 Chernuschinskaj	2805	"	1.40
FP – Filter Pearlite, Nizhnia Volga			
78 Tersinskaj	2383	"	1.38
377 Pologaj	2106	"	1.40
372 Pologaj	2103	"	1.40
2 Demidivskaj	2643	"	1.43
329 Pologaj	2100	"	1.40
44 Maily-Haranskaj	3100	"	1.36
42 Maily-Haranskaj	3100	"	1.36
26 Ovrazhnaj	2641	"	1.39
81 N-Korobovskaj	2439	"	1.40
17 Kluchevskaj	2966	"	1.36
71 Tereninskaj	2380	"	1.38
AGMS – Finishing Hollow Glass Microspheres, Nizhnia Volga			
108 Sasovskaj	2520	"	1.38
13 Pamiatnaj	2592	"	1.36
141 Pamiatno-Sasovskaj	2595	"	1.38
143 Pamiatno-Sasovskaj	2604	"	1.36
29 Chernuschinskaj	2982	"	1.40
7 Chernuschinskaj	3022	"	1.40
8 Chernuschinskaj	2929	"	1.40
14 Chernuschinskaj	3070	"	1.40
ASHM – Aluminium Silicate Ceramic Hollow Glass Microspheres, Zapolairnaj			
244	3200	"	1.36
1022	1400	"	1.50
1023	1405	"	1.52
1043	1436	"	1.50
1044	1432	"	1.50
1116	1415	"	1.50
1141	1355	"	1.52
1142	1428	"	1.50
1146	1411	"	1.47
1153	1420	"	1.50
1156	1350	"	1.50
ASHM – Aluminium Silicate Ceramic Hollow Glass Microspheres, Ubileinoe			
272	1228	"	1.35
ASHM – Aluminium Silicate Ceramic Hollow Glass Microspheres, Urengoiskoe			
741	-	-	1.50
2361	2799	2806-1300	1.50
8337	-	-	1.35
8338	1406	-	1.35
10261	1283	Circulation loss	1.50
10262	1362	"	1.40
10263	1329	Wellhead	1.40
10264	1302	"	1.40
AGMS – Finishing Hollow Glass Microspheres, Zapolairnaj			
1021	1441	Underlift	1.50
1025	-	-	1.50
1026	1420	Wellhead	1.50
1040	1399	Partial circulation loss	1.5
1041	1425	Wellhead	1.50
1042	1420	-	1.40

Well number, oilfield	Casing MD m	TOC m	Mean Cement Weight g/cm³
1045	1350	Wellhead	1.46
1046	1425	"	1.47
1093	1400	"	1.50
1094	1401	"	1.48
1095	1398	"	1.49
1101	1419	"	1.50
1111	1420	"	1.50
1112	1425	Underlift	1.50
1114	1407	Wellhead	1.51
1115	1431	"	1.50
1143	1440	"	1.50
1144	1406	"	1.50
1145	1410	Full circulation loss	1.50
1154	1417	Wellhead	1.48
1155	1418	"	1.45
AGMS – **Finishing** Hollow Glass Microspheres, Urengoiskoe			
2359	2792	-	1.50
AGMS – **Finishing** Hollow Glass Microspheres, Komsomolskoe			
1321	1089	Wellhead	1.50
1322	1084	"	1.50
106-н	1030	"	1.40
AGMS – **Finishing** Hollow Glass Microspheres, Bovanenkovskoe			
6502	450	Conductor	1.50
HMS- **High-Strength** Hollow Glass Microspheres, Urengoiskoe			
2359	2792	-	1.50
AGMS – **Finishing** Hollow Glass Microspheres, Komsomolskoe			
1321	1089	Wellhead	1.50
1322	1084	"	1.50
106-н	1030	"	1.40
AGMS – **Finishing** Hollow Glass Microspheres, Bovanenkovskoe			
6502	450	Conductor	1.50
HMS – **High-Strength** Hollow Glass Microspheres, Urengoiskoe			
738	3612	Wellhead	1.40
8408	2883	Underlift	1.40
201336	3279	Wellhead	1.40
HMS – **High-Strength** Hollow Glass Microspheres , Peszovskoe			
208	3500	1 stage before casing shoe	1.50

Convention: EPS – expanded pearlite sand, FP – filter pearlite, GMS – hollow glass microspheres, AGMS – finishing hollow glass microspheres, ASHM – aluminium silicate ceramic HGMS, HMS – high-strength HGMS

The industrial oilfield testing confirmed the economic and technical benefits of the light-weight microspheres cements.

Aluminum silicate hollow microspheres (ASHM) were used to reduce costs. ASHM are the production wastes of the Kamensk-Schahtinskaj PowerStation. They consist of hollow spherical elements with aluminum silicate shells with the following properties: diameter – from 5 up to 100 microns, wall thickness – 2-15 microns, density – 0.3-0.4 g/cc, melting temperature – 1200-1300°C, hydrostatic collapse strength – 35.0-40.0 MPa (5075 to 5800 psi). ASHM inside gas phase consists of a mixture of nitrogen and CO_2.

For deeper wells, when the strength requests exceed 50 MPa (7250 psi), high-strength microspheres (HMS) manufactured by "Fiberglass," Andreevka City, Moscow region were used.

Aluminum oxide hollow microspheres from (corundum) are also produced in Russia. The main application of these microspheres is in high-temperature applications, and the greatest benefit is obtained when the corundum microspheres are used as a powder. High melting temperature, low thermal conduction, and small microsphere densities are used to form ultra lightweight refractories with a minimum binder quantity, for long operation at temperatures up to 1800°C.

The main characteristics of these aluminum oxide microspheres are shown in Table 18.

Table 18. Aluminium Oxide Microspheres Characteristics

Grade	Chemical Composition mass %	Volume Density g/cm^3	Dimensions, μm*			Melting Temp. ^{0}C	Dielectric Properties***	
			d90**	d50**	d10**		ε	tgδ
T	Al_2O_3 99.7	0.29-0.40	230	137	76	1800	2.4	0.0003

* Typical significances

** Maximal particle size for the fractions with 90, 50, and 10% microspheres weight-part concentration correspond to integral percentile curve

*** For a frequent interval of 0.1-10 Hz

These aluminum oxide microspheres are also used to manufacture new tool-class, high-porous grinding wheels and for metal working. The corundum microspheres increase grinding tool capacity 2.5 to 8 times when grinding composite alloying steels and permanent magnets and provide excellent processing quality. The important advantage of the aluminum oxide microsphere wheels is the high ecological processing cleanness compared to traditional high porous wheels.

Aluminum oxide microspheres have low dielectric permeability and their small dielectric losses ensure their effective application in composite materials for HF – SHF radio engineering and electronics engineering. These materials are used in the production of foil-clad dieletic, printed boards. An important advantage of aluminum oxide microspheres is their high stability in humid environments, ensuring high operational stability.

Neviansky cement works (Sverdlovsk region – Southern Ural) started using aluminum oxide microspheres in light-weight cement in 1998. Portland cement is manufactured from the power station's waste. These power stations are working on Ekibastus coal, cleared from organic impurities. In accordance with preliminary information, the microspheres density is ~0.4 g/cm^3. In Table 19, the properties of light-weight cements containing aluminum oxide microspheres used in the Sverdlovsk region are compared with other lightening components. Their application differs from glass, since cement thickening agents are used to prevent the microspheres from floating upward.

Table 19. Oil-Well Cement with Aluminum Oxide Microsphere Properties at the Temperature of 20^0C

Oil-well Cement	Weight g/cm	Fluidity sm	Water/ Solid Fraction Ratio %	Setting period h-min		Water Sediment %	Thickening Time h-min	Strength In 48 hours MPa	
				Start	End			Bend	Comp
1. At the All-Union state standard 1581-91 request	1.35-1.65	18-22	0.6-1.3	>2 h	<18 h	<3		0.7	
2. Vermiculite-cement based on the $CaCl_2$ solution	1.5	24	0.8	4 h 55 min	9 h 35 min		>3 h	0.7	
3. Gel Cement	1.5	20	0.8	13 h 20 min	16 h 40 min	0		0.7	
4. Glass microsphere additive	1.5	25	0.8	8 h 20 min	10 h 40 min	1		1.6	5
5. Aluminum silicate microspheres	1.5	24	0.8	9 h 25 min	11 h 45 min	0	3 h 10 min	2	6
7. Aluminum silicate MS + powder Bentonite	1.5	22	0.8	8 h 15 min	9 h 00 min	0		2.2	8.7
7. Aluminum silicate microspheres	1.3	21	0.6	10 h 45 min	13 h 15 min	1		1.3	4
8. Aluminum silicate MS + powder Bentonite	1.31	25	0.65	12 h 40 min	16 h 20 min	0	6 h 20 min	1.2	3.12
	1.4	25	0.6	10 h 35 min	13 h 10 min	0	6 h 20 min	1.6	4.47
	1.43	30	0.9	10 h 50 min	2 h 15 min	0	7 h 50 min	1.48	3

These aluminum oxide microspheres are manufactured by the company OOO "Bentonite of Ural" together with the company OAO "Neviansky Cementnik" under industrial conditions based on the oil-well Portland cement PC-DO-50, manufactured by "Neviansky Cement Works."

Despite limited oilfield experience with light-weight cements (0.7 g/cm^3 and less), the data in Tables 13 and 15 and in Figs. 6 and 7 as well as expert consensus and separate laboratory experiments, confirm the ability to produce effective light-weight oilfeld cements with densities of 0.7 g/cm^3 using microspheres. Design of these light-weight cements must consider cement strength, gas permeability, and cement properties for specific application conditions.

Conversion Chart:

1 MPa = 145 psi
1 meter = 3.28 feet
1 g/cc = 8.34 lb/gal

1.1 MICROSPHERE MANUFACTURERS IN RUSSIA AND POLAND

1. Novgorod Fiberglass Works
   Novgorod, Tel/Fax: (81622) 3-54-21

2. LLC [Bentonit Urala]
   622011, Ekaterinburg, Sibirjaka St., 145, Office 490
   Tel: (3432) 55-84-48; 55-51-67; Fax: (3432) 55-94-05

3. Branch of LLC [Bentonit Urala]
   624356 Sverdlovskaj Region, Kachkanar City, Block #4, Building #59
   Tel: (34341) 2-57-94; Tel/Fax: (34341) 2-57-84

4. JSC [Polymersintez]
   600016, Vladimir city, Frunze St., 77
   Tel: (09222) 7-62-23; Fax: (09222) 1-55-83

5. Poland Drilling Mud Service
   Poland, Krosno City, Armii Krajowej St., 3
   Tel/Fax (0-131) 2-39-11; Tel: (0-131) 2-39-41; (0-131) 6-19-55

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Appendix 2

Quarterly Report 2

Ultra-Lightweight Cement

Quarterly Report

January 1 to March 31, 2001

Fred Sabins

Issued April 15, 2001

DOE Award Number
DE-FC26-00NT40919, Tasks 1 and 3

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

1.0 Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultralight hollow glass spheres (ULHS). Work reported herein addresses Task 1: Assess Ultra-Lightweight Cementing Problems and Task 3: Test Ultra-Lightweight Cements. Results reported this quarter include a review and summary of Halliburton Energy Services (HES) and BJ Services historical performance data for lightweight cement applications. These data are analyzed and compared to ULHS cement and foamed cement performances. Similar data is expected from Schlumberger, and an analysis of this data will be completed in the following phases of the project. Quality control testing of materials used to formulate ULHS cements in the laboratory was completed to establish baseline material performance standards. A testing protocol was developed employing standard procedures as well as procedures tailored to evaluate ULHS and foamed cement. This protocol is presented and discussed. Results of further testing of ULHS cements are presented along with an analysis to establish cement performance design criteria to be used during the remainder of the project. Finally, a list of relevant literature on lightweight cement performance is compiled for review during the next quarter.

2.0 Table of Contents

3.0 List of Graphical Materials

3.1 Figures

3.2 Tables

4.0 Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a well bore. The slurry is pumped into the annular space between the borehole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, to isolate various formations from one another, and to control fluid movement within the well.

Typical cement fluid density ranges from 14 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitate application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, called lost circulation, increases the time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections: surface casings and intermediate casings. Since formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are relatively low.

The minimum practical density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength. Lower temperature further delays strength development. Achieving density requirements lower than this threshold or strength requirements greater than minimum necessitate use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent as candidate material for producing ultra-lightweight cements. These small, hollow glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS. The development will be achieved through a carefully designed program of modeling, design, laboratory testing, and field testing.

The phase of the project documented in this report involves further evaluation of ULHS cement, initial evaluation of foamed cement, and comparison of historical lightweight cement performance data from HES and BJ Services with the ULHS and foamed cement data. The compressive strength characteristics of these ULHS cements were also analyzed.

5.0 Executive Summary

The second quarter of this investigation focused on the completion of the evaluation of ULHS materials. The basic performance criteria were established to underpin the design of field-applicable cements for evaluation in the remainder of the project. Performance testing for foamed cement was initiated. In addition, a full suite of testing methods for ULHS and foamed cement were identified, and a routine quality control (QC) procedure was completed and implemented. Finally, historical data on lightweight cements were analyzed and a comprehensive literature search on lightweight cement data was initiated.

6.0 Experimental

Experimental methods employed in this investigation are based on generally-accepted laboratory test procedures for oilwell cements. Where applicable, standard methods presented in the API RP 10B[1] are followed. These tests include: thickening time, compressive strength, rheology, and free fluid.

Non-standard test procedures were necessary because of the unique nature of the ULHS. The spheres are brittle and can break when mixed in a slurry and subjected to differential pressure or shear. Additionally, the sphere's specific gravity is less than water, so the spheres can float, resulting in solids segregation. These non-standard laboratory methods include slurry mixing, density vs. pressure, and slurry stability.

Non-standard testing procedures for ULHS cements are outlined in detail in Appendix A. Procedures that are under development for consideration by ISO for laboratory mixing of foamed cements are also presented in this appendix. The results of testing presented in this report and Quarterly Report 1 indicate that these test procedures produced meaningful, representative data for lightweight cement. These test procedures will be adopted for the remainder of this work.

7.0 Results and Discussion

Laboratory data presented in the body of this report only contains sufficient information to denote trends or emphasize conclusions. Complete composition and data are presented in Appendix B.

7.1 BJ Services and HES Historical Data Analysis

Project members, Halliburton Energy Services (HES), and BJ Services, provided the data used in this study of lightweight cements (Appendix C). Data was compiled from field laboratory tests of active cement applications. These data represent a significant population of actual lighweight cement applications. Exact compositions were not specified because of the proprietary nature of these formulations. However, density, 24-hr. compressive strength, and BHCT information were complete. Similar data is expected from Schlumberger, and an extended analysis of all data will be completed in the following phases of the project. A summary of the data received to date is contained in Tables 7.1 through 7.3 (Page 8).

Table 7.1—Summary of Testing Data Sets from HES and BJ Services

Type of Cement	No. of Tests in Data Set	Type of Applications and Compositions							
		Offshore	Land-Based	With Bentonite	With Sodium Silicate	With Calcium Sulfate	With Microspheres	With HEC	With Blastfurnace Slag
HES Unfoamed	3778	most	small %	1097 (29%)	1077 (29%)	787 (21%)	137 (4%)	286 (8%)	20 (0.5%)
HES Foamed	294	all*	n/a	unspecified	unspecified	unspecified	unspecified	unspecified	unspecified
BJ Unfoamed	178	50	127	28 (16%)	55 (31%)	unspecified	48 (27%)	unspecified	unspecified

*Water depth ranged from 113 ft to 7,600 ft, with a large majority between 2,000 and 5,000 ft.

Table 7.2—Summary of Density Data

Type of Cement	Percentage of Tests within a Density Range (%)		
	9.0 to 10.9 lb/gal	11.0 to 11.9 lb/gal	12.0 to 13.0 lb/gal
HES Unfoamed	0.7	26.6	72.7
HES Foamed	11.0	22.0	67.0
BJ Unfoamed	16.0	32.0	55.0

Table 7.3—Types of Cement Used in Historical Test Data

Type of Cement	Base Cement Components (%)									
	Class A	Class C	Class G	Class H	TLW/ TXI	Microfine	Fly Ash/ Class A	Fly Ash/ Class H	Slag	Others
HES Unfoamed	19.0	—	—	35.0	20.0	7.0	6.0	11.0	2.0	—
HES Foamed*	47.0	—	—	9.4	—	43.0*	—	< 1.0	< 1.0	—
BJ Unfoamed	12.0	33.0	12.0	42.0	—	—	—	—	—	= 1.0

*All tests between 10.0 and 11.9 lb/gal were run using an unknown percentage of Microfine cement. Only 33 (19%) of the 12.0 to 12.9 lb/gal were run using Microfine cement. All remaining tests were either Class A (a large majority) or Class H.

This study investigates compressive strength information for lightweight cement systems. The compressive strength data is organized into three practical categories:

- 500 psi and above
- 200 to 499 psi
- Below 200 psi

This data analysis focuses on the 24-hour compressive strength of the two general categories of lightweight cements: foamed and unfoamed. Compressive strength is not necessarily the only deciding variable for cement evaluation, but it was chosen because it is readily available from the data. Because of insufficient information regarding composition, further analysis by composition is impractical.

Figure 1 on Page 9 depicts the data distribution for the two different categories of lightweight cements (foamed and unfoamed). The data for the unfoamed cements combines approximately 3,780 data sets from HES and approximately 170 data sets from BJ. HES also provides approximately 310 data sets for foamed slurries. No foamed cement data was provided by BJ at the time of this report.

The data is based on a variety of traditional lightweight cement systems including bentonite slurries, microfine cements, sodium silicate slurries, slurries with fumed silica, and hollow-sphere slurries (different from those studied in this project). Because more historical data is expected, only general relationships have been analyzed among the existing data. A detailed evaluation will be completed when the new data is received.

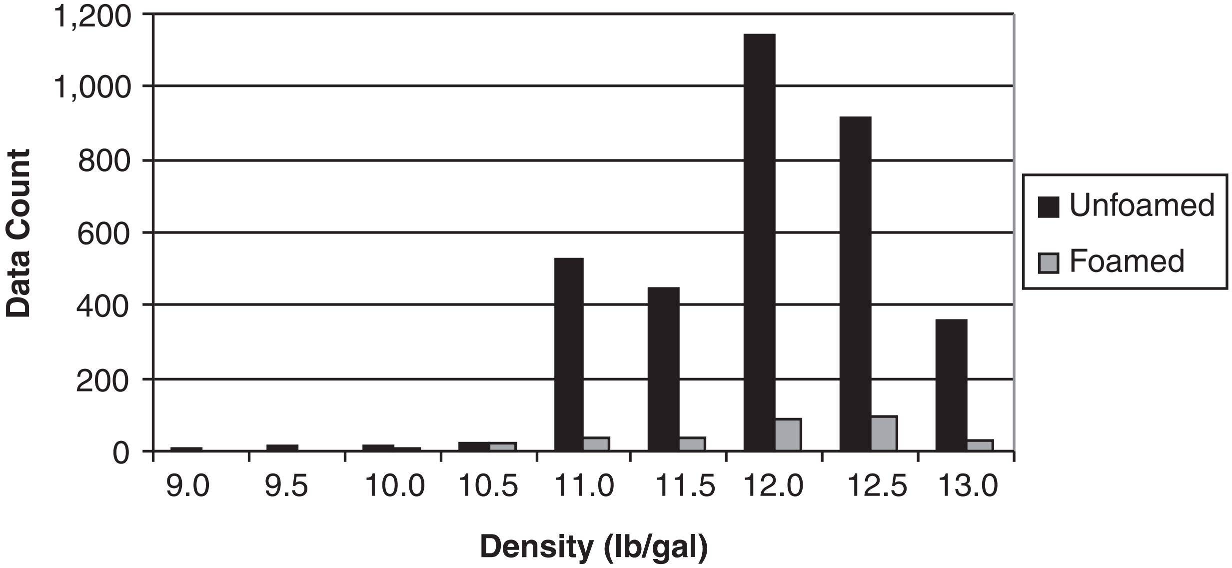

Fig. 1—Data distribution for foamed and unfoamed cements

The database contains limited temperature data for a large percentage of the unfoamed slurries. BHCT is chosen as one way to differentiate the data because it is the temperature parameter common to most of the data sets. Most (97%) of the foamed cement data collected was for BHCT of 100°F or below. Forty-eight percent (48%) of the unfoamed cement data is for BHCT of 100°F or below. The data analysis is divided into three broad temperature categories: 1) all temperatures, 2) BHCT of 100°F and below, and 3) BHCT of 101°F and above. The temperature categories will be divided into smaller segments (20°F) for analysis once the historical data set is complete.

This study examines lightweight cement systems with a density of 13.0 lb/gal or less. To better trace the trends of slurry density versus compressive strength, the density values are divided into ranges with 0.5 lb/gal increments. For example, the density range of 11.0 lb/gal covers all densities from 11.0 to 11.4 lb/gal, and the 11.5 lb/gal density range covers all densities from 11.5 to 11.9 lb/gal.

Most of the slurry densities are 11.0 lb/gal or greater (see Figure 1). Ninety-nine percent (99%) of the unfoamed cements and 90% of the foamed cements have densities of 11.0 lb/gal or greater.

Figures 2 through 4 (Pages 10 and 11) present data for conventional unfoamed cements. Figure 2 shows the percentage of all cements that fall into the three compressive-strength categories. Figures 3 and 4 display the data for temperatures below 100°F (Figure 3) and above 101°F (Figure 4). These charts show percentage plots of each cement density division with compressive strength within each temperature category. Note the trend of low strength at low density.

Figure 3 depicts the data count associated with each of the different densities. The small number of data points below 11.0 lb/gal came mostly from BJ slurries that contained hollow ceramic or glass spheres. The small amount of data from these specialized slurries tends to contradict the general trend of an increase in compressive strength with an increase in density. This same anomaly can also be seen in Figure 4. The fact that these data points are for cements with ULHS strengthens the stipulation that ULHS can extend the practical lower density limit of cement.

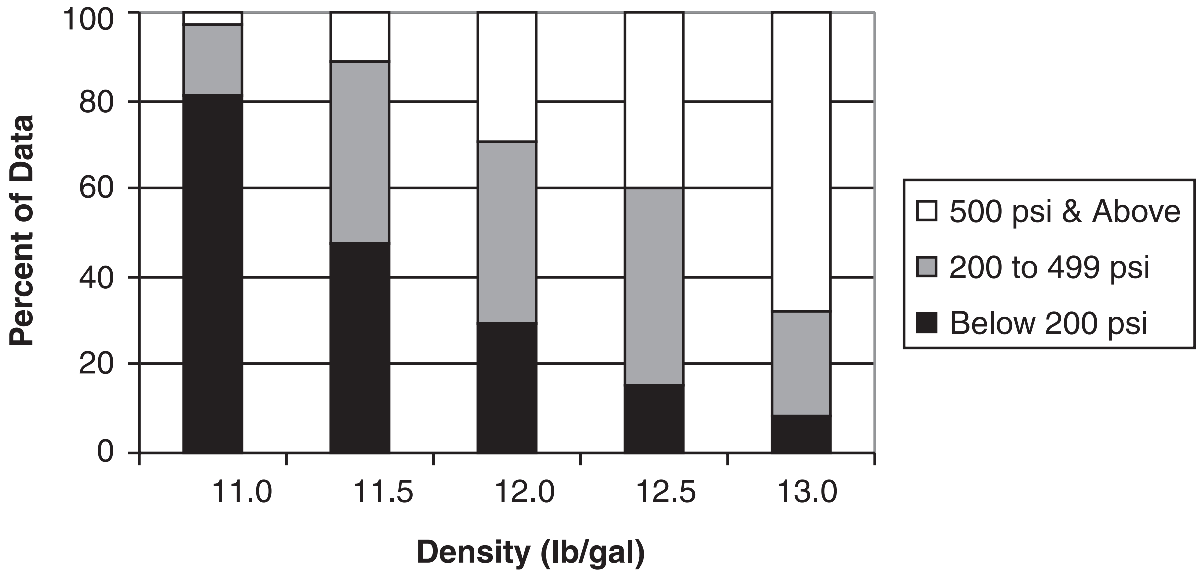

Fig. 2—24-hr compressive strength for all temperature categories of unfoamed cement

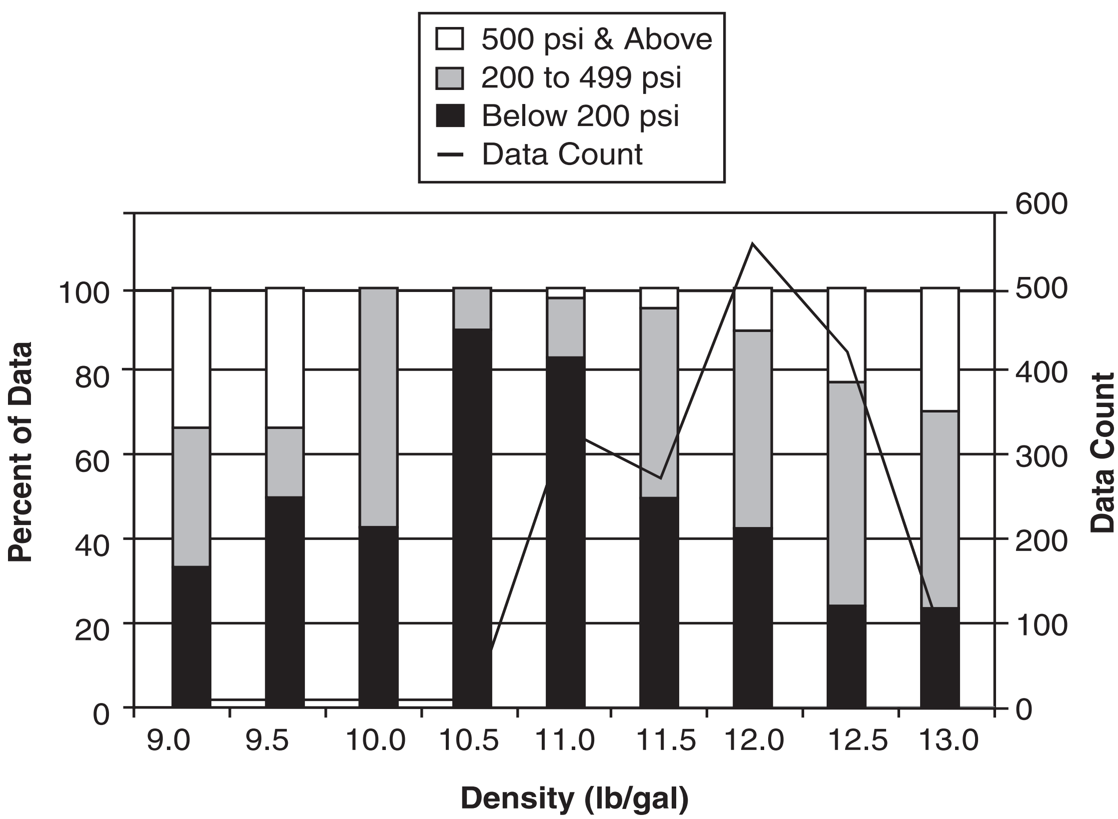

Fig. 3—24-hr compressive strength for unfoamed cement at 100°F and below

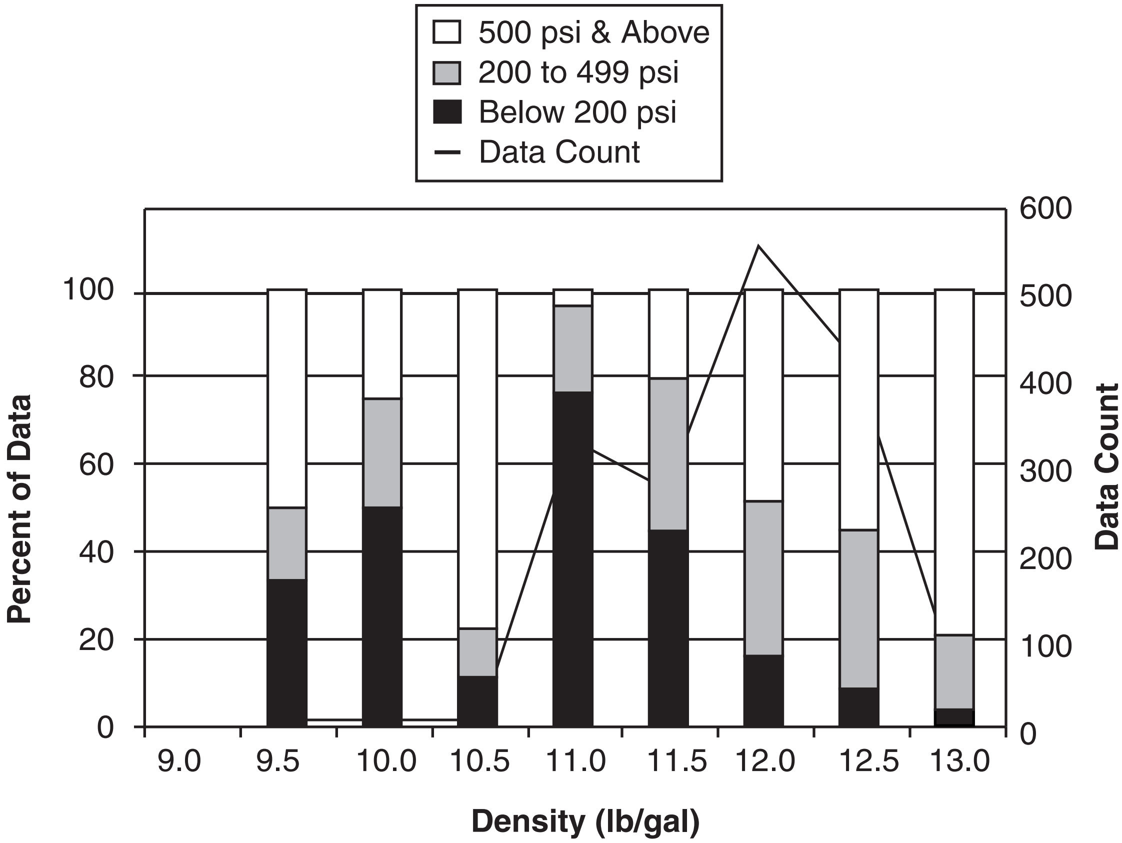

Fig. 4—24-hr compressive strength for unfoamed cement at 101°F and above

Figures 5 and 6 (Page 12) present foamed cement data from the HES data. Note that the trend identified for unfoamed cements also applies to the foamed cements. The majority of the foamed slurries in the historical data set have a BHCT between 60 and 65°F, which could account for the lower compressive strength.

The service company data reviewed to date indicate that the compressive strengths of cements at densities below 12.5 lb/gal are lower than those of cements at higher densities. Competent and strong lightweight cements are particularly scarce for low-temperature applications.

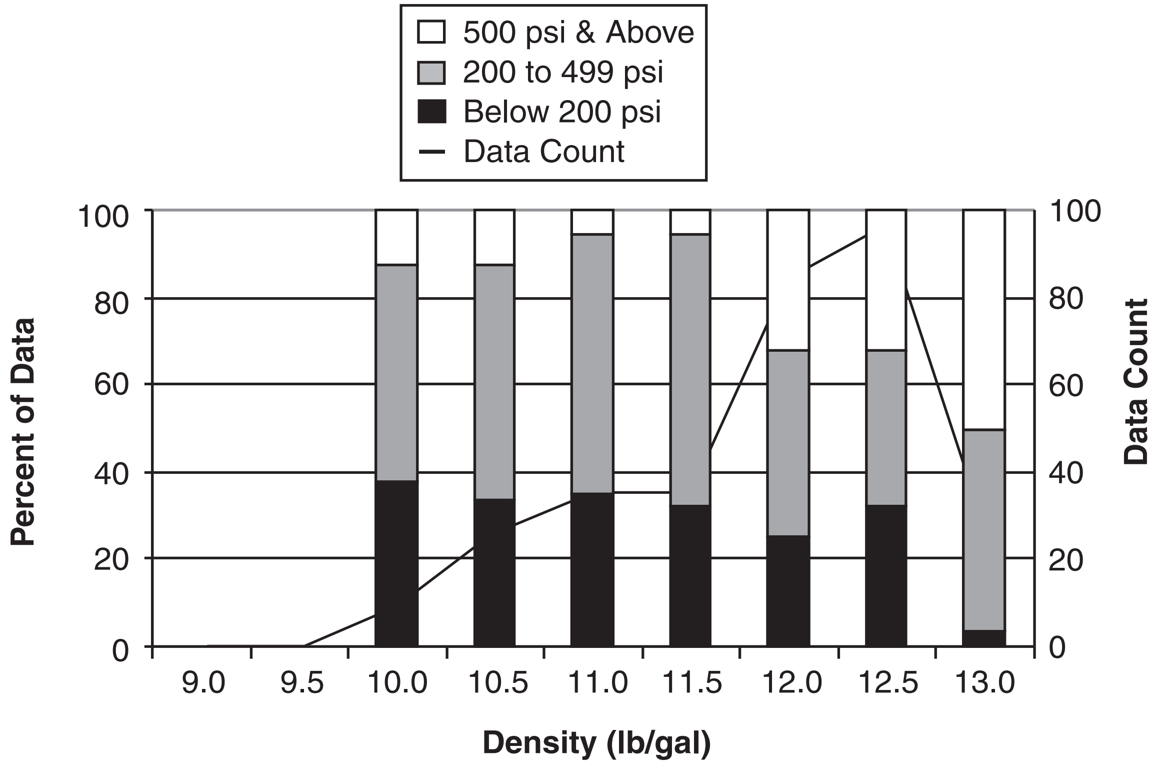

Fig. 5—24-hr compressive strength for all temperatures of foamed cement

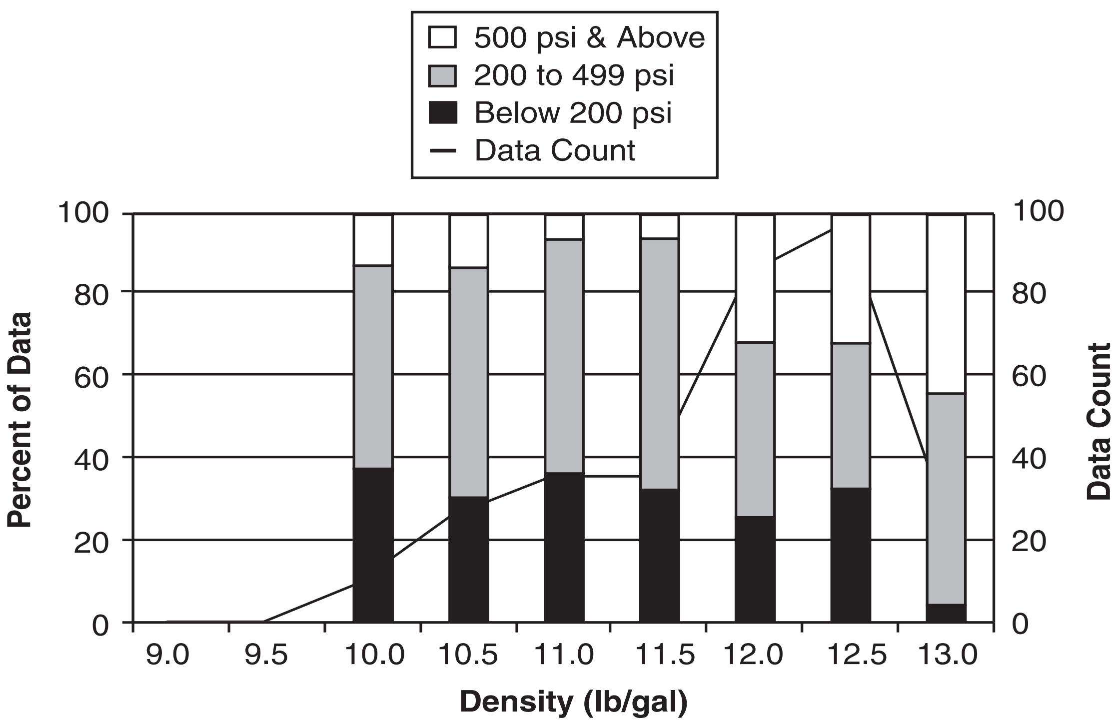

Fig.6—24-hr compressive strength for foamed cement at 100°F and below

7.1.1 High-Strength Microsphere Performance

Figure 7 compares the 24-hour compressive strengths of unfoamed cement alternatives with a BHCT of 100°F or below. This figure shows the 90th percentile of compressive strengths for the unfoamed, historical data that was collected in the comprehensive study. The 90th percentile was chosen for comparison because it is a favorable representation of the data, with 90% of the data distribution being at or below the specified compressive strength. Compressive strength data was also collected and presented for slurries containing high-strength ULHS. The curing temperature for the ULHS slurries was 80°F.

Cement slurries containing ULHS and their associated test data are further discussed in Section 7.3. Figure 7 shows that at densities less than 12.0 lb/gal, ULHS slurries have higher compressive strength than the 90th percentile of unfoamed, historical cements, even considering all temperatures.

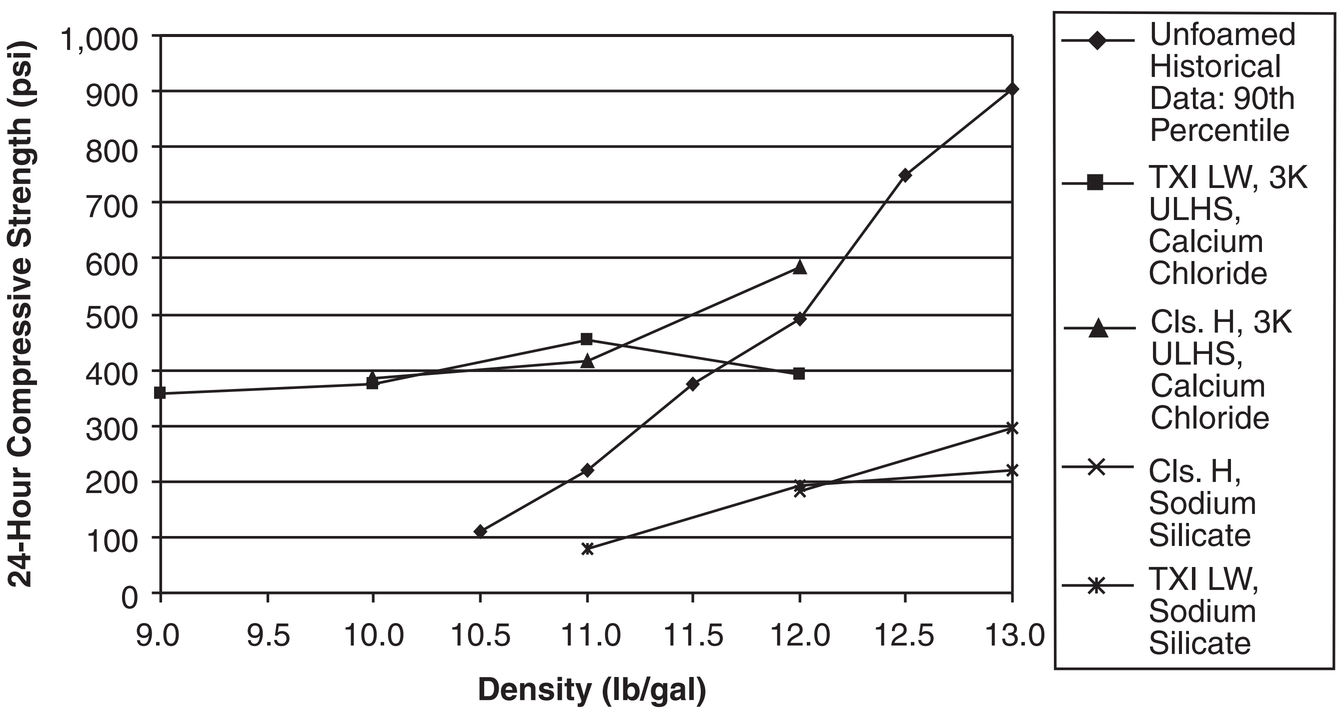

Fig. 7—Compressive strengths of unfoamed cements

7.1.2 Alternative Foamed Slurry

Figure 8 compares the 24-hour compressive strengths of foamed cement alternatives with BHCT of 100°F or below. This figure contains the 90th percentile of the foamed cements that were collected in the comprehensive study of lightweight slurries. Compressive-strength data is discussed in Section 7.1 of this report. Figure 8 shows that the alternative foamed slurry that was specifically designed for this project significantly outperformed the 90th percentile of historical data. The majority of the foamed slurries in the historical data set have a BHCT between 60 and 65°F, which could account for the lower compressive strength.

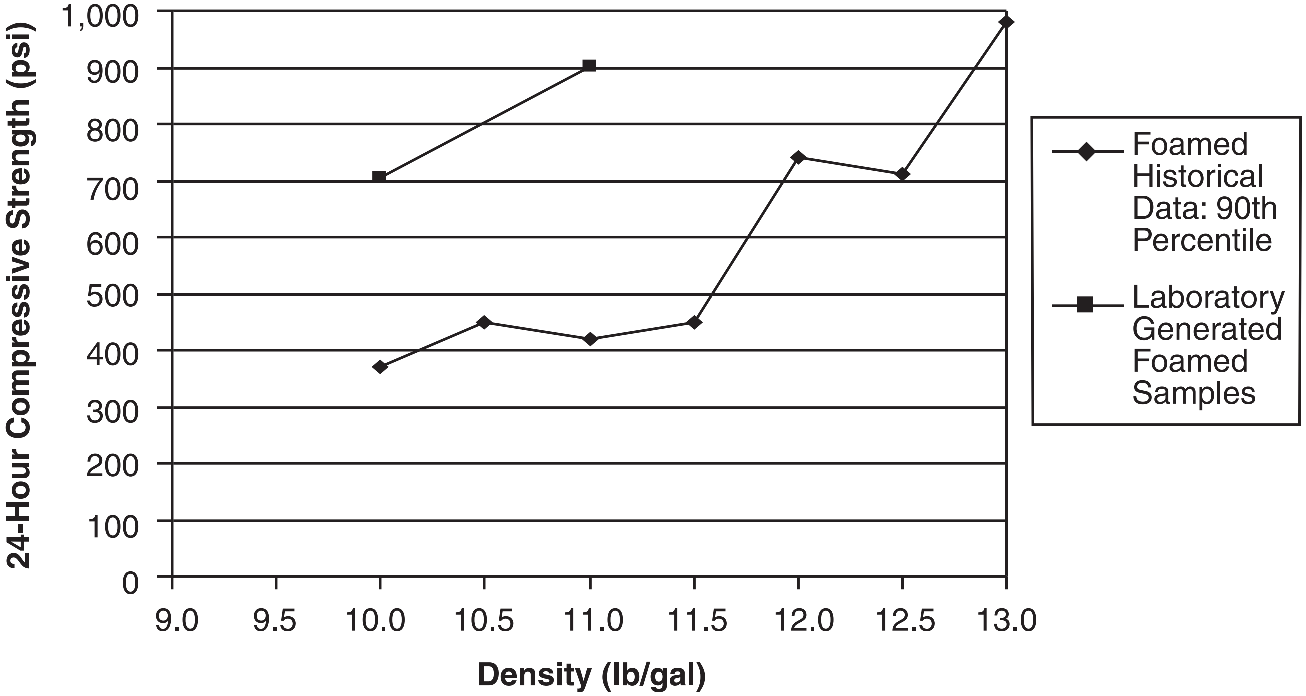

Fig. 8—Compressive strengths of foamed cements

7.2 Cement Quality Control Program

An extensive quality-control program was initiated because of the large quantity of cement used over the course of this project. Each bucket of cement is labeled with a materials log number and date upon receipt. When a bucket is first opened for use, the date of opening is also recorded into the materials log. This log number will be referenced on the lab sheets for each test performed. Where applicable, tests according to the API Specification 10A are conducted. Additionally, several other tests tailored specifically for the test conditions and materials (rheology and low-temperature compressive strength development) are included in this QC Program.

The Class A and Class H cement performance requirements are presented in API Specification 10A. Because the Lightweight Oilwell cement is not an API cement, it is tested according to QC procedures developed by the manufacturer.

This quality-control program is necessary because of the large volume of cement used during this DOE project. Initially, the testing lab received five 5-gallon buckets of API Class A cement (analogous to ASTM Type I cement), ten 5-gallon buckets of API Class H cement, and nineteen 3-gallon buckets of Lightweight Oilwell cement from TXI. Both API Specification tests and tests recommended by Advisory Board Members are being performed for the cement quality control program. The physical requirements used for testing each of the cements are listed in Table 7.4. To accelerate the rate of compressive-strength development at low temperatures, calcium chloride ($CaCl_2$) is being used with both classes of cement according to Table 7.5. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

All of these tests have been run to provide a baseline for each type of cement. This data will provide a comparison when examining other data for this project. The complete set of tests will be conducted periodically throughout the DOE Project. Table 7.6 (Page 16) shows the first set of data conducted by the testing lab on the three cements received.

Quality control tests initiated in the first quarter of work were completed during this quarter. A complete summary of this data is presented in Appendix D. These data track well with performance data that was provided by the vendors and presented in the previous report. The test results exceeded the required specifications, and this process will be repeated when new cement supplies are received. Data will be presented in the appendices of future reports.

Table 7.4—Cement Slurry Compositions for Quality-Control Testing Program

Cement	Mix Water (%)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Class A	46	15.6	772	355	API
TXI LW	75	13.2	541	406	TT and CS
TXI LW	105	12.1	426	447	FW
Class H	38	16.4	860	327	API

Table 7.5—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (%)
80	0.0
60	1.0
45	2.0

Table 7.6—Quality Control Testing of Cement Compositions Specified in Table 7.4

	Lightweight	Class A	Class H
Free Water (% by vol.)	0.8	0	1.2
Initial Viscosity (Bc)	6	8	13
Spec 5 Thickening Time (hr:min to 100 Bc)	2:20	2:21	1:54
Compressive Strength (psi)			
45°F (2% $CaCl_2$)	166	737	
60°F (1% $CaCl_2$)	254	1194	
80°F (24 hr)	523	1689	
100°F (8 hr)		754	1202
100°F (24 hr)		2607	
120°F (24 hr)	1579		
140°F (8 hr)			1964
Viscometer Readings[a] (rpm)			
300	57	80	85
200	50	65	70
100	42	49	53
60	38	40	45
30	33	34	38
6	22	17	14
3	12	10	8

[a]After 20 minutes conditioning on atmospheric consistometer at 80°F

7.3 Design of Cement Slurries Containing ULHS

7.3.1 Comparison of UCA vs. Crush Strength

A series of compressive-strength comparison tests were prepared with ULHS cements to determine the accuracy of measuring compressive strength with a UCA. The UCA tests were run using the lightweight correlation that is programmed in as one of the three density options. The trapped air in the ULHS can alter the ultrasonic signal, creating inaccurate measurements. Results of these tests are presented in Figures 9 through 14 (Pages 17 through 22). The results indicate that UCA vs. crush strength agreement is fairly good for Class A cements. However, agreement is not acceptable for TXILW cements containing ULHS.

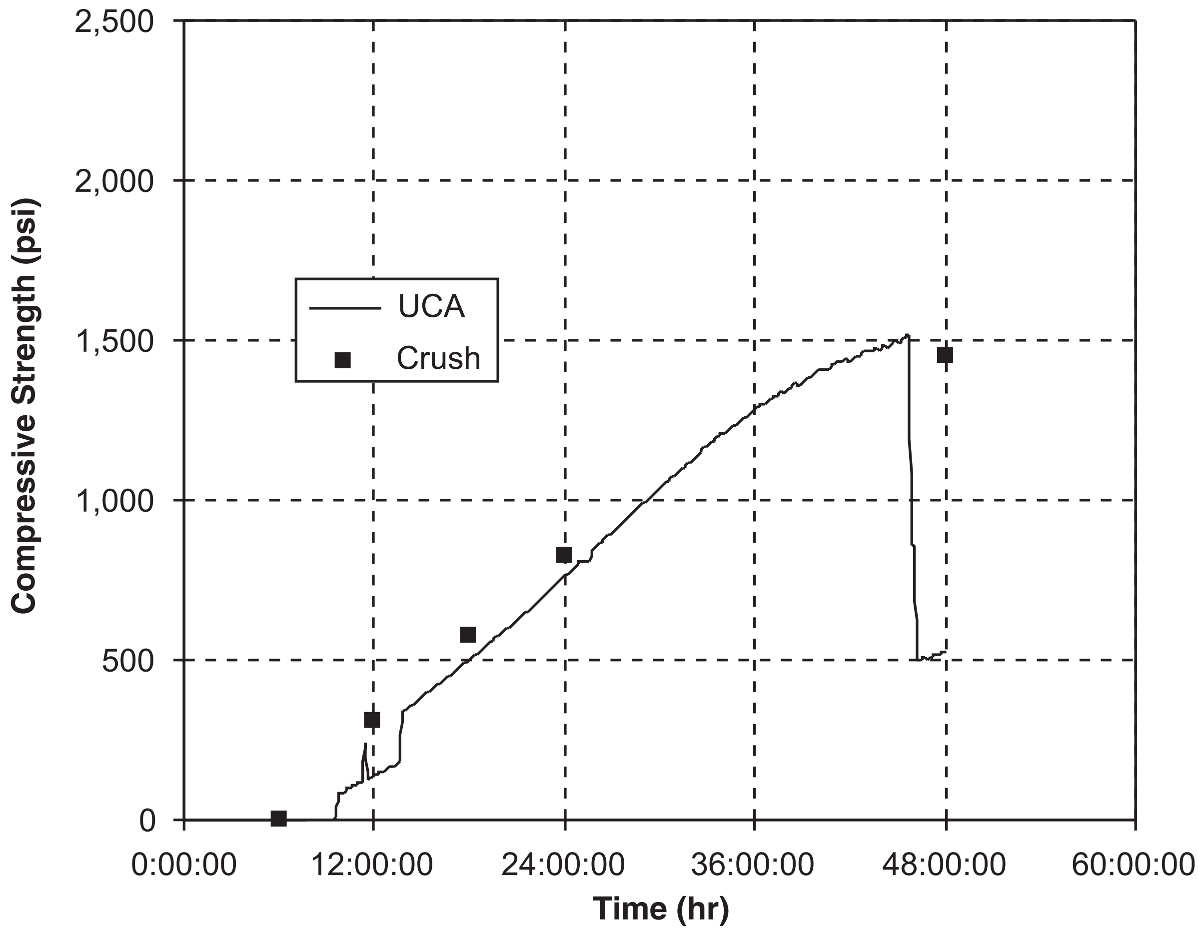

Fig. 9—Comparison of UCA (lightweight correlation) vs. crush strength for Class A cement + 15% 3K ULHS mixed at 10.95 lb/gal

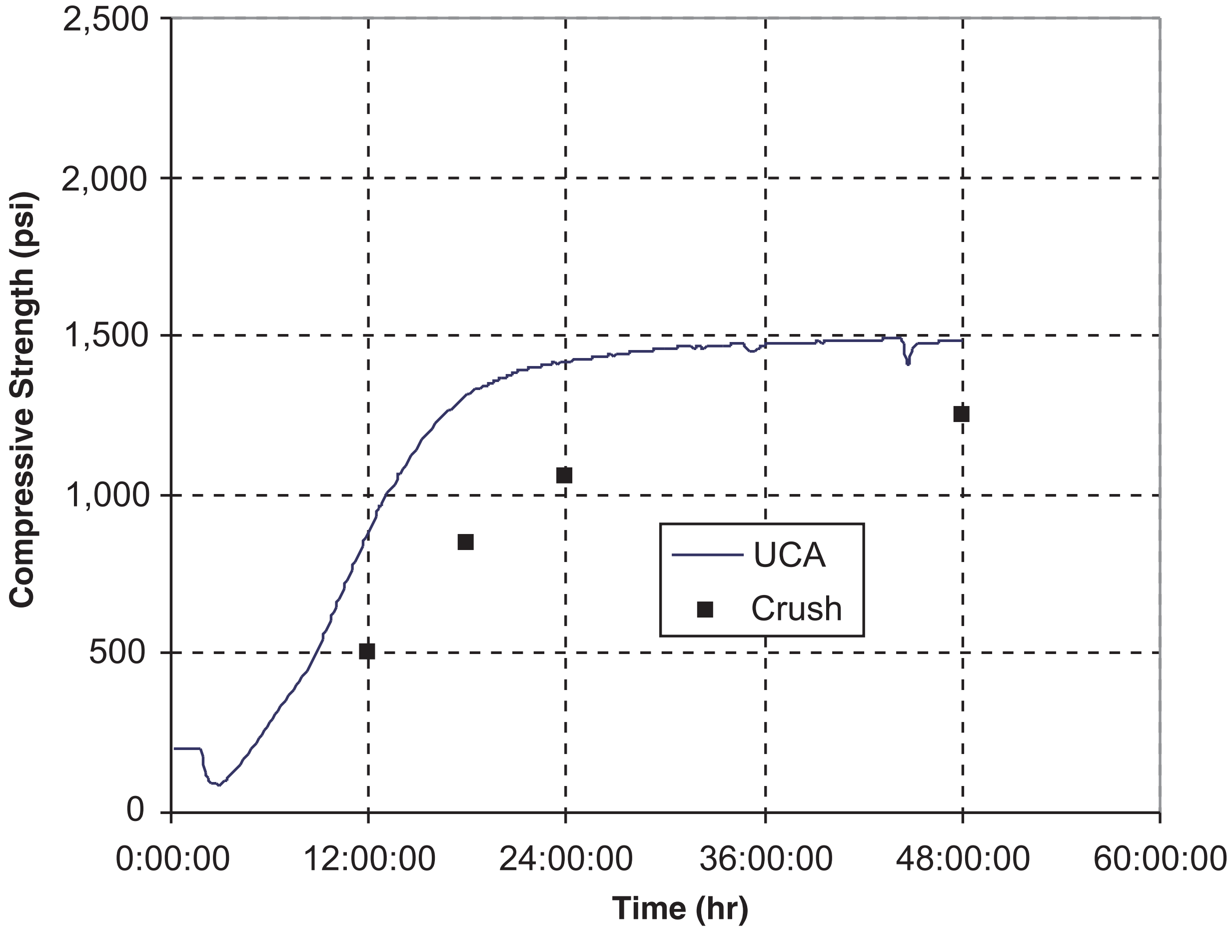

Fig. 10—Comparison of UCA (lightweight correlation) vs. crush strength for TXILW + 27.56% 3K ULHS mixed at 9.0 lb/gal

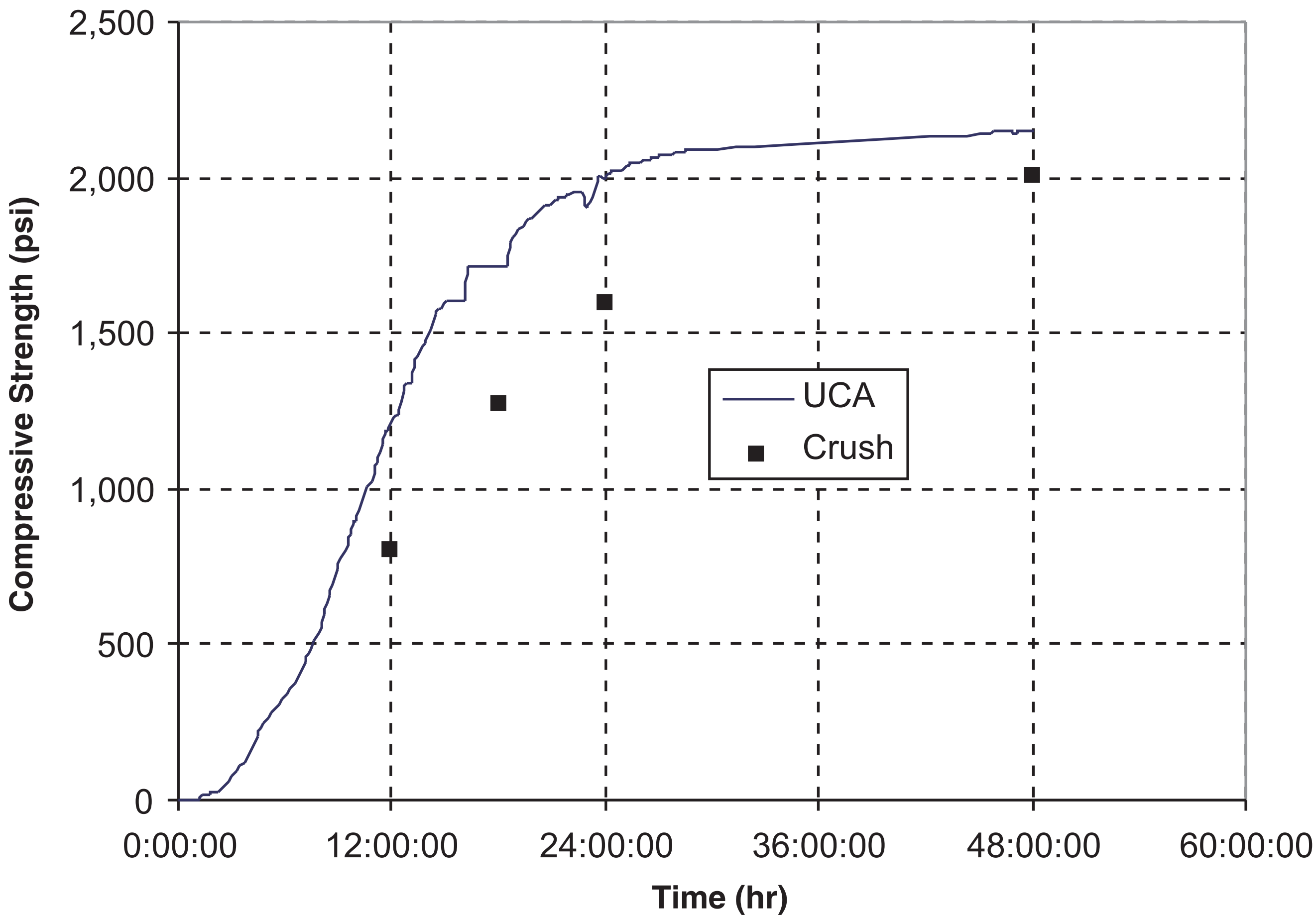

Fig. 11—Comparison of UCA (lightweight correlation) vs. crush strength for TXILW + 6.12% 3K ULHS mixed at 11.5 lb/gal

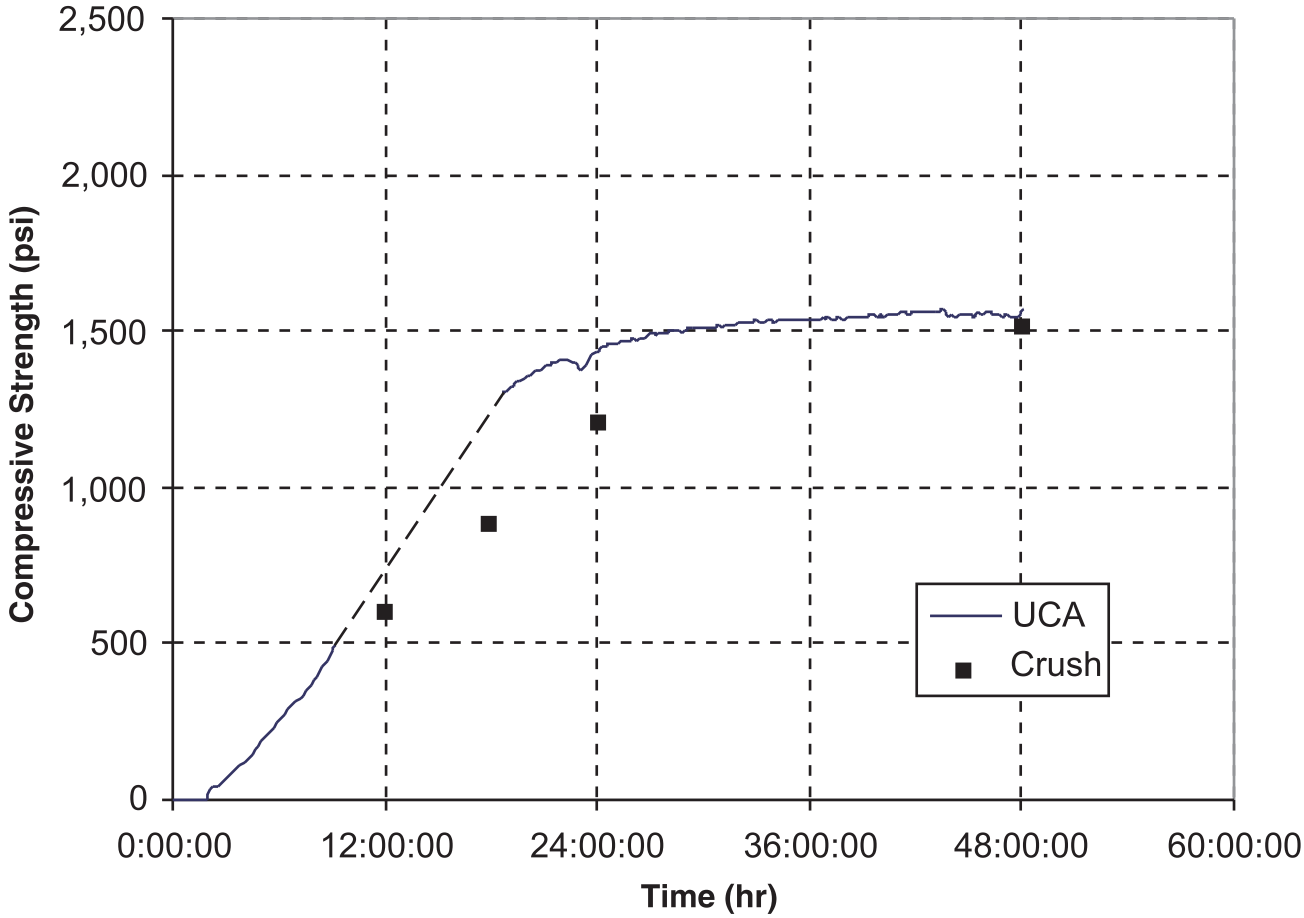

Fig. 12—Comparison of UCA (lightweight correlation) vs. crush strength for TXILW +16.49% 3K ULHS mixed at 10.0 lb/gal

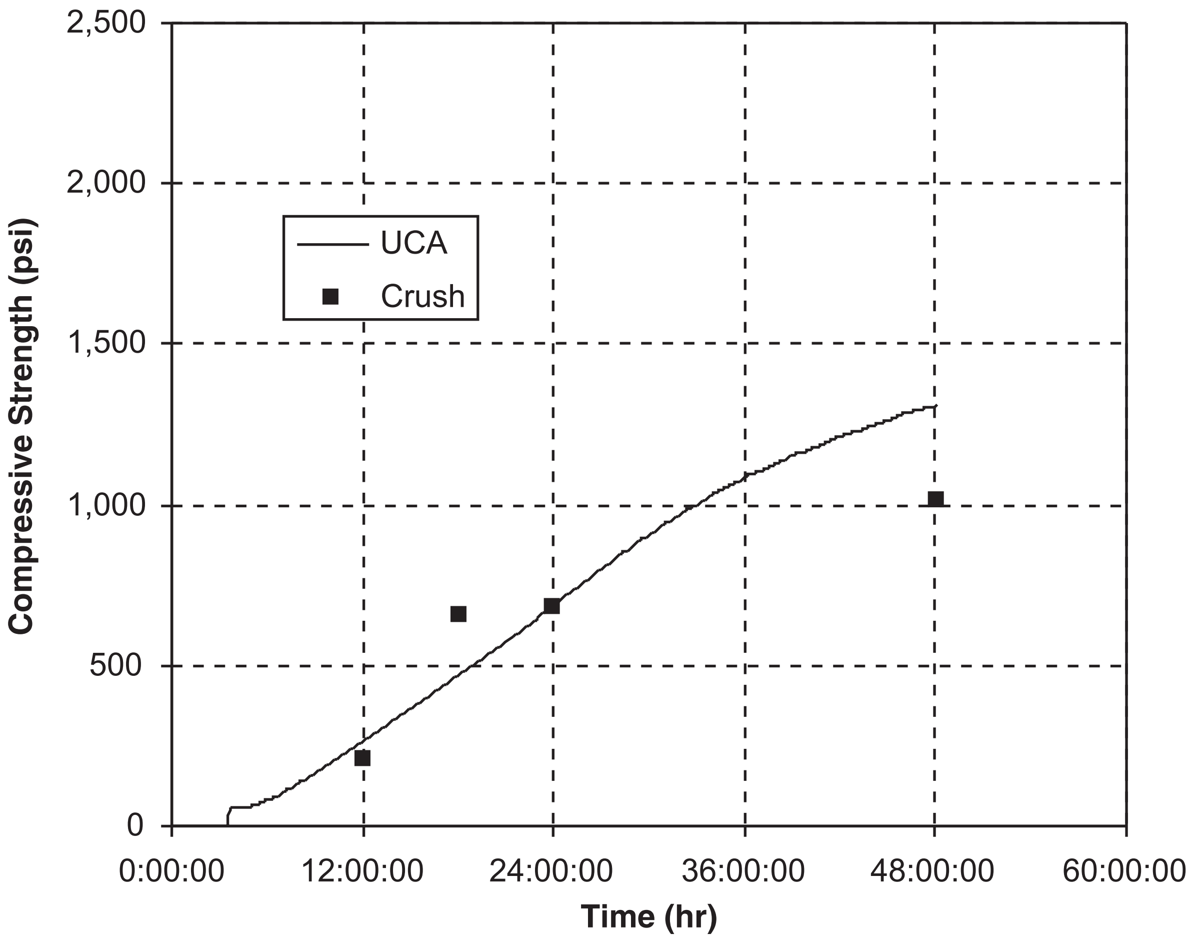

Fig. 13—Comparison of UCA (lightweight correlation) vs. crush strength for Class A cement + 20% 3K ULHS mixed at 10.15 lb/gal

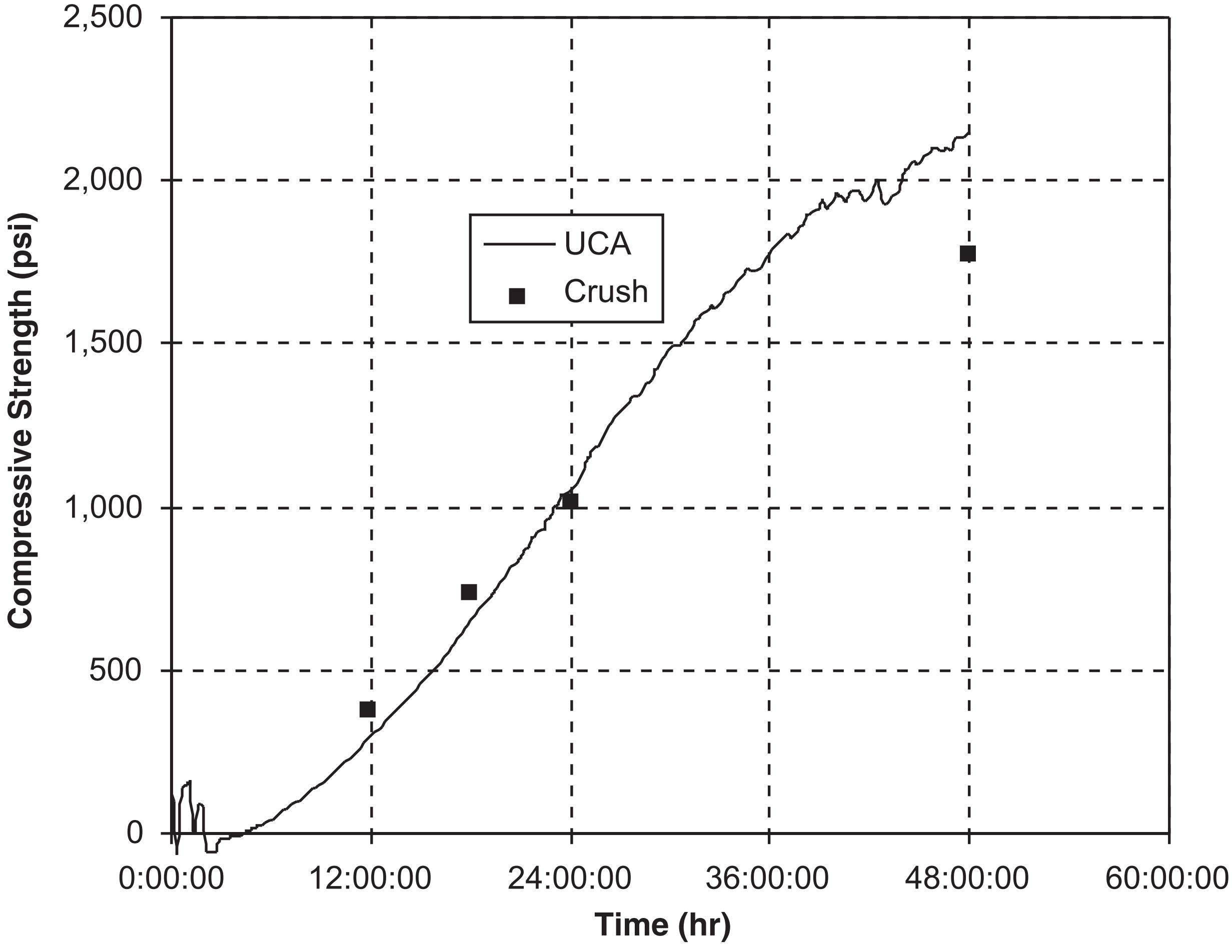

Fig. 14—Comparison of UCA (lightweight correlation) vs. crush strength for Class A cement + 10% 3K ULHS mixed at 12.0 lb/gal

7.3.2 Glass Bead Specific Gravity vs. Applied Pressure

In Report 1, data for three different kinds of ULHS were presented. Work during the second quarter has completed analysis of specific gravity vs. applied pressure performance for all ULHS materials in cement. The data are presented in Figure 15. From this figure it appears that the 5K beads are more sensitive to pressure than the 4K beads. These findings will be investigated in future studies of the project.

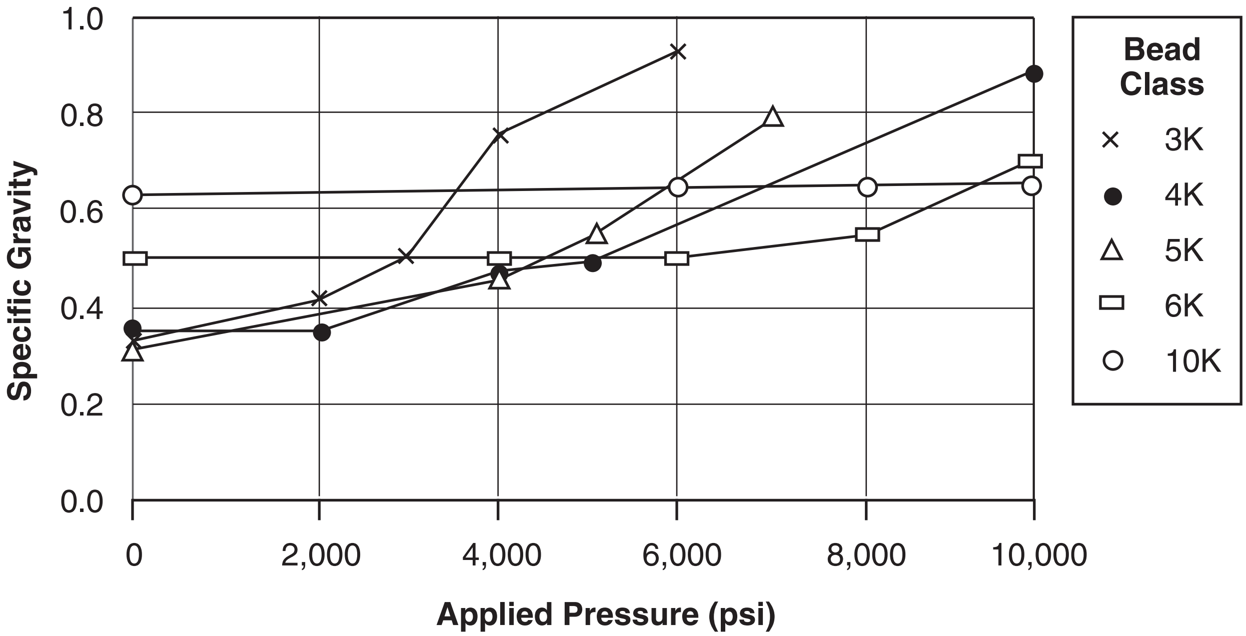

Fig.15—Specific gravity vs. applied pressure for ULHS cements

7.3.3 Rheology: Ascending/Descending Speed

The rheology effects of running a rotational viscometer in descending and ascending order were measured for ULHS cements in the first phase. However, the testing was repeated, following API procedures. The results of repeat testing with six different ULHS cements and mix water concentrations are shown in Figures 16 through 21 (Pages 24 through 26). This testing evaluated the centrifugal effects of the rotational viscometer on the stability of the slurries. Figures 16 through 21 show the results of this testing. The data indicate that little separation is indicated by running the tests in ascending and then descending order.

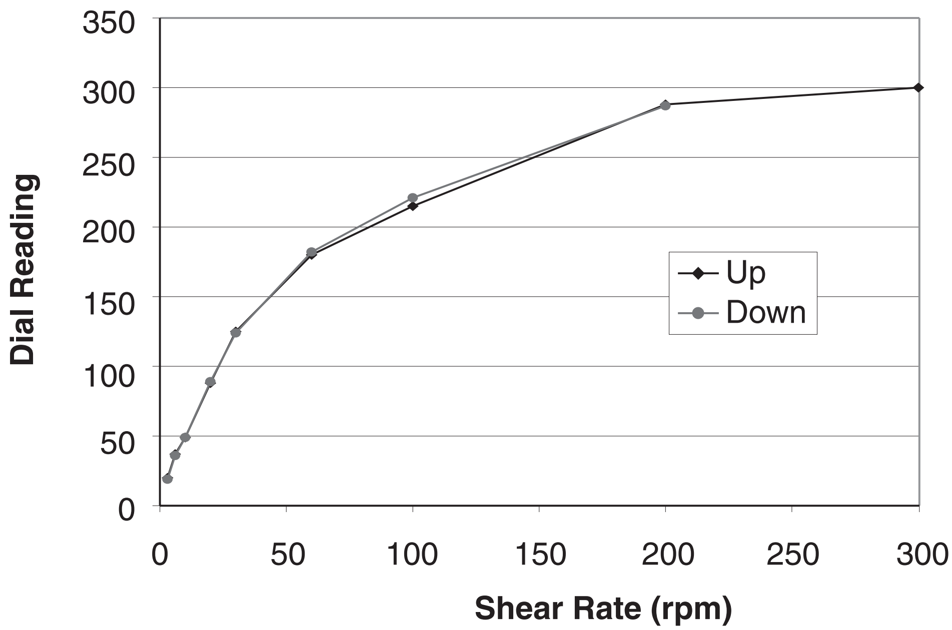

Fig. 16—Rheology of an 11.5-lb/gal slurry of TXILW + 9.98% 3K ULHS mixed with 5.5 gal/sk of fresh water

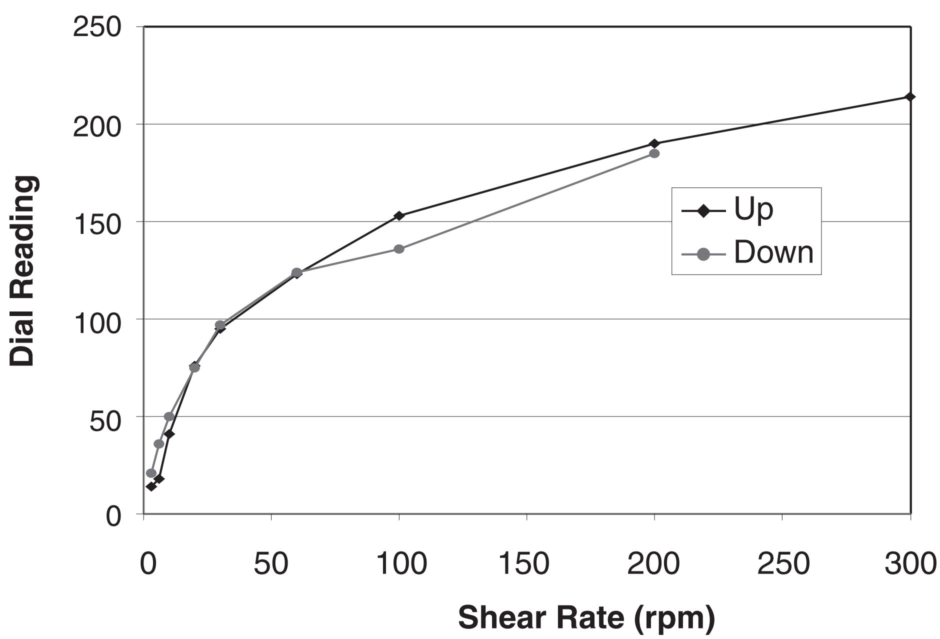

Fig. 17—Rheology of an 11.5-lb/gal slurry of TXILW + 9.21% 3K ULHS mixed with 6.0 gal/sk of fresh water

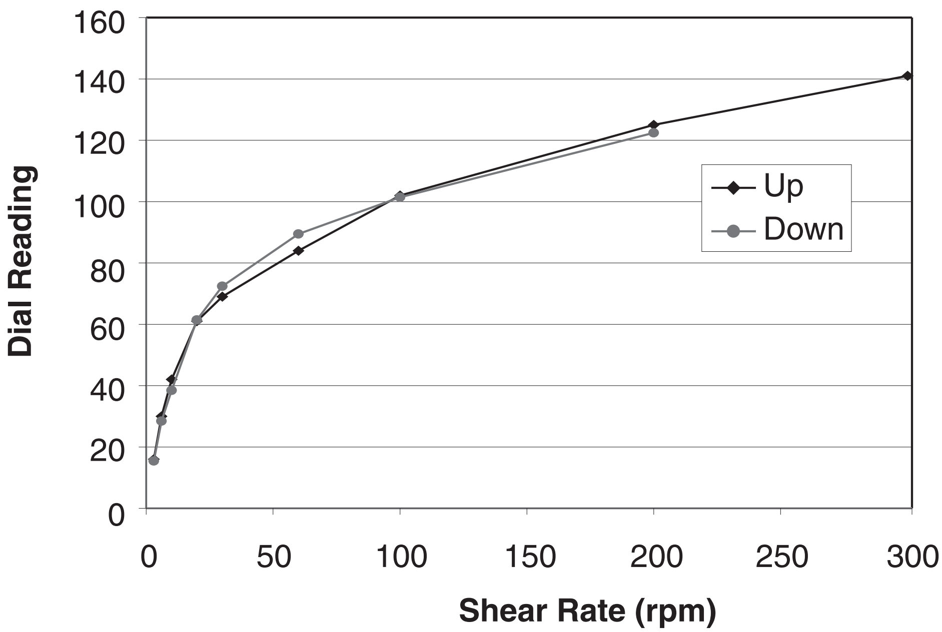

Fig 18—Rheology of an 11.5-lb/gal slurry of TXILW + 8.44% 3K ULHS mixed with 6.5 gal/sk of fresh water

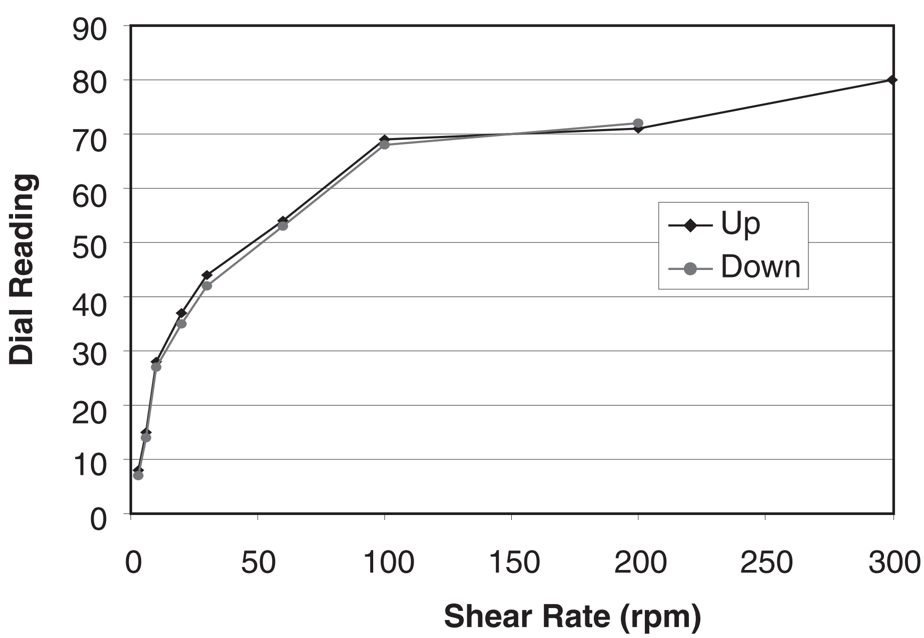

Fig. 19—Rheology of an 11.5-lb/gal slurry of TXILW + 7.67% 3K ULHS mixed with 7.0 gal/sk of fresh water

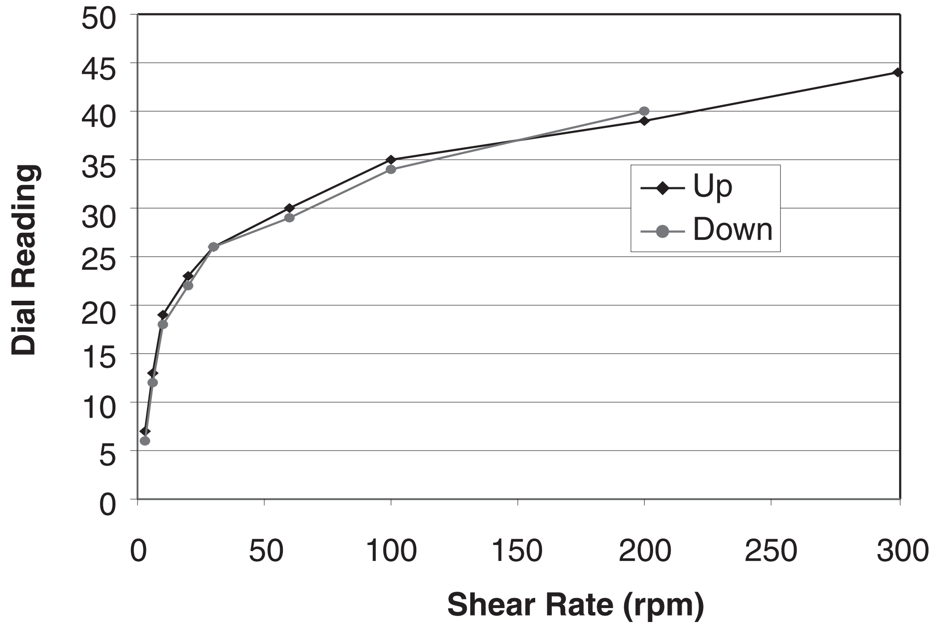

Fig. 20—Rheology of an 11.5-lb/gal slurry of TXILW + 6.12% 3K ULHS mixed with 8.0 gal/sk of fresh water

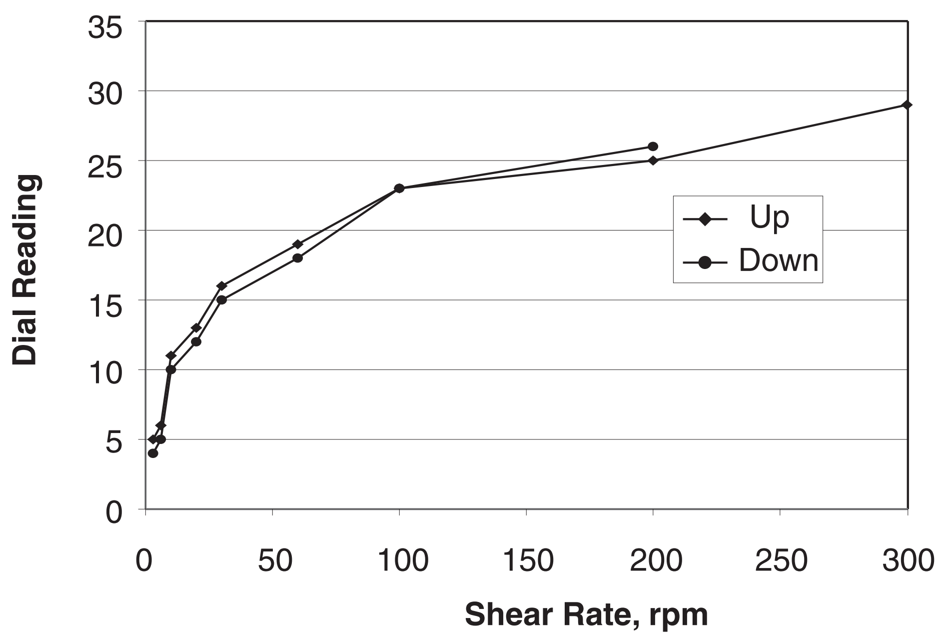

Fig. 21—Rheology of an 11.5-lb/gal slurry of TXILW + 4.58% 3K ULHS mixed with 9.0 gal/sk of fresh water

7.3.4 Shear Effect on Slurry Density

Mixing of ULHS with a Waring blender causes breakage of some spheres due to shearing by the blender blade. This breakage alters the slurry density and yield. Investigation of the effects of high shear on the ULHS breakage was initiated in the first phase of this project. However, results from the initial testing indicated that a procedure change was needed because random density variations in the atmospheric density measurements were introduced by air entrainment. Experiments were repeated using defoamer and a pressurized mud balance to determine density variations. The data presented in Table 7.7 indicates that the higher strength ULHS are essentially unaffected by the level of shear imparted by a Waring blender. The data indicate that all ULHS suffered some breakage, but the degree of breakage, as manifested by an increase in slurry density, was considered negligible. Therefore, cements containing ULHS will be mixed according to standard laboratory procedures. It should be noted that actual field mixing is not as likely to have the same harsh shearing effect as what is seen in these laboratory tests. However, field mixing effects must be measured from full-scale tests.

Table 7.7—Waring Blender Shear Energy Effect on Class A Slurries

ULHS	Water (gps)	Density at Shear Time		
		0 sec	35 sec	50 sec
13.0 lb/gal Slurries				
6.64% 3K	6.00	12.9	13.1	13.2
6.40% 4K	6.15	13.0	13.1	13.2
6.40% 5K	6.15	13.1	13.3	13.3
6.40% 6K	7.07	13.0	13.1	13.1
10.0 lb/gal Slurries				
18.0% 3K	12.00	9.9	10.1	10.2
18.74% 4K	12.00	10.0	10.0	10.1
18.74% 5K	12.00	10.0	10.0	10.1
25.14% 6K	12.00	10.0	10.0	10.1

7.4 Comparison of ULHS and Foamed Cements

A series of lightweight cements was created using ULHS or foamed cement to establish realistic performance for these materials. Initial testing focused on compressive-strength development.

The results shown in Tables 7.8 through 7.10 (Page 28) indicate that the range of application for foamed cements is extended compared to historical data or to cements with traditional lightweight additives.

Table 7.8—TXI Lightweight Cements 24-hr Compressive Strength With and Without 3K ULHS

Density (lb/gal)	Additives	Temp. (°F)	Compressive Strength (psi)
9.0	ULHS, 2% $CaCl_2$	65	300
9.0	ULHS, 2% $CaCl_2$	80	410
10.0	ULHS, 2% $CaCl_2$	65	310
10.0	ULHS, 2% $CaCl_2$	80	440
11.0	ULHS, 2% $CaCl_2$	65	395
11.0	2% Na_2SiO_2	65	60
11.0	ULHS, 2% $CaCl_2$	80	510
11.0	2% Na_2SiO_2	80	95
12.0	ULHS, 2% $CaCl_2$	65	390
12.0	1% Na_2SiO_2	65	200
12.0	ULHS, 2% $CaCl_2$	80	395
12.0	1% Na_2SiO_2	80	180
13.0	0.5% Na_2SiO_2	65	150
13.0	0.5% Na_2SiO_2	80	290

Table 7.9—Class H Cement 24-hr Compressive Strength With and Without 3K ULHS

Density (lb/gal)	Additives	Temp. (°F)	Compressive Strength (psi)
10.0	ULHS, 2% $CaCl_2$	65	320
10.0	ULHS, 2% $CaCl_2$	80	450
11.0	ULHS, 2% $CaCl_2$	65	365
11.0	ULHS, 2% $CaCl_2$	80	470
12.0	ULHS, 2% $CaCl_2$	65	519
12.0	3% Na_2SiO_2	65	115
12.0	ULHS, 2% $CaCl_2$	80	650
12.0	3% Na_2SiO_2	80	241
13.0	2% Na_2SiO_2	65	205
13.0	2% Na_2SiO_2	80	380

Table 7.10—Foamed Cement 24-hr Compressive Strength Development

Density (lb/gal)	Temp. (°F)	Compressive Strength (psi)
10.0	80	705
11.0	80	900

7.5 U.S. Literature Review

A literature search on lightweight cements and alkali-aggregate reactions was conducted during this quarter. Preliminary results are presented in Appendix E. Many of these papers are summarized. No time has been devoted to preparing a complete summary of the reference literature. This will be done during the next quarter.

8.0 Conclusions

Based on initial results presented herein, the following conclusions can be drawn:

- Historical lightweight cement performance data analysis has given a reference point to establish further testing. The data set will be more completely analyzed as more data are added. ULHS cements could possibly extend this lower limit to below 10.0 lb/gal.

- Waring blender shear during mixing results in negligible breakage of the specific ULHS materials being studied in this project. The ULHS manufacturer does not recommend the use of a high-speed blender for mixing. Further mixing studies will be investigated in the next project quarter.

- For this project, UCA is acceptable for showing general trends of strength development, but actual compressive strength measurements should be gathered from crush tests.

- Rotational viscometer operation in ascending or descending order has no effect on rheology measurement of the specific ULHS slurries designed for this project.

- Laboratory designed test procedures for ULHS and foamed cements are established.

- Ongoing quality control procedures are established, and the results will be reported in appropriate appendices.

9.0 References

1. API Recommended Practice 10 B, 22nd Edition, December 1997: "Recommended Practice for Testing Well Cements," American Petroleum Institute.

2. API Specification 10A, 22nd Edition, January 1, 1995: "Specification for Cements and Materials for Well Cementing," American Petroleum Institute.

3. ISO 10426-2: Petroleum and Natural Gas Industries - Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements, 1998.

10.0 List of Acronyms and Abbreviations

lb/gal—pound(s) per gallon
lb/ft—pound(s) per foot
rpm—revolutions per minute
gal/sk—gallon(s) per sack
gps—gallon(s) per second
g/cc—grams per cubic centimeter
g—gram
cc—cubic centimeter
psi—pound(s) per square inch
ULHS—ultralight hollow glass spheres
API—American Petroleum Institute
avg.—average
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
TXI—Texas Industires, a cement supplier
TXILW—a lightweight cement available from TXI
CSI—Cementing Solutions, Inc.
QC—quality control
Bc—Bearden units of consistency
AT—atmospheric
3M—Minnesota Mining and Manufacturing
3K—3,000-psi designation
4K—4,000-psi designation
5K—5,000-psi designation
6K—6,000-psi designation
10K—10,000-psi designation
TT—thickening time test
CS—compressive strength test
FW—free water test

Appendix A—Non-Standard Test Procedures Developed for ULHS Cements

A.1 Procedure 1—Mixing Beads without High Shear

Note: Mixing glass beads into a cement slurry using a Waring blender can break beads, thereby altering the slurry density.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and glass beads into separate containers.

2. Mix the cement slurry according to Section 5.3.5 of API RP 10B.

3. Pour the slurry into a metal mixing bowl and slowly add the glass beads while continuously mixing by hand with a spatula.

A.2 Procedure 2—Mixing Beads with High Shear

Mix the slurry, including the beads, according to API RP 10B. Measure the density with a pressurized mud balance to assess the degree of density change due to breakage.

A.3 Procedures for Performing Stability Test

1. Prepare the cement and bead slurry as described in the *Mixing Beads with High Shear* instructions above.

2. Pour 250 mL of the thoroughly mixed slurry into a 250-mL graduated cylinder and seal to prevent evaporation.

3. Stand the graduated cylinder upright in an 80°F water bath with water level equal to the height of cement in the graduated cylinder, and leave the cylinder in the bath for 1 hour.

4. Mark the 250-mL graduated cylinder into three sections (Top, Middle, Bottom).

   Top 1/3 Section: 170 to 250 mL
   Middle 1/3 Section: 80 to 170 mL
   Bottom 1/3 Section: 0 to 80 mL

5. Fill a (30-mL) syringe with 1 to 5 mL of the cement and bead mixture to remove any air trapped in the tip of the syringe; then eject the slurry into the waste bin, leaving the tip filled. Wipe any residue from the outside of the syringe.

6. Tare the syringe from Step 5 on a balance.

7. Refill the syringe with a least 10 mL of the cement and bead mixture from the top 1/3 section of the graduated cylinder. Wipe any residue from the outside of the syringe.

8. Weigh and record the weight and volume of the syringe containing the mixture.

9. Calculate the specific gravity of the mixture by dividing the recorded weight of the cement and bead mixture by the volume of the mixture measured into the syringe. Compute the density by multiplying by the density of water (8.33 lb/gal).

Example: Syringe plus Cement and ULHS = 38.14 g
Volume of Cement and ULHS = 30 mL

38.14 g ÷ 30 mL = 1.271 g/mL
1.271 g/mL × 8.33 = 10.59 lb/gal

10. Eject the slurry into a waste bin, and repeat Steps 6 through 9 with the other two (middle and bottom) 1/3 sections of the graduated cylinder. Use a length of tubing attached to the syringe tip to access the lower portions of the cylinder.

A.4 Calculations for Determining Density Difference Due to Separation

1. Using the data obtained in Section A.3, subtract the top density from the bottom density.

2. Divide this value by the bottom density and multiply by 100.

3. The resulting value is the percent of density difference caused by glass bubble separation.

Example: Top Density = 15.0 lb/gal
Bottom Density = 15.5 lb/gal

15.5 – 15.0 = 0.5
(0.5 ÷ 15.5) × 100 = 3.23% density difference

4. Repeat Steps 1 through 3 for the middle data.

A.5 Laboratory Mixing, Testing Procedures, and Testing Scope for Foamed Cement

This part of ISO 10426 defines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries.

A.6 Preparing Unfoamed Base Slurry

A.6.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density	=	14.5 lb/gal
Surfactant weight	=	10 lb/gal

Base Slurry Calculations:	Weight	Volume
Cement	94 lb	3.59 gal
Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
Water	55.39 lb	6.65 gal
Total	151.39 lb	10.44 gal

Calculation of:	Weight %	Contributions
Cement	62.09 %	(94/151.39)
Surfactant	1.32 %	(2/151.39)
Water	36.59 %	(5.39/151.39)

Slurry without Surfactants:	Weight	Volume
Cement	94 lb	3.59 gal
Water	55.39 lb	6.65 gal
Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

A.7 Equipment

A.7.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure A.1, Page 34.) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

A.7.2 Mixing Blade Assembly

The mixing blade assembly can be either a single mixing blade as supplied by the manufacturer or a multiple, stacked-blade assembly. Testing-to-date has not identified a significant difference in the two blade assemblies.

A.7.3 Single Blade Assembly

The single blade assembly should conform to ISO/DIS 10426-2, clause 5.

A.7.4 Multi-Blade Assembly

The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO/DIS 10426-2, clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure A.1.

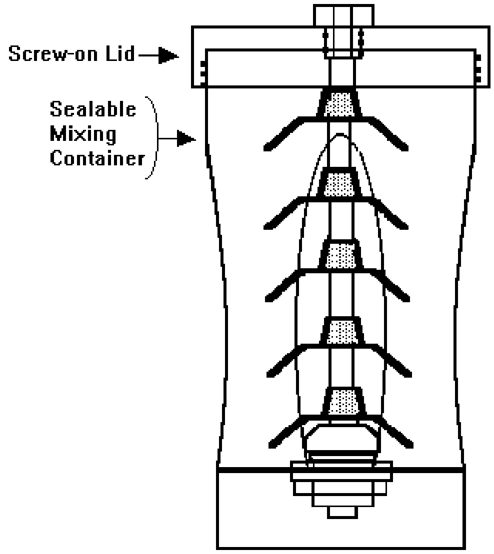

Fig. A.1—Example of a typical blending container

A.8 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

A.9 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section A.6.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section A.7.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Test samples, without the addition of foaming surfactants, should be prepared according to ISO/DIS 10426-2, clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3,3 rev/s (200 rpm) at 66,7 rev/s (4,000 rpm) and ± 8,3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO/DIS 10426-2, clause 6.

A.10 Determining Slurry Volumes and Weights

A.10.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times SGUFS \qquad (2)$$

Where:	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	SGUFS	=	Specific gravity of the foamed slurry

Example:	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Volume percent air	=	(14.5 -10) ÷ 14.5 × 100 = 31.03%
	Unfoamed slurry volume	=	1170 - (1170 × 31.03%) = 806.95 mL
	Unfoamed slurry weight	=	806.95 × 1.74 = 1404.1 g

A.10.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 3.

$$GS = TGUFS \div TGS \times GUFS \qquad (3)$$

Where:

GS	=	Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)
TGUFS	=	Total grams unfoamed slurry prepared in A.6
TGS	=	Total grams surfactant that would be used in TGUFS

$$GUSM = GUFS - GS \qquad (4)$$

Where:

GUSM	=	Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example:

Unfoamed slurry weight	=	1404.1 g
Percent by weight of surfactant	=	1.32 %

Surfactant weight	=	1404.1 × 0.0132 = 18.5 g
Slurry weight	=	1404.1 - 18.5 = 1385.6 g

A.11 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section A.10.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section A.10.2.

A.11.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section A.7.3 or A.7.4, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port, and verify that the slurry completely fills the slurry mixing container. If the slurry does not fill the mixing container at the end of the 15 second mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

A.11.2 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weight the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry.

A pressurized slurry density balance should never be used to determine the density of a foamed cement prepared at atmospheric pressure since this can compress the gas bubbles, and the slurry density indication will be high. The non-pressurized slurry density balance is also not recommended because the small hole in the center of the lid can cause a restriction that may partially pressurize the slurry and cause errors in the density determination.

A.12 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

A.12.1 Determining Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Preferred Method—Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder can not be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

Optional Method 1—Perform the above test in a smaller graduated cylinder, such as a standard 50-mL TC (to contain), standard 100-mL TC, or a wide-mouth 100-mL TC cylinder.

Optional Method 2—Perform the above test in an open-top sample container or in a plastic container with a lid. For containers that are not transparent, there will only be a visual inspection of the top surface at the conclusion of the 2 hours.

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 508-mm (2-in.) diameter, 1016-mm (4-in.) tall cylinders or any appropriate covered container. Cut or break the samples into sections, mark them from the top to the bottom, and measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined ($W \div V = SG$). The slurry density can also be determined ($SG \times 8.33 = lb/gal$).

Evaluate foam stability at an elevated temperature <190°F.

The PVC curing mold (Figure A.2, Page 39) is prepared by applying primer/cleaner and glue to the PVC parts and assembling them. Allow sufficient time for the glue to harden. Apply Teflon® tape to the brass fittings.

The atmospheric prepared foamed slurry is poured into the PVC mold and the large brass fitting screwed into the top. Slurry must exit the center hole of the large brass fitting. The small brass plug is then screwed into the large brass fitting and both tightened. Cure at the desired temperature until set. The specimen may be cured in a vertical position or at a specific angle if requested. After curing, cool to room temperature, remove the brass fitting and plug from the top, and examine the top of the foam. Note any obvious problems in the top of the foamed slurry. Cut the PVC into multiple pieces (at least three), marking each piece to reference the top to bottom sections. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Carefully cut the PVC longitudinally along each segment until the PVC can be removed. Examine the set foamed sections for signs of instability. These specimens can then be tested for density using the Archimedes principal described above. Compressive strengths can also be determined on each section providing the sample is a uniform cylinder.

The following materials are for the PVC curing mold:

- ¼-in. brass plug
- 1-in × ¼-in. brass reducer
- 1-in. PVC collar
- 1-in. PVC Schedule 40
- Tubing (6 to 8 in. long)
- 1-in. PVC cap

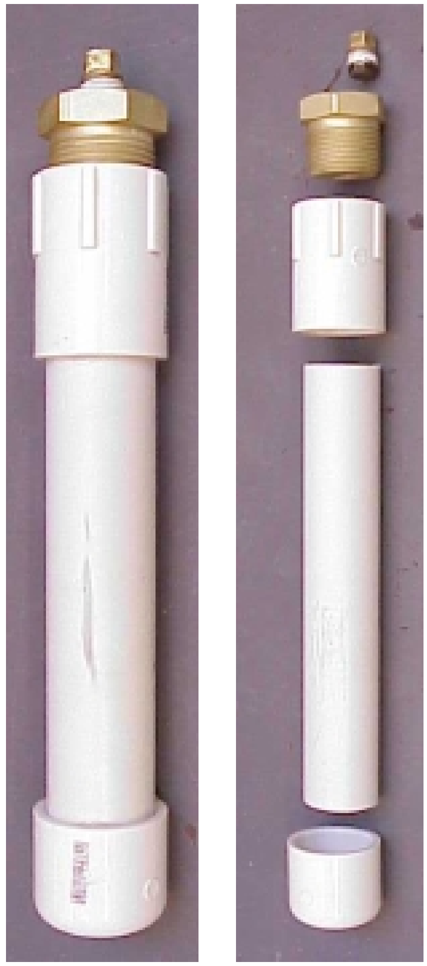

Fig. A.2—PVC curing mold

Signs of foam instability include the following:

- More than a trace of free fluid
- Bubble breakout noted by bubbles appearing on the surface of the sample. In severe cases, bubble coalescing (breaking, enlargement, merging, etc.) may be seen on the surface.
- Excessive column height reduction. If the foamed sample temperature is greater than room temperature when poured, a small amount of shrinkage in volume will occur as the sample cools. Minor meniscus effects are normal.
- Signs of density segregation as indicated by streaking or light to dark coloring change from top to bottom.
- Large variations in density from sample top to bottom.

A.12.2 Determining Compressive Strength

Atmospheric prepared foamed cement is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated, which will result in an undesired density decrease. The mold can be a standard 508-mm (2-in.) cube mold with a cover clamped to the top. Plastic cylinder molds (508-mm [2-in.] diameter by 1016-mm [4-in.] height) with a sealable top have also been used and placed into a clamp device.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is a good seal to keep the slurry from expanding out of the curing mold.

A.12.3 Determining Permeability

For determination of the permeability of atmospheric-prepared foamed cement, the preferred procedure is to pour the foamed cement slurry into permeability test molds. These test specimens are then cured and tested for permeability while still in the permeability mold. If the foamed cement slurry is poured into a mold in which the specimen must be removed, cored, cut, or sealed in the permeability testing apparatus; the specimen may not be strong enough to perform these operations without damaging it. The curing of atmospheric-prepared foamed cement slurries should be conducted under atmospheric pressure as for the compressive strengths in Section A.12.2.

The permeability testing of the cured specimens will be performed using the procedures in ISO/DIS 10426-2, clause 11.

A.12.4 Determining Other Tests on Base Unfoamed Slurry

A slurry that is foamed at atmospheric pressure should not be tested under pressure. Testing an atmospheric pressure prepared slurry under pressure will compress the foamed slurry and allow contamination when tested in a HPHT consistometer for thickening time. A compressed foamed slurry will also result in testing a heavier slurry if compressive strength specimens are cured under pressure.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO/DIS 10426-2, clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

A.12.5 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO/DIS 10426-2, clause 9.

A.12.6 Determining Fluid Loss

Fluid-loss tests performed with an atmospheric-prepared foamed cement are not likely to yield reliable results. Fluid-loss testing of a cement slurry that has been foamed requires special modifications to the fluid-loss cell and the foamed cement slurry must be prepared and transferred into the fluid-loss cell under pressure. The fluid-loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry. The static fluid-loss test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO/DIS 10426-2, clause 10.

TXI Lightweight Slurries

Initial Slurry Designs Used To Determine the Mixability of ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
10.00	1.92	6.5	18.96	Unspecified
10.00	1.97	7.0	18.46	Unspecified
10.00	2.02	7.5	17.97	Unspecified
10.00	2.07	8.0	17.48	Unspecified
10.00	2.27	10.0	15.50	Unspecified
10.00	2.37	11.0	14.52	Unspecified
10.00	1.87	6.0	19.01	1% Melcret K3F
10.00	1.92	6.5	18.51	1% Melcret K3F
10.00	1.97	7.0	18.02	1% Melcret K3F
10.00	2.02	7.5	17.53	1% Melcret K3F
11.50	1.49	5.5	9.98	Unspecified
11.50	1.53	6.0	9.21	Unspecified
11.50	1.58	6.5	8.44	Unspecified
11.50	1.62	7.0	7.67	Unspecified
11.50	1.70	8.0	6.12	Unspecified
11.50	1.78	9.0	4.58	Unspecified

Crush Test Slurry Designs Used for Comparing Conventional, Foam, and ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
Conventional				
11.00	2.45	14.96	None	2% Sodium Silicate
12.00	1.77	9.92	None	1% Sodium Silicate
12.00	2.38	14.05	None	3% Sodium Silicate
13.00	1.42	7.16	None	2% Sodium Silicate
13.00	1.86	10.20	None	5% Sodium Silicate
ULHS				
9.00	2.45	8.01	28.71	2% $CaCl_2$
10.04	2.40	7.53	22.00	2% $CaCl_2$
11.00	1.81	7.79	9.98	2% $CaCl_2$
Foam				
9.00	1.38	7.00	None	.02% Witcolate, .01% Aromox C12, 2% $CaCl_2$
10.00	1.38	7.00	None	.02% Witcolate, .01% Aromox C12, 2% $CaCl_2$
11.00	1.38	7.00	None	.02% Witcolate, .01% Aromox C12, 2% $CaCl_2$

Class A Slurries

Initial Slurry Designs Used To Determine the Mixability of ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
10.00	2.33	7.20	21.91	Unspecified
10.00	2.38	7.60	21.60	Unspecified
10.00	2.42	8.00	21.27	Unspecified
10.00	2.44	8.20	21.12	Unspecified
10.00	2.52	9.00	20.94	Unspecified
10.00	2.57	9.50	20.10	Unspecified
10.00	2.62	10.00	19.70	Unspecified
10.00	2.67	10.50	19.31	Unspecified
10.00	2.72	11.00	18.92	Unspecified
10.00	2.22	6.00	22.41	1% Melcret K3F
10.00	2.28	6.50	22.49	1% Melcret K3F
10.00	2.35	7.20	21.94	1% Melcret K3F
10.00	2.37	7.50	21.23	1% Melcret K3F
10.00	2.30	6.50	22.55	3% Melcret K3F
10.00	2.37	7.20	22.00	3% Melcret K3F
13.00	1.46	4.80	8.26	Unspecified
13.00	1.49	5.20	7.65	Unspecified
13.00	1.50	5.40	7.34	Unspecified
13.00	1.53	5.80	6.72	Unspecified
13.00	1.54	6.00	6.42	Unspecified
13.00	1.61	7.00	4.87	Unspecified
13.00	1.41	4.00	9.00	1% Melcret K3F
13.00	1.43	4.40	8.39	1% Melcret K3F
13.00	1.46	4.80	7.77	1% Melcret K3F

Class A Slurries

Crush Test Slurry Designs Used for Comparing Conventional, Foam, and ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
Conventional				
11.50	2.76	16.87	None	3% Sodium Silicate
12.00	2.38	14.05	None	3% Sodium Silicate
13.00	1.86	10.20	None	2% Sodium Silicate
ULHS				
9.05	3.26	11.50	31.00	2% $CaCl_2$
10.09	2.46	8.37	21.33	2% $CaCl_2$
11.07	2.15	8.37	13.63	2% $CaCl_2$
12.05	1.92	8.37	7.65	2% $CaCl_2$
Foam				
9.00	1.31	6.03	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$
10.00	1.31	6.02	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$
11.00	1.31	6.02	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$

Class H Slurries

Initial Slurry Designs Used To Determine the Mixability of ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
13.00	1.46	4.80	8.27	Unspecified
13.00	1.49	5.20	7.65	Unspecified
13.00	1.53	5.80	6.72	Unspecified

Crush Test Slurry Designs Used for Comparing Conventional, Foam, and ULHS Slurries

Density (lb/gal)	Yield (ft^3/sk)	Water Requirement (gal/sk)	ULHS (%bwoc)	Additives (%bwoc)
Conventional				
12.00	2.38	14.05	None	3% Sodium Silicate
13.00	1.86	10.20	None	2% Sodium Silicate
ULHS				
9.00	3.09	10.00	31.00	2% $CaCl_2$
10.00	2.48	8.37	21.33	2% $CaCl_2$
10.00	2.40	7.53	22.00	2% $CaCl_2$
11.00	2.17	8.37	13.63	2% $CaCl_2$
11.00	1.98	6.22	16.00	2% $CaCl_2$
12.00	1.92	8.37	7.65	2% $CaCl_2$
Foam				
9.00	1.30	6.02	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$
10.00	1.30	6.02	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$
11.00	1.30	6.02	None	.03% Witcolate, .01% Aromox C12, 2% $CaCl_2$

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-1	y		3907	9.2		95	9800	5:49	676	1800	Slag
HES-11	y		120	9.2	82	80	165	8:00+	80	80	TLW
HES-11	y		1100	9.8		85	3361	5:00+			TLW
HES-3		n		10.0		60	7600	4:45			A
HES-4	y		210	10.0		91	2100		183	271	A
HES-11	y		210	10.0		91	2100		155	244	TLW
HES-4	y		210	10.0		91	2100		126	185	Micro-fine
HES-11		n		10.0		119	6100	4:16			TLW
HES-11		n		10.0		119	6100	5:18		176	TLW
HES-11	y		2945	10.0		47	6200	5:00+		0	TLW
HES-5	y		142	10.0	120	103	2500	5:00+	85	156	H
HES-6		n		10.1	130	111	2752	4:38	4900		
HES-3	y		1605	10.5		75	2600	7:31	83	226	A
HES-2				10.5	181	145	7200	2:30	423	982	H
HES-11	y		250	10.5	92	80	1000	7:00+	FIRM	72	TLW
HES-11	y		250	10.5	92	80	1000	7:00+	50	70	TLW
HES-11	y		722	10.5	0	85	1305	6:00+	0	0	TLW
HES-11	y		220	10.5	97	83	1308	5:00+	FIRM	50	TLW
HES-4	y		2945	10.6		47	6200	5:00+		64	A
HES-3	y		1605	10.8		75	2600	2:21			A
HES-3	y		1605	10.8		75	2600	3:15			A
HES-3	y		2100	10.8		60	3650		0	54	A
HES-3	y		2100	10.8		60	3650		57	64	A
A	y		148	10.8	94	82	1200	4:00+	SET	110	H
HES-3	y		167	10.9		87	1732	2:57			A
HES-11	y		100	11.0	130	103	4500		184		TLW
HES-3	y		1711	11.0		80	2600	3:42			A
HES-4	y		210	11.0		91	2100		436	863	A
A	y		210	11.0		91	2100		89	128	Micro-fine
F		n		11.0	220	182	12055	4:20	238	286	Micro-fine
HES-2		n		11.0	181	145	7200	2:17	526	581	H
HES-3	y		1490	11.0		80	2505	2:29	377	487	A
A	y		1000	11.0		60	14085	7:00+		102	H
HES-11	y		31	11.0	86	80	555	6:00+	0	0	TLW
HES-11	y		31	11.0	86	80	555	6:00+	31	113	TLW
HES-3		n		11.0		60	7600	5:18			A
A	y		150	11.0	92	80	1000	4:00+	112	274	A
HES-3	y		100	11.0	130	103	4500	4:35	247	642	A
HES-4	y		100	11.0	130	100	4500	4:27	404	564	A
HES-11	y		100	11.0	130	103	4500	4:02	0	95	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	75	129	TLW
A	y		50	11.0	136	104	4799	6:00+	111	188	H
HES-11	y		100	11.0	130	103	4500		107	159	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	53	95	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	87	92	TLW
HES-3	y		1736	11.0		60	2450	4:19	105	175	A
A	y		480	11.0	97	84	1400	6:00+	126	345	A
A	y		174	11.0	95	80	1000	6:00+	115	205	A
HES-2	y		110	11.0	94	83	1300	5:00+	80	490	A
HES-11	y		80	11.0	160	116	6425	4:43			TLW
HES-11	y		1120	11.0	140	112	7990	2:53	30	90	TLW
HES-11	y		253	11.0	122	97	3862	7:00+	40	150	TLW
A	y		238	11.0	102	86	1894	6:00+	40	70	H
A	y		153	11.0	90	80	800	5:00+	FIRM	30	H
A	y		180	11.0	146	111	5555	7:00+	170	220	A
A	y		37	11.0	139	105	4500	6:00+	175	185	A
F	y		210	11.0		135	1868	2:00	172	180	Micro-fine
A	y		50	11.0	133	103	4400	2:04	270	280	A
HES-7	y		2841	11.0	0	72	5600	7:00+	0	0	A
A	y		193	11.0	96	83	1300	5:00+	120	190	A
A	y		300	11.0	125	98	3897	4:00+	130	200	H
HES-1	y		3214	11.0		80	6350	6:00+	115	160	Slag
F		n		11.0		228	12402	7:50	250	300	Micro-fine
HES-11		n		11.0	240	192	13000	5:55			TLW
HES-11		n		11.0	240	192	13000	6:00	90	324	TLW
A	y		180	11.0	128	102	4200	6:30+	76	103	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F		n		11.0	213	172	9713	5:00+	307	334	Micro-fine
A	y		385	11.0	118	102	4500	6:00+			A
A	y		50	11.0	133	103	4400	2:55	150	160	A
HES-3	y		1470	11.1		70	2600	5:03			A
A	y		50	11.1	161	122	7000	7:00+	37	50	H
HES-11	y		100	11.2	96	83	1300	6:00+	0	89	TLW
HES-11	y		380	11.2		95	6000	5:30+	32	86	TLW
HES-11	y		380	11.2		95	6000	4:30+	75	139	TLW
HES-11	y		380	11.2	154	115	6000	6:53	225	436	TLW
HES-11	y		380	11.2		70	1450	6:00+	38	67	TLW
HES-11	y		100	11.2	96	83	1300	7:00+	0	0	TLW
A	y		148	11.2	128	101	4863	5:00+	0	150	H
HES-7	y		100	11.2	96	83	1300	7:00+	0	74	H
HES-11	y		76	11.2	145	110	8174	4:00+	374	531	TLW
HES-11	y		100	11.2	171	125	7000	5:50	184	305	TLW
HES-11	y		76	11.2	211	163	12182	3:45	460	500	TLW
HES-7	y		2100	11.2		65	2500	6:00+	0	0	A
HES-11	y		76	11.2	211	163	12182	3:40	450	570	TLW
HES-11	y		380	11.2	154	115	6000	6:47	191	614	TLW
B	y		200	11.3	120	98	4000	4:30	86	128	H
F		n		11.3	194	156	8625	2:08	285	341	Micro-fine
A	y		123	11.3	113	94	3200	5:00+	130	200	H
A	y		280	11.4	102	89	3223	5:00+	75	127	H
A	y		110	11.4	95	80	1000	4:30+	95	120	H
A	y		420	11.4	115	99	4334	6:00+	138	201	A
A	y		420	11.4		102	4500	6:00+	187	257	A
A	y		420	11.4		102	4500		56	99	H
A	y		385	11.4		98	4094	5:00+	69	175	A
A	y		113	11.4	90	80	753	4:00+	50	100	H
A	y		164	11.4	93	81	1100	4:30+	101	163	A
A	y		113	11.4	95	84	2000	4:00+	60	110	H
A	y		113	11.4	101	89	6460		80	160	H
A	y		113	11.4	101	89	6460	4:00+	70	130	H
A	y		222	11.4	125	100	3850	5:00+	50	110	H
A	y		164	11.4	93	81	1100	4:00+			A
A	y		260	11.4	120	96	4820	5:00+	60	120	H
A	y		164	11.4	125	100	4084	4:00+	178	193	A
A	y		127	11.4	136	105	4700	7:00+	120	210	A
A	y		45	11.4	128	101	4000	5:00+	88	170	H
A	y		225	11.4	139	106	4853	5:00+	130	180	H
A	y		324	11.4	92	80	900	5:30+	70	121	H
A	y		80	11.4		84	2295	6:00+			H
A	y		108	11.4	91	80	1000	4:00+	50	110	H
A	y		108	11.4	108	92	2500	4:00+	60	120	H
A	y		90	11.4	92	80	1000	4:00+	52	140	A
A	y		228	11.4	92	80	1000	4:00+	60	152	A
A	y		181	11.4	92	80	1000	4:00+	130	150	H
A	y		181	11.4	110	93	3768	4:00+	140	155	H
A	y		236	11.4	118	97	4112	5:00+	78	130	H
A	y		47	11.4	119	96	3000	5:00+	90	173	A
A	y		245	11.4	126	100	4398	4:30	129	212	A
A	y		148	11.4	128	101	4000	4:00+	120	135	H
A	y		68	11.4	89	80	820	4:20	250	320	A
A	y		68	11.4	136	105	4700	2:20	230	390	A
A		n		11.4		80	50			70	A
A		n		11.4	80	80	270	4:00+		86	A
HES-11	y		20	11.4	97	84	1450	4:00+	87	113	TLW
HES-11	y		20	11.4	150	116	6400	3:45	255	419	TLW
A	y		43	11.4	152	115	6000	6:30+	142	155	H
A	y		236	11.4	95	83	1300	6:00+	83	107	A
A	y		420	11.4		100	3538	6:00+	98	147	A
A	y		427	11.4	100	89	2000	5:30+	75	140	H
A	y		165	11.4	118	96	3120	7:00+	140	220	A
A	y		236	11.4	118	97	4112	5:00+	70	130	H
A	y		427	11.4	117	99	4200	5:00+	85	158	H
A	y		420	11.4		84	1502	6:30+	90	171	A

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		372	11.4		82	1200	8:20	111	193	A
A	y		372	11.4		82	1200	8:20	111	193	A
A	y		260	11.4	95	83	1300	5:00+			H
A	y		260	11.4	95	83	1340	5:00+			H
A	y		420	11.4		85	1600	7:16	103	206	A
A	y		420	11.4		83	1200	5:30+	98		A
A	y		199	11.4	92	80	1050	5:00+	110	140	H
A	y		372	11.4	116	97	3500	6:03	274	348	A
A	y		260	11.4	125	99	3600	5:00+	50	110	H
A	y		236	11.4	95	83	1300	6:00+	89	112	A
HES-11	y		38	11.4	95	80	1000		36	229	TLW
A	y		120	11.4	197	147	9000		0	SET	H
A	y		25	11.4	88	80	700	2:00+	90	140	A
A	y		80	11.4	100	87	1700	5:00+	99	145	H
A	y		43	11.4	120	98	3500	3:30+	60	110	H
A	y		25	11.4	116	96	3000	3:00+	79	125	A
A	y		890	11.4	121	103	4500	6:00+	57	113	H
A	y		800	11.4	146	114	6000	6:30+	0	115	H
A	y		150	11.4	90	80	800	7:00+	0	51	H
A	y		30	11.4	92	80	1000	6:00+	0	60	H
HES-11	y		385	11.4		74	1450	4:00+	70	137	TLW
A		n		11.4	92	80	1000		60	120	H
HES-11	y		160	11.4		80	1000	6:00+	79	106	TLW
A	y		100	11.4	120	96	3100	5:00+	170	290	A
A	y		160	11.4	96	83	1300	6:00+			H
A	y		118	11.4	148	106	4500	5:00+	66	147	H
HES-11	y		57	11.4	92	80	1000	4:00+	92	109	TLW
A	y		150	11.4	115	94	2700	7:00+	0	52	H
A	y		8	11.4	108	92	2500	5:00+	65	116	H
A	y		8	11.4	108	92	2500	5:00+	58	81	H
HES-11	y		220	11.4	104	90	2180	4:00+	133	388	TLW
A	y		220	11.4	115	96	3525	3:00+	199	251	A
HES-11	y		78	11.4	116	96	3710	4:48	310	600	TLW
HES-11	y		160	11.4	119	98	3902	6:44	122	583	TLW
HES-11	y		40	11.4	119	98	3500	4:00+	168	601	TLW
HES-11	y		10	11.4	125	100	3800	5:00+	350	558	TLW
A	y		180	11.4	124	100	4000	4:00+	105	153	A
HES-11	y		25	11.4	124	100	4000	3:28	325	384	TLW
HES-11		n		11.4		80	1000	4:00+	79	110	TLW
B	y		100	11.4	92	80	1000	4:00+	300	310	A
A	y		52	11.4	117	96	3892	4:30+	50	130	H
A	y		238	11.4	126	100	4173	4:30+	70	120	H
A	y		90	11.4	125	98	3500	4:00+	85	125	A
A	y		90	11.4	120	98	3500	5:00+	145	216	A
A	y		210	11.4	114	98	3800	4:13	144	216	A
A	y		228	11.4	120	98	4275	5:00+	120	195	A
A	y		12	11.4	128	101	4000	4:30+	90	135	A
A	y		107	11.4	138	106	4800	4:30+			H
A	y		226	11.4	125	100	4000	4:30+	109	122	H
A	y		238	11.4	128	101	4600	4:36	160	206	A
A	y		245	11.4	143	109	5200	4:30+	78	116	A
A	y		90	11.4	140	107	5000	5:00+			H
A	y		9	11.4	140	108	5200	4:30			A
A	y		12	11.4	156	118	6350	7:00+	130	160	H
A	y		9	11.4	140	108	5200	7:30+	105	115	H
A		n		11.4	96	83	1300	5:00+	120	170	A
A	y		645	11.4		80	2500	4:00+	50	110	A
A	y		25	11.4	128	101	4000	5:00+	116	143	H
A	y		50	11.4	128	101	4000	4:00+	170	290	A
A	y		180	11.4	136	105	4700	6:00+	125	141	H
A	y		100	11.4	140	107	5000	5:00+	130	240	A
A		n		11.4	142	108	5200	6:30+	0	60	H
A	y		170	11.4	95	84	1400	4:00+	74	117	H
B	y		50	11.4	115	96	3000	4:00+	95	110	H
A	y		38	11.4	133	103	4937	8:00+	99	120	H
A	y		61	11.4	125	102	4300	4:00+	78	134	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		220	11.4	139	105	4677	7:00+	190	230	H
A	y		181	11.4	121	98	3500	4:00+	70	110	H
A	y		80	11.4	140	107	5000	7:00+	130	155	H
A	y		250	11.4		80	1000	6:30+	123	132	A
A	y		90	11.4	140	108	5350	4:00+	170	250	H
A	y		55	11.4	152	115	6345	4:00+	130	150	H
A	y		200	11.4		80	900	5:00+	0	102	H
A	y		35	11.4	95	81	1150	4:00+	50	121	H
A	y		358	11.4	102	89	2000	4:30+	69	157	A
A	y		365	11.4	122	98	3450	6:05	140	190	A
A	y		261	11.4	130	103	4500	5:00+	107	122	H
A	y		261	11.4	130	103	4500	4:30+	164	167	A
HES-3	y		6224	11.4		79	10000	6:49	0	160	A
A	y		155	11.4	90	80	900	5:00+	87	106	H
A	y		151	11.4	90	80	1000	4:00+	69	197	A
A	y		35	11.4	94	81	1100	6:00+	83	124	H
A	y		218	11.4	115	96	3150	4:00+	160	179	A
A	y		50	11.4	91	81	1100	5:00+	78	121	H
A	y		160	11.4	150	114	7150	5:00+	140	160	H
A	y		54	11.4	91	80	1050	4:30+	191	240	A
HES-11	y		80	11.4	103	88	1800	4:00+	88	108	TLW
A	y		45	11.4	98	84	1400	5:30+			H
A	y		151	11.4	90	80	1000	4:00+	119	205	A
A	y		151	11.4	93	81	1147	5:00+	130	150	H
A	y		35	11.4	113	93	2500	5:00+	94	197	H
A	y		35	11.4	117	95	3175	5:00+	87	116	H
A	y		126	11.4	103	89	2000	5:30+	83	131	H
A	y		126	11.4	103	89	2000	5:30+	93	119	H
A	y		20	11.4	118	93	2500	4:00+	184	243	A
A	y		151	11.4	120	98	3500	4:30+	86	99	H
A	y		107	11.4	95	82	1200	9:35	118	159	A
A	y		151	11.4	90	80	1000	4:00+	60	155	A
A	y		185	11.4	128	101	4000	4:00+	90	160	A
A	y		206	11.4	92	80	1000	4:00+	70	105	H
A	y		280	11.4	105	90	2000	6:30+	79	139	H
A	y		40	11.4	110	93	2500	4:00+	90	130	H
A	y		390	11.4	108	92	2630	6:00+	75	219	A
A	y		1430	11.4		75	2600	5:00+	50	110	A
A	y		38	11.4	118	97	3500	4:00+	88	164	H
A	y		293	11.4	109	96	3500	5:00+	95	165	H
A	y		340	11.4	115	97	3800	7:00+	58	79	H
A	y		206	11.4	124	99	4211	4:00+	75	115	H
HES-11	y		2000	11.4		90	4505	7:00+	55	215	TLW
A	y		35	11.4	135	105	4800	4:00+	102	133	H
A	y		35	11.4	135	105	4800	4:00+	111	192	A
A	y		110	11.4	140	107	5000	4:00+	103	110	H
A	y		130	11.4	128	101	4000	7:00+	60	120	H
A	y		90	11.4	142	108	5372	4:00+	130	160	H
A	y		200	11.4	128	101	5986	6:00+	28	79	H
A	y		60	11.4	130	103	4500	5:00+	90	129	H
HES-11	y		50	11.4	130	103	4500		0	111	TLW
HES-11	y		50	11.4	130	103	4500	5:23	97	173	TLW
A	y		162	11.4	138	104	4500	4:00+	120	150	H
A	y		68	11.4	135	104	4854	4:00+	140	280	H
A	y		21	11.4	124	100	4000	4:00+	125	155	H
HES-11	y		2000	11.4		92	4500	6:00	42	179	TLW
A	y		60	11.4	128	101	4000	4:00+	127	139	A
A	y		150	11.4	142	107	5080	6:00+	89	142	H
A	y		150	11.4	153	113	5600	7:30+	90	121	H
A	y		9	11.4	143	109	5200	6:00+	120	148	H
A	y		52	11.4	119	97	3400	7:00+	80	176	H
A	y		110	11.4	135	105	4600	4:00+	102	134	H
A	y		42	11.4	140	108	8020	6:00+	0	157	H
A	y		53	11.4	99	86	1921	4:00+	195	208	A
A	y		85	11.4	92	80	1000	4:00+	110	140	A
A	y		108	11.4	94	82	1200	4:00+	25	140	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		42	11.4	106	92	2794	6:00+	101	155	H
A	y		85	11.4	110	93	2500	4:00+	120	180	A
A	y		194	11.4	138	104	5525	5:00+	102	133	H
HES-11	y		2000	11.4	90	80	5000	6:00+	0	80	TLW
HES-11	y		722	11.4	130	103	4500	5:00+	217	497	TLW
A	y		157	11.4	143	105	4500	4:00+	130	160	H
A	y		90	11.4	146	110	5250	5:30+	0	172	H
A	y		160	11.4	140	108	5200	6:00+	78	135	H
A	y		42	11.4	140	108	6883	6:00+	122	130	H
A	y		168	11.4	115	97	3500	4:00+	162	185	A
A	y		42	11.4	140	108	7132	6:00+	80	120	H
A	y		87	11.4	145	114	6000	5:00+	136	164	H
A	y		42	11.4	140	108	7487	6:00+	0	125	H
A	y		42	11.4	140	108	8423	6:00+	0	110	H
A	y		60	11.4	145	108	6350	5:00+	125	132	H
A	y		154	11.4	155	112	5400	2:14	206	397	A
A	y		154	11.4	158	112	5200	6:30+	110	160	H
A	y		68	11.4	92	80	1000	3:00+			A
A	y		167	11.4	94	82	1200	4:00+	110	140	H
A	y		68	11.4	91	80	1000	3:00+	109	171	A
A	y		50	11.4	105	91	2200	5:00+	106	130	H
A	y		68	11.4	105	90	2100	3:00+			A
A	y		68	11.4	105	90	2100	3:00+	115	175	A
A	y		160	11.4	135	104	4500	6:00+			H
A	y		180	11.4	155	110	5000	5:00+	61	158	H
A	y		45	11.4	152	112	5500	5:30+	101	118	H
A	y		151	11.4	115	97	3500	5:00+	83	158	H
A	y		151	11.4	115	97	3500	5:00+	75	165	H
A	y		155	11.4	120	98	3635	5:00+	92	125	H
A	y		54	11.4	118	97	3500	4:00+	100	149	H
A	y		150	11.4	115	96	3000	5:00+	105	178	H
A	y		151	11.4	115	97	3500	4:00+	95	125	H
A	y		58	11.4	139	105	4500	5:00+	116	131	H
A	y		35	11.4	136	103	4300	5:00+	105	150	H
A	y		100	11.4	128	102	4400	5:00+	120	128	H
A	y		250	11.4	134	104	4550	9:30+	68	120	H
A	y		54	11.4	124	100	4000	4:00+	115	146	H
A	y		50	11.4	130	101	4000	5:30+			H
A	y		194	11.4	92	80	1000	5:00+	88	155	H
A	y		65	11.4	141	108	5100	5:00+			H
A	y		154	11.4	92	80	800	4:00+	100	130	H
A	y		95	11.4	90	80	998	3:00+	110	140	H
A	y		164	11.4	90	80	1000	3:00+	SET	130	H
A		n		11.4	90	80	1000	3:00+	55	125	A
A	y		300	11.4	98	86	1630	5:00+	70	140	A
A	y		500	11.4		80	1600	5:00+	108	376	A
A	y		294	11.4	93	82	1175	5:30+			H
A	y		95	11.4	94	83	1856	3:00+	100	145	H
A	y		121	11.4	125	100	3800	4:00+	65	140	H
A	y		294	11.4	120	97	3200	5:00+	98	168	H
A	y		70	11.4	135	106	5000	5:30+			A
A	y		70	11.4	135	106	5000	4:30+	60	110	H
A	y		110	11.4	138	107	5000	5:00+	95	121	H
A	y		148	11.4	90	80	800	4:00+	83	143	H
A	y		65	11.4	141	108	5100	5:00+	93	128	H
A	y		41	11.4	128	99	3670	5:00+	100	120	H
A	y		100	11.4	132	104	5100	6:00+	80	100	H
A	y		100	11.4	126	101	4200	7:00+	60	100	H
A	y		220	11.4	120	98	4636	6:30+	60	75	H
A	y		100	11.4	150	109	6488	5:30+	100	110	H
A	y		100	11.4	150	109	5078	8:00+	110	170	H
A	y		220	11.4	134	104	4500	7:00+	80	100	A
A	y		204	11.4	92	80	1000	5:00+	40	77	H
A	y		204	11.4	120	97	3300	5:00+	45	100	H
A	y		45	11.4	138	104	4948	6:00+	80	120	H
A	y		22	11.4	152	115	6000	7:00+	50	72	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		42	11.4	136	104	4500	6:00+	40	100	H
A	y		55	11.4	130	104	4630	5:00+	50	100	H
A	y		220	11.4	91	80	1000	4:00+	FIRM	70	H
A	y		35	11.4	126	99	4378	7:00+	80	110	H
A	y		14	11.4	132	104	4500	5:30+	40	110	H
A	y		60	11.4	92	82	1000	5:39	160	200	A
A	y		61	11.4	130	100	4000	2:40			A
A	y		90	11.4	0	91	1000	4:30+	40	60	H
A	y		90	11.4	132	104	4500	5:00+	90	130	H
A	y		23	11.4	134	104	4500	7:00+	60	120	A
A	y		300	11.4	98	84	1400	5:00+	20	80	A
A	y		16	11.4	110	92	2500	7:00+	20	80	A
A	y		41	11.4	95	80	1000	3:00+	50	80	H
A	y		48	11.4	90	80	800	3:00+	FIRM	80	H
A	y		36	11.4	92	80	1000	5:00+	50	100	H
A	y		36	11.4	128	100	4000	5:30+	90	120	H
A	y		73	11.4	125	96	3000	4:27	80	100	A
A	y		55	11.4	90	80	800	4:00+	50	70	H
A	y		90	11.4	134	104	4500	9:00+	50	160	H
A	y		25	11.4	124	100	4000	4:00+	88	165	H
A	y		750	11.4		80	1825		15	40	H
B	y		65	11.4	145	107	5016	7:30+	40	60	H
A	y		68	11.4	132	103	6022	4:30+	225	250	H
A	y		1550	11.4		80	5000	6:00+	20	65	H
A	y		87	11.4	93	80	800	5:00+	40	80	A
A	y		87	11.4	138	106	4800	5:00+	40	60	A
A	y		110	11.4	140	107	5000	5:00+	110	130	A
A	y		80	11.4	133	99	3771	5:00+	50	60	H
A	y		1061	11.4		70	2800	10:00+	0	FIRM	H
A	y		100	11.4	146	117	6500	5:00+	40	60	H
A	y		227	11.4	104	90	2000	5:00+	50	110	A
A	y		1050	11.4		77	2800		0	65	H
A	y		245	11.4	94	82	1200	4:00+	FIRM	100	H
A	y		200	11.4	134	104	4585	5:30+	50	170	H
A	y		45	11.4	140	107	5000	7:00+	40	60	H
A	y		131	11.4	145	106	4500	6:00+	60	170	H
A	y		131	11.4	95	80	1000	5:00+	30	60	H
A	y		46	11.4		75	1000	5:00+	35	80	H
A	y		143	11.4	115	99	4790	6:00+	60	80	A
A	y		55	11.4	140	107	5000	6:00+	70	90	H
A	y		256	11.4	90	80	1000	4:30+	30	60	H
A	y		82	11.4	140	107	5000	5:00+	30	80	H
A	y		82	11.4	140	107	5000	5:00+	60	100	H
A	y		650	11.4		120	5155	1:15			A
A	y		650	11.4	122	106	5155	2:34	170	280	A
HES-9	y		98	11.4		130	4500	4:03	60	280	77.5/22.5 TLW/MM
A	y		120	11.4	92	80	1000	5:00+	30	70	H
A	y		245	11.4	124	101	4205	5:00+	60	90	H
A	y		191	11.4	114	94	3030	5:00+	FIRM	40	H
A	y		296	11.4	125	102	4500	5:00+	0	70	H
A	y		80	11.4	160	116	6425	8:00+			H
A	y		50	11.4	104	86	1600	6:00+	30	80	H
A	y		258	11.4	95	82	1200	5:00+	40	70	H
A	y		258	11.4	131	102	4329	5:00+	60	100	H
A	y		50	11.4	162	114	5500	8:00+	60	100	H
A	y		50	11.4	162	114	5500	5:00+			H
A	y		50	11.4	112	93	2500	5:00+	40	70	H
A	y		221	11.4	132	101	4000	6:45+	70	110	H
A	y		100	11.4	140	106	4700	5:00+	35	55	H
A	y		50	11.4	90	80	800	5:00+	0	50	H
A	y		100	11.4	94	80	1000	5:00+	30	50	H
A	y		61	11.4	135	104	4500	5:00+	60	100	H
A	y		191	11.4	92	80	1000	4:00+	0	50	H
A	y		58	11.4	105	92	2617	6:00+	80	140	H
A	y		191	11.4	132	103	4772	6:00+	90	130	H
A	y		180	11.4	90	80	800	5:00+	40	80	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		100	11.4	116	97	3500	7:00+	110	160	H
A		n		11.4	134	104	4550	5:00+	100	110	H
A	y		180	11.4	124	100	4540	6:00+	50	90	H
HES-7	y		2841	11.4	0	75	5600	5:00+	0	0	A
A	y		6500	11.4	0	68	11000	6:00+	0	0	H
A	y		180	11.4	111	93	2710	5:00+	FIRM	40	H
A	y		227	11.4	91	80	1000	5:00+	70	120	H
A	y		120	11.4	92	80	1000	4:00+	FIRM	20	H
A	y		120	11.4	116	95	3000	5:00+	70	110	H
A	y		120	11.4	122	97	3500	5:00+	40	60	H
A	y		191	11.4	92	80	1000	5:00+	80	120	H
A	y		300	11.4	98	84	1500	4:00+	150	180	A
A	y		34	11.4	122	97	3500	4:00+	70	110	H
A	y		120	11.4	138	108	5000	7:30+	100	140	H
A	y		30	11.4	130	104	4500	8:00+	70	110	H
A	y		84	11.4	122	97	3300	6:00+	70	80	H
B	y		372	11.4	95	84	1500	4:00+	0	100	H
A	y		50	11.4	160	120	6500	5:00+	190	210	H
A	y		100	11.4	90	80	800	4:00+	FIRM	70	H
A	y		202	11.4	95	80	800	5:00+	70	90	H
A	y		25	11.4	100	91	2500	8:00+	70	130	H
A	y		60	11.4	120	96	3500	4:00+	60	100	H
A	y		180	11.4	92	80	1000	3:00+	70	110	A
A	y		180	11.4	141	108	5100	4:00+	90	140	A
A	y		210	11.4	122	99	4000	6:00+	55	110	H
A	y		55	11.4	0	105	4600	6:00+	110	160	H
A	y		163	11.4	120	102	4500	5:00+	60	105	H
A	y		314	11.4	128	100	4000	6:00+	80	130	H
A	y		155	11.4	98	84	1500	6:00+	90	130	H
A	y		155	11.4	148	113	5747	6:00+	110	140	H
A	y		241	11.4	115	96	5047	9:00+	60	90	H
A	y		100	11.4	143	108	4900	7:00+	30	60	H
A	y		50	11.4	92	80	950	4:00+	80	140	A
A	y		50	11.4	125	98	3500	2:43	271	410	A
A	y		100	11.4	117	96	3180	6:00+	FIRM	110	H
A	y		100	11.4	134	104	4500	7:00+	60	110	H
A	y		40	11.4	128	100	4063	6:00+	60	170	H
A	y		50	11.4	92	80	1000	3:00+	0	50	H
A	y		58	11.4	90	80	700	5:00+	FIRM	50	H
A	y		73	11.4	95	80	1000	4:30+	40	70	A
A	y		77	11.4	98	82	1200	6:00+	90	140	H
A	y		300	11.4	115	95	2900	4:00+	110	180	A
A	y		199	11.4	96	83	1300	5:00+	120	210	A
A	y		517	11.4	103	90	2100	7:00+	82	127	A
A	y		184	11.4	97	80	1000	4:00+	50	110	H
A	y		184	11.4	122	98	3758	4:00+	80	130	H
A	y		100	11.4	88	80	750	3:00+	0	50	H
A	y		100	11.4	115	97	3500	4:00+	0	50	H
A	y		104	11.4	118	97	3500	4:30+	120	140	H
A	y		45	11.4	93	80	1000	4:00+	0	60	H
A	y		45	11.4	138	104	4500	7:30+	192	386	H
A	y		82	11.4	92	80	1000	4:00+	80	130	H
A	y		95	11.4	109	93	2786	4:00+	175	290	H
A	y		38	11.4	122	98	3500	4:00+	130	160	H
A	y		175	11.4	122	98	3500	7:00+	110	130	H
A	y		134	11.4	98	85	1500	5:00+	100	150	H
A	y		126	11.4	98	85	1659	5:00+	100	140	H
A	y		79	11.4		95	4927	6:00+	120	290	H
A	y		79	11.4		95	4927	4:00+	100	180	H
A	y		79	11.4	134	106	4927	5:00+	130	160	H
A		n		11.4	171	128	7600	4:48	170	270	H
A	y		48	11.4	130	102	4200	5:00+	50	190	A
A	y		370	11.4		95	4904	5:00+	115	135	H
A	y		78	11.4	90	80	800	5:00+	110	210	A
A	y		78	11.4	110	93	2500	5:00+	120	190	A
A	y		250	11.4	127	100	3915	4:00+	130	200	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		40	11.4	94	82	1200	3:00+	50	95	H
A	y		40	11.4	94	82	1200	4:00+	0	120	H
A	y		202	11.4	90	80	800	6:00+	40	55	H
A	y		82	11.4	128	101	4043	4:00+	110	180	H
A	y		183	11.4	92	80	1000	5:00+	120	240	A
A	y		227	11.4	135	104	4516	5:00+	50	70	A
HES-11	y		38	11.4	134	104	4500	6:00+	244	1247	TLW
HES-11	y		385	11.4	130	106	5000	5:30+	164	433	TLW
A	y		180	11.4	92	80	1000	6:00+	95	130	A
A	y		30	11.4	114	93	2500	5:00+	280	289	A
A	y		124	11.4	129	99	3500	7:00+	110	160	H
A	y		18	11.4	135	102	4000	4:30+	85	109	H
A	y		85	11.4	134	104	4528	7:00+	60	120	H
A	y		55	11.4	140	105	4635	7:00+	130	160	H
A	y		102	11.4	143	108	5000	7:00+	138	175	H
A	y		142	11.4	158	110	5175	5:00+	122	132	H
A	y		150	11.4	155	110	5000	5:00+	107	137	H
A	y		25	11.4	116	96	3000	3:53	276	391	A
A	y		22	11.4	95	82	1200	4:30+	0	125	H
A	y		50	11.4	93	80	1000	4:00+	105	120	H
A	y		340	11.4	100	89	2000	5:00+	140	150	A
A	y		22	11.4	135	105	4660	6:00+	90	160	H
A	y		152	11.4	140	107	5000	6:00+			A
A	y		120	11.4	143	109	5300	4:00+	124	163	H
A	y		176	11.4	140	107	5000	7:00+	190	270	A
A	y		175	11.4	90	80	800	6:00+	87	112	H
A	y		175	11.4	114	95	2943	5:30+	0	155	H
A	y		120	11.4	110	93	2500	6:17	262	376	A
A	y		175	11.4	111	93	2500	5:00+			H
A	y		175	11.4	90	80	900	6:30+	70	120	H
A	y		689	11.4		87	2000	4:00+	50	120	A
A	y		689	11.4	138	108	5300	5:00+	90	159	A
A	y		40	11.4	134	104	4500	5:00+	50	100	H
A	y		100	11.4	115	100	2500		98	151	H
A	y		65	11.4	126	100	4000	4:00+	40	110	H
A	y		303	11.4	126	103	4889	5:30+	130	180	A
A	y		124	11.4	124	98	4044	4:00+	50	85	H
A	y		80	11.4	92	80	1000	4:00+	90	140	H
A	y		45	11.4	95	80	900	6:53	110	150	A
A	y		107	11.4	125	96	3000	3:53	150	200	A
A	y		45	11.4	116	96	3000	3:39	130	160	A
A	y		222	11.4	110	93	2905	6:00+	140	170	H
A	y		240	11.4	115	97	3500		0	50	H
A	y		240	11.4	115	97	3500	13:26	0	100	A
A	y		44	11.4	127	100	3900	4:00+	130	180	H
A	y		334	11.4	103	89	2000	5:00+	160	180	A
A	y		232	11.4	110	93	2500	4:43	120	145	A
A	y		152	11.4	112	93	2600	4:00+	120	160	H
A	y		65	11.4	110	93	2500	4:00+	30	70	H
A	y		200	11.4	92	80	1000	4:00+	SET	140	H
A	y		106	11.4	95	80	1000	5:00+	30	42	H
A	y		72	11.4	117	96	3316	5:00+	40	110	H
A	y		25	11.4	108	92	2500	5:00+	30	60	A
A	y		1163	11.4		70	3100	4:00+	FIRM	60	H
A	y		87	11.4	140	107	5190	4:00+	40	80	H
A	y		58	11.4	132	103	4300	5:00+	80	100	A
A	y		233	11.4	120	100	4000	6:00+	50	65	A
A	y		75	11.4	128	101	4000	5:30+	130	180	H
A	y		160	11.4	120	100	4000	4:00+	35	60	H
A	y		100	11.4	129	99	3500	6:00+	50	65	H
A	y		80	11.4	140	106	4700	6:00+	60	140	H
B	y		67	11.4	91	80	1000	5:00+	30	70	H
A	y		334	11.4	138	107	5186	5:00+			A
A	y		58	11.4	122	98	3850	4:30+	130	180	H
A	y		222	11.4	98	85	1881	5:00+	125	195	A
A	y		200	11.4	108	90	2000	5:00+	120	130	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		225	11.4	116	96	3089	4:00	110	180	A
A	y		220	11.4	125	100	4000	4:00+	160	180	A
A	y		220	11.4	125	100	4000	4:00+	120	140	H
A	y		89	11.4	140	107	5143	4:00+	110	160	H
A	y		30	11.4	140	105	4500	6:00+	50	101	H
A	y		212	11.4	138	106	4839	4:00+	170	180	A
A	y		79	11.4		80	3000		0	130	H
A	y		517	11.4	123	101	4643	4:00+	0	90	A
A	y		50	11.4	133	103	4400	5:00+	120	170	H
A	y		40	11.4	92	80	1000	4:04	250	310	A
A	y		340	11.4	104	90	2129	5:00	110	150	A
A	y		48	11.4	124	98	3500	4:00+	150	200	H
A	y		38	11.4	105	90	2000	4:00+	170	220	A
A	y		63	11.4	124	98	3500	7:00+	130	190	H
A	y		63	11.4	130	101	4000	4:00+	150	190	H
A	y		40	11.4	140	107	5133	4:00+	140	210	A
A	y		220	11.4	96	83	1500	5:00+	0	60	H
A	y		220	11.4	102	88	3189	5:00+	0	60	H
A	y		9	11.4	126	100	3800	5:30+	170	215	A
A	y		72	11.4	122	98	4082	4:00+	110	150	H
A	y		40	11.4	115	96	3000	4:00+	120	190	H
A	y		80	11.4	140	106	4800	4:00+	150	190	H
A	y		80	11.4	138	105	4700	4:00+			H
A	y		37	11.4	143	105	4500	6:30+	165	195	H
A	y		38	11.4	88	80	800	4:00+	180	210	A
A	y		58	11.4	126	103	4500	4:00+	277	347	TLW
A	y		114	11.4	152	115	6000	8:09	150	170	H
A		n		11.5	128	101	4000		142	229	Micro-fine
HES-11	y		3200	11.5		73	7000	7:00+	0	0	TLW
HES-3	y		6220	11.5		79	10000	4:20			A
F		n		11.5	192	157	9394	3:40	46	255	Micro-fine
HES-11	y		17	11.5	150	116	6400	2:50			TLW
HES-11	y		3000	11.5		65	4500	8:00+			TLW
A	y		80	11.5	116	96	3000	4:00	142	233	H
HES-11	y		50	11.5	114	95	2850	6:30	0	122	TLW
HES-11	y		50	11.5	98	85	1500	7:00+	73	175	TLW
HES-11	y		107	11.5	210	163	12227	4:06	460	890	TLW
A	y		241	11.5	135	107	5075	5:00+	158	288	H
HES-11	y			11.5	142	109	6708	7:12	40	150	TLW
HES-11	y			11.5	142	109	6708		75	230	TLW
HES-11	y			11.5	142	109	6708	6:48	200	530	TLW
HES-11	y			11.5	142	109	6708		75	230	TLW
HES-11	y			11.5	142	109	6708		170	450	TLW
HES-11	y			11.5	145	111	7040	5:30	53	94	TLW
F	y			11.5		90	1600	3:37	94	230	Micro-fine
HES-11	y			11.5		90	1600	6:00+	62	157	TLW
B	y			11.5	99	90	2300	4:38	54	114	A
HES-3	y			11.5		60	4085	4:00+		296	A
HES-3	y			11.5		60	4085			89	A
A	y			11.5	120	96	3080	5:00+	94	134	H
B	y			11.5		91	2400			122	A
HES-7	y			11.5		91	2400			82	A
HES-11	y			11.5		86	1900	5:00+	107	132	TLW
HES-3	y			11.5		100	4600	6:24			FLOSTOP-I
HES-3	y			11.5		75	2600	6:00+			A
HES-3		n		11.5		80	4085	5:30+			A
A	y			11.5		60	4085	5:00+		40	A
A	y			11.5	91	80	900	4:00+	110	140	H
HES-11	y			11.5	122	97	3200	5:00+	133	414	TLW
A	y			11.5	96	84	1500	4:00+	140	175	H
A	y			11.5	96	84	1500	4:00+	135	210	H
B	y			11.5	105	90	2100		36	44	50/50 H/POZ
HES-11		n		11.5		80	80	5:00+	132	341	TLW
B	y			11.5	210	159	11295	6:30+	120	180	65/35 H/POZ
B	y			11.5	210	159	11295	6:30+	120	130	65/35 H/POZ
HES-3	y			11.5		70	3950	4:00+	96	347	A

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-7	y			11.5	0	65	4550	4:30+	0	0	A
HES-7	y			11.5	0	63	7000	5:30+			A
HES-7	y			11.5	200	151	9800	9:00+			50/50 H/POZ
HES-7	y			11.5	200	151	9800	9:00+			50/50 H/POZ
HES-11	y			11.5	96	83	1300	6:00+	102	222	TLW
A	y			11.5	130	103	4500	7:00+	120	150	H
A	y			11.5	134	106	5010	6:00+	95	107	H
F	y			11.5	122	104	3800	3:05	333	494	Micro-fine
F	y			11.5	170	138	7400	3:51	439	519	Micro-fine
F	y			11.5	230	194	13900	4:00+	346	379	Micro-fine
F		n		11.5	195	159	9522	0:43			Micro-fine
F		n		11.5	164	134	7000	3:27	381	477	Micro-fine
A	y			11.5	128	101	4000	4:30+	99	118	H
HES-11	y			11.5	94	83	1300	4:00+	87	184	TLW
HES-11	y			11.5	117	98	4000	5:00+	194	386	TLW
HES-11	y			11.5	106	93	2600	5:00+			TLW
HES-11	y			11.5	94	84	1420	5:00+			TLW
B	y			11.5	257	198	11800	8:30+	180	340	65/35 H/POZ
A	y			11.5	185	136	8100	6:00+	54	71	H
HES-7	y			11.5	0	70	7200	5:00+	0	0	A
HES-11	y			11.5	135	106	5000	4:00+	144	409	TLW
F	y			11.5		92	2900	3:45+	323	347	Micro-fine
B	y			11.5	90	80	1050	6:00+	FIRM	20	50/50 H/POZ
F	y			11.5	225	186	11795	5:00+	625	705	Micro-fine
A	y			11.5	100	83	1300	6:00+		147	A
B		n		11.5		83	1500	6:30+	39	150	A
A	y		320	11.6	102	89	3223	5:00+	99	137	H
A	y		57	11.6	128	101	4000	5:00+			H
HES-3	y		2920	11.6		75	6500	5:20	115	334	A
A		n		11.6		80	50		0	0	A
A		n		11.6	90	80	1000		170	346	A
A	y		126	11.6	140	105	4500	3:00			A
A	y		110	11.6	90	80	760	5:00+	117	143	H
A	y		80	11.6	126	96	4000	4:47	289	416	A
A	y		250	11.6	90	80	880	6:00+	68	131	H
A	y		110	11.6	127	101	4071	5:00+	125	155	H
A	y		320	11.6	102	89	2690	4:00+		142	H
A	y		250	11.6	120	100	3952	6:00+	81	101	H
A	y		250	11.6	120	98	3429	6:00+	75	140	H
A	y		250	11.6	110	95	3100	6:00+	98	126	H
A	y		250	11.6	111	95	3100	6:00+	785	1424	H
A	y		182	11.6	128	103	4500	7:00+	102	152	H
A	y		250	11.6	96	80	800	6:00+	94	121	H
HES-3	y		1450	11.7		100	4600	4:47	191	340	FLOSTOP-I
A	y		320	11.7	164	117	6000	6:55	120	140	H
HES-3	y		6220	11.7		70	8016	6:00+			FLOSTOP-I
HES-3	y		6220	11.7		60	8016		104	327	FLOSTOP-I
B	y		200	11.7	172	132	11000	3:54	66	211	H
HES-11	y		100	11.7	98	85	1500	6:00+	96	273	TLW
A	y		3822	11.7		106	7450	2:30			A
A	y		1420	11.7		95	6600	6:30+	173	315	A
HES-11	y		20	11.7	134	102	4200	5:00+	210	760	TLW
F		n		11.7	166	136	7550	3:55	557	698	Micro-fine
A	y		358	11.7	120	98	3700	4:33	131	181	A
HES-3	y		2649	11.7		80	7234	6:07	141	313	A
A	y		363	11.7	120	98	3657	7:12	110	200	H
A		n		11.8		110	4000	8:00+			H
A		n		11.8		60	100		50	110	A
A		n		11.8		93	2500		0	57	
A		n		11.8		110	4000	9:00+			H
A		n		11.8		110	4000	9:00+			H
A		n		11.8		110	4000	9:58			H
A		n		11.8		80	1000		110	250	A
A		n		11.8		110	4000	8:00+			H
HES-11		n		11.8	80	80	1000	5:58	157	200	TXI
A		n		11.8		96	3000	5:25	232	325	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F		n		11.8	140	140	6278	4:40	140	580	Micro-matrix
A	y		10	11.8	114	95	3015	4:17	211	273	A
HES-11		n		11.8	118	93	2500	4:45		166	TXI
HES-11		n		11.8	103	86	1630	4:07		280	TXI
B		n		11.8	95	80	1000	4:00+	160	200	H
A	y		50	11.8	120	96	3100	5:00+	40	80	H
B	y		75	11.8	145	107	4700	4:52	100	130	H
A	y		60	11.8	130	101	4000	4:00+	110	160	H
B	y		75	11.8	145	108	5131	4:02	70	100	H
B	y		75	11.8	116	94	2831	5:00+	160	200	H
A	y		122	11.8	128	101	4000	5:30+	140	240	H
A	y		122	11.8	95	82	1250	5:00+	130	220	H
A	y		75	11.8	91	80	750	5:00+	56	97	H
A	y		20	11.8	93	82	1200	6:00+	65	115	H
A	y		20	11.8	102	82	1200	5:00+	142	206	H
A	y		20	11.8	93	82	1200	4:00+	100	130	H
A	y		120	11.8	130	102	6226	4:00+	50	139	H
A		n		11.8	98	82	1250	5:00+	170	220	A
A		n		11.8	132	102	4200	5:00+	40	90	A
HES-11	y		1500	11.8		70	5200	7:00+	32	50	TLW
A	y		35	11.8	134	104	4500	5:30+	227	328	H
A	y		80	11.8	114	95	3100	5:00+	155	190	H
A	y		80	11.8	126	96	4000	5:00+	299	426	A
A	y		80	11.8	124	95	4000	4:00+	167	325	A
A	y		85	11.8	126	96	4000	10:00+	211	296	A
A	y		100	11.8	95	80	1000	8:00+	30	80	H
A	y		100	11.8	144	108	5386	8:00+	80	115	H
A	y		100	11.8	115	95	3000	6:00+	40	90	H
A	y		100	11.8	90	80	800	6:00+	0	56	H
A	y		100	11.8	116	96	3500	6:00+	50	100	H
A	y		30	11.8	141	108	5100	5:00+	142	163	H
B	y		180	11.8	134	104	4535	4:17	122	178	H
B	y		180	11.8	130	102	4216	4:21	168	205	H
A	y		200	11.8	145	109	5200	7:30+	0	63	H
A	y		220	11.8	125	99	3950	6:30+	145	175	H
A	y		250	11.8	132	101	5400	7:00+	135	155	H
HES-11	y		300	11.8	112	99	3800	6:30+	81	193	TLW
HES-11	y		300	11.8		80	1000	6:00+	47	55	TLW
A	y		365	11.8	112	92	2414	4:00+	159	228	A
A	y		45	11.8	128	104	4985	6:00+	94	106	H
A	y		360	11.8	92	80	1000	4:00+	120	200	H
A	y		30	11.8	129	103	4500	5:00+	143	169	H
B	y		35	11.8	112	95	3000	5:00+	40	100	H
B	y		35	11.8	112	95	3000	5:00+	40	100	H
B	y		35	11.8	92	80	1000	5:00+	0	FIRM	H
B	y		35	11.8	92	80	1000	5:00+	0	60	H
B	y		35	11.8	140	108	5000	6:00	50	90	H
B	y		35	11.8	140	108	5000	5:00	50	130	H
B	y		75	11.8	89	80	750	5:00+	70	80	H
B	y		75	11.8	90	80	800	3:30+	30	110	H
B	y		75	11.8	126	100	4000	4:00+	60	140	H
A	y		90	11.8	130	102	4200	6:00+	50	130	H
A	y		10	11.8	140	107	5000	5:30+	128	194	H
B	y		110	11.8	135	105	4800	5:41	120	140	H
A	y		100	11.8	134	104	4693	4:30+	180	230	H
A	y		100	11.8	121	98	3600	5:00+	115	190	H
A	y		100	11.8	115	93	2500	5:00+	155	210	H
A	y		120	11.8	140	116	5200	5:00+	164	188	H
A	y		145	11.8	128	101	4000	4:00+	98	138	H
A	y		145	11.8	92	80	1000		0	169	H
A	y		140	11.8	132	101	4323	10:00+	80	100	H
A	y		15	11.8	140	107	5000	6:30+	105	140	H
A	y		265	11.8	109	93	4431	5:00+	110	255	H
A	y		350	11.8	115	97	3500	3:37	258	372	A
A	y		333	11.8	120	97	5000	5:00+	95	280	A
A	y		25	11.8	130	104	4700	6:30+	215	250	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		22	11.8	125	100	4000	5:00+	130	200	H
A	y		20	11.8	135	106	5000	5:00+	162	222	H
B		n		11.8	122	98	3500	5:00+	50	103	65/35 A/POZ
B		n		11.8	115	93	2550	5:00+	130	160	65/35 A/POZ
A		n		11.8	147	110	5250	5:00+	90	100	H
A	y		800	11.8	130	102	4200	4:32		262	A
HES-11	y		800	11.8	125	103	4500	6:00+	235	365	TLW
HES-11	y		800	11.8	103	91	2300	6:00+	149	374	TLW
A		n		11.8	85	80	300		108	140	A
A		n		11.8	85	80	300		190	205	A
A	y		100	11.8	92	80	1000	5:00+	130	300	A
B	y		218	11.8	134	104	4500	4:00+	70	150	H
HES-11	y		50	11.8	139	106	4900	3:00+	820	1680	TLW
HES-11	y		850	11.8	105	91	2575	4:06	70	160	TLW
A	y		75	11.8	127	99	4200	8:00+	163	260	H
A	y		50	11.8	122	99	3540	2:39	150	355	A
B	y		75	11.8	120	98	3500	5:05	90	170	H
B	y		75	11.8	90	80	750	5:00+	43	80	H
B	y		75	11.8	140	106	5016	3:30	150	250	H
B	y		65	11.8	116	96	3000	4:00+	125	190	H
B	y		65	11.8	90	80	750	4:00+	50	150	H
B	y		95	11.8	90	80	753	4:19	150	170	A
B	y		95	11.8	125	100	3751	4:00+	0	140	H
B	y		97	11.8	135	102	4600	3:15	160	220	H
B	y		97	11.8	125	100	4080	4:22	140	180	H
B	y		97	11.8	90	80	750	4:00+	110	150	H
HES-11	y		925	11.8	121	103	4610	4:33			TLW
HES-3	y		925	11.8		80	2050	5:00+			A
A	y		625	11.8	100	87	1707	4:00+	125	175	H
A	y		1420	11.8		98	6000	5:00+	120	160	A
A	y		700	11.8	130	101	4000	7:00+	75	127	H
HES-7	y		3778	11.8		70	6100	4:00+	0	120	H
E	y		3778	11.8		70	6100	5:30+	140	210	H
A	y		4000	11.8	0	90	6000	4:00+	90	220	A
A	y		520	11.8	125	101	4148	4:00+	220	235	A
A	y		520	11.8	0	80	2085	4:00+	80	210	H
B		n		11.8	156	114	5800	5:30+			65/35 A/POZ
HES-11		n		11.8	140	102	4500	3:55	0	187	TXI
A	y		1120	11.8		110	4950	8:00+	50	138	H
A	y		1120	11.8		85	1850	6:00+			H
A	y		1120	11.8		99	5149	4:00+	160	350	A
A	y		1120	11.8		79	2018	3:30+	139	305	A
HES-3	y		1560	11.8		65	4100	7:00+	89	124	FLOSTOP-I
HES-3	y		2760	11.8		93	6300	4:13	111	426	A
HES-3	y		4243	11.8		80	6321	6:00			A
HES-3	y		4243	11.8		90	8321	3:00			A
HES-3	y		4243	11.8		90	8321	5:31	140	261	A
HES-11	y		340	11.8	125	101	4342	8:14	26	325	TLW
A	y		350	11.8	103	90	2100	6:20	239	292	A
A	y		350	11.8	103	90	2100	4:38	140	290	A
A	y		50	11.8		80	3000			320	A
A	y		50	11.8		80	3000			250	A
HES-7	y		40	11.8	100	85	1500	5:30+	85	100	H
A	y		160	11.8	114	94	3314	6:00+	80	110	H
A	y		200	11.8	122	97	5518	8:00+	110	160	H
A	y		200	11.8	95	80	1012	8:00+	60	148	H
HES-11	y		340	11.8	125	101	4342	8:28	26	365	TLW
B	y		280	11.8	180	132	8929	4:58	140	360	65/35 H/POZ
F	y		340	11.8	182	150	9231	2:38			FLOSTOP-I
F	y		340	11.8	182	150	9231	4:45	690	704	FLOSTOP-I
A	y		160	11.8	145	108	5387	5:00+	230	270	H
A	y		160	11.8	109	92	2683	5:00+	75	100	H
A	y		160	11.8	90	80	825	5:00+	80	100	H
A	y		210	11.8	112	93	5284	7:00+	80	200	H
A	y		350	11.8	135	106	5000	6:00+	126	194	H
A	y		220	11.8	97	85	2797	4:00+	190	210	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		280	11.8		90	1500	6:00+	27	66	TLW
B		n		11.8		99	3500	3:01			A
B		n		11.8	287	243	15500	3:40	294	560	65/35 H/POZ
A	y		160	11.8	92	80	1000	4:00+	122	218	A
A	y		160	11.8	120	98	3500	4:30+	75	221	H
A	y		160	11.8	92	80	1000	4:00+	100	157	H
A	y		260	11.8	133	104	4500	4:30+	211	308	A
A	y		225	11.8	118	98	6800	6:00+	0	FIRM	H
A	y		225	11.8	146	107	9310	6:00+			H
A	y		225	11.8	114	95	4480	6:00+	80	110	H
A	y		225	11.8	146	110	9777	6:00+	0	0	H
A	y		225	11.8	146	110	9777	5:27	150	188	H
HES-11	y		40	11.8	115	95	2950	5:12	0	280	TLW
A	y		50	11.8	102	89	2000	5:30+	120	189	H
A	y		50	11.8	89	80	800	5:00+	88	124	H
B	y		150	11.8	112	94	3000	8:45	190	230	H
A		n		11.8	140	105	4600	8:15	100	140	A
HES-11	y		2266	11.8		95	5100	4:15	107	276	TLW
HES-3	y		6417	11.8		75	8100	4:20	SET	151	A
HES-3	y		6417	11.8		75	8900	4:20	466	1109	A
A	y		2100	11.8		65	2500	6:00+		57	A
HES-11	y		1970	11.8		80	3500	4:00+	0	83	TLW
HES-11	y		63	11.8	97	82	1200	4:30+		193	TLW
A	y		50	11.8		115	6000	10:00+	90	100	H
HES-7	y		50	11.8	152	115	6000	9:30+	60	100	H
HES-11	y		50	11.8		115	6000	7:03	190	270	TLW
A	y		50	11.8		115	6000	10:00+	104	127	H
HES-7	y		65	11.8	171	125	7000	7:00+	151	189	H
HES-11	y		65	11.8	171	125	7000	5:12	230	682	TLW
A	y		45	11.8	94	81	1100	4:00+	100	170	A
HES-11	y		65	11.8	170	128	7500	8:05	160	260	TLW
HES-11	y		65	11.8	170	127	7400	5:10	480	600	TLW
HES-11	y		65	11.8	170	127	7400	7:03	0	490	TLW
HES-11	y		65	11.8	170	128	7500	7:56	140	300	TLW
HES-11	y		70	11.8	146	114	6000	7:00+	333	572	TLW
HES-11	y		70	11.8	133	112	6000		336	550	TLW
A	y		50	11.8	96	84	1702	6:00+			A
A	y		50	11.8	95	84	1698	6:00+	231	273	A
A	y		50	11.8	95	84	1698	4:00+	231	273	A
A		n		11.8	119	96	3000	2:43			A
A	y		50	11.8		80	1000			229	A
A	y		50	11.8	118	97	3200	5:00+	90	155	H
B	y		202	11.8	150	107	4500	8:00+	60	110	H
B	y		202	11.8	90	80	800	4:45+	30	50	H
A		n		11.8	127	101	3920	5:00+	60	125	A
HES-11		n		11.8	150	109	5000	2:19			TXI
HES-11		n		11.8	150	109	5000	3:38	299	391	TXI
B		n		11.8	134	105	4700	6:00+	60	111	65/35 A/POZ
A		n		11.8	250	205	12200	1:12			H
A		n		11.8	250	205	12200	1:40			H
A		n		11.8	132	104	4500	5:00+	55	125	A
B		n		11.8	116	96	3000	5:00+			65/35 A/POZ
A	y		246	11.8	95	82	1200	4:30+	112	371	A
A	y		246	11.8	132	104	4500	6:00+	130	185	H
A	y		10	11.8	128	101	4000	4:00+	140	260	A
A	y		10	11.8	128	101	4000	4:00+	120	170	H
A	y		10	11.8	92	80	1000	4:00+	155	225	A
HES-11	y		10	11.8	92	80	1000	6:30+	210	360	TLW
A	y		95	11.8		90	2000	5:00+	120	150	A
A	y		200	11.8	97	85	1500	7:00+	155	240	H
HES-11	y		182	11.8	96	83	1300	4:00+	120	240	TLW
A		n		11.8	145	108	4900	2:26			A
HES-7		n		11.8	196	149	13661	5:00+	150	180	H
HES-11	y		25	11.8	105	91	2200	5:30+	94	249	TLW
HES-7	y		25	11.8	114	95	3011	4:00+	SET	150	H
B	y		25	11.8	94	82	1160	4:00+	110	170	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-7	y		25	11.8	116	96	4370	4:00+	75	230	H
HES-11	y		40	11.8	108	92	2300	5:00+	355	421	TLW
HES-11	y		40	11.8	108	92	2300	5:00+	121	346	TLW
HES-11	y		40	11.8	108	92	2300	5:00+	90	189	TLW
HES-11	y		30	11.8	124	98	5500	4:00	240	650	TLW
HES-11	y		30	11.8	92	80	1000	5:00+	160	230	TLW
B	y		75	11.8	191	144	10415	3:36	390	470	H
B	y		75	11.8	99	89	1950	7:00+	140	240	H
B	y		75	11.8	102	89	1950	4:00+	150	165	H
HES-11	y		50	11.8	109	93	2673	5:00+	140	520	TLW
HES-7	y		186	11.8	160	122	9263	4:00+	90	140	H
HES-7	y		186	11.8	160	122	9400	4:00+	130	1520	H
HES-7	y		186	11.8	200	152	13912	5:30+	165	199	H
HES-7	y		186	11.8	173	130	11700	4:30+	125	230	H
A	y		200	11.8	105	91	2900	5:00+	140	184	H
B	y		200	11.8	175	140	13500	3:15	74	165	H
A	y		200	11.8	119	98	4077	5:30+	130	220	H
A	y		200	11.8	105	92	2500	6:00+		180	H
A	y		200	11.8	153	117	6508	4:30	140	290	H
A	y		200	11.8	112	95	4000	5:00+	190	375	H
A	y		200	11.8	134	104	5978	5:00+		80	H
HES-7	y		200	11.8	199	151	13800	5:43	67	96	H
HES-7	y		200	11.8	199	151	13800	5:43	67	96	H
A	y		200	11.8	105	91	2500	5:00+		175	H
B	y		200	11.8	135	104	5000	5:00+	78	178	H
A	y		200	11.8	134	105	7427	5:00+	100	115	H
A	y		200	11.8	0	103	6000	7:00+	80	110	H
HES-7	y		200	11.8	175	134	14075	6:00+	130	180	H
HES-7	y		200	11.8	175	134	14075	5:00+	120	220	H
A	y		200	11.8	100	89	2000	5:00+	61	92	H
A	y		200	11.8	119	98	4224	4:00+	108	132	H
HES-7	y		250	11.8	188	142	13652	5:30+	230	450	H
HES-7	y		250	11.8	188	142	13652	5:00+	210	415	H
A	y		200	11.8	140	107	5369	6:00+	350	730	H
HES-11	y		300	11.8	75	75	647	5:00+	32	70	TLW
A	y		200	11.8	132	106	5500	6:00+	70	120	H
HES-11	y		35	11.8		85	1500	6:30			TLW
A	y		60	11.8	140	105	4500	4:30+	151	210	H
A	y		60	11.8	128	103	4500	6:00+		120	H
A	y		60	11.8	92	80	800	4:00+	190	210	H
A	y		60	11.8	92	80	800	3:30+	128	200	H
A	y		35	11.8	135	105	4800	4:00+	144	183	H
A	y		175	11.8	92	80	1000	5:00+	35	134	H
A	y		175	11.8	134	104	4500	5:00+	60	115	H
B	y		50	11.8	90	80	750	4:00+	130	175	A
A	y		20	11.8	134	104	4500	7:00+	110	140	H
A	y		65	11.8	131	103	4660	7:00+	310	690	H
A	y		90	11.8	140	106	4860	6:00+	135	165	H
HES-11	y		180	11.8		91	2300	6:00+	50	64	TLW
HES-7	y		20	11.8	151	114	5900	8:30+	109	152	H
A	y		20	11.8	124	100	4000	5:30+	98	130	H
A	y		20	11.8	90	80	800	5:00+	76	103	H
A	y		20	11.8	90	80	800	6:00+	78	106	H
A	y		326	11.8	95	85	2060	6:00+	75	137	H
A	y		326	11.8	122	99	3995	6:00+	99		H
A	y		326	11.8	92	81	1100	6:00+	72		H
A	y		385	11.8	95	84	1500	6:00+	91	176	H
A	y		450	11.8	115	97	3500	4:30	117		A
A	y		20	11.8	124	100	4000	5:30+	57	95	H
B	y		25	11.8	127	101	4200	5:56	220	250	H
HES-11	y		35	11.8		85	1500	6:15	56	177	TLW
HES-11	y		35	11.8		80	1200	8:00	50	625	TLW
A	y		12	11.8	93	81	1509	4:00+	180	230	A
HES-11	y		60	11.8	242	195	14978	7:34	770	800	TLW
HES-11	y		60	11.8	212	167	12680	7:40	0	860	TLW
HES-11	y		60	11.8	128	101	4000			280	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		160	11.8	126	100	3800	4:56	165	221	A
HES-11		n		11.8		93	2500	3:36	151	268	TXI
F		n		11.8	216	174	9685	3:47	669	728	F
F		n		11.8	216	174	9685	5:00+			F
B		n		11.8	119	96	3000	8:49	120	150	65/35 A/POZ
F		n		11.8	179	145	8002	3:13	324	526	F
B		n		11.8	123	94	2530	5:26	130	295	A
B		n		11.8	150	104	4200	4:52			A
A	y		55	11.8	142	107	5000	7:00+	170	220	A
A	y		60	11.8	92	80	1000	6:00+	80	210	H
A	y		60	11.8	92	80	1000	4:00+	80	210	H
A	y		10	11.8	113	95	3000	3:00+	120	175	H
A	y		190	11.8	87	80	750		188	382	A
B	y		190	11.8	88	80	800	5:00+	20	80	H
A	y		260	11.8	135	105	4750	6:00+	253	407	A
A	y		260	11.8		93	1100	4:00+	162	324	A
A	y		365	11.8	112	91	3243	4:00+	149	174	A
A	y		365	11.8	90	82	1200	5:30+			A
HES-11	y		365	11.8	112	96	3476	7:00+	246	429	TLW
B	y		30	11.8	116	95	2800	5:50	100	200	H
B	y		25	11.8	90	80	750	6:00+	120	210	H
A		n		11.8	120	96	3000	4:15	290	330	A
A		n		11.8	120	96	3000	4:12	280	320	A
A		n		11.8	110	95	3000	6:00+	190	300	A
A	y		1100	11.8		90	6000	3:50	172	285	A
HES-11	y		1932	11.8		80	3400	5:00+	102	173	TLW
HES-11	y		1932	11.8		90	4500	4:30+	183	647	TLW
HES-3	y		2649	11.8		80	7234	3:23			A
HES-3	y		2920	11.8		70	5000	6:00+			A
HES-3	y		2920	11.8		75	6500	2:54			A
HES-11	y		75	11.8		80	1000	7:30	29	63	TLW
HES-11	y		75	11.8		104	4500	6:02	209	318	TLW
A	y		40	11.8	94	82	1200	5:00+	140	200	H
HES-11	y		70	11.8	117	96	3000	7:00+	150	447	TLW
A	y		90	11.8	128	101	4200	6:00+	57	102	H
A	y		160	11.8	132	100	3943	5:00+	110	180	H
A	y		160	11.8	92	80	1000	4:00+	30	140	H
A	y		150	11.8	160	121	9900	6:00+	40	80	H
A	y		150	11.8	160	119	8681	5:00+	70	150	H
A	y		150	11.8	165	122	8750	5:00+	190	210	H
A	y		175	11.8	96	86	3190	5:00+	130	190	A
A	y		290	11.8		108	5000	5:30+	72	155	H
HES-11	y		290	11.8		108	5000	5:53	119	485	TLW
B	y		180	11.8	116	96	3000	4:00+	160	220	H
B	y		180	11.8	116	96	3000	5:00+	180	220	H
B	y		180	11.8	92	80	850	4:00+	50	150	H
A	y		354	11.8	102	87	1967	5:00+			H
F	y		30	11.8		213	11410	2:30	341	478	F
HES-11	y		30	11.8		83	1000	6:30	0	103	TLW
A	y		220	11.8	135	106	5000	5:00+	128	475	H
HES-11	y		220	11.8	230	183	14043	3:00			TLW
A	y		250	11.8	135	106	5000	5:00+	143	674	H
A	y		40	11.8	118	97	3500	4:00+	85	130	A
A	y		200	11.8	140	107	5000	5:30+	125	170	H
A		n		11.8	100	85	1500	6:00+	164	330	A
HES-11		n		11.9	135	105	4700	5:54	361		TLW
F		n		11.9	255	215	14600	3:36	870	1040	Micro-fine
HES-11		n		11.9	203	156	11060	2:40	1030	1380	TLW
HES-11		n		11.9	203	156	11060	2:44	1190	1230	TLW
HES-11	y		110	11.9	90	80	1000	6:30+	109	240	TLW
HES-11	y		110	11.9	125	100	4000	7:00+	360	763	TLW
HES-11	y		110	11.9	132	101	4700	5:57			TLW
HES-11	y		110	11.9	143	107	4800	4:28			TLW
F	y		85	11.9		223	12905	4:18	250	430	Micro-fine
HES-11	y		90	11.9	144	109	5300	6:28	127	280	TLW
F	y		140	11.9	300	252	15278	3:08	440	460	Micro-fine

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		260	11.9	95	82	1250	6:30+	28	65	TLW
HES-11	y		265	11.9	106	91	6350	6:00+	66	179	TLW
HES-11	y		265	11.9		86	3050	6:00+	50	138	TLW
HES-11	y		265	11.9	105	93	2900	7:00+	50	178	TLW
HES-11	y		265	11.9	92	80	1000	6:00+	200	250	TLW
HES-11	y		252	11.9	118	98	3708	6:00+	195	753	TLW
HES-11	y		252	11.9	118	98	3600	6:00+	139	841	TLW
HES-11	y		252	11.9	118	97	3542	4:27	222	414	TLW
HES-11	y		25	11.9	116	96	3300	6:30+	158	565	TLW
HES-11	y		25	11.9	92	80	1000	5:00+	114	214	TLW
HES-11		n		11.9		129	6200	5:26	62	415	TLW
A	y		1419	11.9		95	6600	3:34			A
HES-3	y		2761	11.9		93	6300	3:24			A
F	y		40	11.9	242	208	12091	3:00	510	830	Micro-fine
B	y		200	11.9	130	102	4200	6:00+	121	227	65/35 A/POZ
HES-11	y		75	11.9	164	123	7000	5:46	123	841	TLW
HES-11	y		75	11.9	164	123	7000	9:14	520	999	TLW
F	y		200	11.9		255	12170	4:06	390	620	Micro-fine
HES-11	y		220	11.9	120	97	3789	5:00+	46	220	TLW
HES-11	y		95	11.9	115	96	3200	7:16	79	354	TLW
A	y		220	11.9		129	9485	5:00+	135	160	H
F	y		380	11.9	235	205	15531	3:41	450	610	Micro-fine
F	y		35	11.9		238	13482	5:28	430	630	Micro-fine
HES-11	y		220	11.9	106	92	3235	7:18	81	217	TLW
HES-11	y		220	11.9	111	95	3300	5:00+	250	818	TLW
HES-11	y		125	11.9	91	81	1100		81	166	TLW
HES-11	y		125	11.9	92	81	1100		107	217	TLW
HES-11	y		115	11.9	93	80	1050	6:00+	88	460	TLW
HES-11	y		115	11.9	130	101	4050	5:00+	150	233	TLW
F	y		55	11.9	227	190	12824	3:10	360	690	Micro-fine
F	y		55	11.9	247	204	12824	3:36	770	820	Micro-fine
HES-11	y		1750	11.9		71	2825		89	301	TLW
HES-11	y		40	11.9	90	80	1000	4:00+	116	340	TLW
HES-11	y		40	11.9	120	98	3500	5:00+	240	450	TLW
B	y		135	11.9	92	80	1000	6:00+	60	140	H
HES-11	y		225	11.9	120	98	3400	6:02	171	291	TLW
HES-11	y		40	11.9		77	650	5:00+	28	56	TLW
HES-11	y		155	11.9	92	80	1000	3:30+	147	219	TLW
HES-11	y		150	11.9	110	91	2200	5:30+	79	263	TLW
HES-11	y		220	11.9		93	3373	6:00+	379	950	TLW
A		n		12.0	128	101	4000	4:07	228	415	Micro-fine
A		n		12.0	0	110	3000	6:44			H
A		n		12.0		110	4000	6:00+			H
B		n		12.0		93	2500	4:05	281	350	C
HES-11		n		12.0	80	80	1000	4:16	186	358	TXI
A		n		12.0	90	80	1000		161	308	A
F	y		230	12.0	168	138	8024	4:45	612	921	Micro-fine
B		n		12.0		160	10000	6:00+	562	783	75/25 A/POZ
B		n		12.0		160	10000	6:00+	672	1192	65/35 A/POZ
B		n		12.0		101	4000	4:58			50/50 H/POZ
B		n		12.0		85	4000			50	75/25 A/POZ
HES-11		n		12.0	80	93	2500	4:48	425	693	TXI
A		n		12.0	128	101	4000	4:07	228	415	Micro-fine
B		n		12.0	120	96	3000		116		65/35 A/POZ
		n		12.0	120	96	3000		74		A
B		n		12.0	90	80	1000		58	86	65/35 A/POZ
B		n		12.0		93	2500		0	50	HPLC
A		n		12.0	93	87	1000		269	454	A
A		n		12.0	95	80	1000			234	H
F		n		12.0	237	202	14500	4:03	842	992	Micro-fine
HES-11		n		12.0	142	108	5200	5:18			TLW
		n		12.0	94	83	1300	8:00+	85	110	A
HES-11		n		12.0	150	113	5800	5:00+			TLW
B		n		12.0	125	96	3000	2:30	200	240	85/15 H/POZ
B		n		12.0	130	101	4000	3:57			65/35 A/POZ
HES-3		n		12.0		65	5479	3:36	0	80	FLOSTOP I

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A		n		12.0		65	5479	5:00+	0	FIRM	A
		n		12.0	138	106	4800	7:00+	FIRM	130	A
A	y		6200	12.0		105	14000	5:55	310	330	H
A	y		6200	12.0		79	10000	6:19	105	248	A
		n		12.0	128	101	4000	7:00+	70	180	A
F		n		12.0	128	108	4015	3:00	510	515	Micro-fine
F		n		12.0	128	108	4015	4:18	250	400	Micro-fine
HES-11		n		12.0	104	90	2000	4:52	285	651	TLW
F	y		30	12.0	0	173	7750	4:00	145	750	Micro-fine
F	y		30	12.0	186	186	8881	3:26	590	1460	Micro-fine
HES-11	y		30	12.0	128	101	4000	4:30+	93	289	TLW
B	y		30	12.0	145	111	5684	3:58	260	280	H
B	y		30	12.0	102	89	1950	4:00+	90	230	H
A	y		25	12.0	104	90	2000	5:50	165	500	A
F		n		12.0	230	189	11800	3:51	225	380	Micro-fine
B		n		12.0	125	100	4000	7:00+	80	200	65/35 H/POZ
HES-11		n		12.0	206	158	10500	3:45	821	932	TLW
HES-11		n		12.0	255	207	14180	3:52	703	808	TLW
B		n		12.0	132	101	4000	4:03	115	198	65/35 A/POZ
HES-11		n		12.0	105	90	2150	6:05	240	430	TLW
B		n		12.0	120	99	4000	5:00+	90	120	65/35 A/POZ
		n		12.0	127	101	4100	5:00+	FIRM	200	A
B		n		12.0	224	176	12040	4:32	188	463	65/35 H/POZ
B		n		12.0	205	156	11800	3:36	310	830	65/35 H/POZ
F		n		12.0	238	199	13158	4:00	410	590	Micro-fine
		n		12.0	134	104	4684	5:00+	105	180	A
		n		12.0	134	105	4500	7:00+	130	220	A
		n		12.0	116	96	3000	5:00+		220	A
B		n		12.0	190	146	9825	5:30+	310	490	65/35 H/POZ
F		n		12.0	163	133	6884	4:33	530	1000	Micro-fine
B		n		12.0	128	101	4000			119	65/35 H/POZ
		n		12.0	122	98	3500	7:00+	75	190	A
B	y		102	12.0	126	99	4032	5:00+	220	270	H
B	y		70	12.0	90	80	750	5:00+	110	135	H
B	y		120	12.0	120	96	3000	6:00+	60	110	H
B	y		120	12.0	90	80	750	6:00+	37	60	H
B	y		122	12.0	130	101	4000	5:41	80	120	H
B	y		122	12.0	95	82	1200	5:00+	0	70	H
A	y		140	12.0	120	93	3000	5:00+	170	325	H
F	y		50	12.0	202	162	8750	3:25	1055	1577	Micro-fine
B	y		102	12.0	126	99	4032	5:00	130	150	H
HES-11	y		188	12.0	126	100	3800	4:40	322	1087	TLW
B	y		20	12.0	128	101	4000	12:38	115	154	65/35 H/POZ
B	y		20	12.0	128	101	4000	9:34		90	65/35 H/POZ
F	y		15	12.0		145	5852	4:00+	58	321	Micro-fine
A	y		15	12.0	141	108	7040	5:00+	104	150	H
HES-11	y		25	12.0	150	121	7400	4:04			TLW
HES-11	y		15	12.0	140	113	6000	4:30			TLW
HES-11	y		15	12.0	94	82	1250	6:00+		250	TLW
		n		12.0	134	104	4500	6:00+	46	130	A
B		n		12.0	118	97	3150	4:47			65/35 A/POZ
B		n		12.0	113	94	2650	4:17			65/35 A/POZ
		n		12.0	155	130	8600	5:00+	245	536	A
F		n		12.0	96	89	1295	2:30			Micro-fine
A		n		12.0	117	96	3100	6:00+	110	150	A
B		n		12.0	226	184	15070	2:42			65/35 H/POZ
B		n		12.0	196	149	9685	5:12	510	1090	50/50 H/POZ
B		n		12.0	122	98	3500	7:30+	106	236	65/35 H/POZ
B		n		12.0	140	107	5000	5:00+			65/35 H/POZ
B		n		12.0	160	119	6400	4:30+			65/35 H/POZ
B		n		12.0	185	151	8802	4:00+	159	352	65/35 H/POZ
		n		12.0	115	96	3000	5:00+	FIRM	150	A
F		n		12.0		97	3600		436	445	Micro-fine
		n		12.0	130	103	4500	6:00+	110	120	A
B		n		12.0	130	101	4000	6:00+			65/35 H/POZ
B		n		12.0	130	101	4000	3:40			65/35 A/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
		n		12.0	134	103	4300	5:00+	130	250	A
		n		12.0	134	104	4500	6:00+	40	170	A
B		n		12.0	122	98	3500	3:53			65/35 A/POZ
B		n		12.0	105	91	2300	5:00+	65	115	65/35 A/POZ
B		n		12.0	105	91	2300	5:00+	65	115	65/35 A/POZ
B		n		12.0		97	3500	4:10	97	117	A
B		n		12.0	207	159	10700	3:45			65/35 H/POZ
HES-11		n		12.0	196	149	9958	4:32	869	889	TLW
B		n		12.0	105	91	2200	4:00+	40	100	65/35 A/POZ
		n		12.0	110	93	2600	6:00+	111	210	A
HES-3	y		6679	12.0		65	7800	5:00+	50	135	FLOSTOP I
HES-11		n		12.0	107	90	2000	4:00+	140	250	TLW
A		n		12.0	125	100	3800	5:00+	180	270	A
B		n		12.0	120	98	3500	3:44			65/35 A/POZ
		n		12.0	116	96	3000	5:00+	110	130	A
A	y		550	12.0	103	90	2182	6:00+	125	370	A
F	y		750	12.0	195	168	11261	3:21	780	1290	Micro-fine
F	y		750	12.0	200	164	10025	3:03	780	1290	Micro-fine
A	y		3822	12.0		58	5373	5:30+			A
A	y		72	12.0	135	104	4500	6:00+	120	180	A
B	y		81	12.0	140	105	4904	7:15	150	325	H
B	y		81	12.0	96	80	1000	4:00+	160	234	H
A	y		70	12.0	133	99	4000	5:43	222	262	A
A	y		70	12.0	126	96	4000	3:32			A
F	y		100	12.0	180	153	8130	3:27	670	740	Micro-fine
B	y		108	12.0	90	80	800	4:00+			H
HES-11	y		112	12.0	125	101	4100	6:30+	429	802	TLW
HES-11	y		140	12.0	171	128	8500	4:08	721	979	TLW
HES-11	y		142	12.0	134	104	4500	6:11	270	410	TLW
B	y		170	12.0	140	106	4800	9:00+	53	131	H
F	y		170	12.0	0	160	8260	8:00	0	70	Micro-fine
F	y		170	12.0	160	160	8260	4:20	90	670	Micro-fine
HES-11	y		250	12.0	90	80	817		65	230	TLW
HES-11	y		250	12.0	122	98	3500	7:29	230	470	TLW
HES-11	y		250	12.0	95	82	2198	5:00+	40	180	TLW
HES-11	y		250	12.0	90	80	821	5:00+	120	200	TLW
HES-11	y		250	12.0	94	82	2198	4:30+	100	180	TLW
F	y		250	12.0	220	182	11652	3:29	860	1190	Micro-fine
HES-11	y		245	12.0	131	104	4700	6:00	440	815	TLW
F	y		280	12.0	155	155	7616	4:54	180	990	Micro-fine
F	y		280	12.0	175	142	7900	3:37	780		Micro-fine
B	y		306	12.0	126	100	3800	4:00+	105	300	H
B	y		306	12.0	92	80	950	3:00+	0	110	H
HES-11	y		365	12.0	106	93	2963	5:38	111	471	TLW
HES-11	y		365	12.0	120	98	4003	7:00+	142	402	TLW
B	y		50	12.0	93	80	900	4:00+	231	270	H
B	y		50	12.0	144	112	6448	3:47	110	161	H
B	y		50	12.0	144	112	6448	5:23	50	204	H
B	y		50	12.0	90	80	900	5:00+	0	245	H
F	y		80	12.0	227	187	11782	4:34	750	1200	Micro-fine
B	y		50	12.0	144	112	6448	5:19	103	178	H
A	y		250	12.0	90	80	800	5:00+	SET	120	H
A	y		300	12.0	126	107	5100	5:00+	119	298	H
A	y		25	12.0	125	99	3700	5:10	193	308	A
A	y		25	12.0	91	80	900	5:00+	256	337	A
F	y		25	12.0	181	147	8400	4:10	290	500	Micro-fine
B	y		35	12.0	128	101	4000	5:00+	220	240	H
B	y		35	12.0	90	80	790	5:00+	50	200	H
HES-11	y		50	12.0	228	181	12700	4:00	797	1120	TLW
HES-11	y		50	12.0	130	106	5000	4:46	309	667	TLW
A	y		50	12.0	110	90	2000	5:00+	147	177	H
HES-11	y		50	12.0	130	106	5000	7:22			TLW
A	y		50	12.0		80	1000		0	89	A
HES-11	y		50	12.0	130	106	5000	4:33	346	691	TLW
A	y		50	12.0	125	99	4250	6:00+	259	333	A
B	y		61	12.0	146	111	5500	5:20	200	220	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		68	12.0	120	102	4500	5:00+	100	240	H
A	y		50	12.0	140	107	5000	5:00+	70	160	A
A	y		72	12.0	134	104	4500	4:00+	220	250	A
F	y		82	12.0	148	121	6000	4:54	237	832	Micro-fine
F	y		80	12.0	211	174	11199	4:23	620	880	Micro-fine
F	y		80	12.0	221	183	12088	2:41			Micro-fine
B	y		80	12.0	230	181	13410	4:15	30	120	65/35 H/POZ
B	y		80	12.0	216	167	11614	4:10	96	200	65/35 H/POZ
B	y		80	12.0	216	167	11614	3:41	70	120	65/35 H/POZ
F	y		85	12.0		184	9428	4:06	510	870	Micro-fine
A	y		10	12.0	140	108	5200	3:56			A
A	y		10	12.0	142	109	5250	5:00+	210	320	H
A	y		75	12.0	130	107	5200	2:57	145	280	A
HES-11	y		107	12.0	210	163	11983	3:58	1090	1710	TLW
HES-11	y		120	12.0	82	80	165	3:20	301	500	TLW
E	y		120	12.0	82	80	165	5:00+			H
F	y		123	12.0	130	109	4500	4:20	192	666	Micro-fine
B	y		111	12.0		156	11000	6:24			H
B	y		130	12.0	132	103	4469	7:54	185	240	H
B	y		130	12.0	92	80	1000	5:00+	120	220	H
HES-7	y		137	12.0	163	125	7947	6:00+	219	273	H
HES-7	y		137	12.0	163	125	7947	6:00+	311	632	H
HES-7	y		137	12.0	133	110	5707	5:00+	108	189	H
B	y		130	12.0	91	80	1000	5:00+	108	269	H
B	y		130	12.0	132	105	5150	4:00+	186	1228	H
A	y		140	12.0		80	1230	5:00+	150	309	A
HES-11	y		145	12.0	140	107	5000	5:02	250	450	TLW
B	y		250	12.0	126	100	3800	5:00+	90	180	H
B	y		250	12.0	135	105	4600	6:22	190	305	H
A	y		160	12.0	134	104	4500	4:00+	306	418	A
F	y		138	12.0		158	7067	5:00+	330	1029	Micro-fine
HES-11	y		209	12.0	136	105	4650	6:00+	0	146	TLW
HES-11	y		209	12.0	92	80	975	6:00+	0	50	TLW
HES-11	y		241	12.0	125	101	4150	5:02	140	418	TLW
A	y		254	12.0	93	81	1100	5:00+	70	160	H
F	y		280	12.0	148	148	5574	3:28	260	820	Micro-fine
F	y		280	12.0	148	121	5574	3:45	260	820	Micro-fine
F	y		280	12.0		160	8100	4:45	616	739	Micro-fine
F	y		267	12.0	92	82	1400	4:00+	130	150	Micro-fine
B	y		272	12.0	92	80	1000	5:30+	106	162	H
HES-7	y		272	12.0	131	102	5920	10:00+	448	920	H
B	y		272	12.0	131	102	5920	5:00+			H
B	y		25	12.0	130	104	4700	4:15			H
F	y		600	12.0	150	128	6100	3:00	120	560	Micro-fine
B	y		25	12.0	113	98	3900	5:00+	80	220	H
B	y		25	12.0	134	104	4500	6:22	110	180	H
HES-11	y		25	12.0	234	185	13333	5:33	315	1014	TLW
A	y		20	12.0	92	80	1000	4:00+	200	330	A
A	y		21	12.0	92	80	1000	4:00+	90	130	50/50 H/POZ
A	y		21	12.0	129	101	4060	4:00+	260	300	A
HES-2	y		600	12.0		80	975	6:00+	141	352	A
F	y		71	12.0		188	12152	4:10	973	956	Micro-fine
HES-11		n		12.0	115	100	3015	4:30+			TLW
HES-11		n		12.0	115	100	3015	4:57	254	490	TLW
B		n		12.0	119	96	3000	4:07			65/35 A/POZ
F		n		12.0	130	109	3850	4:30	114	450	Micro-fine
HES-11	y		650	12.0		103	4630	5:30+	220	520	TLW
HES-11	y		980	12.0	0	87	4100	6:00+	160	430	TLW
B		n		12.0	116	96	3000	4:23			65/35 A/POZ
A	y		3822	12.0		106	7450	2:45			A
A	y		3822	12.0		79	7450	5:30+		124	A
A		n		12.0	135	102	4175	8:00+	90	95	A
B		n		12.0	105	91	2250	5:00+	100	130	65/35 A/POZ
		n		12.0	125	99	3700			120	A
F		n		12.0	152	152	6000	5:38	102	572	Micro-fine
A	y		300	12.0		81	1303	6:00+	170	289	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		1250	12.0	102	88	1800	6:45		363	A
HES-11	y		1491	12.0	0	84	4000	4:00+	160	260	TLW
HES-11	y		1491	12.0	0	84	4000	4:00+	80	200	TLW
HES-3	y		1491	12.0		80	2900	6:00+	364	784	A
F	y		250	12.0	185	157	10103	4:18	780	820	Micro-fine
B	y		633	12.0	106	92	2644	3:31	150	180	A
B	y		633	12.0	106	92	2644	6:00+	120	150	H
HES-11	y		850	12.0	0	80	1950	6:00+	100	220	TLW
HES-3	y		981	12.0		80	2600	3:58	483	727	A
HES-3	y		1195	12.0		80	2770	3:50	420	601	FLOSTOP I
A	y		1195	12.0		80	2770	5:00+		50	A
A	y		1250	12.0	100	87	1800	4:45	344	461	A
A	y		1250	12.0	130	102	4250	4:47	365	618	A
F	y		1250	12.0	160	131	7250	5:13	420	1031	Micro-fine
A	y		1250	12.0	100	87	1700	7:04		198	A
A	y		1250	12.0	130	102	4250	2:45			A
F	y		1250	12.0		60	600	2:30+	0	0	Micro-fine
F	y		760	12.0		242	13500	3:22	560		Micro-fine
HES-11	y		760	12.0		83	2612	5:00+		170	TLW
F	y		760	12.0	242	202	13500	3:00	1895		Micro-fine
F	y		760	12.0	214	176	11200	3:34	750		Micro-fine
F	y		760	12.0	170	143	10000	2:45	400	1410	Micro-fine
A	y		855	12.0	120	105	4900	6:00+	50	80	H
HES-7		n		12.0		123	6200	7:00+		0	A
HES-7		n		12.0		122	5500	7:00+	28	153	A
HES-7		n		12.0		122	5200	6:32	0	218	A
HES-7		n		12.0		122	5500	5:23			A
A		n		12.0	100	84	1450	5:30+	225	385	A
HES-11		n		12.0	105	94	1700	4:12	214	360	TLW
A		n		12.0	85	80	300		30	255	A
A		n		12.0	85	80	300		FIRM	70	A
A		n		12.0	85	80	300				A
A		n		12.0	85	80	300		0	160	A
A		n		12.0	85	80	300		0	80	A
A		n		12.0	85	80	300		140	270	A
		n		12.0	134	104	4500	5:00+	FIRM	50	A
B		n		12.0	206	158	10500	3:08			65/35 H/POZ
		n		12.0	128	101	4000	8:00+			A
		n		12.0	128	101	4000	8:00+	105	140	A
		n		12.0	125	100	4000	6:00+		73	A
F		n		12.0	180	153	8660	3:16	460	530	Micro-fine
B		n		12.0	122	100	4000	4:58	131	217	65/35 A/POZ
A	y		255	12.0	115	101	4350	3:24	439	603	A
HES-11	y		100	12.0		93	2636	6:26	130	287	TLW
HES-7	y		106	12.0	220	173	14010	4:23	153	285	H
HES-11	y		106	12.0	116	96	3000	4:00+	322	1085	TLW
B	y		50	12.0	226	176	13193	4:00	400	530	65/35 H/POZ
HES-7	y		100	12.0	218	170	12500	6:00+	180	208	H
F	y		100	12.0	220	184	12820	3:08	1450	1545	Micro-fine
B	y		150	12.0	218	168	13053	4:13	150	320	65/35 H/POZ
HES-7	y		220	12.0	161	122	8288	6:00+	197	340	H
F	y		221	12.0	174	149	12390	4:25	530	1410	Micro-fine
HES-7	y		206	12.0	158	131	7866	4:00+	180	520	H
B	y		96	12.0	207	159	11120	6:30+	421	1238	50/50 H/POZ
HES-11	y		920	12.0	121	103	4610	5:00	168	408	TLW
A	y		693	12.0	0	90	3400	4:00+	100	210	A
HES-11	y		1711	12.0		90	4200	6:24	106	328	TLW
A	y		1086	12.0		81	5000	7:00+	130	250	H
HES-7	y		100	12.0	185	143	9953	6:00+	295	1215	H
HES-7	y		138	12.0	230	181	16160	5:00+	FIRM	40	H
F	y		240	12.0	153	129	7500	3:19	80	740	Micro-fine
A	y		218	12.0	134	104	4500	4:00+	55	100	H
F	y		206	12.0	165	140	8490	2:43	480	730	Micro-fine
F	y		95	12.0	180	147	8768	2:55	1260	1870	Micro-fine
A	y		30	12.0	122	98	3500	2:20	260	420	A
A	y		58	12.0	88	80	750	6:00+	115	180	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		58	12.0	117	96	3120	6:00+	190	230	H
HES-11	y		60	12.0	145	109	5000	4:20	130	385	TLW
F	y		65	12.0	205	165	9152	3:24	1170	1210	Micro-fine
F	y		356	12.0	210	176	12490	4:10	680	880	Micro-fine
F	y		356	12.0	227	189	12600	3:15	760	1710	Micro-fine
F	y		356	12.0	180	146	8200	5:14	370	890	Micro-fine
B	y		190	12.0	92	80	1000	5:30+	0	60	H
B	y		50	12.0	119	96	3000	3:00+			H
F	y		926	12.0	183	153	10462	5:16	0	540	Micro-fine
HES-11	y		926	12.0	121	103	4610	4:30			TLW
HES-3	y		926	12.0		80	2050	5:00+	414	665	A
F	y		633	12.0	168	146	13174	3:44	490	715	Micro-fine
A	y		720	12.0	117	99	3834	3:43	281	436	A
F	y		720	12.0	124	100	5623	2:21	350	441	Micro-fine
HES-11	y		720	12.0	118	99	3834	5:50	233	286	TLW
F	y		720	12.0	132	112	6400	4:40	158	258	Micro-fine
A	y		720	12.0	117	99	3788	4:28	259	582	A
B	y		720	12.0	99	90	2300	6:00+	0	60	A
HES-11	y		720	12.0	117	99	3834	5:30	106	284	TLW
B	y		720	12.0	99	90	2300	4:30	68	110	A
A	y		720	12.0	117	99	3834	6:27	183	292	A
HES-7	y		700	12.0	117	97	4066	6:00+	70	90	H
B	y		700	12.0	95	88	1850	5:00+	FIRM	100	H
A	y		1605	12.0		100	4600	6:00+	180	320	TLW
A	y		1605	12.0		100	4600	5:30+	110	205	H
A	y		1605	12.0		90	4200	6:13	100	260	TLW
A	y		1419	12.0		95	6600	3:56			A
HES-11	y		1711	12.0		90	4200	5:25			TLW
HES-11	y		1646	12.0		80	4200	8:46	66	169	TLW
F	y		1646	12.0		168	16700	5:30	232	623	Micro-fine
HES-11	y		2200	12.0		70	3550	6:00+		120	TLW
F	y		1500	12.0	0	132	10700	3:35	150	290	Micro-fine
F	y		2663	12.0	0	120	13450	2:55	95	120	Micro-fine
HES-11	y		2081	12.0		70	3700	4:00+	0	120	TLW
HES-11	y		2081	12.0		75	3700	4:00+		0	TLW
HES-11	y		2120	12.0		75	3800	6:00+		0	TLW
		n		12.0	130	101	4000	6:30+	0	66	A
		n		12.0	124	100	4000	7:00+	130	260	A
B		n		12.0	135	109	5500	4:00+	105	310	H
B		n		12.0	114	97	3500	3:00+	220	320	H
F		n		12.0	166	136	7550	4:38	52	1072	Micro-fine
B		n		12.0	132	101	4000	6:30+			65/35 H/POZ
	y		200	12.0	115	96	3000	5:00+	110	200	A
F	y		200	12.0	165	137	8572	3:51	700	1270	Micro-fine
A	y		100	12.0	93	82	1200	6:30+		309	A
B		n		12.0	99	85	1500	5:30+	0	54	65/35 A/POZ
C	y		883	12.0		100	4000	3:38	95	188	A
HES-11	y		518	12.0	0	90	2000	4:30+	78	163	TLW
HES-7	y		2046	12.0		72	5934	5:45	40	60	H
HES-7	y		2046	12.0		72	5934	5:00+	20	170	H
A	y		2100	12.0	0	92	5600	6:17	0	100	A
A	y		2100	12.0	0	65	3600	10:00+	0	0	A
HES-7	y		2841	12.0	0	80	7000	5:15+	30	110	A
HES-11	y		517	12.0		99	4150	4:45	160	240	TLW
HES-11	y		517	12.0		72	1700	4:00+	110	170	TLW
HES-11	y		760	12.0	110	93	2550	7:30	64	147	TLW
HES-11	y		760	12.0	103	92	2550	8:45	58	152	TLW
A	y		1306	12.0		80	2490	5:00+	110	250	A
A	y		1306	12.0		88	4190	5:00+	110	250	A
HES-11	y		3227	12.0		70	4875		60	117	TLW
HES-11	y		3227	12.0		70	4875	5:00+	0	50	TLW
A	y		3227	12.0		70	4875	4:00+	0	50	A
HES-11	y		3227	12.0		70	4875	4:00+	0	0	TLW
F	y		3227	12.0	0	128	14735	3:30	95	640	Micro-fine
HES-11	y		3227	12.0		70	4875	4:00+	0	100	TLW
HES-11	y		3325	12.0		70	5200	5:00+	0	0	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		3467	12.0		65	5200	5:30+	FIRM	30	TLW
A	y		525	12.0		80	2300	4:00+		0	A
E	y		525	12.0		80	2300	4:30+	0	0	TLW
HES-2	y		525	12.0		80	2300	4:00+	0	50	A
E	y		525	12.0		80	2300	4:30+	0	0	TLW
HES-11	y		525	12.0		80	2300	4:00+	90	152	TLW
A	y		4100	12.0		75	8500	5:10		373	A
A	y		4100	12.0		72	7250	5:00+		191	A
HES-3	y		4243	12.0		80	6321	3:23			A
HES-11	y		856	12.0	127	99	3950	6:26	26	405	TLW
HES-11	y		856	12.0	103	90	2200	5:00+	140	318	TLW
HES-11	y		856	12.0	103	90	2100	7:30+	79	177	TLW
F	y		900	12.0		175	15200	4:45	818	1590	Micro-fine
A	y		6500	12.0	0	65	5119	10:16	0	40	TLW
HES-11	y		750	12.0	118	101	5400	5:00+	1660	2275	TLW
HES-11		n		12.0	250	201	13050	4:07	600	707	TLW
HES-11		n		12.0	250	201	13050	5:30+	530	588	TLW
HES-11		n		12.0	250	201	13050	3:51	232	239	TLW
HES-11		n		12.0	250	201	13050	5:30+	436	1036	TLW
B		n		12.0	125	98	3500	5:30+			65/35 A/POZ
B		n		12.0	210	161	10700	5:28	114	456	65/35 H/POZ
HES-11		n		12.0	150	122	5528	3:30	130	390	TLW
		n		12.0	116	96	3000	6:00+	FIRM	160	A
B	y		40	12.0	170	127	7500	8:30+	60	70	65/35 H/POZ
B	y		40	12.0	120	98	3500	5:00+	104	258	65/35 A/POZ
B	y		40	12.0	209	158	10100	5:58	310	460	65/35 H/POZ
A	y		50	12.0	133	103	4400	2:26	280	500	A
A	y		51	12.0	116	96	3005	2:50	170	380	A
A	y		51	12.0	92	80	1000	4:00+	75	220	A
B	y		50	12.0	120	96	3000	5:39	100	150	H
B	y		50	12.0	90	80	750	5:00+	60	100	H
A	y		51	12.0	114	95	2800	4:10	220	380	A
A	y		51	12.0	88	80	700	4:00+	121	261	A
B	y		52	12.0	134	104	4400	4:00+	170	225	H
B	y		55	12.0	122	98	3912	4:55	115	160	65/35 A/POZ
A	y		55	12.0	90	80	800	4:39	232	440	A
F	y		100	12.0	170	143	10226	4:40	386	933	Micro-fine
F	y		170	12.0	186	150	8244	3:49	1091	1564	Micro-fine
A	y		360	12.0		55	670	3:00+	54		A
A	y		380	12.0	92	82	1200	4:00+	130	160	H
A	y		380	12.0	118	96	3999	6:00+	220	350	H
HES-11	y		342	12.0		100	4729	7:44	162	413	TLW
HES-11	y		342	12.0		100	4729	6:46	187	404	TLW
HES-11	y		342	12.0		89	2000	6:15	54	105	TLW
HES-11	y		342	12.0		102	4676	6:35	128	225	TLW
HES-11	y		300	12.0	119	96	3000	6:00+	233	322	TLW
F	y		300	12.0	198	162	9900	3:28	990	1340	Micro-fine
HES-11	y		252	12.0	96	80	1000	4:30+	50	285	TLW
HES-11	y		252	12.0	116	96	3000	4:48	190	430	TLW
A	y		275	12.0	130	105	4900	5:30	240	290	H
HES-11	y		250	12.0	121	98	4836	5:00+	498	967	TLW
HES-11	y		250	12.0	110	93	3905	4:30+	150	180	TLW
F	y		283	12.0	270	232	12676	4:12	690	850	Micro-fine
F	y		283	12.0	191	159	7398	3:47	470	600	Micro-fine
F	y		285	12.0		242	11972	3:41	1044	1374	Micro-fine
F	y		285	12.0		205	11600	3:04	1112	1222	Micro-fine
HES-11	y		478	12.0		85	1500	8:00	105	204	TLW
A	y		350	12.0	105	92	2500			69	H
HES-11	y		80	12.0	100	85	1500	7:00+	130	330	TLW
A	y		100	12.0	105	92	2500			53	H
A	y		100	12.0	105	92	2500			72	H
HES-11	y		292	12.0	128	101	4000	4:35	280	640	TLW
HES-11	y		292	12.0	128	101	4000	3:26			TLW
A	y		360	12.0	118	97	5000	4:00+	190	300	H
F	y		250	12.0	105	94	2100	4:00+	55	120	Micro-fine
HES-11	y		288	12.0		119	6641	8:02	0	371	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		329	12.0		91	4250	7:37	53	132	TLW
HES-11	y		390	12.0		89	2000	6:15	31	42	TLW
A	y		22	12.0	134	104	4500	6:00+	270	295	A
B	y		50	12.0	158	116	8222	5:00+	100	130	65/35 H/POZ
A	y		285	12.0	122	98	3450	4:00+	100	170	H
A	y		324	12.0	92	82	1200	6:00+	150	220	H
A	y		324	12.0	120	97	3400	5:00+	110	228	H
HES-11	y		324	12.0	120	97	3225	4:00+	550	940	TLW
HES-11	y		347	12.0		102	4270	7:25	34	197	TLW
B	y		219	12.0	126	100	4000	6:24	50	130	H
B	y		219	12.0	90	80	1000	7:00+		90	H
F	y		220	12.0	126	126	3575	3:32	70	250	Micro-fine
A	y		220	12.0		83	1543	4:30+	28	164	H
HES-11	y		220	12.0	120	96	3217	5:00+	370	740	TLW
HES-11	y		265	12.0	116	96	3000	5:30+	171	346	TLW
HES-11	y		265	12.0	116	96	3000	3:35			TLW
F	y		280	12.0	172	147	8400	2:39	470	1230	Micro-fine
F	y		280	12.0	172	147	8400	5:02	720	1170	Micro-fine
HES-11	y		300	12.0	108	92	3134	6:00+	193	314	TLW
HES-11	y		300	12.0	112	94	4903	5:30+	204	331	TLW
A	y		61	12.0	90	80	900	4:00+	120	240	A
B	y		61	12.0	170	113	5200	8:00+	66	227	65/35 H/POZ
A	y		220	12.0		100	4117	6:00+	87	173	H
A	y		324	12.0	92	82	1200	4:00+	140	170	H
HES-11	y		324	12.0	118	96	3400	4:00+	220	485	TLW
HES-11	y		342	12.0	127	102	4800	7:56	71	244	TLW
A	y		200	12.0	130	102	4200	3:07			A
A	y		235	12.0	114	95	3000	5:00+	100	110	H
HES-11	y		342	12.0	127	97	3220	7:06	347	600	TLW
F	y		342	12.0	131	111	6200	3:33	161	379	Micro-fine
HES-11	y		342	12.0	104	92	6116	4:00+		235	TLW
B		n		12.0	100	85	1500	5:00+	61	111	65/35 H/POZ
B		n		12.0	152	115	6000	5:00+	90	185	65/35 H/POZ
B		n		12.0	122	98	3500	4:30+	0	89	65/35 H/POZ
F	y		208	12.0	100	88	1700	5:00+	80	100	Micro-fine
A	y		218	12.0	103	89	2379	5:00+		109	H
		n		12.0	100	85	1500	5:00+			A
F		n		12.0	220	181	11117	10:31+	636	1546	Micro-fine
		n		12.0	140	107	5000	7:00+	220	370	A
		n		12.0	125	101	4200	4:00+	90	160	A
B		n		12.0	170	127	7700	4:30+	266	510	65/35 H/POZ
B		n		12.0	170	128	7500	5:48	120	170	65/35 H/POZ
B		n		12.0	212	162	10600	6:56	90	120	65/35 H/POZ
		n		12.0	122	98	3500	5:00+			A
HES-11		n		12.0	181	145	7200	2:20	1152	1425	TLW
B		n		12.0	116	96	3000	6:04	83	151	65/35 A/POZ
B		n		12.0	270	224	14625	6:00+			65/35 H/POZ
B		n		12.0	130	101	4000	6:00			65/35 H/POZ
		n		12.0	115	99	4000		80	105	A
		n		12.0	130	101	4000	7:00+	135	225	A
B		n		12.0	120	100	4000		66	264	65/35 H/POZ
B		n		12.0	155	114	5800	6:00+			65/35 H/POZ
B		n		12.0	120	100	4000		87	300	65/35 A/POZ
		n		12.0	115	95	2910	5:00+	110	200	A
B		n		12.0	120	100	4000	4:39			65/35 A/POZ
B		n		12.0	122	98	3500	5:00+			65/35 A/POZ
		n		12.0	155	117	6200	7:00+	SET	120	A
F		n		12.0	188	150	7727	4:01	990	1310	Micro-fine
HES-11		n		12.0	119	98	3500	5:00+	234	656	TLW
		n		12.0	120	96	3200	7:00+			A
F		n		12.0		280	12862	2:41	535	588	Micro-fine
A		n		12.0	110	96	3500	7:03	110	170	A
		n		12.0	122	98	3500		70	180	A
F		n		12.0	221	191	12650	3:05	505	560	Micro-fine
F		n		12.0		210	10393	5:20	1265	1355	Micro-fine
		n		12.0	129	102	4100	6:00+	100	240	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B		n		12.0	107	92	2450	7:00+	170	295	65/35 A/POZ
B		n		12.0	110	93	2600	5:00+	120	160	65/35 A/POZ
		n		12.0	117	97	3300	5:00+	20	70	A
		n		12.0	116	96	3000	5:00+	128	137	A
B		n		12.0	108	92	2400		0	116	65/35 H/POZ
B		n		12.0		85	1000	6:00+			65/35 A/POZ
		n		12.0	130	102	4200	7:00+	110	1200	A
B		n		12.0	130	101	4000	6:00+	0	176	65/35 H/POZ
F		n		12.0	190	153	8451	3:10	1090	1360	Micro-fine
F		n		12.0	160	130	6500	3:00	770	1090	Micro-fine
		n		12.0	110	95	3000	5:00+	105	120	A
		n		12.0	126	100	3800	7:00+	75	195	A
B		n		12.0	128	101	4000	6:00+	80	200	65/35 A/POZ
B		n		12.0	265	213	15100	5:19	430	550	65/35 H/POZ
B		n		12.0	156	118	6350	5:30+		255	65/35 H/POZ
F		n		12.0	140	117	6004	4:45	255	673	Micro-fine
B		n		12.0	164	123	7000	6:00+		493	65/35 H/POZ
B		n		12.0	160	117	6100	6:00	65	125	65/35 H/POZ
F	y		1025	12.0	159	135	10076	3:35	708	825	Micro-fine
F		n		12.0	138	117	4860	4:30+	130	420	Micro-fine
F	y		40	12.0	140	116	5085	1:07			Micro-fine
F	y		40	12.0	140	116	5085	0:37			Micro-fine
F	y		158	12.0	164	164	7173	4:32	230	620	Micro-fine
F	y		200	12.0	165	136	7428	3:02	540	1010	Micro-fine
HES-11	y		120	12.0	122	98	3500	5:00+	0	265	TLW
A	y		120	12.0	91	80	920	4:00+	164	260	A
F	y		138	12.0	119	103	3272	4:00+	95	110	Micro-fine
A	y		145	12.0	116	96	3000	5:00+	400	450	A
HES-11	y		167	12.0	120	98	3500	4:47	375	944	TLW
A	y		253	12.0	115	97	3500	6:01	380	450	A
A	y		253	12.0	119	98	3500	4:00+	110	240	A
A	y		253	12.0	115	97	3500	4:14	363	490	A
A	y		184	12.0	90	80	900	4:00+	160	305	A
F	y		195	12.0	126	108	3804	4:30+	90	200	Micro-fine
HES-11	y		222	12.0	115	95	5724	5:30+	SET	350	TLW
HES-11	y		222	12.0	125	99	8539	5:30+	195	360	TLW
HES-11	y		227	12.0	116	96	6200	4:00+	25	630	TLW
HES-11	y		227	12.0	105	90	6323	5:30	90	360	TLW
F	y		230	12.0	147	122	6514	2:24	404	686	Micro-fine
B	y		303	12.0	126	106	5000	5:00	110	150	H
HES-7	y		295	12.0	119	96	3750	4:00+	100	160	H
B	y		200	12.0	110	91	2305		76	155	65/35 H/POZ
F	y		200	12.0	128	108	3671	6:30+	333	1147	Micro-fine
HES-11	y		215	12.0	134	104	4500	5:48	580	969	TLW
B	y		210	12.0	112	89	1975	6:00+	60	130	50/50 A/POZ
F	y		210	12.0	102	84	1859	4:25	305	346	Micro-fine
B	y		210	12.0	88	80	856	10:00+	50	118	50/50 A/POZ
HES-11	y		210	12.0		84	1859	5:30+	76	130	TLW
HES-11	y		210	12.0	88	80	856	10:09	97	142	TLW
HES-11	y		210	12.0	97	84	2100	9:48	88	131	TLW
HES-11	y		210	12.0	110	97	2600	4:11	313	465	TLW
HES-11	y		210	12.0	102	84	1859	7:00+	103	189	TLW
B	y		210	12.0	94	80	905	6:00+	50	64	50/50 A/POZ
A	y		210	12.0		91	2100	4:08	109	320	Micro-fine
HES-2	y		210	12.0		91	2100		595	1914	A
A	y		210	12.0	110	97	2600	3:35	243	329	A
HES-11	y		210	12.0	110	97	2600	6:00+	69	121	TLW
F	y		50	12.0	174	174	7825	3:54	426	895	Micro-fine
HES-7	y		240	12.0	128	100	4000	4:30+	80	110	H
B	y		38	12.0	113	95	3000	4:30+	50	105	H
A	y		20	12.0	107	92	2500	5:44	232	318	A
B	y		20	12.0	108	92	2500	6:00+	FIRM	50	65/35 H/POZ
A	y		120	12.0	123	103	4500	5:00+	0	170	H
A	y		120	12.0	118	99	4034	3:00+	100	120	H
A	y		120	12.0	128	103	4630		141	229	H
A	y		120	12.0	120	100	4000	4:00+	110	130	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
F	y		42	12.0		130	4851	2:41	113	362	Micro-fine
B	y		65	12.0	143	105	4500	5:30+	150	215	H
B	y		65	12.0	94	80	1000	4:00+	160	230	A
HES-11		n		12.0	206	156	10000	3:58	500	873	TLW
A	y		77	12.0	90	80	700	5:00+	130	150	H
F	y		80	12.0	180	146	8000	3:09	690	1030	Micro-fine
A	y		80	12.0	95	82	1250	5:53	105	210	A
HES-11	y		100	12.0	94	80	1000	5:30+	100	510	TLW
HES-11		n		12.0		210	4060	3:10	956	1029	TLW
B		n		12.0	116	96	3000	6:00+	100	113	65/35 A/POZ
F		n		12.0	202	166	10129	3:46	400	780	Micro-fine
F		n		12.0	203	166	10134	3:29	400	780	Micro-fine
A	y		3797	12.0		82	9500	4:56	120	170	A
HES-7	y		1200	12.0		72	5934	7:00+	40	140	H
A	y		1025	12.0	102	89	2053	5:00+	90	180	A
F	y		1025	12.0	128	110	4150	4:30+	100	190	Micro-fine
A	y		1025	12.0	104	90	2287	5:00+	0	0	A
A	y		1025	12.0	125	102	4400	7:00+	160	270	A
F	y		1025	12.0	126	108	3849	3:30	90	200	Micro-fine
A	y		3030	12.0		120	12000	7:58	166	217	H
A	y		3633	12.0		96	9896	6:00+	100	150	H
HES-11	y		2095	12.0		90	4673	7:00+	104	289	TLW
HES-11	y		6627	12.0		125	14820	4:25	233	578	TLW
HES-11	y		6627	12.0		125	14820	3:08			TLW
F	y		6627	12.0		105	12700	2:03	70	90	Micro-fine
HES-11	y		6627	12.0		125	15000	3:25	122	309	TLW
A	y		6739	12.0	120	96	4136	6:00+	140	250	H
HES-11	y		6739	12.0		125	15500	3:40	176	396	TLW
HES-11	y		6588	12.0		120	14550	3:41	205	530	TLW
A	y		1300	12.0	110	94	4000	5:00+	221	304	A
A	y		1300	12.0	122	100	6000	5:00+	211	298	A
HES-11	y		1334	12.0		75	4500	7:00+	56	230	TLW
HES-11	y		1334	12.0		63	2750	5:00+	0	115	TLW
HES-11	y		1400	12.0		80	1780	4:00+	120	220	TLW
HES-7	y		3200	12.0		145	13685	3:53	300	380	H
HES-11	y		6037	12.0	0	90	12000	5:55	FIRM	430	TLW
A	y		2707	12.0		105	6500	5+00+	120	250	A
A	y		2707	12.0		90	5000	4:00+	185	290	A
A	y		2707	12.0		101	6250	6:00+	230	310	A
HES-2	y		2945	12.0			5100			159	A
HES-2	y		2945	12.0	72	72	5100	2:56			A
A	y		2945	12.0	72	72	5100	5:00+		32	A
HES-2	y		3000	12.0			5500		0	54	A
F	y		3000	12.0	0	159	19597	3:49	740	770	Micro-fine
A	y		3800	12.0		82	9500	4:56	120	170	A
HES-3	y		3944	12.0		70	3950	4:00+	92	324	A
HES-3	y		5378	12.0		80	9050	4:03	67	204	A
HES-3	y		5378	12.0		80	9050	6:05			A
HES-7	y		3855	12.0	0	72	5450	4:30+	0		A
HES-7	y		3845	12.0	0	63	7000	6:00+	74	149	A
B	y		14	12.0	300	270	18261	4:24	211	244	H
B	y		48	12.0	106	90	2000	4:00+	160	250	H
HES-7	y		54	12.0	105	90	2000	4:00+	128	308	H
HES-11	y		52	12.0	150	115	6000	5:00+	122	208	TLW
HES-11	y		52	12.0	0	255	17000	7:10	0	0	TLW
HES-11	y		52	12.0	318	276	17000	7:57	0	0	TLW
F	y		49	12.0		62	400	2:00+	0	120	Micro-fine
B	y		60	12.0	100	82	1200	5:00+	115	184	H
B	y		60	12.0	100	87	1700	5:00+	60	195	H
B	y		60	12.0	100	87	1700	4:00+	106	206	H
B	y		60	12.0	130	103	4500	4:00+	144	254	H
B	y		46	12.0	302	261	16867	3:10	360	550	H
HES-7	y		45	12.0	105	89	2000	5:30+	0	114	H
HES-11	y		60	12.0	230	178	11500	7:50		633	TLW
HES-11	y		50	12.0		83	1000	6:00+	0	0	TLW
A	y		240	12.0	126	102	4553	8:30+	141	270	H

*Slurry Type	Offshore Yes	No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	24 hr	Base Cement Type
HES-11	y		200	12.0	155	110	5000	5:29	411	412	TLW
A	y		174	12.0	155	110	5000	4:10	155	205	H
F	y		172	12.0	280	242	13259	3:38	430	960]	Micro-fine
F	y		170	12.0	259	206	10336	3:44	730	880	Micro-fine
B		n		12.0	120	99	4000	7:00+	40	120	65/35 A/POZ
B		n		12.0	128	101	4000	6:00+			65/35 H/POZ
B		n		12.0	135	102	4200	3:08	94	188	65/35 A/POZ
F	y		150	12.0	0	224	10929	3:35	534	860	Micro-fine
A	y		160	12.0	175	121	7500	5:45	120	230	H
B		n		12.0	131	102	4230	3:38			65/35 A/POZ
A		n		12.0	104	88	1800	4:01	50	200	A
HES-7		n		12.0		50	50			51	A
		n		12.0	124	100	4000	7:00+	60	100	A
		n		12.0	122	97	3500	5:00+	80	125	A
		n		12.0	135	104	4450	5:00+	140	195	A
B		n		12.0	128	100	4000	5:00+	100	125	65/35 A/POZ
		n		12.0	110	94	3000		95	120	A
HES-11		n		12.0	93	84	1500		94	248	TLW
B		n		12.0	256	211	12600	3:08	750	760	65/35 H/POZ
F		n		12.0	225	184	11070	3:20	820	1600	Micro-fine
		n		12.0	125	98	3500	5:00+	40	150	A
HES-11		n		12.0		178	13500	6:12		792	TLW
HES-11		n		12.0		178	13500	8:56			TLW
A		n		12.0	113	95	3000	8:00+	240	340	A
B		n		12.0		96	3000	5:30+	89	152	65/35 A/POZ
		n		12.0	122	98	3500	6:30+			A
B		n		12.0	128	101	4000	4:05			65/35 A/POZ
F		n		12.0	104	94	2000	3:00	230	270	Micro-fine
F		n		12.0	250	202	11154	3:29	820	980	Micro-fine
HES-11		n		12.0	165	126	9485	2:50	720	840	TLW
		n		12.0	133	103	4400	6:00+	120	310	A
B		n		12.0	122	98	3500	5:00	120	175	65/35 A/POZ
		n		12.0	150	112	5620	8:00+			A
B		n		12.0	95	80	1000	6:00+	30	140	H
B		n		12.0	118	96	3000	3:38			65/35 A/POZ
B	y		67	12.0	142	111	6316	4:00+	100	120	H
A	y		191	12.0	134	104	5598	5:30+	220	280	H
A	y		200	12.0	134	104	5512	5:30	160	223	H
B	y		200	12.0	171	128	10105	5:00+	240	480	65/35 H/POZ
A	y		191	12.0	134	104	5030	5:00+	240	250	H
F	y		212	12.0		173	9038	4:50	FIRM	670	Micro-fine
HES-11	y		220	12.0	115	96	5000	6:00+	90	380	TLW
F	y		332	12.0		176	13365	3:03	700	1710	Micro-fine
F	y		174	12.0	164	136	8303	3:06	420	780	Micro-fine
B	y		75	12.0	143	109	5250	5:34	60	170	H
A	y		525	12.0		89	2370	6:00+	55	210	A
A	y		525	12.0		89	2370	7:18	130	370	A
HES-11	y		525	12.0	134	106	4940	6:10	270	676	TLW
HES-2	y		525	12.0	110	97	3700	6:11	50	80	A
F	y		525	12.0		140	5580	5:43	210	946	Micro-fine
HES-2	y		525	12.0	100	91	2370	5:00+	112	140	A
HES-11	y		525	12.0	140	110	5595	5:29	276	643	TLW
F	y		90	12.0	265	224	15054	9:00+	1580	1940	Micro-fine
HES-11	y		94	12.0	140	109	5400	5:15	224	649	TLW
B	y		60	12.0	135	105	4800	6:56	70	150	H
B	y		60	12.0	135	105	4800	7:02	100	190	H
B	y		95	12.0	130	102	4100	4:55	110	150	H
A	y		130	12.0	142	108	5200	6:00+	82	116	H
B	y		128	12.0	140	107	5000	5:00+	144	176	65/35 A/POZ
B	y		128	12.0	92	80	1000	4:00+		100	65/35 A/POZ
B	y		122	12.0	134	104	4727	6:04	210	290	H
B	y		122	12.0	134	104	4644	5:36	160	210	H
B	y		122	12.0	116	96	3831	5:58	196	253	H
B	y		124	12.0	132	103	4400	6:15	170	240	H
B	y		124	12.0	134	104	4644	6:20	190	300	H
F	y		137	12.0	253	214	14600	3:06	510	955	Micro-fine

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		150	12.0	135	106	5000	4:47	165	263	H
A	y		182	12.0	96	83	1300	4:00+	160	200	H
HES-11	y		182	12.0	142	108	5200	7:29	55	195	TLW
B	y		150	12.0	128	101	4000	5:00+	429	487	65/35 H/POZ
B	y		150	12.0	128	101	4000	5:06	819	890	65/35 A/POZ
B		n		12.0	180	143	10764	6:11	180	370	65/35 H/POZ
B		n		12.0	120	96	3000	5:40	330	520	85/15 H/POZ
B		n		12.0	180	180	10764	4:16	410	550	65/35 H/POZ
B	y		380	12.0	104	89	2000	5:00+	40	160	H
B	y		380	12.0	150	114	5800	5:05	70	120	H
A	y		51	12.0	122	98	3500	6:00+	159	215	A
F	y		51	12.0	110	97	2500	2:39	294	332	Micro-fine
F	y		51	12.0	175	144	8841	3:04	350	798	Micro-fine
F	y		108	12.0	170	138	7500	3:56	540	1000	Micro-fine
F	y		108	12.0	182	148	8500	3:35	1000	1050	Micro-fine
F	y		108	12.0	210	172	10500	4:28	1150	1320	Micro-fine
HES-11	y		108	12.0	118	97	3200	5:30+	250	550	TLW
F	y		108	12.0	194	159	9500	4:44	990	1650	Micro-fine
A	y		530	12.0	98	87	1800	6:00+	140	340	H
F	y		209	12.0		140	13270	2:53	1092	1216	Micro-fine
A	y		325	12.0	104	90	2425	3:00+	110	228	A
A	y		325	12.0	105	90	2100	4:00+	124	244	A
F	y		325	12.0	104	94	2000	4:30+	171	296	Micro-fine
B	y		328	12.0	135	104	4500	5:15	128	230	65/35 A/POZ
A	y		328	12.0	98	85	1500	4:00+	325	360	A
B	y		328	12.0	142	108	5100	4:28	120	185	65/35 A/POZ
F	y		200	12.0	166	166	8050	5:17	270	1090	Micro-fine
B	y		190	12.0	98	85	1500	4:00+	40	120	H
B	y		200	12.0	97	85	1500	6:00+	30	75	H
HES-11	y		385	12.0	189	151	11390	6:07		567	TLW
B	y		380	12.0	120	99	4393	5:30	140	250	H
HES-11	y		380	12.0	141	113	6000	5:39	285	776	TLW
A	y		380	12.0	140	112	5800	6:24	130	200	H
B	y		380	12.0	100	83	1300	7:00+	120	240	H
HES-11	y		420	12.0	201	167	14300	4:43	237	1560	TLW
B		n		12.0	120	97	3300	5:00+	25	25	65/35 H/POZ
F		n		12.0	92	80	800	6:00+	182	324	A
B	y		37	12.0	126	104	4600	4:57	90	190	H
HES-11	y		37	12.0	115	96	3000	5:00+	121	487	TLW
A	y		35	12.0	126	103	4500	6:30+	211	244	H
A	y		29	12.0	125	101	4100	5:00+	230	405	A
A	y		65	12.0	140	108	5150	6:00+	170	220	A
A	y		65	12.0	140	107	5000	4:00+	230	380	A
A	y		30	12.0		114	6000	7:00+	185	250	H
B	y		48	12.0	116	96	3000	5:37	160	200	H
F	y		50	12.0	144	119	5800	2:34	270	580	Micro-fine
F	y		55	12.0	140	116	5852	3:20	260	610	Micro-fine
F	y		60	12.0	165	138	9065	5:00+			Micro-fine
B	y		60	12.0	129	102	4100	6:01	80	240	H
HES-7	y		60	12.0		145	9265	7:00+			H
HES-7	y		60	12.0	88	80	800	5:00+	40	50	H
HES-7	y		60	12.0	120	98	3700	5:00+	45	60	H
B	y		55	12.0	92	80	1000	4:00+	25	130	H
HES-7	y		55	12.0	120	98	3700				H
F	y		60	12.0	165	138	9065	6:30+	260	930	Micro-fine
HES-7	y		60	12.0	90	80	1000	6:00+		0	H
F	y		60	12.0	165	138	9065	0:59			Micro-fine
HES-7	y		60	12.0	167	145	9265				H
HES-7	y		60	12.0	167	145	9265	7:00+	186	265	H
HES-11	y		96	12.0	94	83	1856	4:30+			TLW
B	y		90	12.0	202	154	11210	5:30+	189	330	65/35 H/POZ
F	y		90	12.0	188	188	9200	6:25	195	1690	Micro-fine
F	y		90	12.0	0	190	10000	3:15	520	870	Micro-fine
B	y		90	12.0	180	144	11950	4:42	268	1051	65/35 H/POZ
B	y		90	12.0	180	144	11950	4:57	0	955	65/35 H/POZ
F	y		90	12.0	192	159	10135	4:23	1054	1077	Micro-fine

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		60	12.0	93	81	1110	6:00+	160	240	H
B	y		60	12.0	93	81	1110	6:00+	120	230	H
B	y		60	12.0	138	106	4820	6:57	140	180	H
B	y		110	12.0	131	102	4230	4:53	170	210	H
B	y		60	12.0	120	98	3320	7:30+	90	150	H
B	y		60	12.0	120	98	3320	5:55	200	280	H
B	y		105	12.0	115	96	3000	4:30+	58	192	H
HES-11	y		75	12.0	129	102	4300	6:58	464	1260	TLW
F	y		105	12.0		210	11576	4:52	340	550	Micro-fine
F	y		110	12.0		160	7120	4:44	370	980	Micro-fine
F	y		113	12.0		148	8300	4:15	390	1000	Micro-fine
F	y		130	12.0	215	177	11300	4:18	890	990	Micro-fine
HES-11	y		184	12.0	135	104	4500	6:00+	93	230	TLW
HES-11	y		184	12.0	88	80	900		116	326	TLW
HES-11	y		184	12.0	135	104	4500	3:00			TLW
HES-11	y		184	12.0	117	96	3000	4:00+	221	867	TLW
A	y		200	12.0	118	97	3670	4:00+	150	190	A
A	y		235	12.0	133	103	5400	3:30+	372	328	A
A	y		235	12.0	98	85	1500	3:00+	126	238	A
A	y		235	12.0	132	103	4570	4:00+	228	318	A
A	y		235	12.0	98	85	1500	3:00+	130	252	A
F	y		235	12.0	85	84	500	4:00+	189	303	Micro-fine
HES-11	y		280	12.0	133	104	4800	5:26	316	889	TLW
HES-11	y		370	12.0	125	90	4500	6:56	104	363	TLW
F	y		350	12.0	90	86	797	4:00+	150	190	Micro-fine
B	y		372	12.0	112	95	4280	6:45	110	170	H
F	y		372	12.0		205	16000	5:13	610	1280	Micro-fine
B	y		372	12.0	95	84	1500	5:00+	FIRM	90	H
B	y		372	12.0	95	84	1500	5:00+	20	110	H
A	y		25	12.0	128	101	4000	5:00+	280	340	A
A	y		25	12.0	125	100	4000	7:00+	260	330	A
B	y		30	12.0	139	108	5150	5:12	135	210	H
F	y		30	12.0	224	183	11130	3:21	760	1080	Micro-fine
B	y		181	12.0	174	134	10893	4:35	80	183	65/35 H/POZ
HES-11	y		181	12.0	96	86	1650	7:33	166	260	TLW
B	y		181	12.0	146	114	7250	5:30+	106	177	65/35 H/POZ
B	y		181	12.0	111	98	2591	7:00+	60	130	H
B	y		181	12.0	146	114	7250				65/35 H/POZ
HES-7	y		110	12.0	137	107	5000	5:30+	80	100	H
B	y		110	12.0	94	83	1300	5:00+	70	200	H
B	y		110	12.0	94	83	1300	5:00+	90	240	H
B	y		110	12.0	93	82	1200	4:00+	150	270	A
B	y		110	12.0	94	83	1300				H
B	y		110	12.0	125	102	4500	6:28	130	260	H
B	y		100	12.0	158	120	6685	2:56	120	190	H
B	y		100	12.0	88	80	800	6:00+	25	130	H
F	y		100	12.0	170	145	11000	3:47	650	1520	Micro-fine
B	y		100	12.0	96	84	1450	5:00+	30	90	H
HES-11	y		100	12.0	91	80	1000	5:30+	81	155	TLW
B	y		100	12.0	93	81	1100	5:00+	50	90	H
F	y		100	12.0	228	190	11882	3:10	910	655	Micro-fine
B	y		100	12.0	96	84	1450	8:00+	FIRM	90	A
B	y		100	12.0	93	81	1100	5:00+	170	260	H
HES-11	y		100	12.0	134	104	4500	4:33	445	975	TLW
B	y		100	12.0	152	115	6000	7:04	60	250	H
B	y		100	12.0	113	95	3000	6:36	60	120	H
HES-11	y		100	12.0		104	4600	6:30+	257	703	TLW
F	y		140	12.0	166	135	7200	3:38	621	981	Micro-fine
F	y		60	12.0	195	160	9672	3:45	650	1670	Micro-fine
F	y		164	12.0	0	182	8500	3:45	100	540	Micro-fine
F	y		164	12.0	182	182	8500	2:17	680	720	Micro-fine
F	y		40	12.0		199	9900	4:38	440	1030	Micro-fine
F	y		40	12.0		199	9900	5:26	430	1020	Micro-fine
F	y		230	12.0	200	200	10086	4:06	450	1300	Micro-fine
HES-11	y		211	12.0	125	103	4500	6:20	116	310	TLW
HES-11	y		180	12.0	125	103	4500	4:50			TLW

*Slurry Type	Offshore		Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi)		Base Cement Type
	Yes	No							12 hr	24 hr	
HES-11	y		303	12.0	126	103	4889	5:08	330	720	TLW
HES-11	y		380	12.0	95	84	1400	5:00+	129	367	TLW
HES-11	y		380	12.0	95	84	1400	3:30	145	367	TLW
F	y		280	12.0	0	80	585	5:27	FIRM	90	Micro-fine
A	y		288	12.0	139	105	5550	5:00+	138	242	A
A	y		288	12.0		78	1300	5:00+		313	A
HES-11	y		288	12.0	139	105	5550	4:12	70	330	TLW
A	y		288	12.0		90	4600	6:00+		265	A
A	y		288	12.0	140	107	5000	5:00+	90	190	A
A	y		288	12.0	95	83	1300	6:00+	279	380	A
HES-11	y		288	12.0	139	105	5550	4:12	70	330	TLW
B	y		62	12.0	92	80	1000	6:00+	60	120	H
B	y		62	12.0	134	104	4500	6:00+		140	H
B	y		62	12.0	134	104	4500	5:04	270	340	H
B	y		62	12.0	124	98	4200	6:00+	90	150	H
B	y		62	12.0	92	80	1000	6:00+		140	H
B	y		62	12.0	128	100	4000	5:03	130	220	H
B	y		62	12.0	92	80	1000	6:00+		100	H
B	y		62	12.0	134	104	4500	4:01	250	315	H
B	y		62	12.0	124	100	4000	5:30	190	260	H
HES-7	y		62	12.0	187	161	11745	6:30+	228	310	H
B	y		62	12.0	134	104	4500	7:15	190	240	H
B	y		62	12.0	92	80	1000	6:00+	60	90	H
B	y		62	12.0	124	100	4000	5:00	70	160	H
B	y		62	12.0	124	98	4200	6:00+	120	140	H
B	y		55	12.0	90	80	800	4:00+	30	90	H
B	y		63	12.0	114	94	3000	6:15+	70	135	H
F	y		62	12.0	215	177	11050	3:43	900	1220	Micro-fine
B	y		62	12.0	135	105	4600	5:00	160	215	H
B	y		62	12.0	135	105	4600	4:30+	185	235	H
B	y		62	12.0	92	80	1000	4:00+	100	170	H
HES-11	y		62	12.0	112	94	2650	4:00	293	527	TLW
F	y		62	12.0	224	193	12077	2:36	650	990	Micro-fine
B	y		62	12.0	132	104	4500	6:37	90	200	H
F	y		80	12.0	130	130	5820	6:08	100	310	Micro-fine
		n		12.0	124	100	4000	6:00+	110	180	A
F		n		12.0	225	184	11200	3:10	1050	1260	Micro-fine
B		n		12.0	110	95	3000	5:00+	145	240	65/35 A/POZ
B		n		12.0	115	96	3000	8:00+			65/35 A/POZ
F	y		50	12.0	181	147	8500	4:27	470	920	Micro-fine
F	y		50	12.0	235	196	13061	6:20	790	950	Micro-fine
B		n		12.0	125	97	3100	10:12	120	390	85/15 H/POZ
B		n		12.0	125	97	3100	2:46	200	235	85/15 H/POZ
F		n		12.0	205	174	9582	3:47	830	1150	Micro-fine
B		n		12.0	136	104	4500	3:08			65/35 A/POZ
B		n		12.0	97	84	1400	5:00+			65/35 A/POZ
		n		12.0	129	101	4280	5:00+	60	120	A
F		n		12.0	180	142	6200	5:30+			Micro-fine
F		n		12.0	160	129	6300	3:02	990	1000	Micro-fine
F		n		12.0	115	100	2700			1100	Micro-fine
F		n		12.0	115	100	2700	3:00+	345		Micro-fine
A	y		50	12.0	124	100	4000	6:00+	300	370	A
F		n		12.0	140	115	4300	4:00	240	610	Micro-fine
B		n		12.0	122	98	3500	6:00+			65/35 A/POZ
		n		12.0	122	98	3500	5:00+	124	245	A
B		n		12.0	114	95	3100	5:00+	90	110	65/35 A/POZ
B		n		12.0	124	100	4000	5:07	150	196	65/35 A/POZ
B		n		12.0	179	131	7630	6:00+			65/35 H/POZ
F		n		12.0	215	185	11000	4:10	750	1020	Micro-fine
		n		12.0	105	90	2000	5:00+	95	125	A
		n		12.0	122	97	3300	5:00+	SET	100	A
HES-10		n		12.0		80	1000			60	A
		n		12.0	135	105	4600	7:00+			A
B		n		12.0	126	100	3800	6:00+	1049	1510	65/35 H/POZ
B		n		12.0	105	91	2250	5:00+	40	100	65/35 A/POZ
		n		12.0	150	104	4200	9:22	60	140	85/15 H/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
		n		12.0	150	104	4200	2:45	239	300	85/15 H/POZ
HES-7	y		127	12.0	95	80	1000	6:00+	FIRM	550	H
A	y		75	12.0	134	103	4340	5:00+	150	180	A
A	y		103	12.0	134	104	4500	4:30+	306	318	A
A	y		100	12.0	92	80	1000	4:00+	47	289	A
A	y		90	12.0	125	98	3500	4:00+	194	253	A
A	y		90	12.0	90	80	800	4:00+	133	258	A
A	y		103	12.0	116	96	3800	3:00+	142	254	A
B	y		103	12.0	140	109	5500	6:32	114	348	65/35 A/POZ
B	y		103	12.0	94	83	1300	6:00+	84	170	65/35 A/POZ
A	y		110	12.0	92	80	1020	3:00+	97	206	A
A	y		110	12.0	89	80	800	4:00+	47	290	A
A	y		110	12.0	122	98	3500	4:00+	160	320	A
A	y		110	12.0	116	96	3000	4:00+	198	363	A
F	y		111	12.0	0	190	9716	3:59	400	1230	Micro-fine
A	y		111	12.0	138	106	5146	6:03	173	350	A
A	y		110	12.0	92	80	1000	4:00+	97	206	A
A	y		110	12.0	127	100	4610	4:00+	255	304	A
A	y		110	12.0	132	103	4330	4:00+	363	394	A
A	y		110	12.0	92	80	1000	4:30+	152	188	A
A	y		110	12.0	134	104	4500	4:00+	236	322	A
F	y		90	12.0	192	165	10722	3:05	870	1170	Micro-fine
A	y		110	12.0	125	103	4500	4:50	267	372	A
HES-7	y		127	12.0	135	107	5000	6:00+	FIRM	155	H
HES-7	y		127	12.0	103	88	1900	6:00+	30	105	H
HES-7	y		127	12.0	143	108	4973	6:00+	100	173	H
A	y		120	12.0	92	80	1000	4:00+	150	175	A
A	y		120	12.0	134	104	4500	4:00+	210	265	A
A	y		111	12.0	92	80	1000	4:00+	130	240	A
A	y		111	12.0	125	100	3800	4:00+	159	200	A
B	y		143	12.0	128	101	4597	5:00+	180	220	H
B	y		143	12.0	128	101	4597	5:31	200	230	H
B	y		143	12.0	93	81	1100	4:00+	135	210	H
A	y		181	12.0	92	80	1000	6:00+	124	221	H
A	y		181	12.0	128	101	4000	6:00+	150	250	H
B	y		186	12.0	166	128	10618	5:00+	260	480	65/35 H/POZ
B	y		186	12.0	148	112	9221	5:30+	220	250	65/35 H/POZ
F	y		202	12.0	130	110	5286	4:02	218	240	Micro-fine
F	y		210	12.0	150	150	5711	2:59	324	805	Micro-fine
A	y		215	12.0	132	103	4300	6:00+	170	225	H
A	y		220	12.0	125	99	3700	8:00+	210	250	H
A	y		220	12.0	128	101	4000	7:30+	121	237	H
A	y		220	12.0	128	101	4000	6:00+	187	200	H
B	y		290	12.0	145	110	5400	5:27	140	160	65/35 A/POZ
B	y		60	12.0	128	101	4000	4:42	99	285	H
B	y		60	12.0	89	80	750	4:00+	50	157	H
B		n		12.0	110	92	2500	5:00+	30	80	65/35 A/POZ
		n		12.0	122	94	2500	6:00+	140	210	A
B	y		122	12.0	174	130	7950	4:06	95	282	H
B	y		122	12.0	96	83	1350		160	380	H
B	y		122	12.0	96	83	1350	4:00+	120	195	H
B	y		120	12.0	185	136	8100	4:15	257	284	H
HES-7	y		108	12.0	93	80	1028	6:00+	FIRM	40	H
HES-7	y		320	12.0	120	105	5000	6:30+	SET	90	H
HES-7	y		722	12.0	150	117	8355	6:00+	70	100	H
B	y		1514	12.0		95	6000	4:00+	240	550	65/35 A/POZ
B	y		1514	12.0		95	6000	4:00+	130	200	65/35 A/POZ
HES-3	y		2649	12.0		75	3784	2:45			A
HES-3	y		2920	12.0		70	5000	5:30+	119	419	A
HES-3	y		3270	12.0		70	5200	3:23			FLOSTOP I
HES-3	y		3270	12.0		70	5200	4:34	140	340	FLOSTOP I
HES-3	y		3270	12.0		70	5200	3:42			FLOSTOP I
A	y		1051	12.0		76	2800	4:00+	128	300	A
A	y		1051	12.0		97	4882	6:00+	140	310	A
		n		12.0	128	103	4500	6:00+	60	130	A
F	y		40	12.0		140	4903	6:38	1041	1755	Micro-fine

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F	y		40	12.0	275	275	11464	6:09	880	955	Micro-fine
HES-11	y		47	12.0		131	8200	4:25			TLW
B	y		45	12.0	88	80	700	4:00+	100	170	H
A	y		40	12.0	134	104	4500	5:00+	90	200	A
A	y		40	12.0	92	80	1000	4:00+	60	210	A
A	y		40	12.0	94	80	1000	6:30	220	465	A
A	y		35	12.0	134	104	4500	4:22	220	300	A
A	y		35	12.0	92	80	1000	4:00+	130	280	A
HES-7	y		44	12.0	134	104	4500	6:00+	90	160	H
HES-7	y		44	12.0	134	104	4500	8:00+	80	140	H
HES-7	y		20	12.0	139	106	4600	5:00+	150	180	H
HES-7	y		20	12.0	140	106	4700	5:00+	50	110	H
HES-7	y		20	12.0	139	105	4500	5:00+	80	150	H
HES-7	y		20	12.0	148	107	4700	8:00+	110	190	H
HES-7	y		20	12.0	148	107	4700	8:00+	160	220	H
B	y		53	12.0	113	95	3000	6:00+	95	150	H
B	y		53	12.0	93	80	1000	4:00+	130	195	H
B	y		53	12.0	150	111	6010	7:54	50	230	H
B	y		52	12.0	94	80	1050	4:00+	120	240	H
B	y		52	12.0	152	112	5500	7:30	0	160	H
HES-11	y		57	12.0	141	105	4500	4:19	766	1040	TLW
HES-11	y		57	12.0	141	105	4500	6:00+	561	662	TLW
HES-11	y		57	12.0	134	104	4900	5:00+	480	1093	TLW
A	y		62	12.0	89	80	800	6:00+	160	200	A
A	y		62	12.0	119	98	3500	5:00+	290	440	A
A	y		70	12.0	128	101	4000	4:00+	130	465	A
HES-11	y		38	12.0	134	104	4500	6:30+	500	891	TLW
F	y		66	12.0	167	136	7220	3:40	730		Micro-fine
B	y		22	12.0	172	125	7000	7:30+	186	470	65/35 H/POZ
B	y		145	12.0	123	98	5054	6:00+	60	100	H
HES-11	y		160	12.0	150	114	7150	2:20	640	840	TLW
HES-11	y		160	12.0	125	100	4400	4:30	430	625	TLW
HES-11	y		160	12.0	125	100	4400	5:16			TLW
HES-7	y		160	12.0	160	128	9451	5:00+	130	200	H
F	y		153	12.0	158	135	7800	3:41	196	940	Micro-fine
HES-11	y		175	12.0	97	84	1950	5:30+	108	247	TLW
F	y		184	12.0	150	123	6000	3:32	260	820	Micro-fine
F	y		184	12.0	85	84	500	4:00+	220	247	Micro-fine
F	y		291	12.0		240	1074	3:00	1240	1590	Micro-fine
A	y		256	12.0	83	82	586	4:00+	0	98	H
A	y		300	12.0	138	105	4500	5:00+	120	140	H
F	y		300	12.0	0	117	3918	3:48	160	480	Micro-fine
F	y		300	12.0	0	103	2298	4:15+	150	450	Micro-fine
A	y		40	12.0	95	82	1175	5:00+	91	228	H
A	y		40	12.0	144	109	5300	8:00+	243	345	H
A	y		296	12.0	118	96	3000	5:00+	330	420	A
A	y		296	12.0	116	96	3000	5:00+	170	240	A
F	y		325	12.0	120	120	3054	5:00	155	190	Micro-fine
HES-11	y		354	12.0	135	98	3129	5:30	440	975	TLW
HES-11	y		35	12.0		102	4500	6:15	61	125	TLW
HES-11	y		35	12.0		102	4500	6:48	52	234	TLW
B	y		36	12.0	170	128	7595	6:42	170	260	65/35 H/POZ
B	y		40	12.0	129	99	3500	6:30	220	260	H
B	y		40	12.0	89	80	750	5:30+	130	210	H
HES-11	y		85	12.0	92	80	1000	6:00+	50	125	TLW
HES-11	y		240	12.0	207	166	13380	6:17	75	815	TLW
A	y		245	12.0	110	93	2500	4:00+	160	310	A
HES-11	y		225	12.0	188	150	11370	4:52	497	1194	TLW
HES-11	y		225	12.0	210	169	14000	7:33	0	1322	TLW
HES-11	y		225	12.0	210	169	14000	5:22	95	954	TLW
B	y		210	12.0	120	98	3600	4:00+	150	260	H
B	y		240	12.0	120	98	3600	6:20	115	188	H
B	y		210	12.0	181	136	8593	3:53	540	550	H
HES-11	y		210	12.0	120	98	3600	6:00+	110	250	TLW
F	y		40	12.0	233	196	13640	3:21	605	1340	Micro-fine
A	y		54	12.0	90	80	850	5:00+		81	A

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		54	12.0		92	4500	4:14			A
A	y		54	12.0	145	114	6025	5:00+			H
A	y		35	12.0	115	97	3500	5:23	157	332	A
B	y		68	12.0	93	82	1200	4:00+	105	170	H
B	y		68	12.0	130	103	4500	4:30+	110	310	H
B	y		105	12.0	138	106	4900	5:00+	60	160	H
HES-11	y		100	12.0		109	5150	4:50	368	730	TLW
F	y		126	12.0	87	85	558	5:00+	130	175	Micro-fine
HES-11	y		126	12.0	123	99	5965	4:00+	300	700	TLW
HES-11	y		126	12.0	108	92	4300	4:00+	100	340	TLW
F	y		126	12.0	123	106	5940	4:50	100	230	Micro-fine
HES-7	y		126	12.0	190	145	9792	4:05	158	167	H
HES-11	y		151	12.0	106	91	4533	5:00+	155	260	TLW
HES-11	y		151	12.0	132	103	7660	4:00+	270	530	TLW
HES-11	y		151	12.0	124	100	6029	5:00+	230	520	TLW
HES-7	y		152	12.0	229	183	13866	6:00+	91	135	H
HES-7	y		155	12.0	208	161	12288	4:50	573	800	H
HES-7	y		155	12.0	222	174	14554	5:30+	186	224	H
F		n		12.0		92	1000	5:50			Micro-fine
F		n		12.0		92	1000	5:00+		203	Micro-fine
B	y		28	12.0	136	103	4300	4:20	181	236	H
B	y		28	12.0	136	103	4300	4:36			H
B	y		28	12.0	136	103	4300	6:18	103	108	H
B	y		28	12.0	136	103	4300	3:03		196	H
B	y		28	12.0	136	103	4300	5:29			H
A	y		36	12.0	146	111	5425	5:30+		180	H
B		n		12.0	106	90	2000	4:41		659	65/35 A/POZ
F		n		12.0	116	101	3000	5;12	95	220	Micro-fine
		n		12.0	120	96	3000	7:00+	50	200	A
F		n		12.0	205	165	8896	3:07			Micro-fine
B		n		12.0	123	99	3600	5:00+	0	96	65/35 A/POZ
B		n		12.1		230	14000			1030	75/25 POZ/A
B		n		12.1	215	165	11433	2:26			65/35 H/POZ
B	y		47	12.1		80	1000			96	65/35 A/POZ
HES-3	y		2761	12.1		80	4900	4:02	172	573	A
HES-3	y		2000	12.1		80	3500	4:02	183	580	A
HES-3	y		2841	12.1		80	4925	3:34		154	A
HES-3	y		2920	12.1		70	5000	3:51			A
HES-11	y		47	12.1	153	113	8100	5:15+	70	160	TLW
B	y		200	12.1	172	132	11000	3:47	166	233	H
B		n		12.1	170	127	7500	5:06	330	415	65/35 H/POZ
B		n		12.1	225	176	12100	6:03	890	940	65/35 H/POZ
HES-3	y		3270	12.1		65	5200	6:00+			FLOSTOP I
HES-3	y		3270	12.1		65	5200	7:10	57	345	FLOSTOP I
B	y		280	12.1	93	82	1200	4:30	131	176	H
HES-3	y		6224	12.2		70	7700	3:45	0	331	A
B		n		12.2	245	199	14900	7:34	970	990	65/35 H/POZ
HES-11		n		12.2	207	159	10600	4:30	522	1511	TLW
B		n		12.2	124	97	3200	3:10	250	290	85/15 A/POZ
B		n		12.2	190	145	9400	8:50	0	252	65/35 H/POZ
HES-11	y		20	12.2	159	120	6600	4:20	313	876	TLW
HES-11		n		12.2	173	132	8400	3:39	450	800	TLW
B	y		10	12.2	212	164	11000	6:30+	510	600	50/50 H/POZ
B	y		83	12.2	185	139	8800	3:20	140	310	65/35 H/POZ
B	y		83	12.2	197	150	9807	6:00+	210	370	65/35 H/POZ
B	y		83	12.2	191	145	9400	5:00+	85	235	65/35 H/POZ
B	y		83	12.2	185	139	8800	4:19	135	230	65/35 H/POZ
B	y		83	12.2	210	163	11600	6:00+	250	420	65/35 H/POZ
B	y		83	12.2	200	152	10320	3:31	120	170	65/35 H/POZ
HES-11	y		107	12.2	210	163	12227	4:08	0	1190	TLW
HES-11	y		167	12.2		90	1950	4:30+	189	557	TLW
B	y		20	12.2	116	96	3000	5:49			65/35 A/POZ
HES-3	y		1756	12.2		80	3500	4:03			FLOSTOP I
A		n		12.2	85	80	300		160	306	A
HES-3	y		1646	12.2		90	4200	4:46	475	580	FLOSTOP I
A	y		250	12.2	130	103	4835	4:00+	305	450	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		890	12.2	121	104	4500	5:30+	152	253	H
HES-3	y		1419	12.2		80	3500	7:20	253	450	A
HES-11		n		12.2	193	146	9450	3:54	505	824	TLW
B		n		12.2	224	171	10800	3:14			65/35 H/POZ
F	y		2521	12.2	0	107	7200	3:42	760	850	FLOSTOP I
F	y		2521	12.2	0	107	7200	3:38			FLOSTOP I
HES-3	y		2841	12.2		80	4925	2:46			A
HES-3	y		2588	12.2		70	3590	4:46			A
HES-3	y		4243	12.2		70	6321	4:30	0	324	A
B	y		50	12.2	230	181	13410	3:59			65/35 H/POZ
HES-11	y		350	12.2		110	5925	5:06	50	500	TLW
B	y		210	12.2	186	137	12735	6:30+	130	260	65/35 H/POZ
A		n		12.2		80	50			56	A
B		n		12.2	105	90	2100		51	91	65/35 A/POZ
HES-7	y		1000	12.2	100	90	2200	6:00+		48	H
HES-3	y		2100	12.2		70	3000	3:25	180	419	A
HES-3	y		2707	12.2		70	4105	4:00+	0	154	FLOSTOP I
HES-3	y		2707	12.2		70	4105	3:52	190	280	FLOSTOP I
HES-11	y		63	12.2	114	94	2800	5:00+	445	780	TLW
A	y		63	12.2	114	94	2800	5:00+	230	260	H
A		n		12.2	104	88	1800		170	255	A
B		n		12.2	215	167	11800	3:40	521		65/35 H/POZ
B		n		12.2	119	96	3000	3:02	380	520	85/15 A/POZ
B		n		12.2	220	172	11700	4:32			65/35 H/POZ
B	y		130	12.2	216	167	11624	5:30+	780	940	50/50 H/POZ
HES-8	y		50	12.2	92	80	800	6:00+	85	215	A
F	y		372	12.2	145	121	6800	3:40	275	1100	Micro-fine
HES-11	y		180	12.2	95	82	1250	6:00+	150	170	TLW
HES-11	y		380	12.2	130	103	4500	6:32	200	480	TLW
HES-3	y		50	12.2		80	960	3:30	965	1522	A
HES-11		n		12.2	200	148	9000	3:25			TLW
B		n		12.2		143	10150	4:00			50/50 H/POZ
	y		122	12.2	92	80	1000	4:00+	109	189	H
A	y		1136	12.2		90	5882	3:11	63	423	A
HES-3	y		3236	12.2		60	5200	4:37	0	190	FLOSTOP I
HES-11	y		167	12.2	130	101	4000	4:08	550	1240	TLW
HES-11	y		167	12.2	130	101	4000	4:51	700	850	TLW
HES-11	y		1490	12.3	121	103	4962	5:00	378	937	TLW
HES-11		n		12.3		96	2900	2:28	277	575	TXI
HES-11	y		126	12.3	184	139	10599	3:50	817	1330	TLW
HES-3	y		2672	12.3		70	3950	5:32			FLOSTOP I
HES-3	y		2672	12.3		80	3875	3:55	456	537	FLOSTOP I
HES-3	y		3907	12.3		70	3950	4:27			A
HES-11		n		12.3	96	82	1200	3:41	431	649	TXI
A	y		1419	12.3		95	6600	3:39			A
HES-3	y		1900	12.3		80	3800	3:43	76	242	A
HES-3	y		1419	12.3		80	3500	5:20	0	182	A
B		n		12.3	115	96	3000	8:00+	78	105	65/35 A/POZ
B		n		12.3	115	93	2500		290	367	50/50 TXI/POZ
B	y		46	12.3	200	151	9800	8:30	85	217	65/35 H/POZ
HES-11		n		12.3		96	2900	3:02	360	437	TXI
HES-3	y		5372	12.3		85	2000	4:45	656	1027	A
HES-3	y		1000	12.3	97	89	2000	3:07			A
A	y		60	12.3	142	107	4800	7:17	199	262	H
B		n		12.3	132	103	4400		576	720	Micro-fine
HES-11		n		12.3	132	103	4400	3:22	332	403	TXI
B	y		120	12.3	91	80	1000	4:00+	180	220	A
B	y		120	12.3	165	127	7800	4:48	380	640	H
HES-7	y		200	12.3	220	172	13450	5:55	555	1300	H
HES-3	y		2100	12.3		70	3000	2:38	111	436	A
B	y		85	12.3	93	80	1000	5:00+	120	230	H
HES-11	y		1564	12.3		93	7400	3:50	160	669	TLW
HES-3	y		3343	12.3		65	5200	3:30+			FLOSTOP I
B	y		35	12.3	90	80	900	7:00+	180	230	65/35 A/POZ
HES-7	y		3845	12.3	0	63	7000	6:00+	78	148	A
B		n		12.3	125	97	3200	4:55	170	320	85/15 A/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		35	12.3	120	98	3600	3:22	170	370	65/35 A/POZ
B	y		110	12.3		245	15500	3:43	164	197	HTLD
B	y		52	12.3	318	276	17000	9:10			65/35 H/POZ
B	y		52	12.3	318	276	17000	9:00+			65/35 H/POZ
B		n		12.3	120	97	3263		640	670	85/15 A/POZ
HES-3	y		1334	12.3		70	2750	5:04	270	850	FLOSTOP I
HES-3	y		1753	12.3		70	4500	2:41	FIRM	170	FLOSTOP I
HES-11	y		3236	12.3		110	10208	3:55	280	504	TLW
HES-3	y		1756	12.3		80	3400	6:58	150	250	FLOSTOP I
B		n		12.3	170	118	6000	3:18	280	560	65/35 H/POZ
HES-3	y		1756	12.3		80	3500	3:45	360	560	FLOSTOP I
HES-3	y		1753	12.3		70	4500	2:41	FIRM	170	FLOSTOP I
HES-7	y		1025	12.3		115	12000	5:30+	162	210	H
HES-3	y		3105	12.3		57	5020	5:00+	FIRM	160	FLOSTOP I
HES-3	y		3105	12.3		78	7170	5:00+	FIRM	160	FLOSTOP I
HES-3	y		6588	12.3		65	7425	4:40	FIRM	190	FLOSTOP I
HES-3	y		1074	12.3		71	2408	2:56	FIRM	380	FLOSTOP I
B	y		70	12.3	256	207	13500	9:00+	0	90	65/35 H/POZ
B	y		35	12.3	125	97	3100	4:03	345	390	65/35 A/POZ
HES-3	y		3500	12.3		65	5475	5:40			FLOSTOP I
HES-11	y		35	12.4	140	107	5000	4:47	274	671	TLW
HES-11	y		18	12.4	160	123	7270	3:32	539	1041	TLW
HES-11	y		16	12.4		113	6200	4:19			TLW
HES-11	y		13	12.4	140	113	6000	4:48		1250	TLW
HES-11	y		35	12.4	154	116	6200	3:28	777	1447	TLW
HES-11	y		13	12.4	146	114	6000	3:52	470	1338	TLW
HES-11	y		13	12.4	146	114	6000	3:42	541	1185	TLW
B		n		12.4		80	50			180	H
HES-11	y		20	12.4	148	115	6200	3:40	500	1260	TLW
F	y		100	12.4	200	200	10500	2:45	542	1920	Micro-fine
HES-11	y		16	12.4	138	109	5320	3:30+	0	1027	TLW
HES-11	y		16	12.4	140	109	5420	4:25	397	895	TLW
HES-11	y		16	12.4	92	82	1200	7:00+		157	TLW
HES-11	y		13	12.4	92	82	1200	7:00+		138	TLW
HES-11	y		18	12.4	93	82	1200	7:42		417	TLW
F	y		220	12.4	148	121	5645	1:38			Micro-fine
HES-11	y		13	12.4	140	113	6000	3:52			TLW
B		n		12.4	177	133	8100	3:56	320	620	65/35 H/POZ
B	y		40	12.4	120	98	3500	6:00+	164	262	65/35 A/POZ
HES-11		n		12.4	186	139	8500	4:55			TLW
F	y		950	12.4		60	600	4:00+	0	99	Micro-fine
B	y		90	12.4	238	181	13110	7:00+			65/35 H/POZ
B	y		90	12.4	203	152	10650	6:22			65/35 H/POZ
B	y		90	12.4	203	152	10650	2:07	173	546	65/35 H/POZ
B		n		12.4	236	188	13000	4:13	357	647	65/35 H/POZ
B		n		12.4	100	91	1485	4:04	169	331	65/35 A/POZ
F	y		100	12.4	200	200	10500	1:25			Micro-fine
HES-11	y		365	12.4		106	5000	7:00+	753	951	TLW
B	y		37	12.4	135	105	4600	6:00+	110	251	65/35 H/POZ
B	y		35	12.4	135	106	4900	6:00+	164	373	65/35 H/POZ
HES-11	y		365	12.4		86	1955	4:26	113	421	TLW
B	y		120	12.4	158	120	6800	5:30+	167	322	65/35 H/POZ
B	y		100	12.4		95	4140	4:30+	55	136	65/35 H/POZ
B		n		12.4		80	50			108	A
B		n		12.4	116	96	3000	5:00+	50	131	65/35 H/POZ
B		n		12.4	230	182	12800	3:20	672	1009	65/35 H/POZ
B		n		12.4	245	196	12800	5:50			65/35 H/POZ
B		n		12.4	220	172	11700	4:57	537	904	65/35 H/POZ
B		n		12.4	218	169	11670	2:25	50	852	65/35 H/POZ
B	y		56	12.4	200	151	9647	5:30+	0	344	65/35 H/POZ
HES-11		n		12.4	138	105	4600	4:10			TLW
B	y		60	12.4	172	128	7600	5:00+	286	822	65/35 H/POZ
HES-3	y		2588	12.4		70	3590	3:37	104	681	A
B		n		12.4	150	109	5000	4:28	185	326	65/35 A/POZ
B		n		12.4	130	101	4000	6:00+	139	237	65/35 H/POZ
B	y		40	12.4	138	104	4500	7:13	144	260	65/35 H/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B		n		12.4	136	104	4500	4:03	96	170	65/35 A/POZ
B		n		12.4	116	96	3200	6:30+		198	65/35 A/POZ
B	y		40	12.4	120	98	3500	3:00			65/35 A/POZ
B	y		53	12.4	193	139	8880	5:30+	0	115	65/35 H/POZ
F		n		12.4	133	111	4412	1:52	576	1056	Micro-fine
B		n		12.4		80	50			89	A
B		n		12.4		90	0	3:36	98	168	A
HES-11	y		145	12.4	140	107	5008	5:44	289	353	TLW
HES-11	y		170	12.4	130	102	4683	5:35	415	707	TLW
B	y		40	12.4	135	135	4513	3:26			65/35 H/POZ
HES-11	y		326	12.4	102	90	2167	6:50			TLW
F	y		200	12.4		170	9910	3:39	1148	1200	Micro-fine
HES-11	y		326	12.4	91	81	1100	9:21		256	TLW
F	y		200	12.4		170	9910	7:00+			Micro-fine
HES-3	y		2588	12.4	62	60	3590	3:15(5:5			A
B	y		30	12.4		94	2800	4:14			H
B	y		30	12.4		94	2800	7:55			H
HES-11	y		95	12.4	148	109	5000	4:59	855	1140	TLW
B	y		80	12.4	134	104	4500	6:00+			65/35 A/POZ
B		n		12.4	134	104	4500	8:00+			65/35 A/POZ
F		n		12.4	250	210	14200	4:30+	811	1689	Micro-fine
HES-11	y		326	12.4	102	90	2167	6:50			TLW
E		n		12.4	175	127	7200	3:30	110	150	H
A	y		93	12.4	104	90	2000	10:00+(*	90	290	A
B	y		93	12.4	104	90	2000	6:30	140	160	H
B	y		80	12.4	230	181	13366	5:08	90	130	65/35 H/POZ
A	y		140	12.4	132	101	4323	5:00+	240	260	H
B		n		12.4	93	80	1000			230	65/35 A/POZ
B	y		83	12.4	204	156	11006	4:00+			65/35 H/POZ
HES-7	y		160	12.4	175	129	8972	6:00+	161	233	H
HES-7	y		160	12.4	175	129	8340	5:30+	210	320	H
HES-7	y		210	12.4		94	3200		0	167	H
HES-7	y		210	12.4		94	3200		0	86	H
B	y		20	12.4	118	97	3200	5:30+	80	180	65/35 A/POZ
B	y		20	12.4	90	80	800	5:00+	75	110	65/35 A/POZ
HES-11	y		80	12.4	225	176	13090	4:31	1318	1580	TLW
HES-7	y		160	12.4	180	134	9105	5:40	200	290	H
B		n		12.4	212	165	11800	4:31	390	1010	65/35 H/POZ
B	y		120	12.4	189	143	9100	5:00+	210	280	65/35 H/POZ
B	y		55	12.4	218	170	12100	5:24	180	395	65/35 H/POZ
B	y		55	12.4	218	169	12100	3:32	800	1400	65/35 H/POZ
B	y		55	12.4	200	154	11000	3:05	225	400	65/35 H/POZ
B	y		55	12.4	213	166	11700	4:21	140	380	65/35 H/POZ
B		n		12.4	115	93	2500	5:00+	200	340	65/35 A/POZ
B	y		80	12.4	254	205	15774	8:04	0	60	65/35 H/POZ
B		n		12.4	217	168	11400	4:02	600	650	65/35 H/POZ
B	y		70	12.4	248	201	14000	3:50	40	140	65/35 H/POZ
B		n		12.4	295	248	15470	5:02	825	1070	65/35 H/POZ
B		n		12.4	250	202	14675	4:20	740	860	65/35 H/POZ
HES-7	y		160	12.4	170	126	8432	6:00+	231	310	H
HES-7	y		158	12.4	144	107	5467	7:00+	165	630	H
B		n		12.4	266	219	14300	8:00+	590	660	65/35 H/POZ
B		n		12.4	162	122	6900	5:06	110	240	65/35 H/POZ
B	y		83	12.4	204	156	11006	3:15	210	340	65/35 H/POZ
B	y		83	12.4	193	146	9800	3:51	120	240	65/35 H/POZ
HES-11	y		219	12.4	116	96	3000	5:24	154	506	TLW
HES-11	y		415	12.4	158	119	12200	3:54	817	1100	TLW
HES-11	y		650	12.4	138	108	5300	4:50	629	1160	TLW
HES-11	y		170	12.4	122	101	4260	5:00+	190	388	TLW
HES-11	y		170	12.4	122	101	4260	5:00+	218	404	TLW
HES-11	y		57	12.4	141	105	4500	5:17	486	684	TLW
HES-11	y		219	12.4	137	104	4350	4:15			TLW
B	y		20	12.4	90	80	800	5:00+	75	110	65/35 A/POZ
HES-11	y		219	12.4	116	96	3000	5:40	283	1010	TLW
B	y		90	12.4	180	144	11950	4:07	359	742	65/35 H/POZ
HES-11	y		15	12.4	122	98	3500	5:03	380	710	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		15	12.4	122	98	3500	6:00+	309	775	TLW
F	y		140	12.4		80	240	2:05	325	500	Micro-fine
B		n		12.4	203	153	9817	3:45			65/35 H/POZ
B		n		12.4	135	104	4400	6:00+			65/35 A/POZ
F		n		12.4	250	210	14200	2:52	850	1139	Micro-fine
HES-11	y		168	12.4	126	99	3500	3:55	0	0	TLW
B		n		12.4		80	1000		182	285	85/15 A/POZ
B		n		12.4	210	160	10400	5:35	600	660	65/35 H/POZ
B	y		49	12.4		98	4385	4:18	245	465	H
B	y		83	12.4	204	156	10725	3:06	105	298	65/35 H/POZ
B		n		12.4	210	160	10400	3:35	640	1160	65/35 H/POZ
B	y		83	12.4	204	156	10970	4:03	103	250	65/35 H/POZ
B		n		12.4	224	162	9650	3:36	490	1040	65/35 H/POZ
B	y		83	12.4	215	159	9807	3:48	90	710	65/35 H/POZ
B		n		12.4	145	108	4900	6:40	220	340	65/35 A/POZ
B	y		83	12.4	206	158	10582	5:12	550	900	65/35 H/POZ
HES-3	y		2081	12.4		70	3700	4:38	200	350	FLOSTOP I
F	y		52	12.4	120	103	3300	5:08	587	875	Micro-fine
B	y		250	12.4	245	200	15050	4:07	106	240	65/35 H/POZ
B	y		250	12.4	245	199	17842	5:36		215	65/35 H/POZ
B		n		12.4	150	115	6000	5:00+			65/35 H/POZ
B	y		83	12.4	210	163	11900	6:20	486	714	65/35 H/POZ
B	y		122	12.4	178	134	8250	6:22	140	440	65/35 H/POZ
B		n		12.4	238	190	13281	6:03			65/35 H/POZ
A	y		255	12.5		73	1340	5:30+		368	A
A	y		130	12.5	95	83	1470	4:49	524	856	A
HES-11	y		265	12.5	90	82	1200	6:05	143	370	TLW
A	y		70	12.5	92	82	1000	3:00+	369	513	A
A	y		84	12.5	92	82	1000	3:30+	211	408	A
A	y		130	12.5	94	82	1300	4:00+	258	469	A
HES-11	y		75	12.5	106	93	2963	6:00+			TLW
HES-3	y		5372	12.5		85	2000	4:56	298	932	A
A	y		130	12.5	107	93	3402	4:00+	225	425	A
HES-11	y		155	12.5	122	98	3500	5:58	396	1291	TLW
HES-11	y		127	12.5	118	97	3748	5:45+	139	205	TLW
HES-11	y		116	12.5	118	97	3748	4:35	0	646	TLW
HES-11	y		127	12.5	118	97	3748	4:45	173	418	TLW
A	y		53	12.5	125	97	3200	2:39			A
A	y		70	12.5	133	99	4000	3:15			A
A	y		23	12.5	126	100	6000	4:30+	289	316	H
HES-11	y		127	12.5	122	98	3798	6:22	216	671	TLW
HES-11	y		116	12.5	122	98	3798	5:18	440	1251	TLW
HES-11	y		127	12.5	125	99	3865	5:56	319	1054	TLW
A	y		255	12.5	115	101	4350	2:22			A
F	y		1736	12.5		80	4200	2:23			TLW/Micro-fine
F	y		1736	12.5		80	4200	2:48			TLW/Micro-fine
F	y		1736	12.5		80	4200	3:00			TLW/Micro-fine
HES-11	y		116	12.5	125	101	4816	4:23	421	711	TLW
A	y		1736	12.5		80	4200	3:28			TLW
A	y		1736	12.5		80	4200	6:00	94	279	TLW
A	y		255	12.5	122	101	4200	3:25	445	678	A
A	y		170	12.5	136	105	4700	6:00+		263	H
HES-11	y		90	12.5	134	102	4200	4:58	201	338	TLW
A	y		76	12.5	130	102	4300	4:00+	320	455	H
HES-11	y		100	12.5	131	104	4600	6:30+	333	442	TLW
B		n		12.5	138	104	4500	6:00+	110	418	65/35 A/POZ
HES-3	y		500	12.5		59	5100	5:00	121	503	A
A	y		90	12.5	146	111	7160	3:14	192	331	H
HES-11	y		90	12.5	144	109	5300	5:15	565	1800	TLW
HES-3	y		3270	12.5		74	6700	5:24	54	140	A
B	y		2161	12.5		93	7400		189	377	65/35 A/POZ
HES-3	y		5370	12.5		60	7600	4:30+	50	108	A
HES-11	y		100	12.5	186	137	8876	3:15	671	1471	TLW
B	y		80	12.5	170	136	9000	5:15		200	65/35 H/POZ
HES-3	y		6500	12.5		65	9150	3:50	185	800	A
HES-11	y		127	12.5	195	147	9945	3:20	1012	1182	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		116	12.5	194	145	10332	3:08	834	873	TLW
HES-11	y		98	12.5	189	144	9540	4:45	0	223	TLW
HES-11	y		98	12.5	205	158	13450		229	400	TLW
HES-11	y		127	12.5	208	158	12466	3:14	658	950	TLW
HES-3	y		5370	12.5		92	10750	3:59			A
HES-3	y		6500	12.5		85	11200	2:30	267	610	A
HES-11	y		127	12.5	219	169	12222	4:10	928	1115	TLW
B		n		12.5	230	180	11900	4:30	275	1200	75/25 POZ/H
B		n		12.5	230	180	11900		270	1065	75/25 POZ/H
HES-11	y		90	12.5	221	176	13829	4:42	1139	1436	TLW
B	y		30	12.5	230	182	13500	6:30	1044	1254	50/50 H/POZ
HES-11	y		90	12.5	225	179	13900	3:45			TLW
F	y		300	12.5	105	95	2700	2:30	624	1285	Micro-fine
HES-11	y		1736	12.5		95	6600	2:53			TLW
HES-11	y		1736	12.5		95	6600	3:23	121	595	TLW
F		n		12.5	204	169	11272	3:11	1334	1368	Micro-fine
F	y		106	12.5		228	13082	3:51	1250	2244	Micro-fine
F	y		106	12.5		228	13082	4:10	550	1730	Micro-fine
A	y		10	12.5	92	80	1000	4:00+	250	510	A
HES-11	y		10	12.5	92	80	1000	4:00+	280	520	TLW
A	y		10	12.5	92	80	1000	4:00+	100	380	A
A	y		10	12.5	92	80	1000	4:00+	278	607	A
HES-11	y		10	12.5	92	80	1000	4:00+	247	645	TLW
A		n		12.5	118	96	3000	2:39			A
A	y		2500	12.5		60	7000			436	A
A	y		2500	12.5		85	10000			512	A
HES-11	y		45	12.5	91	80	900	5:00+	193	230	TLW
A	y		184	12.5	90	80	900	5:00+	172	377	A
A	y		184	12.5	90	80	900	3:00+	150	330	A
HES-11	y		184	12.5	92	80	1000	5:00	221	521	TLW
HES-11	y		45	12.5	122	97	3500	3:38	528	771	TLW
HES-11	y		184	12.5	135	104	4500	1:50			TLW
HES-11	y		184	12.5	135	104	4500	4:30+	293	500	TLW
HES-11	y		209	12.5	139	109	7474	5:01	575	979	TLW
A	y		2588	12.5		73	6650	6:50			A
B	y		153	12.5	170	127	9550	4:09	199	528	65/35 H/POZ
HES-7	y		66	12.5	170	127	8688	4:30+	233	317	H
HES-7	y		155	12.5	169	128	8918	5:30+	0	50	H
HES-7	y		50	12.5	202	151	10750	4:30+	91	192	H
B		n		12.5	200	152	10760	4:07	847	934	65/35 H/POZ
HES-11	y		100	12.5		157	11130	3:04	798	949	TLW
B	y		100	12.5	207	159	11120	6:30+	540	865	50/50 H/POZ
HES-7	y		35	12.5	223	172	11000	6:00+	172	324	H
HES-7	y		85	12.5	214	167	12817	5:02	1600	2500	H
HES-7	y		85	12.5	214	167	12617	4:32	302	407	H
HES-11	y		32	12.5		225	15600	6:23			TLW
HES-11	y		32	12.5		254	15600	5:00			TLW
HES-11	y		60	12.5		283	19000	9:36			TLW
HES-11	y		167	12.5		87	1732	4:30	155	342	TLW
HES-7	y		124	12.5		152	9969	10:26	260	400	H
B	y		130	12.5		143	10800	5:45			H
HES-7	y		66	12.5		169	11562	11:00	370		H
B	y		63	12.5		237	15883	10:30+			HTLD
B	y		63	12.5		258	17400	11:38			HTLD
B	y		60	12.5		283	19000	7:16			HTLD
B	y		60	12.5		283	19000	7:10			HTLD
B	y		60	12.5		283	19000	8:38			HTLD
B	y		63	12.5		283	19000	5:30			HTLD
B	y		63	12.5		283	19000	5:34			HTLD
B	y		50	12.5		283	19000	12:38			HTLD
B	y		63	12.5		283	19000	8:32			HTLD
F		n		12.5	168	136	6976	3:05	1168	1297	Micro-fine
HES-11	y		100	12.5	193	161	11052	5:00+	357	946	TLW
A	y		79	12.5	92	80	1000	4:00+	110	270	H
HES-11	y		1450	12.5	121	103	4962	3:34			TLW
HES-11	y		1450	12.5	121	103	4962	4:10			TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		1491	12.5	121	103	4500	3:42	197	516	TLW
B		n		12.5		95	700	5:00+	105	227	65/35 A/POZ
B	y		150	12.5	92	80	1000		70	185	65/35 A/POZ
B	y		150	12.5	92	80	1000		102	224	65/35 H/POZ
A	y		158	12.5	93	80	1000		430	1376	A
A	y		98	12.5	109	92	4980	5:02	395	613	A
A		n		12.5	112	94	2700	5:44	80	333	A
HES-11	y		722	12.5		50	2500	6:00+	30	115	TLW
HES-11	y		722	12.5		78	2020	7:04	127	162	TLW
HES-11	y		722	12.5		78	2020		76	134	TLW
HES-11	y		2000	12.5		60	2600	6:00+	83	162	TLW
HES-11	y		12	12.5	110	93	2500	5:00+	448	920	TLW
A	y		424	12.5	100	89	2000	4:31	261	654	A
B	y		305	12.5	135	106	4700	5:51		379	65/35 H/POZ
B	y		150	12.5	129	102	4500	8:02	127	241	65/35 H/POZ
B		n		12.5	130	101	4000	7:00+			65/35 A/POZ
HES-11	y		2192	12.5		82	4507	4:00+	110	140	TLW
HES-11	y		3227	12.5		97	6430	5:00	102	115	TLW
B	y		3227	12.5		105	9260	4:38	180	270	65/35 A/POZ
B		n		12.5		240	15400	7:00+			H
HES-7	y		23	12.5	95	82	1200	4:00+	85	173	H
HES-7	y		23	12.5	190	143	9511	5:30+	510	1086	H
B	y		144	12.5	206	156	10300	4:02	262	607	65/35 H/POZ
B		n		12.5	97	84	1400	5:00+		138	65/35 A/POZ
A		n		12.5	97	84	1400	4:45		239	A
B		n		12.5	97	84	1400	4:39		244	A
B		n		12.5		144	8450	5:00+	223	1485	65/35 H/POZ
A		n		12.5		80	50			50	A
HES-11		n		12.5		175	11200	3:07	1174	1550	TLW
HES-11		n		12.5	226	175	11200	3:50			TLW
B		n		12.5	190	155	9174	3:55	480	820	H
B	y		50	12.5	167	125	7250	6:12			65/35 H/POZ
HES-11	y		18	12.5	144	109	5773	3:45	721	970	TLW
HES-11	y		18	12.5	151	115	6508	3:32	597	989	TLW
HES-11	y		18	12.5	151	114	6258	3:32	597	989	TLW
HES-11	y		13	12.5	151	113	6200	3:30	826	1060	TLW
F	y		47	12.5	105	94	2100	2:28	770	950	Micro-fine
B		n		12.5		80	1000		85	156	50/50 A/POZ
B		n		12.5	115	93	2500	4:01	361	512	50/50 TXI/POZ
A	y		385	12.5	130	103	4540	5:00+	275	404	H
B		n		12.5	183	138	8600	5:30+	317	627	65/35 H/POZ
B		n		12.5	212	165	11820	4:02	829	1364	65/35 H/POZ
B		n		12.5	250	202	15135	4:23	1097	1201	65/35 H/POZ
B		n		12.5	85	83	600	3:00+	121	182	65/35 A/POZ
B	y		210	12.5	88	80	856	6:00+	0	62	50/50 H/POZ
HES-11	y		385	12.5	95	83	1300	7:39	0	175	TLW
HES-11	y		385	12.5	95	83	1300	7:13	221	487	TLW
A	y		515	12.5		85	1750	5:00+			A
HES-11	y		222	12.5		80	1000	6:00+	150	349	TLW
HES-11	y		220	12.5		80	1000	6:00+	244	453	TLW
HES-11	y		750	12.5		86	1900	6:00+	159	429	TLW
HES-11	y		220	12.5		80	1000	6:00+	143	563	TLW
HES-11	y		210	12.5		84	1859	6:42	50	375	TLW
A	y		750	12.5		80	1750	5:50	162	379	A
HES-11	y		210	12.5		84	1859	6:00+	113	743	TLW
A	y		400	12.5		82	1200	5:00+	147	445	A
A	y		400	12.5		82	1200	5:00+	85	125	H
HES-11	y		550	12.5	105	94	2996	4:00+	191	502	TLW
A	y		340	12.5	103	91	2901	5:20	248	469	A
HES-11	y		385	12.5	110	93	2600	5:30	217	482	TLW
HES-11	y		385	12.5	110	93	2600	4:18	400	835	TLW
A	y		1072	12.5	90	80	2350	6:13	196	725	A
HES-11	y		50	12.5		90	2110	5:51	151	512	TLW
HES-11	y		45	12.5		93	2600	5:34	316	754	TLW
HES-11	y		50	12.5		93	2600	3:54	38	957	TLW
HES-11	y		280	12.5	110	95	6000	5:00+	126	527	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		342	12.5		90	3716	4:45	100	250	TLW
HES-11	y		342	12.5	111	96	3861	4:57		205	TLW
A	y		2672	12.5		80	3875	5:00+		99	A
A	y		280	12.5	116	97	4500	3:15	404	494	A
B		n		12.5	119	96	3000	3:59	115	202	65/35 A/POZ
A	y		1419	12.5		80	3500	5:00+	159	270	A
A	y		515	12.5		82	3000	5:00+	265	439	A
HES-11	y		290	12.5		95	3050	5:30+		945	TLW
HES-11	y		750	12.5		98	3800	4:00	308	974	TLW
HES-11	y		220	12.5		99	3575	6:00+	150	403	TLW
A	y		400	12.5	116	98	3600	4:48	304	620	A
A	y		300	12.5	116	98	3600	5:00+	116	265	H
HES-11	y		32	12.5		104	4500	5:35	288	1025	TLW
HES-11	y		340	12.5		102	4676	6:37	52	305	TLW
A		n		12.5		92	4700	6:30+	1588	2342	A
HES-11	y		300	12.5		105	5000	7:20	0	162	TLW
HES-11	y		2000	12.5		65	4500	3:48	0	60	TLW
HES-11	y		220	12.5		92	4450	6:00+	367	752	TLW
HES-11	y		280	12.5	128	102	4700	3:11		579	TLW
B	y		525	12.5	127	110	5896	6:37			65/35 H/POZ
HES-11	y		350	12.5		110	5925	3:30			TLW
HES-11	y		220	12.5	142	108	5200	3:33	147	882	TLW
HES-11	y		3200	12.5		70	5200	5:00+			TLW
HES-11	y		350	12.5		111	6030	7:43	0	1254	TLW
B	y		525	12.5	127	110	5896	4:00+	140	240	65/35 H/POZ
HES-11	y		33	12.5		119	6800	8:06	0	377	TLW
A	y		1419	12.5		95	6600	8:00+		265	H
A	y		1419	12.5		95	6600	3:41			A
HES-11	y		290	12.5		124	6500	6:30+	266	580	TLW
HES-11	y		290	12.5		124	6500	4:20	243	551	TLW
HES-7	y		1900	12.5		97	6100	6:00+		106	A
HES-7	y		1900	12.5		90	6100	6:00+	123	196	A
B		n		12.5	165	124	7100	3:45+	209	464	65/35 H/POZ
HES-7	y		1419	12.5		115	7700	5:30+	305	354	A
HES-7	y		1419	12.5		128	8900	7:00+			A
HES-11	y		32	12.5	174	132	8250	4:12	221	1129	TLW
HES-7	y		420	12.5		135	8160	6:00+	95	198	H
HES-11	y		120	12.5	181	138	9400	4:00	0	1609	TLW
HES-11	y		120	12.5	182	139	9060	3:26	489	1355	TLW
HES-11	y		170	12.5	210	156	9650	4:00	102	1556	TLW
HES-11	y		35	12.5	185	142	10700	3:37	262	1530	TLW
HES-7	y		420	12.5		145	10112	5:44			H
HES-11	y		40	12.5	215	161	10100	7:49		0	TLW
B	y		40	12.5	215	161	10100	10:30+	497	738	HTLD
HES-11	y		45	12.5		161	10000	9:48			TLW
HES-11	y		45	12.5		161	10000	10:45	0	0	TLW
HES-11	y		2000	12.5		95	11351	4:18	229	409	TLW
B	y		35	12.5	193	152	11140	4:14	198	1087	65/35 H/POZ
HES-11		n		12.5		161	10100	9:04	0	25	TLW
HES-11	y		385	12.5	206	160	11945	6:15		0	TLW
HES-11	y		420	12.5		164	12300	6:50	0	1205	TLW
HES-11	y		420	12.5		164	13371	5:25	0	1344	TLW
B	y		35	12.5	219	174	12900	3:43	699	1605	65/35 H/POZ
B	y		35	12.5	219	174	12900	4:12	142	1643	65/35 H/POZ
HES-11	y		420	12.5		180	14913	5:24	0	1222	TLW
HES-11	y		420	12.5		197	15165	4:00	1153	1402	TLW
B	y		63	12.5	349	317	19500	8:09	216	486	HTLD
B	y		63	12.5		260	19000	7:59	50	165	HTLD
HES-11	y		150	12.5	95	82	1200	5:30+	101	131	TLW
HES-11		n		12.5	320	271	16050	3:30	343	533	TLW
F		n		12.5	152	124	6000	0:24			Micro-fine
F		n		12.5	152	124	6000	2:50	1089	1653	Micro-fine
HES-11	y		120	12.5	182	148	8700	2:45	1290	1676	TLW
B	y		20	12.5	116	101	3050	3:53	134	249	65/35 A/POZ
HES-11	y		50	12.5		204	9560	3:02	717	1000	TLW
HES-11	y		55	12.5		156	9500	5:57	462	1142	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		844	12.5	108	95	3300	4:16	245	518	A
HES-11	y		360	12.5	136	105	5169	4:26	165	520	TLW
HES-11	y		360	12.5	136	105	5169	8:11	120	424	TLW
B	y		225	12.5	160	120	8100	5:00+	220	448	65/35 H/POZ
B		n		12.5	160	137	9700	3:10			65/35 H/POZ
HES-7	y		117	12.5		180	11970	8:00+	228	268	H
HES-7	y		45	12.5	196	159	14852	3:56	310	385	H
B		n		12.5	250	202	14000	4:11			65/35 H/POZ
HES-3	y		1010	12.5		60	3650		70	191	A
HES-3	y		1010	12.5		60	3650	6:00+	146	229	A
HES-11		n		12.5	228	179	12300	3:13	65	1123	TLW
F	y		800	12.5		60	600	4:00+	73	395	Micro-fine
A	y		450	12.5		60	1452	4:00+	100	160	H
A	y		450	12.5		60	1452	4:00+	68	266	H
A	y		295	12.5	120	100	3950	6:00+	169	340	H
A	y		295	12.5	120	100	3950	6:00+	149	324	H
A	y		372	12.5		95	4950	5:00+	130	190	H
A	y		450	12.5		95	4952	7:00+	178	220	H
A	y		450	12.5		95	4952	7:00+	155	321	H
A	y		295	12.5	130	105	4875	6:00+	163	257	H
B		n		12.5	230	180	11900	4:20	0	105	65/35 H/POZ
HES-11	y		10	12.5	229	181	12425	4:20	1122	1255	TLW
B		n		12.5	282	240	15764		92	265	H
B	y		237	12.5	120	99	3800	4:30+	142	235	65/35 H/POZ
A	y		645	12.5		83	4500	4:00+	153	300	A
HES-11	y		380	12.5	130	103	4500	5:27			TLW
A	y		645	12.5		90	4000	4:29	270	350	A
B		n		12.5	185	139	8750	5:30	0	770	65/35 H/POZ
B		n		12.5	190	140	8300	3:56			65/35 H/POZ
B		n		12.5	212	163	10700	4:33			65/35 H/POZ
B		n		12.5	240	175	10300	5:18	1000	1730	65/35 H/POZ
B		n		12.5	240	174	10100	5:16	158	480	65/35 H/POZ
F	y		2940	12.5		40	3210	4:00+			Micro-fine
F	y		2940	12.5		40	3210	6:00+		165	Micro-fine
A	y		3300	12.5		47	4140		0	92	A
B	y		220	12.5	130	102	4200	3:45	218	349	65/35 A/POZ
HES-3		n		12.5		60	4085			146	A
HES-3	y		3300	12.5		58	5340	5:00+	0	197	A
B		n		12.5	160	117	6300	4:00			65/35 H/POZ
B	y		122	12.5	165	127	7800	5:35	800	940	H
B	y		122	12.5	174	130	7950	4:44	182	527	H
B	y		122	12.5	185	136	8100	4:15	288	1121	H
B		n		12.5	188	142	9000	3:02	135	383	65/35 H/POZ
B		n		12.5	228	161	9000	3:32	880	960	65/35 H/POZ
B		n		12.5	224	174	11500	3:16	113	626	65/35 H/POZ
B		n		12.5	232	184	12756	6:22	702	1440	65/35 H/POZ
HES-3	y		3907	12.5		70	3950	2:59	121	669	A
B	y		325	12.5	144	122	7763	3:02	336	508	65/35 A/POZ
B	y		325	12.5	144	122	7763	3:10	224	562	65/35 A/POZ
A	y		45	12.5	120	103	3000	3:00+			H
A	y		45	12.5	120	103	3000	3:00+			H
HES-10	y		3855	12.5		50	5200	4:00+			TLW
HES-10	y		3855	12.5		50	5200	4:00+			TLW
HES-11	y		1754	12.5	111	94	2825		175	230	TLW
HES-11	y		1754	12.5		71	2825	4:44	170	235	TLW
HES-3	y		2700	12.5		55	2950	3:55	64	216	A
A	y		720	12.5	124	100	3800	6:00+	194	400	H
A	y		720	12.5	124	100	5623	3:31	255	500	A
B	y		50	12.5	122	98	3500	3:15	190	390	65/35 A/POZ
A	y		1754	12.5		70	3016	5:00+	0	120	TLW
HES-11	y		252	12.5	137	105	7000	5:00+	474	1494	TLW
HES-3	y		2700	12.5		70	4200	3:41	0	436	A
HES-3	y		2700	12.5		80	5300	3:00	0	563	A
HES-3	y		2700	12.5		90	5700	2:33	250	378	A
HES-11	y		1754	12.5		94	5560	5:00+	330	500	TLW
HES-11	y		1754	12.5	135	114	6325	3:26		310	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-3	y		4243	12.5		65	6321	4:05	121	787	A
HES-11	y		67	12.5	166	126	7500	4:20	215	1200	TLW
B	y		60	12.5	198	152	10300	5:03	182	921	H
B	y		4243	12.5		105	10900	4:49	0	180	65/35 H/POZ
HES-11	y		981	12.5	115	99	4000	4:16	185	427	TLW
HES-11	y		70	12.5	146	114	6000	4:02	610	717	TLW
HES-11	y		50	12.5	160	122	8300	3:45	1068	1250	TLW
HES-11	y		10	12.5	172	133	9000	2:42			TLW
HES-11	y		10	12.5	172	133	9000	5:08	159	1989	TLW
HES-11	y		138	12.5	182	137	9120	4:26	771	1509	TLW
HES-11	y		10	12.5	190	151	11138	4:05	0	1079	TLW
HES-11		n		12.5	223	173	12100	4:30			TLW
B	y		70	12.5	290	249	17500	6:55	252	309	HTLD
HES-11	y		70	12.5	322	281	17500	6:00+			TLW
B	y		70	12.5	322	281	17500	7:32	139	1362	HTLD
HES-7	y		41	12.5	100	85	1500	5:00+	110	180	H
HES-7	y		167	12.5	111	93	3925	4:00+	150	230	H
HES-7	y		167	12.5	129	102	8549	5:00+	150	220	H
HES-7	y		176	12.5	150	112	6100	5:00+			H
HES-7	y		41	12.5	166	125	7300	5:35	90	230	H
HES-7	y		41	12.5	166	125	7300	7:00+	320	330	H
B	y		150	12.5	188	136	10250	4:15	120	400	65/35 H/POZ
B	y		160	12.5	180	133	10000	5:40	101	372	65/35 H/POZ
B		n		12.5	168	126	7300	4:20	178	259	65/35 H/POZ
F		n		12.5	130	109	4215	1:50		586	Micro-fine
F		n		12.5	138	115	5132	1:30			Micro-fine
HES-3	y		2707	12.5		70	4105	4:00	124	497	FLOSTOP I
HES-3	y		3227	12.5		70	4875	3:47	114	468	FLOSTOP I
B	y		2096	12.5		100	6395	5:23	150	230	65/35 A/POZ
F	y		110	12.5	180	148	8900	3:35	1120	1410	Micro-fine
HES-3		n		12.5		70	3950	4:06	50	280	FLOSTOP I
HES-3		n		12.5		70	4150	3:33	830	880	FLOSTOP I
F	y		29	12.5	270	232	16316	5:48	1430	1480	Micro-fine
HES-3	y		1754	12.5		75	2825	3:24	125	500	FLOSTOP I
F		n		12.5	225	184	11200	3:26	1040	1280	Micro-fine
HES-11	y		3325	12.5		95	7100	5:11			TLW
A		n		12.5	85	80	300			460	A
B		n		12.5	230	181	12770	5:30+	760	1080	75/25 POZ/A
B		n		12.5	200	152	10000	7:00+	580	750	75/25 POZ/A
B	y		40	12.5	188	130	9021	3:33	485	1060	H
B		n		12.5	190	144	9100	5:00+	570	760	75/25 POZ/A
B		n		12.5	194	147	9800	5:00+	580	780	75/25 POZ/A
HES-11		n		12.5	176	132	8000	2:43			TLW
HES-11		n		12.5	196	139	8000	3:53	SET	1160	TLW
B	y		525	12.5	125	102	4384	5:47	190	270	65/35 H/POZ
B	y		525	12.5	126	109	5700	4:00+	140	290	65/35 H/POZ
A	y		450	12.5		95	4952	9:30	265	405	H
HES-11	y		182	12.5	125	107	5150	5:48	200	705	TLW
A	y		633	12.5	120	105	5303	4:00+	150	290	A
B	y		60	12.5	290	249	17500	4:45	200	310	HTLD
B	y		60	12.5	290	249	17500	6:25		220	HTLD
HES-2	y		1086	12.5		70	2400	6:00+	160	450	A
HES-2	y		1086	12.5		70	2400	6:00+	110	350	A
B	y		85	12.5	142	107	4800	4:18	240	340	H
HES-11	y		2081	12.5		85	5100	4:00+	95	130	TLW
HES-11	y		51	12.5	197	149	10503	5:00	0	260	TLW
A	y		1195	12.5		90	4900	5:00+		0	H
B	y		120	12.5	188	145	10043	3:33	210	300	65/35 H/POZ
F	y		550	12.5		155	6800	3:46	1230	1390	Micro-fine
A	y		3153	12.5		70	8800	4:00+	1250	1360	A
B		n		12.5	206	158	10500	6:00+	620	670	75/25 POZ/A
HES-11	y		310	12.5	92	84	1500	5:00+	100	260	TLW
HES-11	y		310	12.5	115	98	3600	6:06	420	940	TLW
A	y		40	12.5	140	107	5602	4:31	185	220	H
B	y		41	12.5	134	104	4500	4:47	105	230	85/15 H/POZ
HES-11	y		222	12.5	118	96	6200	4:00+	70	485	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-3	y		6738	12.5		65	7800	3:39	120	360	FLOSTOP I
A	y		40	12.5	92	80	1000	4:00+	190	330	A
B	y		144	12.5		157	10150	11:20	SET	410	H
A	y		1195	12.5		90	4900	5:00+		72	H
A	y		1195	12.5		90	4900	5:00+	0	58	H
B		n		12.5	211	163	12000	4:03	570	1210	65/35 H/POZ
A	y		224	12.5	128	101	4692	3:51	200	340	H
B		n		12.5	220	172	11700	4:49	790	860	75/25 POZ/A
A	y		40	12.5	140	107	5602	5:42	140	230	H
HES-7	y		143	12.5		160	10750	10:41	0	440	H
A	y		3752	12.5		70	5650	5:00+	130	200	H
A	y		3752	12.5		70	5650	6:00+	150	265	H
A	y		3752	12.5		94	7500	5:00+	185	340	H
A		n		12.5	85	80	300		0	99	A
A		n		12.5	85	80	300		90	410	A
A		n		12.5	85	80	300		0	190	A
A		n		12.5	85	80	300		FIRM	175	A
A	y		663	12.5	115	97	3500	4:00+	110	250	A
B		n		12.5	190	144	9240	4:00	200	840	65/35 H/POZ
B	y		525	12.5	127	109	6600	5:06	150	270	65/35 H/POZ
B	y		525	12.5	127	109	6600	7:03	88	185	65/35 H/POZ
B	y		200	12.5	110	93	2700	4:30+	170	270	50/50 H/POZ
B	y		41	12.5	134	104	4500	4:06	120	200	85/15 H/POZ
HES-11	y		42	12.5	145	110	5300	4:54	850	1175	TLW
A	y		1736	12.5		95	5800	7:22	135	140	H
A	y		1736	12.5		95	5800		70	185	H
B	y		1736	12.5		80	3304	2:00+	160		A
A	y		1136	12.5		80	6150	4:00+	120	180	H
B	y		25	12.5	215	167	11860	0:52			50/50 H/POZ
A	y		663	12.5	115	97	3500	7:00+	100	180	H
A	y		663	12.5	115	97	3500	6:00+	290	390	H
A	y		663	12.5	115	97	3500	6:00+	290	390	H
HES-7	y		587	12.5		88	4500	5:00+	0	140	H
HES-7	y		1753	12.5		70	4500	4:00+		0	H
HES-7	y		420	12.5	190	154	11900	6:30+	440	655	H
A	y		209	12.5	153	117	6508	5:00+	251	469	H
B	y		80	12.5	176	132	8350	5:18	80	195	65/35 H/POZ
A	y		209	12.5	188	141	10678	2:24			H
HES-7	y		209	12.5	188	141	10678	6:30+	230	250	H
A	y		1736	12.5		95	5800	4:30+	137	279	H
HES-3	y		6385	12.5		65	7500	3:44	FIRM	220	FLOSTOP I
E	y		255	12.5	94	87	1240	2:30	65	140	A
HES-7	y		688	12.5	116	97	4066	7:00+	82	250	H
B		n		12.5	95	86	1700	4:14	129	190	85/15 A/POZ
B		n		12.5	115	98	3550	5:00+	80	290	85/15 H/POZ
HES-11	y		100	12.5	129	99	3500	6:15			TLW
HES-11	y		2192	12.5		65	4417	7:00+	0	50	TLW
HES-11	y		2192	12.5		65	4417	6:00+	FIRM	100	TLW
B	y		34	12.5	223	175	12728	3:54	992	1270	50/50 H/POZ
A	y		633	12.5	105	90	3100	5:00+	60	200	H
HES-3	y		2134	12.5		65	3630	6:22	0	190	FLOSTOP I
B	y		525	12.5	137	111	5700	7:39	90	250	65/35 H/POZ
B	y		525	12.5	137	111	6100	5:44	80	280	65/35 H/POZ
A	y		240	12.5	145	108	5077	5:30	160	250	H
HES-11	y		288	12.5		80	1619	5:45+	359	653	TLW
HES-11	y		288	12.5	139	105	5550	5:00	0	0	TLW
HES-11	y		288	12.5	139	105	5550		500	1380	TLW
HES-1		n		12.5		100	6400	7:16			SLAG
HES-1		n		12.5		100	6400	5:40			SLAG
HES-7	y		650	12.5	118	100	4350	6:00+	148	301	H
B	y		277	12.5	172	132	8352	4:22	140	200	65/35 H/POZ
HES-7	y		650	12.5	181	149	12000	5:34	126	190	H
	y		80	12.5	230	181	13410	5:30+			65/35 H/POZ
B		n		12.5	175	127	7200	4:26	250	365	65/35 H/POZ
B	y		277	12.5	207	159	14156	3:35	30	60	65/35 H/POZ
HES-1	y		2940	12.5		81	6400	5:11	255	605	SLAG

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-1	y		2940	12.5		81	7100	5:11	255	605	SLAG
HES-11	y		34	12.5	230	189	11510	3:07	1200	1710	TLW
A	y		1061	12.5		70	2800	10:00+	50	150	H
A	y		2978	12.5		90	8000	5:00+	60	120	H
A	y		2978	12.5		86	7000	5:00+	70	200	H
HES-7	y		478	12.5		94	4650	5:30+	0	80	H
HES-7	y		478	12.5		128	4090	5:30+	194	305	H
A	y		227	12.5	100	80	1000	5:00+	110	380	A
B		n		12.5	228	179	12800	5:26	260	750	65/35 H/POZ
B	y		100	12.5	170	134	11000	4:12	160	207	65/35 H/POZ
A	y		650	12.5	126	101	4485	5:06	140	210	A
HES-7	y		650	12.5	126	101	4486	6:00+	144	298	A
B	y		86	12.5	237	189	13500	3:53	310	340	65/35 H/POZ
B	y		100	12.5	145	113	6021	7:09	80	180	65/35 H/POZ
B		n		12.5	219	166	10700	3:50	510	680	65/35 H/POZ
B	y		650	12.5		63	1874	5:30+	40	100	A
HES-3	y		3400	12.5		65	5200	3:38			FLOSTOP I
A		n		12.5		110	4000	10:00+	250		H
HES-7	y		130	12.5	134	109	5500	8:00+	140	260	H
A	y		372	12.5	140	107	5000	5:57	230	280	H
HES-11	y		722	12.5		65	2620	5:00+	0	FIRM	TLW
A	y		236	12.5	135	105	4700	5:00+	190	290	A
HES-7	y		1200	12.5		70	4500	6:00+	50	150	A
HES-7	y		1200	12.5		70	4500	6:30+	60	110	A
HES-7	y		3244	12.5		73	6800	5:00+	0	75	H
F	y		145	12.5		80	250	3:27	145	210	Micro-fine
HES-7	y		3200	12.5		109	10765	5:30+	30	120	H
HES-7	y		3200	12.5		109	10765	6:00+	30	120	H
HES-11	y		320	12.5	120	96	3000	4:13	310	1180	TLW
HES-7	y		110	12.5	180	135	8300	6:00+	297	396	H
HES-7	y		55	12.5		153	10400	7:00			H
HES-3		n		12.5		53	4358	3:06	90	250	FLOSTOP I
B		n		12.5	120	97	3263	5:00+	160	230	65/35 H/POZ
B		n		12.5	120	97	3263		320	360	65/35 A/POZ
A	y		1072	12.5		92	4200	5:00+	128	200	H
HES-1	y		3800	12.5		82	9500	4:00	543	576	SLAG
A	y		3800	12.5		82	9500	2:15			A
HES-7	y		2320	12.5		80	5000	4:30+	60	100	H
A		n		12.5	110	90	2000	5:30+	130	200	A
A	y		650	12.5	125	101	5831	4:47	160	350	A
B	y		305	12.5	193	147	10300	4:21	540	1000	65/35 H/POZ
HES-7	y		209	12.5	194	147	11858	7:00+	280	390	H
HES-7	y		209	12.5	194	147	11858	6:00+	220	260	H
B	y		83	12.5	209	161	11500	4:13	80	180	65/35 H/POZ
B	y		83	12.5	209	161	11500	4:39	90	190	65/35 H/POZ
B	y		90	12.5	225	176	13986	4:27	225	360	65/35 H/POZ
B	y		80	12.5	235	187	13390	6:54	130	180	65/35 H/POZ
HES-8	y		3210	12.5		70	5450	6:00+	32	92	FLOSTOP III
HES-8	y		3210	12.5		70	5450	6:37	110	455	FLOSTOP III
HES-7	y		360	12.5	182	136	9957	6:00+	370	490	H
HES-1	y		3800	12.5		82	9500	4:50	626	670	SLAG
A	y		1072	12.5	118	100	4200	5:00+	130	180	H
HES-1	y		2945	12.5		81	7110	3:45		0	SLAG
HES-1	y		2940	12.5		82	7110	4:59	0	102	SLAG
B	y		66	12.5	261	209	15100	6:10	220	240	HTLD
HES-11	y		2407	12.5		58	3849	6:00+	123	205	TLW
HES-1	y		2945	12.5		81	7110	4:56	336	580	SLAG
A	y		1070	12.5		80	2200	5:00+	FIRM	230	H
HES-11	y		42	12.5	94	80	1000	5:00+		240	TLW
B	y		36	12.5	180	136	10940	6:25	390	660	65/35 H/POZ
B	y		83	12.5	198	150	10500	6:18	300	1120	65/35 H/POZ
HES-7	y		3940	12.5		109	9725	6:00+	250	280	H
HES-11	y		42	12.5	94	80	1000			180	TLW
HES-11	y		42	12.5	134	101	4650	4:00+		630	TLW
B	y		36	12.5	204	159	14500	8:02	70	200	65/35 H/POZ
B	y		36	12.5	235	180	14500	7:16	125	256	65/35 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		185	12.5	126	98	4527	6:30+	640	1429	TLW
HES-7	y		68	12.5	245	198	15800	9:30+	0	102	H
B	y		372	12.5	120	99	4350	6:00+	80	120	H
B	y		372	12.5	120	99	4350	7:56	100	260	H
A	y		220	12.5	0	75	1600	4:00+	140	420	A
A	y		220	12.5	95	85	1600	6:00+	80	210	H
A	y		220	12.5	150	109	5000	2:30	470	500	A
A	y		220	12.5	150	109	5000	5:00+	170	245	H
A	y		2517	12.5	0	70	5400	5:20	150	410	A
HES-1	y		3800	12.5	0	81	9500	4:18	800	880	SLAG
HES-8	y		3940	12.5	0	109	9725	3:35	610	810	FLOSTOP III
B	y		83	12.5	198	150	10100	3:58	260	610	65/35 H/POZ
B	y		83	12.5	198	150	10250	4:35	370	850	65/35 H/POZ
HES-7	y		209	12.5	202	154	14802	5:30+	350	480	H
HES-7	y		377	12.5	130	100	3906	8:00+	60	160	H
A	y		163	12.5	102	85	1500	5:00+	60	220	H
A	y		1309	12.5	0	65	2300	4:30+	0	160	H
A	y		1309	12.5	0	65	2300	4:30+	0	120	A
A	y		1309	12.5	0	65	2300	5:00+	65	269	A
B	y		280	12.5	218	168	11500	4:55	560	580	65/35 H/POZ
B	y		280	12.5	218	168	11500	6:54	365	630	65/35 H/POZ
A	y		530	12.5	98	86	1707	5:00+	70	390	A
A	y		530	12.5	121	97	5294	6:00+	180	390	A
B	y		90	12.5	160	120	6800	6:17	160	290	65/35 H/POZ
HES-7	y		186	12.5	173	130	11700	5:00+	185	325	H
B	y		83	12.5	198	151	10250	5:36	161	709	65/35 H/POZ
F	y		90	12.5	122	104	3500	3:16	90	180	Micro-fine
A	y		6037	12.5	0	65	9000	5:30+	0	FIRM	A
HES-7	y		55	12.5	204	157	12550	4:25	210	314	H
B		n		12.5	215	168	13400	5:00	330	765	65/35 H/POZ
HES-7	y		110	12.5	0	207	15785	6:00	450	710	H
HES-7	y		110	12.5	0	207	15785	7:18	350	570	H
HES-7	y		377	12.5	150	114	5806	7:00+	70	150	H
HES-11		n		12.5	124	98	3500	4:57	440	1076	TLW
A	y		650	12.5	116	96	5801	6:30+	180	260	A
A	y		650	12.5	125	101	9302	4:50	260	270	A
	y		83	12.5	188	142	9873	5:30+	290	336	H
HES-7	y		5467	12.5	0	75	8400	7:00+	110	256	A
B	y		36	12.5	219	170	11847	4:47	305	1040	65/35 H/POZ
HES-7	y		6037	12.5	0	95	11850		85	164	H
HES-7	y		35	12.5	215	166	11565	3:43	410	478	H
B	y		150	12.5	183	135	8100	5:08	270	430	H
HES-7	y		35	12.5	237	181	11565	5:40	320	430	H
A	y		530	12.5	121	97	5294	4:38	220	420	H
A	y		530	12.5	98	86	1707	5:00+	114	320	H
HES-7	y		209	12.5	196	149	13661	5:13	140	220	H
A	y		650	12.5	0	101	9302	3:20	200	230	A
B	y		55	12.5	307	253	17900	7:47	55	94	HTLD
HES-7	y		650	12.5	164	124	10676	4:30+	230	360	H
F	y		210	12.5	101	88	2300	2:58	220	325	Micro-fine
B	y		110	12.5	162	137	9900	5:28	125	227	H
HES-7	y		110	12.5	162	137	9900	6:00+	270	500	H
HES-7	y		52	12.5	0	145	9600	6:21	213	330	H
B		n		12.5	200	152	9900	3:27	310	600	65/35 H/POZ
A	y		2800	12.5	0	65	3600	5:00+	0	60	A
HES-3	y		2800	12.5	0	60	3960	5:38	1020	1230	FLOSTOP I
HES-7	y		1753	12.5	0	70	5000	6:00+	80	120	A
A	y		650	12.5	113	95	6012	5:40	160	290	H
B		n		12.5	200	152	9900	7:48	260	1000	65/35 H/POZ
HES-7	y		105	12.5	122	97	3500	6:00+	750	830	H
A	y		650	12.5	113	95	6012	4:39	80	340	A
HES-7	y		45	12.5	213	179	13200	4:30+	158	410	H
A	y		176	12.5	127	101	4500	4:30+	300	350	H
B	y		52	12.5	92	80	1000	5:00+	163	200	H
HES-7	y		36	12.5	218	168	11500	4:00+	228	392	H
B	y		36	12.5	219	170	14008	5:33	84	330	65/35 H/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		60	12.5	95	83	1300	5:00+	175	220	H
B	y		52	12.5	128	100	4000	5:10	180	290	H
B	y		77	12.5	220	172	13719	3:55	550	800	65/35 H/POZ
B	y		52	12.5	128	100	4000	5:00+	230	340	H
B	y		52	12.5	92	80	1000	5:00+	110	240	H
HES-7	y		52	12.5	0	152	11208	4:33	210	290	H
B	y		36	12.5	219	170	14053	5:30	172	455	65/35 H/POZ
B	y		52	12.5	129	100	4000	6:00+	215	260	H
HES-11	y		950	12.5	136	108	5342	4:18	200	660	TLW
A	y		1611	12.5	139	110	5424	5:13	130	140	H
HES-11	y		3400	12.5	0	70	5200	7:32	70	250	TLW
HES-11	y		3400	12.5	0	70	5200	7:35	50	430	TLW
B	y		110	12.5	92	80	1000	4:00+	200	270	H
B	y		110	12.5	116	95	3000	5:41	200	440	H
B	y		63	12.5	132	104	4500	6:34	170	360	H
B	y		150	12.5	192	142	8600	5:15	160	830	65/35 H/POZ
HES-11	y		340	12.5	169	127	7400	3:52	770	990	TLW
HES-11	y		340	12.5	187	141	12260	3:03	452	935	TLW
HES-11	y		340	12.5	187	141	12260	2:08			TLW
HES-11	y		340	12.5	187	141	12260	4:18	710	1644	TLW
A	y		3600	12.5	0	65	5200	5:00+	0	0	A
A	y		3600	12.5	0	75	6700	4:19	105	603	A
B		n		12.5	142	108	5000	4:17	122	209	65/35 A/POZ
A	y		220	12.5	95	81	1200	4:00+	180	380	A
HES-11	y		6200	12.5	0	68	5305		57	157	TLW
HES-11	y		6200	12.5	0	68	5305	3:51	105	380	TLW
HES-1	y		3800	12.5	0	79	9500	3:59	329	365	SLAG
HES-7	y		3778	12.5	0	120	13275	9:45	0	80	H
HES-7	y		186	12.5	164	124	9170	5:00+	210	2450	H
HES-7	y		290	12.5	182	137	12718	5:38	138	212	H
HES-7	y		40	12.5	245	192	14000	5:30+	290	340	H
HES-7	y		40	12.5	260	202	14000		340	380	H
HES-11	y		950	12.5	105	91	2890	2:33	220	590	TLW
HES-11	y		950	12.5	141	111	7198	3:44	270	970	TLW
HES-11	y		3400	12.5	0	70	5200	6:45	140	272	TLW
B	y		110	12.5	127	100	4050	3:30+	170	320	H
B	y		110	12.5	127	100	4050	3:38	190	310	H
HES-7	y		110	12.5	127	100	4050	6:00+	130	290	H
B	y		110	12.5	137	107	5000		200	350	H
HES-7	y		85	12.5	140	108	5000	6:00+	79	340	H
HES-7	y		127	12.5	200	152	10752	8:00+	160	190	H
A	y		50	12.5	133	103	4400	6:00+	150	260	H
A	y		3550	12.5	0	85	9858		90	360	H
A	y		3550	12.5	0	83	8378	2:33	275	710	A
A	y		3550	12.5	0	83	8378	3:41	290	440	A
A	y		3550	12.5	0	80	9200	5:00+	0	94	H
HES-7		n		12.5	0	70	12500	7:00+	0	95	A
A	y		420	12.5	102	89	2045	6:00+	180	370	A
A	y		420	12.5	122	99	3957	6:57	230	340	A
B	y		90	12.5	220	177	15500	6:38	540	780	HTLD
HES-7	y		190	12.5	134	102	5621	6:00+	400	543	H
HES-1	y		3800	12.5	0	64	7340	5:00+	410	891	SLAG
B	y		40	12.5	90	80	900	4:00+	242	480	65/35 A/POZ
HES-7	y		209	12.5	135	105	5069	4:00+	70	90	H
HES-7	y		209	12.5	202	153	14000	6:00+	352	419	H
A	y		5200	12.5	0	75	10353	5:00+	50	100	H
A	y		5200	12.5	0	115	10300	8:00+	30	60	H
B	y		300	12.6		110	4235	6:00+	61	116	65/35 H/POZ
B		n		12.6	200	150	10000	4:14	366		65/35 H/POZ
HES-11	y		415	12.6	124	100	5068	3:00			TLW
HES-11	y		1754	12.6	192	159	12875	3:11	530	1340	2/1 TLW/H
HES-11	y		1754	12.6	178	149	11391	3:00	438	1250	2/1 TLW/H
HES-11	y		1754	12.6	174	146	10870	5:01	402	670	2/1 TLW/H
F	y		71	12.6	135	112	4500	3:30	1790	1917	Micro-fine
F	y		71	12.6	135	112	4500	4:17	605	671	Micro-fine
F	y		71	12.6	135	112	4500	4:44	428	494	Micro-fine

*Slurry Type	Offshore Yes	No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	24 hr	Base Cement Type
F	y		71	12.6	125	106	3200	3:30	625	692	Micro-fine
B	y		20	12.6	98	86	1700	4:49	190	270	H
B	y		300	12.6		111	5820	5:00+	60	255	65/35 H/POZ
B	y		150	12.6	215	160	10000	3:54	586	816	65/35 H/POZ
B	y		300	12.6		92	2200	4:30+	109	265	65/35 H/POZ
B	y		300	12.6	110	91	2200	4:30+	79	212	65/35 H/POZ
B	y		300	12.6		82	1100	4:30+	150	188	65/35 H/POZ
HES-11		n		12.6	282	240	15764	6:28	711	711	2/1 TLW/H
B		n		12.6	120	96	3000	4:06	136	280	65/35 A/POZ
B	y		45	12.6		93	6206	5:00+	155	220	65/35 H/POZ
B	y		90	12.6	184	147	12438	6:35	0	236	65/35 H/POZ
HES-11	y		760	12.6	117	99	4303	4:30	128	276	TLW
HES-11	y		50	12.6	95	82	1200	6:00+	79	102	1/1 TLW/H
B	y		240	12.6		139	5600	6:24			65/35 H/POZ
B	y		200	12.6	119	96	4800	4:00+	310	370	H
B	y		2161	12.6		93	7400		189	248	65/35 A/POZ
B		n		12.6	256	207	14700	4:45	1260	1310	65/35 H/POZ
B		n		12.6	256	207	14700	7:55	458	925	65/35 H/POZ
HES-3	y		2920	12.6		65	5200	5:00			FLOSTOP I
B	y		200	12.6	119	96	4800	4:00+	210	440	H
HES-11	y		101	12.6	210	163	12227	4:00	190	1760	TLW
B	y		41	12.6	192	145	10423	5:49	0	1130	65/35 H/POZ
B	y		182	12.6	190	144	9300	4:29	140	440	65/35 H/POZ
B	y		182	12.6	190	144	9300	3:33			50/50 H/POZ
B	y		150	12.6	195	143	8500	3:08			65/35 H/POZ
B	y		110	12.6	146	114	6000	5:36	290	640	H
B	y		41	12.6	205	154	10050	4:48	280	1155	65/35 H/POZ
B	y		40	12.6	106	91	2710	4:00+	270	480	H
HES-11	y		1754	12.6	188	152	14050	3:44	340	1350	2/1 TLW/H
HES-11	y		1754	12.6	218	169	16740	5:50	640	945	2/1 TLW/H
HES-11	y		1754	12.6		94	5500	5:00+	220	590	2/1 TLW/H
HES-11	y		1754	12.6		94	5560	5:00+	100	240	2/1 TLW/H
B		n		12.6	85	80	300			290	85/15 A/POZ
B	y		52	12.6	128	101	4000	5:00	480	555	A
B	y		52	12.6	92	80	1000	4:00+	190	300	A
HES-3	y		6201	12.6		65	7300	3:34	140	280	FLOSTOP I
HES-11	y		760	12.6	138	114	7220	7:18	198	1147	TLW
B		n		12.6	200	155	11000	3:43	359	1130	65/35 H/POZ
B	y		76	12.6		92	2300	4:35	116	214	A
B	y		200	12.6		98	4000	5:36			H
B	y		200	12.6		98	4000	4:37			H
B	y		52	12.6	134	104	4500	5:20	240	410	A
B	y		76	12.6	130	103	4500	4:35	251	551	H
B	y		76	12.6	130	103	4500	4:27	387	721	H
B	y		200	12.6	140	107	5369	5:00	110	160	H
B	y		40	12.6	138	106	5010	8:30			H
B	y		40	12.6	138	106	5010	4:19			H
B	y		553	12.6		120	5500	9:24			H
HES-11	y		1050	12.6		70	2400			287	TLW
B	y		553	12.6		108	6800	7:59		330	H
B	y		76	12.6	114	99	3300	4:15	310	360	A
B	y		35	12.6	107	92	2380	5:20	195		H
B	y		35	12.6	106	91	2300	5:03			H
B	y		35	12.6	106	91	2300	3:30+	256	437	H
B	y		40	12.6	93	80	1000	6:30+		79	H
B	y		40	12.6	100	84	1450	6:30	155	289	H
B	y		76	12.6	91	80	1000	4:00+	170	330	A
B	y		52	12.6	92	80	1000	4:00+	120	390	A
B	y		76	12.6		80	750	4:38	121	239	A
B	y		52	12.6	128	101	4000	5:38	200	530	A
HES-11		n		12.6	100	91	1500	4:18	212	417	2/1 TLW/H
B	y		20	12.6	98	86	1700	5:00+	190	350	H
B		n		12.6	211	163	10900	6:30	280	831	65/35 H/POZ
A		n		12.6		80	270	4:00+	111	231	A
B		n		12.6		93	2500		0	50	HPLC
B		n		12.6		160	12000	5:42	272	529	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B		n		12.6		160	12000	5:36	88	489	H
A		n		12.6	110	90	2000	6:23	366	470	A
B		n		12.6	200	152	10000	4:03	0	1194	65/35 H/POZ
B	y		80	12.6	140	113	5963	4:25	324	829	H
HES-11	y		332	12.6	120	100	4126	4:55	82	663	TLW
HES-11	y		760	12.6	138	114	7220	6:12	556	1482	TLW
B	y		26	12.6		165	10500	8:58			H
B	y		26	12.6		165	10500	5:21			H
B	y		200	12.6		140	9100	5:05			H
B	y		35	12.6		134	8210	14:45			H
HES-7	y		120	12.6		115	6000	14:53			H
B	y		35	12.6		87	1750	5:40			H
B	y		165	12.6		87	1732	3:47	200	341	A
B	y		35	12.6		118	8445	8:00	0	630	H
HES-11	y		1485	12.6	143	119	7252	5:45	122	441	TLW
B	y		35	12.6	157	119	8100	6:47	60	390	H
B		n		12.6	219	167	10750	5:05	700	980	65/35 H/POZ
B		n		12.6	280	214	11671	3:30	390	630	HTLD
B	y		35	12.6		141	8950	4:47	0	395	H
HES-7	y		210	12.6		136	9820	6:45	290	380	H
B	y		110	12.6	140	107	5000		160	250	H
B	y		110	12.6	140	107	5000	4:53	95	230	H
B	y		38	12.6		126	7222	5:36	260	530	H
B	y		52	12.6		184	12930	4:58			H
B	y		110	12.6	140	107	5000	6:44	120	230	H
B		n		12.6	256	207	14700	7:10	680	1260	65/35 H/POZ
B	y		80	12.6	188	142	9483	4:10		75	65/35 H/POZ
B	y		50	12.6	122	97	3500	6:22	170	200	H
B		n		12.6		80	1100	5:00+			50/50 H/POZ
B		n		12.6		190	10000	8:00+			H
B		n		12.6		112	4000	4:16			H
B	y		52	12.6		187	14555	10:07			H
B	y		52	12.6	137	104	4500	4:25	250	290	H
B	y		52	12.6	0	143	10600	5:32	SET	570	H
HES-11	y		2800	12.6	0	82	12424	9:29			TLW
HES-11	y		2588	12.6	0	82	12424	7:02	160	380	TLW
B	y		2800	12.6	0	82	12424	10:16	90	211	H
B	y		2800	12.6	0	73	6820	10:32	130	200	H
B	y		2800	12.6	0	79	9938	6:19	25	120	H
B		n		12.6	280	214	11671	2:28			HTLD
B	y		52	12.6	0	143	10600	7:50	FIRM	440	H
B	y		2000	12.6	0	75	6400	7:29	100	220	H
B	y		52	12.6	0	152	11208	4:01	280	620	H
B	y		3000	12.6	0	73	6600	8:29	140	230	H
B	y		52	12.6	0	145	9600	4:30	80	350	H
B	y		55	12.6	92	80	900	5:00+	90	300	H
B	y		55	12.6	131	103	4400	6:43	270	420	H
B	y		2800	12.6	0	80	8720	6:50	70	140	H
B	y		2800	12.6	0	73	6894	7:28	90	180	H
B	y		2000	12.6	0	87	9200	4:20	150	410	H
B	y		50	12.6	122	97	3500	4:04	135	220	H
HES-7	y		200	12.6	145	108	9531	6:00+	254	400	H
B	y		110	12.6	182	137	8930	4:27	230	490	H
B	y		181	12.6		123	7683	6:14	170	620	H
B	y		35	12.6		126	7289	4:37	480	670	H
HES-7	y		190	12.6		148	10200	6:03		220	H
HES-7	y		190	12.6		148	10200	8:55	170	600	H
B	y		2588	12.6		77	8100	5:40			H
B	y		2588	12.6		73	6700	5:53	60	150	H
B	y		2588	12.6		73	6700	6:00+	30	40	H
B	y		50	12.6	120	98	3817	7:33	99	280	H
B		n		12.6	265	218	14700	8:22	644	1290	65/35 H/POZ
B		n		12.6	250	202	14000	6:31	450	680	65/35 H/POZ
B	y		41	12.6	106	91	2800	4:41	100	190	H
B	y		35	12.6		142	9000	7:45			H
B	y		52	12.6	117	96	3100	4:34	130	270	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		144	12.6		129	8792	3:48			H
B	y		190	12.6	134	105	5300	6:00	128	800	H
B	y		38	12.6	126	98	4114	5:47			H
B	y		38	12.6	91	81	1100	6:23	50	100	H
B		n		12.6	250	202	14000	5:32	300	565	65/35 H/POZ
B		n		12.6	225	175	11600	4:32	280	750	65/35 H/POZ
B	y		35	12.6		118	8673	4:49	280	370	H
B	y		69	12.6		174	12833	7:10	128	720	H
B	y		144	12.6	172	129	7900	3:39	400	450	H
B	y		35	12.6	115	96	3800	3:36	250	420	H
B	y		52	12.6		150	10443	8:40	0	950	H
B	y		190	12.6	148	148	10200	9:03	0	510	H
B	y		2800	12.6	0	75	7090	7:41	105	280	H
HES-7	y		200	12.6	145	108	9531	4:00+			H
B	y		52	12.6	134	104	4500	4:19	150	350	H
B	y		35	12.6	119	97	3300	3:50	180	340	H
B	y		76	12.6		137	8510	5:53	FIRM	380	H
HES-7	y		99	12.6	215	164	13487	3:46	243	377	H
HES-7	y		200	12.6	129	103	4555	6:00+	220	315	H
B		n		12.6	272	228	16621	6:12	450	490	65/35 H/POZ
HES-7	y		200	12.6	129	103	4555	6:00+	120	1710	H
B		n		12.6	260	211	14900	4:18	320	1000	65/35 H/POZ
B	y		200	12.6	129	103	4555	3:52	160	200	H
B		n		12.6	140	116	5000	4:07	130	290	65/35 A/POZ
HES-7	y		52	12.6	162	141	8900	5:58	387	510	H
HES-7	y		52	12.6		141	8900	5:37	242	1350	H
B	y		35	12.6		119	6430	5:29			H
B	y		52	12.6		120	6650	5:34			H
B	y		52	12.6		120	6650	4:43	208	430	H
B	y		181	12.6		107	6038	6:29	140	300	H
B	y		35	12.6		94	2857	4:51	100	250	H
HES-7	y		35	12.6	244	192	13700	6:31	200	340	H
B	y		52	12.6	128	101	4000	6:02	150	154	H
B	y		35	12.6	123	99	3657	3:44	196	350	H
B	y		35	12.6		131	7900	5:49	0	330	H
B		n		12.7	215	166	11030	5:20	291	990	65/35 H/POZ
B	y		139	12.7	165	126	7500	5:10	272	519	65/35 H/POZ
B		n		12.7	235	187	12900	5:13			65/35 H/POZ
HES-11	y		261	12.7	112	94	2600	5:30+	342	567	TLW
HES-11	y		261	12.7		94	2650	5:30+	26	851	TLW
HES-11	y		261	12.7	113	95	2930	5:30+	376	874	TLW
B		n		12.7	110	93	2500			385	65/35 A/POZ
HES-11	y		261	12.7	118	97	3180	5:36	405	1227	TLW
HES-11	y		261	12.7		101	4200	5:35	656	662	TLW
HES-11	y		261	12.7		105	4750	4:35	777	928	TLW
HES-11	y		80	12.7	124	100	4030	5:05		1446	TLW
HES-11	y		105	12.7	189	144	9400	4:25		1205	TLW
B		n		12.7	190	143	9000	4:33	360	1200	65/35 H/POZ
HES-11	y		130	12.7		171	12632	6:20	116	1695	TLW
B		n		12.7	225	175	11600	2:19			65/35 H/POZ
HES-8	y		800	12.7		65	1625	5:44	248	391	A
HES-11	y		225	12.7	120	98	3400	5:07	175	753	TLW
B	y		529	12.7	127	110	5896	4:57			65/35 H/POZ
HES-11	y		354	12.7		93	3500	4:20	326	594	TLW
HES-11	y		354	12.7		93	3500	4:10	567	1028	TLW
HES-11	y		130	12.7		171	12850	6:10	323	1593	TLW
HES-8	y		1500	12.7		65	2800	5:36	83	90	A
HES-11	y		130	12.7	218	171	12632	6:00	581	1529	TLW
HES-11	y		800	12.7		65	1625		115	200	TLW
HES-8	y		800	12.7		70	1625	6:00+	0	0	A
HES-11	y		800	12.7		70	1625	6:30+	40	57	TLW
B		n		12.7	177	133	8100	5:27		667	65/35 H/POZ
B	y		40	12.7	163	122	6900	4:54	243	765	65/35 H/POZ
B		n		12.7	220	167	11050	3:03	233	1163	65/35 H/POZ
HES-8	y		1500	12.7		74	3870	3:52	226	250	A
HES-11	y		200	12.7	165	124	7281	3:52	594	1405	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		82	12.7	170	136	9000	4:58		309	65/35 H/POZ
A	y		82	12.7		80	100			544	A
B		n		12.7	126	100	3850	3:31			65/35 A/POZ
B		n		12.7		153	10496	7:12			25/75 H/POZ
B	y		122	12.7	91	80	924	4:00+	0	390	H
B	y		120	12.7	95	83	1300	6:00	220	421	H
HES-11	y		1100	12.7		70	2400	6:30+	119	202	TLW
A	y		250	12.7	115	97	3500	2:40	320	380	A
B	y		137	12.7	124	100	4044	5:50	172	427	H
B	y		137	12.7	119	98	3500	5:28			H
HES-11	y		107	12.7	128	101	4000	6:00+	844	1653	TLW
HES-11	y		1100	12.7		85	4700	4:40	346	694	TLW
HES-11	y		1100	12.7	116	100	4700	4:59	298	594	TLW
B		n		12.7	223	173	11250	3:58			65/35 H/POZ
B	y		122	12.7		115	6007	6:41	190	683	H
B		n		12.7	215	165	10800	3:19			65/35 H/POZ
B		n		12.7	224	175	12000	4:58	0	831	65/35 H/POZ
B		n		12.7	228	178	11800	2:42			65/35 H/POZ
B		n		12.7	188	142	9000	6:10	0	138	65/35 H/POZ
B		n		12.7	170	123	6810	3:14	231	686	65/35 H/POZ
A	y		210	12.7	140	104	4410	5:15	245	380	H
B	y		290	12.7	125	107	4906	2:28	200	379	65/35 A/POZ
HES-11	y		80	12.7	160	123	7600	4:17	293	1462	TLW
B	y		111	12.7		99	3730	7:07			H
B	y		1470	12.7		70	2600	6:46			A
B	y		250	12.7		80	1000	6:47			H
HES-7	y		45	12.7	202	154	11157	4:58			H
HES-11	y		80	12.7	175	134	8800	4:54	0	1447	TLW
B	y		34	12.7	194	148	12600	6:01	64	290	65/35 H/POZ
B		n		12.7	197	152	10650	4:01			65/35 H/POZ
B		n		12.7	230	182	12750	5:58	80	720	65/35 H/POZ
HES-11	y		354	12.7	130	106	5000	3:57			TLW
B		n		12.7	134	104	4500		177	330	65/35 A/POZ
B		n		12.7	150	113	5800	6:15	320	571	65/35 H/POZ
B	y		122	12.7	91	80	920	6:39	150	340	H
A	y		7612	12.7		82	14000	4:00+	80	210	H
HES-3	y		2920	12.7		65	5200	4:30	140	610	FLOSTOP I
A	y		3214	12.7		95	9400	5:00+	194	330	H
HES-11		n		12.7	203	156	11060	3:29	890	1160	TLW
HES-11		n		12.7	203	156	11060	2:45	1342	1414	TLW
A	y		210	12.7	132	103	4500	7:00+	400	450	H
B		n		12.7	214	158	9600	6:22	40	775	65/35 H/POZ
B		n		12.7	196	142	8350	4:20	440	1110	65/35 H/POZ
A	y		3125	12.7		70	7500	7:00+	70	220	H
B		n		12.7	270	224	14700	6:00+			65/35 H/POZ
B		n		12.7	284	234	14600	8:00+	660	800	65/35 H/POZ
HES-11	y		260	12.7	182	134	9620	2:38	1045	1147	TLW
B		n		12.7	220	170	11220	3:51	410	840	65/35 H/POZ
B		n		12.7	260	212	13750	7:50	0	620	65/35 H/POZ
F		n		12.7	230	192	12838	4:07	570	880	Micro-fine
B		n		12.7	212	157	9600	6:22	40	630	65/35 H/POZ
HES-3	y		3500	12.7		65	5475	3:15	FIRM	160	FLOSTOP I
B		n		12.7	293	245	15280	8:00+			65/35 H/POZ
A	y		3125	12.7		80	8400	5:00+	110	150	H
B		n		12.7	280	229	14360	5:26	815	1200	65/35 H/POZ
B		n		12.7	287	238	14800	6:30	679	790	65/35 H/POZ
B		n		12.7	273	221	13850	6:12	430	650	65/35 H/POZ
B		n		12.7	263	209	13089	6:22	590	810	65/35 H/POZ
B		n		12.7	238	190	13150	5:44	710	850	65/35 H/POZ
HES-11	y		40	12.7	207	159	11644	3:45	877	1584	TLW
B		n		12.7	305	260	16100	6:22	660	790	65/35 H/POZ
B		n		12.7	152	115	6000	4:39			65/35 H/POZ
B	y		34	12.7	194	148	12600	4:07	228	553	65/35 H/POZ
B		n		12.7	187	131	7168	2:12			HLC
HES-11	y		800	12.7		60	850	6:37	67	191	TLW
HES-11	y		120	12.7	160	120	6700	3:50	1000	1700	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		688	12.7	138	115	7100	4:10	121	224	65/35 H/POZ
B		n		12.7	220	170	11200	4:41			65/35 H/POZ
A	y		57	12.7	97	85	1500	3:00+	250	400	A
B		n		12.7	105	90	2100	6:00+	53	97	65/35 A/POZ
B		n		12.7		101	4300	2:37			65/35 A/POZ
B		n		12.7	122	99	3527	6:11	230	270	65/35 A/POZ
B		n		12.7	122	99	3527	5:21	265	330	65/35 A/POZ
B		n		12.7	186	140	8800	4:02			65/35 H/POZ
B		n		12.7	204	154	9750	5:40			65/35 H/POZ
B	y		35	12.7	206	158	10500	4:01	159	662	65/35 H/POZ
B		n		12.7	190	144	9200	4:40	0	1725	65/35 H/POZ
B		n		12.7		170	10000	6:19	0	982	65/35 H/POZ
HES-11	y		40	12.7	207	159	10800	3:52	0	1346	TLW
HES-11	y		170	12.7	145	106	4500	5:00+	875	950	TLW
HES-11	y		170	12.7	127	100	4900	5:21	394	825	TLW
B		n		12.7	200	152	10000	3:45	685		65/35 H/POZ
B		n		12.7	198	149	9450	5:00+			65/35 H/POZ
B		n		12.7	191	145	9300	6:00	0	100	65/35 H/POZ
B		n		12.7	221	172	11750	4:43			65/35 H/POZ
B		n		12.7	205	154	9600	2:45			65/35 H/POZ
B		n		12.7	130	101	4000	3:49	170	231	65/35 A/POZ
B	y		23	12.7		125	8865	7:00+		977	25/75 H/POZ
B		n		12.7	178	130	7500	4:12	370	790	65/35 H/POZ
B	y		10	12.7		119	5200	5:18	250	442	65/35 H/POZ
HES-11	y		260	12.7	182	134	9620	3:32	1617	1953	TLW
B		n		12.7	208	160	10700	6:31	0	1381	65/35 H/POZ
B	y		18	12.8	92	80	1000	5:17	170	345	65/35 A/POZ
B	y		22	12.8	113	95	3000	3:00+	247	688	65/35 A/POZ
HES-7	y		134	12.8	190	145	11139	4:09	312	521	H
B	y		134	12.8	190	145	11139	4:37	105	280	65/35 H/POZ
HES-11	y		295	12.8	121	98	3471	5:33	525	1040	TLW
HES-11	y		295	12.8	133	104	4450	4:54	840	1920	TLW
B		n		12.8	191	143	8900	3:03	600	1712	50/50 H/POZ
B		n		12.8	299	236	12900	3:45			65/35 H/POZ
HES-8	y		3944	12.8		70	3950	2:44	787	1682	A
B	y		16	12.8	90	80	800	3:00+	210		65/35 A/POZ
HES-11	y		760	12.8	138	113	6200	5:30	249	2055	TLW
B	y		18	12.8	92	80	1000	6:45	197	268	65/35 A/POZ
HES-11	y		760	12.8	138	114	7172	6:00	247	1345	TLW
B		n		12.8		80	2500	5:00+	139	290	65/35 A/POZ
B		n		12.8	110	93	2500	4:40	255	329	65/35 A/POZ
B		n		12.8	101	91	2500	5:14	128	282	65/35 A/POZ
B		n		12.8	111	93	2500	4:20			65/35 A/POZ
B	y		430	12.8	122	98	3500	6:00+			65/35 A/POZ
B		n		12.8		90	3000	6:00+	320	1818	65/35 A/POZ
B	y		18	12.8	116	96	3000	3:04	402	530	65/35 A/POZ
B		n		12.8	115	97	3500	3:30			65/35 A/POZ
B		n		12.8	115	97	3500	4:07			65/35 A/POZ
B		n		12.8	113	95	3000	3:18	237	412	65/35 A/POZ
B	y		40	12.8	206	158	10550	5:00+	259	1115	65/35 H/POZ
B	y		18	12.8	89	80	850	4:00+	230	290	65/35 A/POZ
B		n		12.8	205	157	10350	3:25			65/35 H/POZ
HES-11	y		120	12.8	190	153	12375	4:40	1079	1651	TLW
HES-3	y		6500	12.8		55	7950	4:42	0	150	A
HES-11	y		80	12.8	160	131	6200	2:40			TLW
B		n		12.8	100	87	1700	6:18			65/35 A/POZ
B		n		12.8	109	91	2250	5:05	201	389	65/35 A/POZ
B		n		12.8	215	164	10400	5:00			65/35 H/POZ
B	y		52	12.8	213	166	13035	2:15			H
B	y		52	12.8	213	166	13035	3:24	185	268	H
B	y		1470	12.8		80	5600	5:55			H
B	y		1470	12.8		80	5600	5:28			H
F		n		12.8	262	216	13000	3:30	1784	2023	Micro-fine
HES-11	y		760	12.8	138	114	7310	5:15	263	1229	TLW
HES-11		n		12.8	122	98	3500	3:31	753	1464	TLW
B		n		12.8	120	98	3500	3:57		250	65/35 A/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B		n		12.8	206	159	10845	4:03	80	1657	65/35 H/POZ
B		n		12.8	134	104	4500	5:12	148	325	65/35 H/POZ
B	y		100	12.8	164	122	8200	4:10	257	669	65/35 H/POZ
B	y		100	12.8	172	130	9900	4:39	300	710	65/35 H/POZ
B		n		12.8	220	172	11800	4:30	0	1078	65/35 H/POZ
B		n		12.8	236	188	12995	7:20			65/35 H/POZ
B		n		12.8	223	173	11500	7:45			65/35 H/POZ
HES-11		n		12.8	145	119	5200	3:24	878	1279	TLW
B	y		200	12.8	129	103	5000	5:05			65/35 H/POZ
HES-11	y		470	12.8		105	4600	4:32	550	800	TLW
HES-11	y		1050	12.8		65	4500	7:00+	0	0	TLW
B		n		12.8	95	80	1000			226	65/35 H/POZ
A		n		12.8	0	75	6000	5:57	45	142	A
B	y		18	12.8	118	97	3200	4:30+	277	580	65/35 A/POZ
HES-7		n		12.8	218	170	11875	4:23	2020	3280	H
B	y		22	12.8	90	80	900	5:00+	190	250	65/35 A/POZ
B	y		18	12.8	92	80	1000	4:00+	180	250	65/35 A/POZ
B	y		22	12.8	116	96	3000	2:30	245	380	65/35 A/POZ
HES-11		n		12.8	155	126	6350	3:06	1170	1260	TLW
B	y		22	12.8	118	97	3200	3:30+	240	415	65/35 A/POZ
HES-7	y		189	12.8	132	103	4300	7:00+	126	260	H
B	y		62	12.8	214	187	13200	10:00+		0	H
B	y		432	12.8	165	124	9550	3:56	110	270	65/35 H/POZ
HES-11	y		68	12.8	245	198	15800	6:34	1022	1663	TLW
B		n		12.8	218	170	11875	5:30	450	580	65/35 H/POZ
B	y		1047	12.8	180	135	9100	4:05	440	530	H
HES-11	y		760	12.8		104	6750	4:00			TLW
A		n		12.8	0	75	6000	6:00+	0	68	A
A		n		12.8	0	65	8000	6:42	0	190	A
HES-7	y		470	12.8	145	114	6000	5:27	395	1211	TLW
HES-7	y		68	12.8	245	198	15800	7:25	325	434	H
HES-11	y		760	12.8	128	111	6090	2:48			TLW
B	y		365	12.8	139	107	8800	5:34	177	287	65/35 H/POZ
B	y		365	12.8	142	107	8800	6:00+	133	157	65/35 H/POZ
B		n		12.8	140	109	5400	5:38	207	362	65/35 H/POZ
B		n		12.8	169	128	7700	5:30+	144	167	65/35 H/POZ
B		n		12.8	180	136	8366	3:38	410	723	H
B		n		12.8	180	138	10300	5:23	90	336	65/35 H/POZ
HES-11		n		12.8	105	95	3100	4:28	381	880	TLW
HES-11		n		12.8	213	166	12100	7:15	0	1647	TLW
HES-11		n		12.8	213	166	12100		1432	1894	TLW
HES-11		n		12.8	145	119	5000	2:40	885	1695	TLW
HES-11	y		760	12.8	128	111	6090	4:45	170	390	TLW
B	y		113	12.8	185	139	9615	3:30	220	390	65/35 H/POZ
HES-7	y		1120	12.8	0	123	11393	4:00+	130	270	H
B	y		134	12.8	185	142	9779	3:46	140	340	65/35 H/POZ
B	y		134	12.8	185	142	9779	4:25	110	196	65/35 H/POZ
B	y		134	12.8	190	146	11410	3:32	110	190	65/35 H/POZ
B	y		182	12.8	190	156	9700	3:17	510	660	H
B	y		60	12.8	290	249	17500	7:10	605		HTLD
B	y		60	12.8	290	249	17500	7:20	240	400	HTLD
HES-7	y		152	12.8	165	115	8700	4:00+			H
HES-7	y		225	12.8	161	121	7233	5:11	270	460	H
HES-11	y		107	12.8	210	163	12227	4:31	1150	1640	TLW
HES-11	y		48	12.8	139	106	5200	4:30+	750	1570	TLW
B	y		50	12.9	310	255	16000	8:00+			HTLD
B	y		200	12.9		140	9100	6:28			H
B	y		1100	12.9	135	104	4500	4:36	208	464	65/35 H/POZ
B	y		350	12.9	255	206	14600	5:28	487	731	HTLD
B		n		12.9	210	163	11750	6:26	0	248	H
B		n		12.9	315	265	15815	4:24			HTLD
B		n		12.9	275	226	14500	5:43	765	1950	HTLD
B		n		12.9	290	237	14500	5:00+			HTLD
B	y		35	12.9		175	13010	3:44	52	296	H
B		n		12.9	270	223	14500	5:20	680	1220	HTLD
B		n		12.9	275	226	14400	4:33	530	600	HTLD

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B		n		12.9	275	226	14400	1:55			HTLD
B		n		12.9	260	210	13520	4:22	620	880	HTLD
B		n		12.9	275	226	14430	4:46	650	760	HTLD
B		n		12.9	145	106	4500	5:00+	115	270	60/40 A/POZ
HES-1	y		3214	12.9		95	9037	6:36	390	455	SLAG
B	y		50	12.9	240	196	16000	7:00+	490	790	HTLD
B		n		12.9	223	183	11300	3:37	348	553	H
B		n		13.0		96	3500		86	168	65/35 A/POZ
B		n		13.0		96	3500		71	81	25/75 A/POZ
B		n		13.0	225	176	12000	4:40	780	1225	25/75 H/POZ
HES-11		n		13.0	111	98	2500	2:29	523	848	TLW
B		n		13.0	230	167	10000	4:23	400	940	65/35 H/POZ
B		n		13.0	230	166	9855	4:20			65/35 H/POZ
HES-11		n		13.0	172	125	6942	5:45	1865	2362	TLW
A		n		13.0	115	100	3000		260	442	A
B	y		40	13.0	175	133	8560	5:22	0	418	H
HES-11	y		40	13.0	210	176	12300	3:15	1724	1796	TLW
HES-11		n		13.0	100	91	1500	2:56	397	850	TLW
HES-11		n		13.0	206	158	10500	4:18	611	694	TLW
B		n		13.0	235	187	12850	5:40	1156	1670	65/35 H/POZ
HES-11		n		13.0	95	80	1000	4:00+	131	301	TLW
B		n		13.0	204	156	10321	5:53	310	975	65/35 H/POZ
B		n		13.0	224	175	12019	4:19	980	1080	65/35 H/POZ
HES-11		n		13.0	222	173	11800	3:54			2/1 TLW/H
HES-11		n		13.0	100	91	1700	4:00+	595	858	TLW
HES-11		n		13.0		170	12423	6:18	1408	1954	2/1 TLW/H
HES-11		n		13.0	135	112	4600	2:37	1240	2034	TLW
B	y		102	13.0	187	133	10095	3:14	430	720	H
B	y		77	13.0	160	115	5800	3:33	188	838	65/35 H/POZ
HES-11	y		15	13.0	165	134	7100	4:03	0	1249	TLW
HES-11	y		15	13.0	128	102	4200	3:00+	203	634	TLW
HES-11		n		13.0	230	182	12900	6:00+			2/1 TLW/H
HES-11		n		13.0	215	168	12720	5:50	840	1125	2/1 TLW/H
HES-11		n		13.0	222	175	12913	5:40	1020	3483	2/1 TLW/H
HES-11		n		13.0	178	140	9400	6:30	707	1691	2/1 TLW/H
HES-11		n		13.0	230	185	13945	4:07	1342	2526	2/1 TLW/H
B		n		13.0	215	168	12720	5:25	385	816	65/35 H/POZ
B		n		13.0	185	142	9500	5:42	0	641	65/35 H/POZ
B		n		13.0	250	186	11300	3:39	690	870	65/35 H/POZ
B		n		13.0	134	103	4350	4:45	440	510	A
B		n		13.0	142	108	5000	2:24			65/35 A/POZ
HES-3		n		13.0		50	6600	8:20			A
B		n		13.0	215	166	11150	5:26	1686	1730	50/50 H/POZ
B		n		13.0	329	292	18300	8:00			HTLD
B		n		13.0	345	314	19500	7:02	---	113	HTLD
B		n		13.0	345	314	19500	6:52	315	1563	HTLD
B		n		13.0		207	13000	15:00+	350	390	HTLD
B		n		13.0		207	13000	14:00+	0	220	HTLD
HES-11		n		13.0	215	167	11780	4:51	747	1068	2/1 TLW/H
HES-7	y		3800	13.0		120	9660	6:30+	0	375	H
B	y		84	13.0	300	244	16316	5:44			65/35 H/POZ
B	y		84	13.0	300	244	16316	3:52	600	776	65/35 H/POZ
HES-11	y		240	13.0	141	116	4700	2:58	1096	1737	TLW
B	y		43	13.0	219	170	13067	4:05	1710	1980	50/50 H/POZ
HES-7	y		27	13.0	216	169	12800	6:02	543	676	H
HES-11	y		55	13.0	98	85	1500			711	TLW
HES-11	y		55	13.0	98	85	1500	2:02	393	825	TLW
HES-11	y		60	13.0	183	138	8600	4:03	420	1550	TLW
B	y		85	13.0	207	159	10660	6:30+	370	870	65/35 H/POZ
B	y		85	13.0	207	159	10660	3:19	120	310	65/35 H/POZ
B	y		80	13.0	200	152	10204	5:56	0	571	65/35 H/POZ
	y		10	13.0	215	167	11200		467	553	H
B	y		10	13.0	215	167	11200	7:08	0	1173	65/35 H/POZ
B	y		110	13.0	206	158	10500	3:04	767	1011	50/50 H/POZ
HES-11	y		120	13.0	190	157	13048	5:26	0	1814	TLW
HES-11	y		120	13.0	211	167	13048	5:20	0	855	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11	y		120	13.0	165	137	10600	5:13	26	2211	TLW
HES-11	y		120	13.0		240	17500	9:47			TLW
HES-11	y		120	13.0		240	17500	8:15	80	100	TLW
HES-7	y		130	13.0	204	156	13038	5:04	450		H
HES-7	y		130	13.0		147	9549	6:00			H
HES-7	y		137	13.0		132	9814	5:43	920		H
HES-7	y		137	13.0		132	8000	6:27	260	420	H
HES-11	y		147	13.0	92	80	1000	6:00+	219	632	TLW
B	y		170	13.0	160	127	9917	5:09	89	628	65/35 H/POZ
B	y		170	13.0	160	130	8641	4:29	66	358	65/35 H/POZ
HES-7	y		180	13.0	193	146	9925	3:44	316	340	H
B	y		180	13.0	193	146	9925	3:04	305	535	50/50 H/POZ
HES-11	y		180	13.0	143	115	7200	3:26	1313	2440	TLW
HES-11	y		180	13.0	143	115	7200	3:29	1050	1730	TLW
B	y		210	13.0	148	112	5650	4:44	178	263	65/35 H/POZ
F	y		200	13.0	160	160	8100	0:18			Micro-fine
HES-11	y		250	13.0	133	104	6872	7:20	673	1549	TLW
HES-11	y		250	13.0	134	104	5664	4:27	725	1199	TLW
HES-11	y		250	13.0	136	105	6085	4:18	342	654	TLW
HES-11	y		250	13.0	134	105	6485	4:45	474	1191	TLW
HES-11	y		250	13.0	140	109	7700	5:45	539	1250	TLW
HES-11	y		250	13.0	148	112	7475	3:38	309	1324	TLW
HES-11	y		250	13.0	134	105	6485	4:30	746	1235	TLW
HES-11	y		1491	13.0	143	119	7252	4:57	361	1465	TLW
MICROFINE	y		1800	13.0		74	3870	3:21			A
HES-11	y		220	13.0	120	105	5300	7:14	430	1170	TLW
HES-11	y		200	13.0	0	80	50		150	270	TLW
B	y		645	13.0		111	6500	6:30+	60	135	50/50 H/POZ
HES-11	y		700	13.0	142	107	4800	4:30	466	1200	TLW
B	y		630	13.0	141	109	5144	4:20	222	290	H
A	y		557	13.0	141	109	5144	6:19	140	180	H
B	y		557	13.0	141	109	5148	4:40	200	410	H
HES-3	y		1195	13.0		80	2770	2:49			FLOSTOP I
HES-7	y		1756	13.0		120	12183	4:54	430	616	H
HES-11	y		760	13.0		104	6750	6:20		300	TLW
B	y		2046	13.0		80	8537			187	65/35 A/POZ
A	y		340	13.0	130	106	5000	6:00+	310	1250	H
B	y		220	13.0	178	134	14596	4:00	404	551	65/35 H/POZ
HES-7	y		600	13.0	156	118	7400	6:00+	315	407	H
HES-7	y		600	13.0	156	118	7400	6:30+	862	1246	H
HES-7	y		2000	13.0	0	82	12429	10:00+	0	188	H
B	y		220	13.0	159	120	10907	3:14			65/35 H/POZ
A	y		300	13.0	114	97	3525	5:00+	170	350	H
HES-3	y		1611	13.0		80	3700	2:50			A
HES-3	y		1611	13.0		80	3700	3:55	588		A
HES-3	y		1611	13.0		80	3700	1:36			A
HES-3	y		1611	13.0		80	3700	2:22	1244	1671	A
HES-3	y		1611	13.0		80	3700	2:35			A
B	y		688	13.0	138	117	6950	2:45	208	851	65/35 H/POZ
HES-7	y		1419	13.0		95	6600	6:47	268	537	A
HES-7	y		1419	13.0		140	9744	6:40	309	554	A
HES-7	y		1419	13.0		128	8900	6:15	224	530	A
HES-11	y		2200	13.0		82	4500	5:10	130	180	TLW
HES-7	y		3393	13.0	0	75	8000	5:00+	0	74	A
HES-7	y		5100	13.0	0	90	13000	5:57	174	240	H
B		n		13.0	285	236	14830	7:00+	0	95	HFC-12.5
HES-11		n		13.0	190	152	7820	2:19	2084	2338	TLW
B		n		13.0	200	150	9400	5:42	425	667	65/35 H/POZ
B	y		3000	13.0	0	80	8720	3:49	0	172	H
A	y		1785	13.0		45	2975	4:00+	0	108	A
HES-7	y		1968	13.0		101	9600	5:13	230	351	H
HES-3	y		517	13.0		70	1109	2:28	520	920	FLOSTOP I
HES-3	y		517	13.0		86	1695	1:31	1590	2790	FLOSTOP I
HES-3	y		517	13.0		80	1109	2:35	700	1410	FLOSTOP I
HES-7	y		2840	13.0	0	80	8720	12:00+	102	386	H
HES-11	y		2161	13.0		93	7400	3:38	499	1371	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-1	y		833	13.0		80	2400	4:45	1052	1226	SLAG
HES-7	y		1965	13.0		71	5100	8:00+	FIRM	120	H
B	y		2025	13.0	0	75	6400	5:33	100	310	H
HES-7	y		2025	13.0	0	75	6400	5:30+	60	120	H
HES-7	y		2025	13.0		79	5700	10:00+	32	120	H
HES-7	y		3329	13.0		80	8000	4:00+	230	260	H
HES-7	y		3329	13.0		80	9020	6:00+	60	230	H
A	y		3329	13.0		80	9000	4:00+	70	200	A
B	y		3325	13.0		104	9100	3:28	210	340	65/35 A/POZ
HES-11	y		4243	13.0		150	16000	2:30			2/1 TLW/H
HES-11	y		4243	13.0		150	16000	4:12	518	1418	2/1 TLW/H
HES-7	y		5467	13.0	0	86	10000	5:30+	170	250	H
HES-7	y		5467	13.0	0	75	8400	7:00+	150	290	A
FOAMED	y		5467	13.0	0	75	8400	6:30+			A
B		n		13.0	250	201	13050	3:34	286	712	25/75 H/POZ
B		n		13.0	250	201	13050	5:45	395	510	25/75 H/POZ
HES-7	y		45	13.0	198	148	9600	5:07	260	360	H
B	y		50	13.0	220	164	10100	6:36	272	1318	65/35 H/POZ
HES-7	y		50	13.0	166	121	7291	5:00+	351	503	H
B	y		51	13.0	159	133	8500	2:37	370	490	H
B	y		55	13.0		150	11913	4:00+	310	460	50/50 H/POZ
B	y		40	13.0	146	111	5500	5:44	110	120	85/15 H/POZ
B	y		40	13.0	189	143	9100	4:00+		260	65/35 H/POZ
B	y		280	13.0	0	132	8929	2:08			65/35 H/POZ
HES-7	y		34	13.0	176	132	8000	4:00+	140	290	H
HES-7	y		60	13.0	176	132	8539	4:00+	289	760	H
HES-7	y		293	13.0	131	100	4200	5:00+	185	290	H
HES-11		n		13.0		155	12131	4:04	1227	1696	2/1 TLW/H
B		n		13.0	230	181	12500	6:34	0	51	65/35 H/POZ
B		n		13.0	131	102	4100	4:47	110	220	A
HES-11		n		13.0	130	109	4100	3:15	660	1010	TLW
HES-11		n		13.0	230	178	11500	6:00	624	967	2/1 TLW/H
B		n		13.0	197	147	9000	4:35	0	560	65/35 H/POZ
B		n		13.0	230	180	12000	4:49			65/35 H/POZ
B		n		13.0	205	160	10000	4:52	0	886	25/75 A/POZ
B		n		13.0	205	160	10000	5:09	0	979	25/75 A/POZ
B		n		13.0	205	160	10000	4:38	49	1146	25/75 H/POZ
POZMIX		n		13.0	205	160	10000	5:09	645	719	Pozmix 140
B		n		13.0	205	160	10000	4:06	40	1360	25/75 H/POZ
HES-11		n		13.0	178	145	8910	5:39	1153	1516	2/1 TLW/H
B		n		13.0	95	83	1275	7:00+	0	138	65/35 H/POZ
HES-11		n		13.0	228	177	11400	6:38	387	1655	2/1 TLW/H
B		n		13.0	210	162	10900	4:27			50/50 H/POZ
B		n		13.0	261	213	14600	5:13	780	920	65/35 H/POZ
B		n		13.0	220	176	13550	5:15	1340	1700	50/50 H/POZ
HES-11		n		13.0		215	15100	5:50	784	1214	2/1 TLW/H
HES-11		n		13.0		150	9650	5:15	1037	1764	2/1 TLW/H
HES-11		n		13.0		145	10235	5:34			2/1 TLW/H
HES-11		n		13.0		155	10800	5:30+	380	1273	3/2 TLW/H
HES-11		n		13.0	200	153	10500	5:30+	736	1946	2/1 TLW/H
B		n		13.0		136	8350	2:58	454	674	H
B	y		36	13.0		145	10374	7:00	112	970	H
A	y		210	13.0	102	88	2112	7:23	300	570	A
B	y		210	13.0	101	87	1750	5:30+	40	240	50/50 H/POZ
B	y		210	13.0	101	87	1750	5:00+	50	160	50/50 H/POZ
B	y		300	13.0	169	127	7400	4:30+	390	780	50/50 H/POZ
HES-7	y		250	13.0	0	141	9733	5:47	425	575	H
HES-7	y		40	13.0		141	8950	5:20	366	485	H
HES-7	y		40	13.0		112	5545	8:20	395	520	H
B	y		40	13.0	115	96	3240	5:21	220	280	H
B	y		20	13.0	166	141	10200	3:32	104	641	65/35 H/POZ
HES-11	y		40	13.0	180	136	8500	4:20	545	1090	TLW
HES-11	y		82	13.0		115	3500	2:52	300	564	TLW
B	y		58	13.0	194	147	9500	7:55	105	768	65/35 H/POZ
HES-7	y		250	13.0	0	141	9733	5:23			H
A	y		154	13.0	155	112	5400	3:54	253	370	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B		n		13.0	241	201	13428	4:15	297	536	H
B		n		13.0	238	199	13210	3:40	625	855	H
B		n		13.0	215	166	11000	2:58			65/35 H/POZ
B		n		13.0	140	115	4490	3:42	460	630	H
HES-1	y		2940	13.0		94	11770	4:06	290	338	SLAG
HES-1	y		2940	13.0		94	11770	4:30	672	726	SLAG
HES-7	y		6000	13.0	0	84	14000	7:00+	84	213	H
HES-7	y		2500	13.0	0	113	10200	3:21	244	346	H
HES-7	y		3500	13.0	0	120	11650	3:30+	162	270	H
HES-7	y		3500	13.0	0	135	14650	4:00+	210	592	H
HES-7	y		3500	13.0	0	135	14650	2:30	0	94	H
HES-7	y		3600	13.0	0	125	12500	4:38	280	290	H
HES-7	y		3600	13.0	0	125	12500	5:56			H
HES-7	y		3600	13.0	0	140	14600	6:30+			H
HES-7	y		5000	13.0	0	85	9500	5:00+	204	312	H
HES-7	y		5000	13.0	0	105	11557	4:32	161	329	H
HES-7	y		2407	13.0	0	94	8500	6:00+	90	290	H
HES-7	y		2320	13.0		82	6500	6:15+	118	259	H
HES-11	y		1334	13.0		75	4500	5:00+	225	410	TLW
HES-7	y		2559	13.0	77	70	5200	7:00+	0	131	H
HES-7	y		2559	13.0	77	70	5200	9:23		125	A
HES-7	y		3210	13.0		73	6300	15:57	0	160	H
HES-7	y		3257	13.0		77	7500	10:00+	45	140	H
HES-1	y		3000	13.0		100	11875	4:55	0	410	SLAG
HES-3	y		3944	13.0		70	5650	1:47	800	1720	A
HES-7	y		3875	13.0	0	73	6435	6:00+	30	60	A
HES-7	y		3875	13.0	0	75	9100	5:00+	90	235	H
HES-7	y		3845	13.0	0	87	10383	5:30+	267	380	H
HES-7	y		4000	13.0	0	75	9000	6:30+	85	220	A
HES-7	y		4000	13.0	0	82	9000	6:30+	156	271	A
HES-7	y		3982	13.0	0	75	8200	5:00+	120	210	H
HES-7	y		3982	13.0	0	70	7020	6:00+	FIRM	870	H
HES-7	y		84	13.0	0	135	8000	5:47	382	509	H
HES-11	y		50	13.0	230	178	11500	9:00		1197	TLW
HES-11	y		60	13.0	106	90	2000	5:00+	250	500	TLW
HES-11	y		52	13.0	0	255	17000	7:00	943	1347	TLW
B	y		55	13.0		203	13400	10:00+			HTLD
B	y		85	13.0		135	8000	5:13	0	860	H
HES-7	y		85	13.0	145	109	5000	8:00+	510	967	H
A	y		158	13.0	93	80	1000		728	1412	A
B	y		150	13.0	233	167	9500	4:47	62	236	65/35 H/POZ
B		n		13.0	172	127	7300	5:00	226	827	65/35 H/POZ
HES-11		n		13.0	150	113	5800	5:00+	932	2318	2/1 TLW/H
HES-11		n		13.0	150	113	5800	5:00+	389	793	2/1 TLW/H
B		n		13.0		80	50			88	50/50 A/POZ
B		n		13.0		80	50			105	50/50 A/POZ
B		n		13.0	221	159	9400	8:00+	290	730	65/35 H/POZ
B		n		13.0	206	146	8700	4:25	470	710	65/35 H/POZ
HES-7		n		13.0		135	8300	7:07	400	525	H
B		n		13.0	300	253	15800	5:17	0	1465	HTLD
B		n		13.0	116	96	3000	6:00+		340	65/35 A/POZ
HES-11		n		13.0	225	180	11600	4:06	1077	2535	2/1 TLW/H
B		n		13.0	118	96	3000	3:58	267	515	A
B		n		13.0	124	98	3500	4:35	262	461	A
HES-11		n		13.0	186	140	8810	3:00	1226	1682	TLW
B		n		13.0	200	150	9500	3:36			65/35 H/POZ
B	y		350	13.0	135	103	5250	3:00+	209	761	65/35 A/POZ
B	y		240	13.0	174	130	9600	5:30+	0	0	50/50 H/POZ
B	y		240	13.0	177	133	9585	6:30+		0	50/50 H/POZ
HES-11	y		21	13.0	198	149	10298	2:30	1012	1460	2/1 TLW/H
HES-11	y		21	13.0	198	149	10298	3:10	802	1609	2/1 TLW/H
HES-11	y		16	13.0	205	157	10400	3:05	1240	1420	2/1 TLW/H
HES-11	y		18	13.0	210	163	11820	3:40	779	1890	2/1 TLW/H
HES-11	y		18	13.0	201	154	11028	3:17	1090	2060	2/1 TLW/H
B	y		63	13.0	252	205	15100	4:58	260	1110	65/35 H/POZ
B	y		95	13.0	194	147	9514	4:47	242	1250	65/35 H/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		95	13.0	185	139	8550	4:45	0	1230	65/35 H/POZ
B	y		102	13.0	242	194	13400	4:40	768	935	HLC
B	y		102	13.0	242	194	13400	8:11	870	1120	65/35 H/POZ
HES-7	y		124	13.0		146	9450	4:00	230	340	H
HES-7	y		50	13.0		153	10400		310	360	H
HES-7	y		51	13.0	165	123	8360	5:00+	1060	1330	H
HES-7	y		51	13.0	145	111	5500	5:00+	443	1000	H
HES-7	y		51	13.0	145	110	5500	5:00+	483	1620	H
HES-7	y		51	13.0	190	143	9511	5:00+	1339	3577	H
HES-7	y		51	13.0	155	126	6246	3:00+	310	520	H
HES-7	y		70	13.0	164	123	7000	5:00+	275	710	H
HES-7	y		70	13.0	196	149	10200	3:48	431	508	H
HES-7	y		70	13.0	196	149	10200	3:33	494	520	H
HES-7	y		70	13.0	195	148	10160	3:50	349	1100	H
HES-7	y		70	13.0	145	111	6100	5:00+	609	833	H
A	y		186	13.0	113	96	3809	5:00+	230	403	H
DIACEL-M	y		325	13.0	191	158	10060	4:00	415	640	H
B	y		200	13.0	113	95	4700	4:00+	250	460	H
HES-11	y		200	13.0		107	4950	7:15			TLW
HES-7	y		20	13.0	208	162	12764		330	380	H
HES-7	y		20	13.0	208	162	12764	4:58	260	320	H
B	y		21	13.0	212	164	11000	3:46	60	460	50/50 H/POZ
B	y		21	13.0	220	172	12250	3:25	240	1290	50/50 H/POZ
B	y		34	13.0	208	163	12400	3:46	1380	1800	50/50 H/POZ
B	y		48	13.0	220	163	10042	4:08	817	1944	65/35 H/POZ
HES-7	y		65	13.0		159	10700	10:00+			H
HES-7	y		65	13.0		169	11562	7:37	475	552	H
HES-7	y		60	13.0		174	11980	5:16			H
HES-11	y		184	13.0	110	93	2750	5:25	453	905	2/1 TLW/H
HES-11	y		235	13.0	118	97	3180	5:30+		1235	TLW
HES-11	y		235	13.0	118	97	3180	6:08		904	TLW
B	y		235	13.0	190	152	11025	4:38	65	645	65/35 H/POZ
HES-11	y		280	13.0	140	107	5000	5:44	545	1312	TLW
B	y		26	13.0	236	188	14358	4:55	512	2110	50/50 H/POZ
B	y		26	13.0	128	101	4000	5:00+	335	700	50/50 A/POZ
B	y		26	13.0	220	172	11700	2:32	600	706	50/50 H/POZ
B	y		26	13.0	220	172	11700	3:02	920	1420	50/50 H/POZ
B	y		26	13.0	220	172	11700	4:20	1080	1550	50/50 H/POZ
HES-7	y		160	13.0	0	218	16309	6:10	420	600	H
B	y		181	13.0	122	100	4000	3:17	320	415	H
B	y		181	13.0	96	86	1650	6:10	220	355	H
HES-11	y		70	13.0		85	525	2:16	320	470	TLW
B	y		70	13.0	268	215	17000	6:54	372	411	HTLD
HES-7	y		70	13.0		209	15110	8:29	295	435	H
B	y		60	13.0		106	4850	7:04			H
B	y		280	13.0	194	147	9500	3:42	188	420	65/35 H/POZ
A	y		150	13.0	134	104	4500	5:18	232	562	H
HES-11	y		280	13.0	139	105	5550	4:30	915	1710	TLW
HES-11	y		280	13.0		80	1619	6:00+	430	705	TLW
HES-11	y		280	13.0	139	105	5550	4:30	915	1710	TLW
HES-7	y		447	13.0		136	3500	4:55	267	470	H
HES-11	y		64	13.0	242	195	14978	5:45			TLW
HES-11	y		64	13.0	242	195	14978	6:10			TLW
HES-11	y		64	13.0	128	101	4000			550	TLW
HES-7	y		64	13.0		161	11745	5:48	470	540	H
B	y		64	13.0		174	12309	8:12	677	1040	H
HES-11	y		64	13.0	242	195	14978	5:55	990	1050	TLW
HES-11	y		64	13.0	212	167	12680	8:06	0	1385	TLW
B	y		64	13.0	0	143	12180	3:43	160	450	H
HES-11	y		64	13.0	242	195	14978		1153	2170	TLW
B	y		64	13.0	0	176	13145	4:02	233	780	H
B	y		63	13.0	157	120	7716	3:54	647	820	H
B	y		60	13.0		80	1000	5:36			H
B		n		13.0	205	156	10200	4:09	58	652	65/35 H/POZ
B		n		13.0	217	180	11760	3:03	0	380	H
B		n		13.0	219	168	10890	4:52	1359	1990	50/50 H/POZ

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
HES-11		n		13.0		150	10000	5:49	1296	1464	2/1 TLW/H
B		n		13.0	230	167	10000	6:30+	740	1320	65/35 H/POZ
HES-7	y		25	13.0	152	115	6080	5:00+	236	522	H
HES-7	y		25	13.0	150	114	6050	5:00+	467	1774	H
B		n		13.0	122	98	3500	2:00			A
HES-11	y		60	13.0	193	145	8790	5:30+			2/1 TLW/H
B	y		60	13.0	171	128	7689	3:10			65/35 H/POZ
B	y		60	13.0		132	8000	4:26	400	1191	65/35 H/POZ
HES-11	y		60	13.0		132	8000	3:53	583	1636	2/1 TLW/H
B	y		60	13.0	215	157	9650	4:34	170	580	65/35 H/POZ
B		n		13.0	165	125	7300	3:12			65/35 H/POZ
B		n		13.0	207	159	10550	2:58	130	570	65/35 H/POZ
B		n		13.0	188	142	9000	3:28	139	1064	65/35 H/POZ
B		n		13.0	219	171	11600	3:47			65/35 H/POZ
HES-7	y		127	13.0	0	155	10300	4:23	243	322	H
B	y		90	13.0	184	147	12438	5:58	0	297	65/35 H/POZ
HES-7	y		127	13.0	0	155	11594	4:30	0	700	H
HES-7	y		127	13.0	0	175	13355	5:33	160	430	H
B	y		190	13.0	166	128	10618	5:08	185	900	65/35 H/POZ
B	y		350	13.0	140	119	8625	5:48	455	556	65/35 H/POZ
B	y		42	13.0		150	9700	5:41	131	847	65/35 H/POZ
B	y		360	13.0	160	119	9350	6:01	290	1000	65/35 H/POZ
HES-11	y		360	13.0	169	131	8300	3:39			2/1 TLW/H
HES-11		n		13.0	190	143	8950	5:28	835	3471	2/1 TLW/H
HES-11		n		13.0	190	145	9050	5:59	1070	1811	2/1 TLW/H
HES-11		n		13.0	190	143	8975	4:00	1531	1778	2/1 TLW/H
B	y		120	13.0		132	7800	5:05			H
B	y		300	13.0		135	8100	7:51			H
B	y		300	13.0	174	134	10800	5:30+	400	2800	50/50 H/POZ
HES-7	y		2526	13.0	0	85	9200	5:25+	100	240	H
HES-1	y		3214	13.0		95	9400	4:42	440	560	SLAG
HES-3	y		3200	13.0		70	5200	2:32			FLOSTOP I
HES-11	y		3236	13.0		110	9908	2:40	540	870	TLW
B	y		40	13.0	206	151	9120	4:00+	1190	2800	50/50 H/POZ
B	y		40	13.0	206	151	9120	2:34	1090	1245	50/50 H/POZ
B	y		40	13.0	206	151	9120	3:51	1025	1225	50/50 H/POZ
HES-7	y		28	13.0		177	11500	11:03			H
B	y		60	13.0	224	162	11108	3:30	745	820	50/50 H/POZ
B	y		60	13.0	190	145	11108	4:13	600	900	50/50 H/POZ
B	y		59	13.0	205	155	10000	4:20	190	261	H
B	y		79	13.0	91	80	1000	4:00+	90	270	50/50 H/POZ
B	y		50	13.0	200	153	10350	8:30+			65/35 H/POZ
HES-7	y		153	13.0	170	125	8890	3:00+	392	670	H
HES-11	y		176	13.0	202	154	11035	3:40	1140	2520	TLW
A	y		174	13.0	117	99	6600	4:00+	300	380	H
A	y		174	13.0	96	87	3000	3:00+	188	375	H
HES-11	y		185	13.0	155	115	12345		920	1180	TLW
HES-11	y		185	13.0	155	115	12345	4:40	1070	1515	TLW
HES-11	y		167	13.0	245	198	14600	5:20	570	729	1/1 TLW/H
B	y		260	13.0	162	122	7950	3:17			H
HES-11		n		13.0	249	201	13350	5:16	1197	1800	2/1 TLW/H
HES-11		n		13.0	200	153	10150	6:30+			2/1 TLW/H
HES-11		n		13.0	208	160	10730	5:18	774	1602	2/1 TLW/H
HES-11		n		13.0	200	153	10150		234	1196	2/1 TLW/H
HES-11	y		225	13.0	192	154	11700	4:36	681	1312	TLW
HES-11	y		225	13.0	207	166	13380	6:08	820	1645	TLW
B	y		245	13.0	212	176	12000	2:55	790	840	H
HES-11	y		225	13.0	210	169	14000	5:20	990	1782	TLW
HES-7	y		225	13.0	160	136	9975	5:08		400	H
HES-11	y		225	13.0	149	123	6716	5:26	1204	1448	TLW
HES-11	y		258	13.0		172	11400	4:27	0	2368	TLW
HES-11	y		258	13.0	233	184	12615	4:42	1161	1455	TLW
HES-11	y		258	13.0		144	11520	4:31	400	2182	TLW
HES-11	y		258	13.0		143	10976	5:39	0	1361	TLW
HES-11	y		258	13.0		185	14550	4:38	547	1316	TLW
HES-11	y		258	13.0	244	196	13473	5:52	1395	1506	TLW

*Slurry Type	Offshore		Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi)		Base Cement Type
	Yes	No							12 hr	24 hr	
B	y		210	13.0		182	12750	8:00+			H
B	y		210	13.0		182	12750	7:03			H
B	y		210	13.0		182	12750	1:07			H
B	y		210	13.0		181	12602	6:11			H
B	y		410	13.0	280	236	16000	6:40	366	481	HTLD
B	y		50	13.0		158	12422	6:16	0	909	H
HES-7	y		250	13.0		181	12700	9:51	380	550	H
B		n		13.0	225	186	11900	4:56	330	818	H
B		n		13.0	170	127	7496	5:43	280	667	50/50 H/POZ
A	y		150	13.0		80	1050	4:00+	124	328	H
HES-11	y		150	13.0		80	1050	4:00+	215	314	TLW
B		n		13.0	230	178	12000	4:42	970	1240	65/35 H/POZ
B		n		13.0	165	125	7100	5:23	430	950	65/35 H/POZ
HES-11		n		13.0		350	1400	2:04	135	220	TLW
B		n		13.0	223	174	12000	4:05	747	1545	50/50 H/POZ
HES-11		n		13.0		380	1130	2:08	160	200	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed HES-8	y		113	7.0	15.2	180	148	8900	180		SET	85	A
Foamed HES-8	y		3800	10.0	15.1		65	5300	54		40	200	A
Foamed HES-8	y		3800	10.0	15.1		75	5450	95		630	730	A
Foamed HES-8	y		3800	10.0	15.5		68	6030	75		50	290	A
Foamed HES-8	y		3800	10.0	15.5		68	6030	61		32	110	A
Foamed HES-8	y		3800	10.0	15.5		65	5450	73		140	370	A
Foamed HES-8	y		3800	10.0	15.5		65	5450	54		FIRM	160	A
Foamed HES-8	y		1646	10.5	15.0		80	3330	60		0	76	A
Foamed HES-8	y		3778	10.5	15.2		70	6100	70		150	440	A
Foamed HES-8	y		6600	10.5	15.1		65	7200	55		70	230	A
Foamed HES-8	y		3800	10.5	15.1		70	7000	70		380	520	A
Foamed HES-8	y		3800	10.5	15.1		65	5300	54		50	220	A
Foamed HES-8	y		3800	10.5	15.1		90	7000	100		450	670	A
Foamed HES-8	y			10.5	15.2		75	6000	65		200	312	A
Foamed HES-8	y			10.5	15.2		75	6000	65		FIRM	FIRM	A
Foamed HES-8	y		3800	10.5	15.1		73	7200	76		FIRM	390	A
Foamed HES-8	y		3800	10.5	16.2		90	7000	100		50	270	A
Foamed HES-8	y		3800	10.5	15.1		90	7000	100		480	660	A
Foamed HES-8	y		1420	10.5	15.4		65	2500	57		30	110	A
Foamed HES-1	y		1420	10.5	15.4		65	3000	60		40	125	A
Foamed HES-8	y		3800	10.5	15.5		73	7200	69		136	350	A
Foamed HES-8	y		3800	10.5	15.5		73	7000	73		70	160	A
Foamed HES-8	y		3800	10.5	15.5		90	7000	100		430	450	A
Foamed HES-8	y		3800	10.5	15.5	0	73	7200	69		110	270	A
Foamed HES-8	y		3800	10.5	15.0	0	64	7337	54		0	90	A
Foamed HES-8	y			10.5	15.4		75	6000	65		110	170	A
Foamed HES-8	y		3800	10.5	15.0	0	64	7281	72		140	360	A
Foamed HES-8	y		3800	10.5	15.5	0	73	7325	64		105	360	A
Foamed HES-8	y		2049	10.8	15.6		65	3900	65		30	280	A
Foamed HES-8	y		2100	10.8	15.6		65	3900	65		40	250	A
Foamed HES-8	y		3480	10.8	17.3	0	121	12638	150		90	135	H
Foamed HES-8	y		3153	11.0	15.2		70	5000	50		0	140	A
Foamed HES-8	y		1968	11.0	15.1		65	3150	50		0	120	A
Foamed HES-8	y			11.0	14.5		70	6880	70		190	310	SLAG
Foamed HES-8	y			11.0	15.2		55	5000	55		180	180	A
Foamed HES-8	y		3150	11.0	15.2	0	65	4330	50		180	650	A
Foamed HES-8	y		3150	11.0	15.1	0	65	4330	50		280	340	A
Foamed HES-8	y		3778	11.0	15.2		70	6100	70		130	430	A
Foamed HES-8	y		3778	11.0	15.2		70	6100	70		180	500	A
Foamed HES-8	y		2841	11.0	15.1		65	3850	47		80	240	A
Foamed HES-8	y		3800	11.0	15.1		65	5300	54		60	230	A
Foamed HES-8	y		3900	11.0	15.2		70	5820	50		0	200	A
Foamed HES-8	y		3153	11.0	15.6		70	6500	68		0	350	A
Foamed HES-8	y		3153	11.0	15.6		70	8800	68		0	350	A
Foamed HES-8	y		2841	11.0	15.1		65	3850	47		15	22	A
Foamed HES-8	y		3944	11.0	15.6		78	6880	57		0	110	A
Foamed HES-8	y		7600	11.0	15.5	0	58	8800	56		90	270	A
Foamed HES-8	y		3500	11.0	15.5	0	58	7300	48		20	80	A
Foamed HES-8	y		1420	11.0	15.4	0	54	2800	55		50	120	A
Foamed HES-8	y		285	11.0	16.3	97	85	1500	85		70	318	H
Foamed HES-8	y		285	11.0	16.4		85	50	85		180	330	H
Foamed HES-8	y		285	11.0	16.4		85	1500	85		180	330	H
Foamed HES-8	y		3944	11.0	15.6		78	6880	70		190	340	A
Foamed HES-8	y		3944	11.0	15.6		78	6880	70		220	430	A
Foamed HES-8	y		3944	11.0	15.4		65	5350	56		FIRM	115	A
Foamed HES-8	y		3944	11.0	15.6		80	6880	57		90	200	A
Foamed HES-8	y		3907	11.0	15.6		80	6880	57		60	260	A
Foamed HES-8	y		1510	11.0	15.4		65	3700	50		360	420	A
Foamed HES-8	y		3393	11.0	15.5	0	60	4500	55		0	250	A
Foamed HES-8	y		3855	11.0	15.4	0	65	4500	50		60	180	A
Foamed HES-8	y		52	11.0	15.0	318	276	17000	150		SET	330	50/50 H/POZ
Foamed HES-8	y		1965	11.1	15.1		70	3750	50		FIRM	50	A
Foamed HES-8	y		2588	11.2	14.1		70	4800	50		0	140	A
Foamed HES-8	y		3500	11.2	15.5	0	67	8000	57		38	70	A
Foamed HES-8	y		3210	11.2	15.6		64	4900	60		143	220	A
Foamed HES-8	y		1700	11.5	15.1		65	3200	65		60	250	A
Foamed HES-8	y		3940	11.5	15.1		60	4975	60		280	370	A
Foamed HES-8	y		3800	11.5	15.1		65	4910	49		40	370	A
Foamed HES-8	y		1500	11.5	15.5		65	4200	50		0	65	A
Foamed HES-8	y			11.5	16.3		65	4200	54		FIRM	260	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed HES-8	y			11.5	15.5		65	4200	54		0	120	A
Foamed HES-8	y		4000	11.5	15.0	0	55	5000	50		40	120	A
Foamed HES-8	y		4000	11.5	15.0	0	65	7100	70		223	480	A
Foamed HES-8	y		4000	11.5	15.0	0	65	7100	70		310	480	A
Foamed HES-8	y		3982	11.5	15.4	0	65	4980	52		0	90	A
Foamed HES-8	y		6700	11.5	15.5	0	58	9419	72		160	375	A
Foamed HES-8	y		3800	11.5	15.5		60	4920	49		FIRM	140	A
Foamed HES-8	y		3855	11.5	15.4	0	65	4550	52		40	150	A
Foamed HES-8	y		3855	11.5	15.4	0	73	6435	65		FIRM	170	A
Foamed HES-8	y		3845	11.5	15.5	0	63	7000	70		200	360	A
Foamed HES-8	y		4000	11.5	15.4		65	5000	52		40	140	A
Foamed HES-8	y		3900	11.5	15.0	0	65	7700	73		190	270	A
Foamed HES-8	y		3900	11.5	15.0	0	55	5842	50		110	520	A
Foamed HES-8	y		1753	11.5	15.5	0	62	3162	49		260	500	A
Foamed HES-8	y		2841	11.5	15.5	0	70	3850	48		70	210	A
Foamed HES-8	y		2841	11.5	15.5	0	70	4400	52		70	220	A
Foamed HES-8	y		2841	11.5	15.5	0	70	4400	52		70	220	A
Foamed HES-8	y		2841	11.5	15.5	0	75	5600	60		100	310	A
Foamed HES-8	y		3982	11.5	15.4	0	65	4980	52		0	80	A
Foamed HES-8	y		3982	11.5	16.3	0	70	7020	67		87	290	H
Foamed HES-8	y		3480	11.5	16.2	0	70	7200	72		190	240	H
Foamed HES-8	y		1646	11.6	15.0		80	3330	80		100	450	A
Foamed HES-8	y		2588	11.6	14.6		70	4800	50		0	240	A
Foamed HES-8	y		1736	11.6	15.0		80	3330	80		0	330	A
Foamed HES-8	y		2594	11.6	15.5	70	65	3400	65		250	360	A
Foamed HES-8	y		5400	11.8	15.0	0	60	5600	50		FIRM	170	A
Foamed HES-8	y		5400	11.8	15.0	0	65	7100	50		FIRM	160	A
Foamed HES-8	y		2100	11.8	15.1		65	2700	54		100	210	A
Foamed HES-8	y		2446	11.8	16.3		65	3800	74		299	410	H
Foamed HES-8	y		3944	12.0	15.1		65	5048	50		50	370	A
Foamed HES-8	y		3944	12.0	15.1		65	5048	50		30	340	A
Foamed HES-8	y		3557	12.0	15.1		65	5823	50		0	50	A
Foamed HES-8	y		1074	12.0	15.1		71	2408	71		800	880	A
Foamed HES-8	y		2588	12.0	15.0		70	4800	50		0	320	A
Foamed HES-8	y		1451	12.0	15.1		100	4600	90	3:49	250	590	A
Foamed HES-8	y		1451	12.0	15.1		100	4600	90		240	990	A
Foamed HES-8	y		3150	12.0	15.2	0	65	4330	50		250	410	A
Foamed HES-8	y		3150	12.0	15.1	0	65	4330	50		310	470	A
Foamed HES-8	y		4000	12.0	15.1	0	65	4700	50		FIRM	200	A
Foamed HES-8	y		4000	12.0	15.1	0	90	6000	100		730	1170	A
Foamed Class A	y		2521	12.0	15.2		70	3600	53		150	340	A
Foamed HES-8	y		2521	12.0	15.2		70	4820	65		235	530	A
Foamed Class A	y		2841	12.0	15.1		65	3850	52		75	270	A
Foamed Class A	y		3500	12.0	15.1		70	4800	54		0	230	A
Foamed HES-8	y		3633	12.0	15.1		65	6019	65		50	460	A
Foamed HES-8	y		3907	12.0	15.1		65	5048	50		85	460	A
Foamed Class A	y		3907	12.0	15.1		65	5048	50		102	290	A
Foamed Class A	y		3030	12.0	15.1		65	5662	72		410	610	A
Foamed Class A	y		3272	12.0	15.1		57	4573	50		FIRM	300	A
Foamed HES-8	y		3900	12.0	15.2		70	5000	40		0	120	A
Foamed HES-8	y		3900	12.0	15.1		65	5048	50		60	250	A
Foamed HES-8	y		3900	12.0	15.2		70	5000	40		0	120	A
Foamed Class A	y		3900	12.0	15.1		70	5000	40		0	140	A
Foamed HES-8	y		4100	12.0	15.1	0	65	7773	50		0	650	A
Foamed HES-8	y		4000	12.0	15.1		65	5800	60		290	520	A
Foamed HES-8	y			12.0	15.1		65	4000	RM		280	740	A
Foamed HES-8	y		7300	12.0	15.5	0	66	10100	72		180	420	A
Foamed HES-8	y		4500	12.0	15.1		70	8392	50		0	0	A
Foamed HES-8	y			12.0	15.2	0	65	8000	55		80	100	A
Foamed Class A	y		2841	12.0	15.1		65	4400	52		40	60	A
Foamed Class A	y		6700	12.0	15.5	0	58	9419	72		130	315	A
Foamed HES-8	y		3944	12.0	15.2		70	5048	50		0	170	A
Foamed HES-8	y			12.0	15.1		65	4000	RM		250	800	A
Foamed Class A	y			12.0	15.1	0	65	4000	75		380	710	A
Foamed HES-8	y			12.0	15.1	0	65	4000	55		FIRM	500	A
Foamed Class A	y		7600	12.0	15.5	0	66	10100	72		230	440	A
Foamed HES-8	y		3125	12.0	16.4		70	5400	58		121	320	H
Foamed HES-8	y		3125	12.0	16.4		70	5400	58		50	380	H
Foamed Class A	y		3557	12.0	15.5		65	5023	50		FIRM	50	A
Foamed HES-8	y		3557	12.0	15.5		65	5823	50		FIRM	80	A

*Slurry Type	Offshore		Water Depth	Slurry Density	Base Slurry Density	BHST	BHCT	Casing Depth	Temp for Comp Str	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal		(°F)	(°F)	(ft)	(°F)	(hr:min)	12 hr	24 hr	
Foamed Class A	y			12.0	16.0	0	90	8000	70		160	570	H
Foamed Class A	y		719	12.0	15.5		63	1874	63		130	314	A
Foamed HES-8	y		719	12.0	15.5		63	1874	63		73	260	A
Foamed HES-8	y		3000	12.0	15.5	0	62	4400	50		90	220	A
Foamed Class A	y		2521	12.0	15.5	0	70	4850	60		150	690	A
Foamed HES-8	y		2521	12.0	15.6		70	5800	76		290	370	A
Foamed HES-8	y		2521	12.0	15.5	0	65	3750	50		40	290	A
Foamed Class A	y		4000	12.0	15.0	0	76	9100	90		503	860	A
Foamed Class A	y			12.0	15.6		65	6800	65		70	330	A
Foamed Class A	y		285	12.0	16.3	135	105	4600	105		500	760	H
Foamed Class A	y		285	12.0	16.3		85	1500	90		360	420	H
Foamed Class A	y		285	12.0	16.3		85	1500	135		480	611	H
Foamed Class A	y		1300	12.0	15.5	0	62	5000	72		310	520	A
Foamed Class A	y		1300	12.0	15.5	0	62	5000	72		370	680	A
Foamed Class A	y		3100	12.0	15.0	0	58	9400	62		30	120	A
Foamed Class A	y		4200	12.0	16.4	0	65	7773	55		FIRM	330	A
Foamed Class A	y		4200	12.0	15.0	0	65	7773	55		0	90	A
Foamed Class A	y		4200	12.0	16.7	0	65	7773	55		0	180	H
Foamed Class A	y		3855	12.0	15.4	0	72	5450	55		150	570	A
Foamed Class A	y		3845	12.0	15.5	0	75	7000	55		180	500	A
Foamed Class A	y		4000	12.0	15.4		65	5800	52		70	220	A
Foamed Class A	y		3480	12.0	15.4	0	65	5564	68		560	1090	A
Foamed Class A	y			12.0	16.9	0	65	4000	45		SET	120	H
Foamed Class A	y			12.0	16.9	0	65	4000	45		SET	110	H
Foamed Class A	y		3393	12.0	15.5	0	70	7500	67		220	360	A
Foamed Class A	y		3900	12.0	15.5	0	65	4700	50		0	FIRM	A
Foamed Class A	y		3900	12.0	15.5	0	90	6000	100		640	950	A
Foamed Class A	y		3325	12.0	15.0	0	65	5037	50		60	240	A
Foamed Class A	y		5467	12.0	15.4	0	68	7000	70		270	410	A
Foamed Class A	y		1400	12.0	15.5	0	62	5000	72		350	740	A
Foamed Class A	y		4000	12.0	16.4	0	65	7773	55		FIRM	260	A
Foamed Class A	y		4000	12.0	16.7	0	65	7773	55		50	340	H
Foamed Class A	y		3982	12.0	15.4	0	65	5650	54		95	300	A
Foamed Class A	y		3200	12.0	15.5	0	75	2265	50		235	570	A
Foamed Class A	y		3200	12.0	15.5	0	65	2265	50		230	585	A
Foamed Class A	y		6800	12.0	17.5	0	80	9300	70			110	H
Foamed Class A	y		3907	12.1	15.4		66	5800	55		FIRM	240	A
Foamed Class A	y		3907	12.1	15.4		66	5800	55		FIRM	130	A
Foamed Class A	y		3800	12.2	15.1		65	5220	70		580	970	A
Foamed Class A	y		3800	12.2	15.1		65	5220	52		FIRM	140	A
Foamed Class A	y		2841	12.2	15.1		47	3800	63		360	720	A
Foamed Class A	y		3800	12.2	15.1		65	5220	53		90	450	A
Foamed Class A	y		2588	12.4	15.1		70	3400	50		0	130	A
Foamed Class A	y		2588	12.4	15.1		70	3400	50		0	140	A
Foamed Class A	y		4600	12.5	15.0	0	60	8085	50		50	124	A
Foamed Class A	y			12.5	15.1		65	5559	57		160	640	A
Foamed Class A	y		6679	12.5	14.8		65	9000	50		0	70	A
Foamed Class A	y		1965	12.5	15.1		70	3400	60		30	260	A
Foamed Class A	y		2025	12.5	15.1		70	3400	50		40	370	A
Foamed Class A	y		3210	12.5	15.1		70	5450	60		120	910	A
Foamed Class A	y		4100	12.5	15.1	0	90	9273	100		700	895	A
Foamed Class A	y			12.5	15.0		65	4850	54		120	350	A
Foamed Class H	y		7612	12.5	15.2		70	10800	67		210	450	A
Foamed Class H	y		7612	12.5	15.2		70	9300	40		0	130	A
Foamed Class H	y			12.5	15.2		55	5000	55		250	350	A
Foamed Class H	y			12.5	15.1		65	5559	57		160	670	A
Foamed Class H	y		6679	12.5	14.8		65	9000	50		0	110	A
Foamed Class H	y		6679	12.5	15.0		65	9000	50		0	115	A
Foamed Class A	y		3100	12.5	15.0	0	60	5200	50		50	220	A
Foamed Class A	y		3100	12.5	15.2	0	65	5100	50		210	315	A
Foamed Class A	y		3100	12.5	15.1	0	65	5100	50		390	500	A
Foamed Class A	y		3778	12.5	15.0		70	5700	45		0	55	A
Foamed Class A	y		3778	12.5	15.2		70	4600	45	3:22	0	50	A
Foamed Class H	y		2663	12.5	15.1	0	65	3978	55		FIRM	190	A
Foamed Class H	y		3150	12.5	15.2	0	65	4330	50		280	450	A
Foamed Class A	y		3150	12.5	15.1	0	65	4330	50		330	500	A
Foamed Class A	y		1968	12.5	15.1		65	5000	52		30	410	A
Foamed Class A	y		5250	12.5	15.0	0	65	7000	50		105	270	A
Foamed Class A	y		5800	12.5	15.1	0	65	7046	50		FIRM	150	A
Foamed Class A	y		2559	12.5	15.0		65	3377	60		150	350	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed Class A	y		5200	12.5	15.1	0	65	8053	50			110	A
Foamed Class H	y		5200	12.5	15.1	0	65	7393	55		340	520	A
Foamed Class A	y		2559	12.5	15.0		65	3377	60		180	190	A
Foamed Class A	y		3210	12.5	15.1		65	5450	70		310	700	A
Foamed Class A	y		3272	12.5	15.1		85	6537	50		0	FIRM	A
Foamed Class A	y		3900	12.5	15.1		70	5700	40		0	115	A
Foamed Class A	y			12.5	15.2		75	6000	65		FIRM	FIRM	A
Foamed Class A	y		1400	12.5	15.1	0	65	6113	65		270	540	A
Foamed Class A	y		6679	12.5	15.0		65	9000	50		SET	160	A
Foamed Class A	y		2000	12.5	15.5		70	3400	50		0	80	A
Foamed Class H	y		5600	12.5	15.1	0	60	8290	55		110	580	A
Foamed Class A	y			12.5	15.1	0	65	8900	40				A
Foamed Class A	y		3257	12.5	15.1	0	70	5450	50		0	0	A
Foamed Class A	y		3800	12.5	15.5		82	9500	90		370	750	A
Foamed Class A	y		4100	12.5	15.0	0	105	10000	120		100	230	A
Foamed Class A	y		4100	12.5	15.0	0	90	8632	105		230	590	A
Foamed Class A	y			12.5	15.4		75	6000	65		170	425	A
Foamed Class A	y			12.5	15.0	0	65	10500	50		0	40	A
Foamed Class A	y		3557	12.5	15.0	0	60	8085	50		45	230	A
Foamed Class A	y		1485	12.5	15.6	0	70	3000	55		235	650	A
Foamed Class H	y		3000	12.5	15.5	0	65	5200	60		130	270	A
Foamed Class A	y		4000	12.5	15.0	0	65	4650	54		70	240	A
Foamed Class A	y		4000	12.5	15.0	0	65	4650	54		45	100	A
Foamed Class A	y		4600	12.5	16.0	0	68	5305	55		140	270	H
Foamed Class A	y			12.5	15.5		65	5000	57		0	90	A
Foamed Class A	y			12.5	16.3		65	5000	57		FIRM	FIRM	H
Foamed Class A	y		3100	12.5	15.5	0	74	2762	68		230	540	A
Foamed Class A	y		4000	12.5	16.0	0	65	6100	50		0	160	A
Foamed Class A	y		5000	12.5	16.4	0	65	7878	55		180	570	A
Foamed Class A	y		3600	12.5	15.0	0	65	9025	50		0	150	A
Foamed Class A	y		3750	12.5	15.0	0	65	5500	55		120	350	A
Foamed Class A	y		3750	12.5	15.0	0	65	6625	50		0	130	A
Foamed Class A	y		3750	12.5	15.5	0	60	6625	55		190	260	A
Foamed Class A	y		6700	12.5	15.5	0	67	11300	99		380	520	A
Foamed Class A	y		3800	12.5	16.3		82	9500	90		160	385	H
Foamed Class A	y		4200	12.5	16.0	0	90	9273	80		0	90	A
Foamed Class A	y		3900	12.5	15.0	0	62	5600	48		SET	60	A
Foamed Class A	y		3900	12.5	15.0	0	73	9400	88		290	500	A
Foamed Class H	y			12.5	15.4		75	6000	65		180	240	A
Foamed Class H	y			12.5	15.6		70	5200	70		220	380	A
Foamed Class A	y		3393	12.5	15.5	0	65	5500	67		222	430	A
Foamed Class A	y		3393	12.5	15.5	0	60	4500	55		190	500	A
Foamed Class A	y		3393	12.5	15.5	0	75	8000	67		490	840	A
Foamed Class A	y		3393	12.5	15.5	0	75	8000	67		530	810	A
Foamed Class A	y		5000	12.5	15.5	0	68	7000	70		290	560	A
Foamed Class A	y		5000	12.5	15.5	0	70	5700	50		203	710	A
Foamed Class A	y		1965	12.5	15.1		70	3750	5		FIRM	130	A
Foamed Class A	y		2700	12.5	16.4	0	60	4340	60		90	320	H
Foamed Class A	y		3500	12.5	15.2		70	6500	70		70	280	A
Foamed Class A	y		6201	12.5	15.5	0	70	8200	79		490	1075	A
Foamed Class A	y		4000	12.5	16.0	0	90	9273	80		210	570	A
Foamed Class H	y		4000	12.5	16.0	0	90	9273	80		20	1310	H
Foamed Class H	y		3855	12.5	15.4	0	65	4500	50		80	200	A
Foamed Class H	y		52	12.5	16.4	150	115	6000	110		40	820	H
Foamed Class H	y		3329	12.5	15.0		65	4850	54		60	300	A
Foamed Class A	y		3329	12.5	15.0		65	4850	54		25	225	A
Foamed Class A	y		3200	12.5	15.1	70	70	5100	60		65	395	A
Foamed Class H	y		3900	12.5	15.2		65	5000	50		FIRM	124	H
Foamed Class A	y		2588	12.6	14.8		70	4800	50		0	420	A
Foamed Class A	y		1965	12.6	15.6	0	65	3700	65		220	510	A
Foamed Class A	y		4700	12.6	16.0	0	65	7238	65		0	450	H
Foamed Class A	y		4700	12.6	16.0	0	65	7238	50		FIRM	560	H
Foamed Class A	y		3500	12.7	15.1		70	5900	63		180	455	A
Foamed Class A	y		4600	12.8	15.0	0	65	8800	50		40	290	A
Foamed HES-8	y		4200	12.8	15.0		70	2540	60		110	290	A
Foamed HES-8	y		3500	12.8	15.1		70	4850	57		FIRM	200	A
Foamed Class A	y		3500	12.8	15.1		70	4850	57		FIRM	150	A
Foamed Class A	y		3940	12.8	15.1		65	6175	65		350	740	A
Foamed Class H	y		3940	12.8	15.1		65	6175	70		360	694	A
Foamed Class H	y		2663	12.8	15.1	0	90	5820	100		650	890	A

*Slurry Type	Offshore		Water Depth	Slurry Density	Base Slurry	BHST	BHCT	Casing Depth	Temp for Comp Str	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	£13.0 lb/gal	Density	(°F)	(°F)	(ft)	(°F)	(hr:min)	12 hr	24 hr	
Foamed Class A	y		3329	12.8	15.1		70	4850	57		0	120	A
Foamed Class A	y		3329	12.8	15.1		70	4850	57		FIRM	130	A
Foamed Class A	y		7612	13.0	15.2		70	8380	40		0	150	A
Foamed Class A	y			13.0	15.1	0	65	8000	55		90	440	A
Foamed Class A	y			13.0	15.1	0	65	8000	55		FIRM	260	A
Foamed Class A	y		2559	13.0	15.0		65	4200	65		200	360	A
Foamed Class A	y		2559	13.0	15.0		65	4200	65		260	410	A
Foamed Class A	y			13.0	15.2	0	65	8000	55		FIRM	270	A
Foamed Class A	y		1210	13.0	15.4	0	75	3800	75		260	490	A
Foamed Class A	y		3000	13.0	15.5	0	75	8200	85		363	1020	A
Foamed Class A	y		2900	13.0	15.5	0	60	3930	50		60	220	A
Foamed Class A	y		2900	13.0	15.0	0	60	3930	50		60	220	A
Foamed Class A	y		2000	13.0	15.5	0	70	4400	60		210	1210	A
Foamed Class A	y		4200	13.0	15.5	0	65	7000	60		232	370	A
Foamed Class A	y		1025	13.0	16.4	170	138	9850	160		300	660	H
Foamed Class H	y		1025	13.0	16.3	170	138	9850	160		290	645	H
Foamed Class H	y		3100	13.0	15.0	0	74	11200	80		120	670	A
Foamed Class A	y		1200	13.0	15.5	0	68	3800	85		490	750	A
Foamed Class A	y		1200	13.0	15.6	0	68	3800	85		450	980	A
Foamed Class A	y		3393	13.0	15.5	0	60	4500	55		210	550	A
Foamed Class H	y		4700	13.0	16.0	0	65	7238	65		0	460	H
Foamed Class A	y		5000	13.0	15.5	0	75	9200	100		120	350	H
Foamed Class H	y		5000	13.0	15.5	0	75	9200	100		380	1130	A
Foamed Class H	y		2000	13.0	15.5	0	70	4400	60		180	500	A
Foamed Class H	y		2000	13.0	15.5	0	70	4000	65		160	580	A
Foamed Class A	y		2700	13.0	16.4	0	60	5440	60		50	290	H
Foamed Class A	y		5467	13.0	15.4	0	75	8400	84		410	710	A
Foamed Class A	y		4000	13.0	16.0	0	65	6691	50		90	430	A
Foamed Class A	y		2025	13.0	15.5	0	70	4400	60		190	510	A
Foamed Class A	y		1500	13.0	17.3	0	113	10200	130		640	670	H
Foamed HES-8	y		3800	10.0 .	15.5		65	5800	58		50	240	A
Foamed Class H	y		3800	10.0 .	15.5		65	5450	55		50	130	A
Foamed Class H	y		2056	12.0 .	15.1		65	4000	50		22	240	A
Foamed Class H	y		2056	12.0 .	15.1		80	6050	50		0	20	A

Product Number:	HES-1
Service Company:	Halliburton
Company Designation:	NewCem
General Description:	Shell "Slag"

Product Number:	HES-2
Service Company:	Halliburton
Company Designation:	Spherelite
General Description:	Pozzalonic Microspheres

Product Number:	HES-3
Service Company:	Halliburton
Company Designation:	Spherelite w/ Microfine Cement
General Description:	Pozzalonic Microspheres w/ Microfine Cement

Product Number:	HES-4
Service Company:	Halliburton
Company Designation:	Spherelite w/ Econolite
General Description:	Pozzalonic Microspheres w/ Sodium Silicate

Product Number:	HES-5
Service Company:	Halliburton

Company Designation: Diacel-M

General Description: Diacel-M

Product Number: HES-6

Service Company: Halliburton

Company Designation: EPSEAL

General Description: EPSEAL

Product Number: HES-7

Service Company: Halliburton

Company Designation: WG-17, WG-17LXP, FWCA

General Description: Freewater Control

Product Number: HES-8

Service Company: Halliburton

Company Designation: Micro-Matrix

General Description: Microfine Cement

Product Number: HES-9

Service Company: Halliburton

Company Designation: Microbond

General Description: Expansive Additives

Product Number: HES-10

Service Company: Halliburton

Company Designation: CalSeal

General Description: Calcium Sulfate

Product Number: HES-11

Service Company: Halliburton

Company Designation: TLW / TXI

General Description: TLW / TXI

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement	MIX H_20
	Yes	No	(ft)	£13.0 lb/gal	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	Type	Fresh
BJ-1 + 2% CaCl2		x		9.5	90	80	1500	3:50	500		H	Fresh
BJ-1		x		9.5	180	144	10000	4:35		480	H	Fresh
BJ-1		x		9.5	180	144	10000	4:06		510	H	Fresh
BJ-1		x		11.5	180	144	10000	4:10	1638	2482	H	Fresh
BJ-1		x		8.5	180	144	10000		223	753	H	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500	4:25		2940	G	Fresh
BJ-2 + 40% Silica		x		12.2	325	225	8000	4:15		2780	G	Fresh
BJ-2		x		11.6	140	116	5000		300	460	G	Fresh
BJ-2 + 5% Lime		x		11.6	140	116	5000		300	360	G	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500			2771	G	Fresh
BJ-2 + 40% Silica + 5% Lime		x		10.8	400	200	3500			1287	G	Fresh
BJ-2		x		10.2	400	200	3500			276	G	Fresh
BJ-2 + 35% Silica		x		10.4	300	250	5000	4:51	1253	2343	G	Fresh
BJ-2 + 35% Silica + 5% Lime		x		14.0	600	110	4500			1963	Type 1	Fresh
BJ-2 + 35% Silica + 5% Lime		x		12.0	600	110	4500			700	Type 1	Fresh
BJ-3 + 35% Silica		x		14.0	600	110	4500			1213	Type 1	Fresh
BJ-1		x		9.3	95	80	1500	8:00+	75	154	H	Fresh
BJ-1 + 2% CaCl2		x		9.3	95	80	1500	8:00+	140	213	H	Fresh
BJ-1		x		10.3	95	80	1500	8:00+	220	403	H	Fresh
BJ-1 + 2% CaCl2		x		10.3	95	80	1500	6:20	300	496	H	Fresh
BJ-1		x		11.3	95	80	1500	8:00+	384	778	H	Fresh
BJ-1 + 2% CaCl2		x		11.3	95	80	1500	3:02	504	1027	H	Fresh
BJ-1		x		12.3	95	80	1500	8:00	556	1053	H	Fresh
BJ-1 + 2% CaCl2		x		12.3	95	80	1500	2:09	820	1238	H	Fresh
BJ-1 + 6% CaCl2		x		9.6	89	80	1000	8:40		450	G	Fresh
BJ-1 + 1.5% CaCl2		x		9.5	90	85	1000	5:27	263	513	G	Fresh
BJ-1 + 1.5% CaCl2		x		9.5	90	85	1000		513	563	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	90	80	1500	3:30	500		A	Fresh
BJ-1 + 2% CaCl2		X		9.5	40		1000			50	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	55		1000			160	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	95		1000		300	670	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	300		1000			1000	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	40		1000			183	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	55		1000			570	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	95		1000		630	1280	A	Fresh
BJ-3		x		8.5	180	144	10000	4:43	223	753	H	Fresh
BJ-1 + 3% CaCl2 + 35% Silica		x		9.0	144	100	3000	2:57	510	813	G	Fresh
BJ-1, 5% CaCl2, 10% "B"		x		9.0	144	100	3000	5:00	165	225	G	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500	4:25		2940	G	Fresh
BJ-2 + 40% Silica		x		12.2	325	225	8000	4:15		2780	G	Fresh
BJ-2 + 40% Silica		x		10.8	400		6000			1914	G	Fresh
BJ-2 + 40% Silica + 5% Lime		x		10.8	400		6000			1114	G	Fresh
BJ-2		x		10.2	400		6000			394	G	Fresh
BJ-2 + 35% Silica + 5% Lime		x		10.4	300	250	5000	4:51	1253	2343	G	Fresh
3% "A"		x		11.8	95	85	1000	4:43		450	A	Fresh
1.5% "A"		x		12.8	80	80	1000	6:00		745	C	Fresh
10% "B"		x		12.5	120	103	7250	2:47		304	C	Fresh
10% "B", 0.2% "A",		x		12.5	120	103	7050	2:58		280	C	Fresh
15% "B"		x		11.7	124	105	5500	5:07	77	129	C	Fresh
16% "B", + dispersant		x		12.1	127	110	8200	2:37		518	C	Fresh
16% "B", + 12 LB Gilsonite		x		11.9	110	100	4570	3:41		265	C	Fresh
16% "B" + 3% Salt + Dis		x		12.1	127	110	8200	1:48		523	C	Fresh
16% "B" + 3% Salt + Dis		x		12.1	105	90	4900	2:54		433	C	Fresh
16% "B" + 3% Salt + Gil		x		12.5	130	110	6800	1:23		375	C	Fresh
3% "A" + 2% CaCl2		x		11.6	80	80	1000	7:20		196	C	Fresh
2% "A"		x		12.4	90	80	1950	6:25		450	C	Fresh
3% "A"		x		11.4	120	105	6000	5:18		255	C	Fresh
3% "A"		x		11.4	110	95	5200	6:50		248	C	Fresh
3% "A"		x		11.9	120	100	5600	5:49		358	C	Fresh
3% "A" + .25% CaCl2		x		11.9	109	102	5800	5:20		394	C	Fresh
3%"A" + 2.0% CaCl2		x		11.6	90	80	1110	6:24		208	C	Fresh
3% "A" + 2% CaCl2		x		11.9	90	80	1135	5:33		338	C	Fresh

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type	MIX H_20 Fresh
3%A" + 2% CaCl2 + Salt		x		11.5	86	80	750	5:55		116	C	Fresh
3% "A" + Gilsonite		x		11.4	160	133	10100	2:43		168	C	Fresh
3%"A" + 5 Lb/sk Salt		x		11.4	120	103	5250	7:06		325	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.4	96	90	2800	8:38		300	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.9	96	90	2800	8:06		325	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.4	116	103	5250	6:52		373	C	Fresh
BJ-6 + "B" + "A"		x		11.8	126	116	7050	3:29	233	296	C	Fresh
BJ-7+12% Salt+ 2% CC		x		12.6	120	105	7500	2:58		343	C	Fresh
6% "B"		x		12.7	98	88	3500	5:21		400	C	Fresh
6% "B" + 3% Salt		x		12.7	120	100	7023	4:23		655	C	Fresh
6%"B"+3% Salt + Gilsonite		x		12.7	108	96	3950	2:43		1008	C	Fresh
8% "B" + 3% Salt		x		12.9	115	97	5795	3:40		750	C	Fresh
16% "B"		x		11.8	144	127	8500	3:54	93	177	H	Fresh
16% "B" + 2% Salt		x		11.7	145	135	10000	2:54		233	H	Fresh
2% "A"		x		12.6	144	121	9200	2:33		823	H	Fresh
2% "A"		x		12.4	135	115	8700	3:13		450	H	Fresh
20% "B"		x		10.5	160	133	10100	3:45	42	56	H	Fresh
BJ-8		x		12.2	80	80	500	5:53		358	A	Fresh
BJ-8		x		12.6	80	80	900	4:37		356	C	Fresh
BJ-9		x		11.0	160	133	10100	2:36	351	483	C	Fresh
BJ-9 + 8% Attapulgite		x		10.5	160	133	10100	3:48	222	306	C	Fresh
BJ-8		x		11.5	120	105	6000	4:00		55	C	Fresh
BJ-8		x		12.4	120	105	6000	3:54		335	C	Fresh
BJ-8		x		13.0	144	119	8000	3:15		711	C	Fresh
BJ-8		x		12.5	80	80	1150	3:45		475	C	Fresh
BJ-8 + 10% Salt		x		12.8	104	91	3000	5:07		400	C	Fresh
BJ-8 + 2% CaCl2		x		12.7	85	80	1000	5:17	188			Fresh
BJ-8 + 2% CaCl2 + 5lb Gil		x		12.5	110	87	2000	5:30		288	C	Fresh
BJ-8 + 2% CaCl2 + 5lb Kol		x		12.6	90	81	1500	5:16		458	C	Fresh
BJ-8 + 3% Salt		x		12.5	100	90	4800	5:14		275	C	Fresh
BJ-8 + 5 lb Gilsonite		x		12.7	90	83	500	6:42		288	C	Fresh
BJ-8 + 5 lb Gilsonite		x		12.3	156	123	9000	4:05		495	C	Fresh
BJ-8 + 5 lb Gilson + 3% Salt		x		12.5	128	108	6000	3:46		432	C	Fresh
BJ-8 + 5 lb Gilson + 2% KCl		x		12.6	85	80	900	5:23		280	C	Fresh
BJ-8 + 5 lb salt		x		12.6	128	108	6000	1:48		270	C	Fresh
BJ-8 + 5 lb salt		x		12.6	114	99	4000	2:46		375	C	Fresh
BJ-8 + 5% Salt		x		12.4	99	88	1900	4:45	307	623	C	Fresh
BJ-8 + 9% Salt		x		12.5	104	97	3750	3:35		375	C	Fresh
BJ-8		x		12.6	120	100	6100	4:13		375	H	Fresh
BJ-8		x		12.6	123	111	6100	3:30		410	H	Fresh
BJ-8		x		12.5	132	123	8050	2:59		520	H	Fresh
BJ-8		x		12.4	140	118	9000	3:45		595	H	Fresh
BJ-8 + 8 lb Gilson + 3% Salt		x		12.4	127	108	6000	4:07	244	406	H	Fresh
BJ-8 + 8 lb Gilson		x		12.4	152	128	9000	4:48	125	360	H	Fresh
BJ-8		x		12.4	183	145	10300	4:35		850	H	Fresh
BJ-8		x		12.7	148	124	9000	3:32		600	H	Fresh
BJ-8		x		12.4	176	145	12000	3:48		730	H	Fresh
BJ-8		x		12.7	149	131	9000	4:36		500	H	Fresh
BJ-8 + 10% Salt		x		12.4	115	108	5800	3:25		587	H	Fresh
BJ-8 + 10% Salt + 2 lb Gil		x		12.8	96	86	2000	5:05		516	H	Fresh
BJ-9 + 2% CaCl2		x		12.4	110	90	5000	7:07		310	C	Fresh
BJ-9 + 8 lb Gilsonite		x		13.0	165	137	11300	4:06		1892	C	Fresh
BJ-9		x		13.0	157	127	11830	4:14		2150	C	Fresh
BJ-9		x		13.0	144	119	8000	3:12		1490	C	Fresh
BJ-9 + 1 lb salt		x		13.0	155	129	9800	4:09		1583	C	Fresh
BJ-9 + 8 lb salt		x		13.0	130	110	5500	3:44		1334	C	Fresh
BJ-9 + 5 lb Gilsonite		x		13.0	175	141	12900	3:35		2163	C	Fresh
BJ-9 + 1 lb KCl + 5 lb Gilson		x		13.0	148	124	8200	3:38		1700	C	Fresh
BJ-9 + 2% KCl + 8 lb Gilson		x		13.0	170	136	11900	2:30		2680	C	Fresh
BJ-9 + 2% Salt + 0.2% "A"		x		13.0	152	127	8000	2:46		1875	C	Fresh
BJ-9 +1 lb Salt + 5 lb Gilson		x		13.0	165	137	10700	3:41		2650	H	Fresh
BJ-9 + 5 lb Salt		x		11.5	119	96	3200	7:55		375	C	Fresh

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density £13.0 lb/gal	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type	MIX H_20 Fresh
BJ-10		x		12.3	168	139	11572	3:58		1512	TXI LW	Fresh
A	x			11.8	107	90	3000		70	150	H	FRESH
A	x			12.0	182	119	9450		400	850	H	FRESH
A	x			12.4	98	80	2300		130	400	H	FRESH
B	x			12.0	142	101	5100		160	485	H	FRESH
A	x			12.4	120	91	3860		125	300	H	FRESH
A	x			11.4	120	105	3900		50	150	H	SEA
A	x			12.0	94	81	2150		90	170	H	SEA
A	x			12.4	130	95	4750		150	285	H	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
B	x			11.4	93	81	2000		90	170	H	SEA
A	x			12.5	310	252	16450		410	845	H	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
A	x			11.8	107	90	3000		70	150	H	FRESH
BJ-8 + 3% SALT	x			12.0	110	93	3345		145	290	A	FRESH
BJ-8	x			12.5	93	80	2000		95	240	A	FRESH
TXI LW + "A"	x			12.8	95	80	2160		95	240	H	FRESH
A	x			11.5	113	94	3100		50	210	H	FRESH
A	x			12.4	107	87	2890		140	380	H	FRESH
A	x			12.5	120	105	3900		160	340	H	FRESH
A	x			11.5	100	85	2420		55	104	H	FRESH
A	x			12.0	124	92	3900		120	300	H	FRESH
TXI LW + "B"	x			12.0	101	88	2500		125	295	TXI LW	SEA
BJ-8	x			12.4	116	92	3220		150	285	H	FRESH
BJ-8	x			12.4	185	130	9550		255	967	H	FRESH
BJ-8	x			12.5	110	92	3000		104	425	TYPE 1	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
A	x			11.4	102	88	2700		50	160	H	SEA
A	x			11.4	122	100	3860		50	135	H	SEA
A	x			11.4	125	100	3950		50	135	H	SEA
B	x			12.6	254	205	15800		SET	400	H	FRESH
A	x			11.4	94	80	2000		50	150	H	SEA
A	x			11.7	224	173	14100		50	200	H	SEA
A	x			11.4	94	80	2000		50	150	H	SEA
A	x			12.5	70	75	800		50	140	H	SEA
A	x			11.4	119	96	3440		50	150	H	SEA
B	x			12.0	94	80	2000		60	175	H	FRESH
A	x			11.4	93	80	2000		60	150	H	SEA
A	x			12.0	94	80	2000		65	170	H	SEA
A	x			12.0	116	93	3300		65	170	H	SEA
BJ-8	x			12.4	92	80	1966		170	356	A	SEA
BJ-8	x			12.4	145	104	5655		65	350	A	SEA
BJ-10	x			12.5	174	128	12100		1050	1460	TXI LW	FRESH
BJ-8	x			11.4	93	80	2000		60	150	H	SEA
A	x			11.4	109	91	3050		50	160	H	SEA
A	x			11.4	93	81	2000		50	150	H	SEA
A	x			11.4	132	104	4920		50	150	H	SEA
A	x			11.4	132	104	4920		50	150	H	SEA
BJ-10 + 4% Gel	x			11.5	90	80	1800		60	530	TXI LW	FRESH
BJ-8	x			12.0	114	93	3110		100	280	H	SEA
BJ-8	x			12.0	114	93	3110		50	170	H	FRESH
BJ-8	x			11.2	124	98	4600		155	250	TYPE 1	FRESH
A	x			11.4	94	80	2000		50	150	H	SEA

Product Number: BJ-1

Service Company: BJ Services Company

Company Designation: LW-7 2000

General Description: Glass Bubbles, Low Strength

Product Number: BJ-2

Service Company: BJ Services Company

Company Designation: LW-6

General Description: Ceramic Bubbles

Product Number: BJ-3

Service Company: BJ Services Company

Company Designation: Perlite

General Description: Expanded Volcanic aggregate

Product Number: BJ-4

Service Company: BJ Services Company

Company Designation: LW-7 10000

General Description: Glass Bubbles, High Strength

Product Number: BJ-5

Service Company: BJ Services Company

Company Designation: None

General Description: Blend LW-6 and High Early strength additive

Product Number: BJ-6

Service Company: BJ Services Company

Company Designation: None

General Description: Blend Anhydrous Sodium Metasilicate and High Strength Additive

Product Number: BJ-7

Service Company: BJ Services Company

Company Designation: Attaclay

General Description: Attapulgite Clay

Product Number: BJ-8

Service Company: BJ Services Company

Company Designation: None

General Description: Poz, Cement, Bentonite Blend

Product Number: BJ-9

Service Company: BJ Services Company

Company Designation: None

General Description: Poz, Cement, Microsilica Blend

Product Number: BJ-10

Service Company: BJ Services Company

Company Designation: TXI Lightweight

General Description: TXI Commercial Lightweight Cement

Product Number: BJ-11

Service Company: BJ Services Company

Company Designation: Prehydrated Gel

General Description: Prehydrated Bentonite Gel

Product Number:

Service Company:

Company Designation:

General Description:

TXI Provided Information			CSI Information				CSI Free Water			CSI Rheologies												
Cmt Class	Mill Production Run Date	Grind	Date Received	CSI Log #	Bucket Opened	Test Date	at %	mL	% by volume	H2O %	Temp °F	300 rpm	200 rpm	100 rpm	60 rpm	30 rpm	6 rpm	3 rpm	PV	YP	10 sec G.S.	10 min G.S.
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-1	11/07/00	11.15.00	105	2	0.8	75	80	57	50	42	38	33	22	12	22.5	34.5	13	120
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-2	12/05/00	1.04.01	105	2	0.8	75	80	58	52	45	38	32	21	13	19.5	38.5	13	125

TXI Provided Information			CSI Information				CSI Thickening Time				
Cmt Class	Mill Production Run Date	Grind	Date Received	CSI Log #	Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	70 Bc	100 Bc
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-1	11/07/00	11.15.00	75.0	5	6	2:02	2:20
LW	9/15 to 9/18/01	62	11/06/00	c-108 B-2	12/05/00	1.5.01	75.0	5	5	2:00	2:17

TXI Provided Information			CSI Information				CSI 45°F Strengths						CSI 60°F Strengths					CSI 80°F Strengths				CSI 120°F Strengths			
Cmt Class	Mill Production Run Date	Grind	Date Received	CSI Log #	Bucket Opened	Test Date	% H2O	Time Hr	Temp °F	% CaCl2	Old	Str psi	Time Hr	Temp °F	% CaCl2	Old	Str psi 1.565	Time Hr	Temp °F	Old	Str psi 1.565	Time Hr	Temp °F	Old	Str psi 1.565
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-1	11/07/00	11.15.00	75.0	24	45	2.0	106	166	24	60	1.0	162	254	24	80	334	523	24	120	1009	1579
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-2	12/05/00	01.04.01	75.0	24	45	2.0	103	161	24	60	1.0	141	221	24	80	282	441	24	120	783	1225

TXI Information		CSI Information				CSI Free Water			CSI Rheology											
Cmt Class	Prod. Date	Date Received	CSI Log #	Date Bucket Opened	Test Date	mL	% by volume	Pass/ Fail	Temp °F	300 rpm	200 rpm	100 rpm	60 rpm	30 rpm	6 rpm	3 rpm	PV	YP	10 sec G.S.	10 min G.S.
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	1.9	0.8	**Pass**	69	89	72	53	45	37	16	10	54	35	**out of**	**sx**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	3	1.2	**Pass**	80	85	70	53	45	38	14	8	48	37	9	19
H	9/28/00	11/07/00	C-108 A-2	11/06/00	01/11/01	3	1.2	**Pass**	80	95	80	60	51	42	20	12	52.5	42.5	15	26
H	9/27/00	11/06/00	C-108 A-2	11/06/00			0.0										0	0		
H	9/27/00	11/06/00	C-108 A-1	11/06/00			0.0										0	0		
H	9/27/00	11/06/00	C-108 A-3	02/22/01			0.0										0	0		
H	9/27/00	11/06/00	C-108 A-1	11/06/00			0.0										0	0		
H	9/27/00	11/06/00	C-108 A-3	02/22/01			0.0										0	0		

TXI Information		CSI Information				CSI Thickening Time						CSI 8hr Strengths					CSI 8hr Strengths				
Cmt Class	Prod. Date	Date Received	CSI Log #	Date Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	15'-30' Bc	100 Bc	Pass/ Fail	Time Hrs	Temp °F	Old	Str psi 1.565	Pass/ Fail	Time Hrs	Temp °F	Old	Str psi 1.565	Pass/ Fail
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	5	**ran**	**out**	**of**	**sx**	8	100	335	**524**	**Pass**	8	140	1334	**2087.71**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/29/00	38.0	5	12	13	2:03	**Fail**	8	100	307	**480**	**Pass**	8	140	1437	**2248.905**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	5	7	13	1:54	**Pass**	8	100	768	**1201.92**	**Pass**	8	140	1255	**1964.075**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/12/01	38.0	5					8	100	664	**1039.16**	**Pass**	8	140	1122	**1755.93**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	02/12/01							8	100	271	**424**	**Pass**	8	140	1097	**1716.805**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01												8	140		**1617**	**Pass**
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01												8	140		**1567**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01												8	140		**1550**	**Pass**
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01												8	140		**1580**	**Pass**

TXI Information		CSI Information				CSI 8hr Strengths					CSI 24hr Strengths					CSI 45°F Strengths					
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	Time Hr	Temp °F	Old	Str psi *1.565	Pass/ Fail	Time Hr	Temp °F	Old	Str psi *1.565	Pass/ Fail	Time Hr	Temp °F	% CaCl2	Old	Str psi 1.565	Pass/ Fail
Class A	9/25 to 9/27/00	11/06/00	C-113 A-1	11/09/00	11.17.00	8.0	100	ran out	of	sx	24	100	ran out		of sx	24	45	2.0	ran out	of	sx
Class A	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	11.27.00	8.0	100	482	754.33	Pass	24	100	1666	2607.29	Pass	24	45	2.0	471	737	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-3	12/04/00	12.05.00	8.0	100	ran out	of	sx	24	100	ran out		of sx	24	45	2.0	ran out	#VALUE!	sx
Class A	9/25 to 9/27/00	11/06/00	C-113 A-4	01/09/01	1.17.01	8.0	100		0		24	100	1652	2585.38	Pass	24	45	2.0		0	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	2.12.01	8.0	100	466	729.29	Pass	24	100	1615	2527.475	Pass	24	45	2.0	666	1042	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.15.01	8.0	100	595	931.175	Pass	24	100	1641	2568.165	Pass			2.0		0	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.22.01	8.0					24	100		2334	Pass			2.0			
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.22.01						24	100		2590	Pass			2.0			
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.22.01						24	100		2250	Pass						

TXI Information		CSI Information				CSI 60°F Strengths						CSI 80°F Strengths				
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	Time Hr	Temp °F	% CaCl2	Old	Str psi 1.565	Pass/ Fail	Time Hrs	Temp °F	Old	Str psi 1.57	Pass/ Fail
Class A	9/25 to 9/27/00	01/00/00	C-113 A-1	11/09/00	11.17.00	24	60	1.0	ran out	of	sx	24	80	1052	1646	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	11.27.00	24	60	1.0	763	1194		24	80	1079	1689	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-3	12/04/00	12.05.00	24	60	1.0	ran out	#VALUE!	sx	24	80	1292	2022	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-4	01/09/01	1.17.01	24	60	1.0		0		24	80		0	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	2.12.01		60	1.0		0					0	
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.15.01					0					0	
Class A	9/25 to 9/27/00	01/00/00	C-113 A-5	11/09/00	2.22.01											
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.22.01											
Class A	9/25 to 9/27/00	11/06/00	C-113 A-5	11/09/00	2.22.01											

TXI Information		CSI Information					CSI Rheology										
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	Temp °F	300 rpm	200 rpm	100 rpm	60 rpm	30 rpm	6 rpm	3 rpm	PV	YP	10 sec G.S.	10 min G.S.
Class A	9/25 to 9/27/00	11/06/00	C-113 A-1	11/09/00	11.17.00	80	75	62	48	40	33	17	10	40.5	34.5	10	19
Class A	9/25 to 9/27/01	11/06/00	C-113 A-2	11/20/00	11.20.00	80	80	65	49	40	34	17	10	46.5	33.5	10	19
Class A	9/25 to 9/27/02	11/06/00	C-113 A-3	12/04/00	12.5.00	80	78	64	50	40	32	16	10	42	36	10	19
Class A	9/25 to 9/27/03	11/06/00	C-113 A-4	01/09/01	1.09.01	80	80	65	52	40	33	17	11	42	38	10	20
Class A	9/25 to 9/27/04	11/06/00	0	01/00/00										0	0		
Class A	9/25 to 9/27/05	11/10/00	0	01/00/00										0	0		
Class A	9/25 to 9/27/00	11/06/00	0	01/00/00										0	0		
Class A	0	3/19/01	C-189 A-1	3/20/01										0	0		

TXI Provided Information		CSI Information				CSI Thickening Time					
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	15 to 30 ft Bc	100 Bc	Pass/ Fail
Class A	9/25 to 9/27/00	11/06/00	C-113 A-1	11/09/00	11.15.00	46.0	4	9	10	2:17	**Pass**
Class A	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	1.5.01	46.0	4	8	11	2:21	**Pass**
Class A	9/25 to 9/27/00	11/06/00	C-113 A-3	12/04/00	1.09.01	46.0	4	4	**ran**	**out**	**of sx**
Class A	9/25 to 9/27/00	11/06/00	C-113 A-4	01/09/01	1.17.01	46.0	4	4	6	2:09	**Pass**
Class A	9/25 to 9/27/00	11/06/00									
Class A	9/25 to 9/27/00	11/06/00									
Class A	9/25 to 9/27/00	11/06/00									

Appendix E— Technical Literature Review of Lightweight Cement Performance

1. Light Weight Cement Systems, What They Are - How They Are Used. L. H. Eilers, Dowell Div., Dow Chem, Proc. Annu. Southwest. Pet. Short Course (1980), 27th

A review, with 10 references, on lightweight cement systems and the role of water and extenders.

2. Low-Density Foamed Portland Cements Fill Variety of Needs R. Montman, D. L. Sutton, W. M. Harms, B. G. Mody Halliburton Serv. Oil Gas J. (1982), 80(30), 209-16

A review, with 9 references, on the properties and uses of foamed cement in oil fields.

3. Cement Encapsulated Lightweight Fine Aggregate T. Yamamoto. Tohoku Denryoku K. K., Japan. Gypsum Lime (1989), 222, 304-10

A review, with 7 references, of the use of coal ash for granulation with cement-encapsulated sand and the manufacturing, physical properties, and uses of the cured material.

4. Lightweight Cement Additives W. Manns, W. Zem. Taschenbuch (1974), Meeting Date 1974-1975, 155-71. Bauverlag GmbH: Wiesbaden, Ger.

A review, with 22 references, is given on lightweight cement additives (bulk d. <1.5 kg/dm3).

5. Real-Time Quality Control of Foamed Cement Fobs: A Case Study. R.D. Thayer, D.G. Ford, S. Holekamp, D.J. Pferdehirt Proceedings of the SPE Annual Technical Conference and Exhibition. Part 3 (of 5). 03 Oct 1993-06 Oct 1993

Foamed cement is a low density cement system prepared by mixing nitrogen gas and surfactants with API portland cement. The lower density limit for conventionally extended slurries is between 11.0 and 12.0 lb/gal. Foaming permits cement slurry densities lower than water (8.33 lb/gal) while maintaining relatively high compressive strengths. These advantages and others have been well documented. Actual field mixing procedures and additive rates are critical and must be monitored to assure a competent foamed cement. Slight variations in base slurry density, base slurry rate, foamer and stabilizer rate, or nitrogen rate can significantly alter the final foam density. Formerly, foam density was measured by a radioactive densometer. This allowed for significant error when densities were less than 8.33 lb/gal. There was no physical means to collect and weigh an actual foamed cement sample.

This paper explains methods to improve the accuracy of the additive rates. It also defines a method for real-time measurement of foamed cement density. The paper describes the use of a high-pressure device downstream of the nitrogen addition that can weigh a pressurized foamed cement sample during the job. It discusses the use of concrete technology to improve the performance of lightweight cements.

6. E. Moulin (Schlumberger Dowell), P. Revil, B. Jain. Proceedings of the 1997 SPE/IADC Middle East Drilling

To successfully cement across and isolate formations with low fracture gradients requires the use of lightweight cement slurries. Conventional lightweight slurries usually have a high water-to-solid ratio, which results in long waiting-on-cement times, limited compressive strength development, and a relatively permeable cement sheath subject to acid and brine attack. A new approach to designing cement slurries effectively decouples the physical properties of set cement from the slurry properties and density, resulting in high performance lightweight cement slurries that reduce rig time and the logistics and costs associated with using conventional slurry designs. This has been clearly demonstrated in the cases of completing in reservoirs with a low fracture gradient (eliminating the risk of block squeeze), replacement of two-stage cement jobs by a single stage, and the use of a single slurry to replace lead/tail cement and side-track plugs. Results are described from various field applications where the technology has been used.

7. Sodium Metasilicate-Modified Lightweight High Alumina Cements For Use as Geothermal Well-Cementing Materials. T. Sugama, N. Carciello. Advanced Cement Based Materials v 3 n 2 Mar 1996.p 45-53

In studying the use of sodium metasilicate- (SMS) modified high alumina cements containing mullite-shelled microspheres as light-weight geothermal cementitious materials, we found that the following were the most advantageous characteristics of the slurries and of the 200 and 300°C autoclaved cements: (1) the slurries have a low density of less than 1.25 glcc, (2) the incorporation of SMS retarded the setting of the cements, (3) sodium calcium silicate hydrate and boehmite were formed in the matrix phase by hydrothermal reactions between the cement and SMS, and (4) there was a favorable reaction between the mullite shell layer in the hollow microspheres and the SMS to form analcime and boehmite phases. For characteristics (3) and (4), the pronounced development of these phases at 300°C generated a dense microstructure in the cements and was reflected by a reduced water permeability and a low rate of porosity.

8. Use of 1.6/1.7 kg/l Slurry For Cementing Production Casings. P. Macculi (AGIP). Proceedings of the 1997 SPE/IADC Middle East DrillingTechnology Conference.

A major concern in drilling operations is the problem of carrying out cementing jobs for production casings where no fracture margin during the slurry displacement exists. In general, a double stage cement job, the use of a liner with a subsequent tie-back or one more casing string is required to resolve this problem.

9. In the Adriatic Offshore we have experimented with the use of lightweight high mechanical resistance slurry (SG equals 1.6/1.7 kg/l) in 7-in. production casing cement jobs in order to complete the operation in a single stage. These cement jobs have been carried out, with positive results, in six of the fourteen Angela platform wells, in three of the four Antonella platform wells, in one Anemone cluster well (double-stage cementing to avoid one more casing string), in the Antares 1 s.t. and the Agostino 11 s.t. wells.

The wells, where the 1.6/1.7 Kg/l lightweight slurry has been used, have an average total depth of 3600 m VD, their intermediate casing shoes are set at an average depth of 1800 m VD. The use of lightweight slurry, composed of 10/30% microsilica by cement, has led to a reduction in the hydrostatic load, an optimization of rheology and filtration control (maximum differential pressure of 400 atm exist at the end of displacement) while guaranteeing the necessary high mechanical resistance. According to field data, we can conclude that the use of lightweight slurry has the following advantages: a single stage cement job can be used instead of the more complex double stage one with the consequent improvement in well and rig safety; in particular cases, a lightweight slurry can avoid setting one more casing string; improved quality of the cement job in comparison with the not always reliable results of a double-stage cementing; operational time and cost reduction.

10. Increasing Well Life by Eliminating the Multistage Cementer and Utilizing a Light Weight High Performance Slurry. T. Mukhalalaty, A . Al Suwaidi, M. Shaheen. Schlumberger Dowell. SPE 11th Middle East Oil Conference (Bahrain 2/20-23/99) Proceedings 425-37 (1999) (SPE Paper #53283)

Increasing well life by eliminating the multistage cementer and utilizing a lightweight high performance slurry. A discussion covers the annulus pressure problem; losses during cementation; poor set cement mechanical properties; different casing schemes; lightweight cement slurries, including those with ceramic hollow spheres; a reduced water slurry system; set cement properties, including compressive strength and permeability; and four case histories. Tables, diagrams, graphs, and references.

11. Application of Foam Cements in Alberta. Olanson, M. T. J Can Pet Technol v 24 n 5 Sep-Oct 1985 p 49-57.

The demand for lightweight cement in areas of low-strength formation has led to the increased use of foamed cement in PanCanadian's wells. Foamed cementing involves mixing surfactant upstream of the cement pumper and injecting nitrogen into the pumper discharge line, with a foam generator installed downstream. The 'constant foam density method' was used. Recent field tests by PanCanadian confirmed that foamed cementing is only slightly more expensive than conventional cement jobs but less costly and involving less mechanical risk than multi-stage jobs. At the same time, it can be considerably less expensive than glass or ceramic microspheres cementing.

12. Foamed Cement a Second Generation N. R. Loeffler, Dow Chem. U.S.A., Dowell Div. Spe (Soc. Pet. Eng. Aime) Permian Basin Oil Gas Recovery Conf. (Midland, Tex. 3/8-9/84) Proc. N.12592, 153-59 (Mar. 1984)

A survey of new applications for foamed cement shows that lightweight nitrified cement systems placed across weak and washed-out zones have been successfully perforated and fractured. For example, an 8.0- to 8.5-lb/gal nitrified cement replaced costly and time-inefficient cement staging in air-drilled holes with fracture gradients in the 0.4- to 0.6-psi/ft range; cost savings for one such treated well was more than $12,000 compared with cementing by staging methods. To meet the special needs of steam flood wells, low-density (> 12 lb/gal) extended cement systems such as bentonite/sodium silicate, perlite, fly ash, hollow glass spheres, etc., are suggested.

Performance data for a 9-lb/gal cement containing glass spheres vs. a 9-lb/gal high-temperature foamed system show major losses of compressive strength; although the foamed system maintains an adequate level of strength (700 psi), the cement containing the microspheres undergoes an immediate severe loss (to < 200 psi). The three general criteria for successful oilfield foamed cement performance are also discussed.

13. ACI Manual of Concrete Practice 1999: Volume 1 Materials and General Properties of Concrete

Part 1 of the American Concrete Institute (ACI) Manual of Concrete Practice contains current committee reports and standards concerned with materials and general properties of concrete. The contents include information on the following topics: concrete notation; cement and concrete terminology; concrete construction and materials tolerances; recommended format for concrete identification in a materials property database; concrete condition survey; concrete durability; mass concrete; cracking of mass concrete; roller compacted mass concrete; prediction of creep, shrinkage and temperature effects in concrete structures; concrete erosion and repair in hydraulic structures; selecting proportions for normal, heavyweight, and mass concrete, structural lightweight concrete, no-slump concrete, and high strength concrete; concrete admixtures; superplasticizers; lightweight aggregate concrete; design of concrete structures subjected to fatigue loading; fire endurance of concrete; use of normal and heavyweight aggregates in concrete; alkali-aggregate reactivity; corrosion of metals in concrete; shrinkage-compensating concrete; selection and use of hydraulic cements; controlled low strength materials; soil cement; pozzolans, fly ash, blast-furnace slag, and silica fume in concrete; high-strength concrete; and high-strength concrete columns.

14. Improved Performance of Lightweight Cement Slurries. JPT, Journal of Petroleum Technology v 49 n 8 Aug 1997.p 852-853

Lightweight slurries are used for cementing across formations with low fracture gradients. Conventional lightweight slurries have a high water-to-cement ratio that results in long waiting periods during cementing, slow development strength, and a relatively permeable cement sheath that is subject to acid and brine attack. However, a new engineering approach has eliminated these characteristics. The resulting high-performance lightweight slurries reduce the rig time, logistics, and costs associated with conventional designs. The new approach considers the quality of the granular mixture in terms of its water demand and optimizes particle size distributions.

15. Fundamental Study on the Properties of High Strength Lightweight Concrete (Part 5).

Tsuiba Hiroyuki; Honda Satoru; Araki Aya, Fukuoka Univ. (Fukuoka University Review Of Technological Sciences), (1993) No. 50, Pp. 137-147. Journal Code: S0905A (Fig. 11, Tbl. 6, Ref. 9) ISSN: 0285-2799

PUB. COUNTRY: Japan

DOCUMENT TYPE: Journal; Article

LANGUAGE: Japanese

AB Super high-rise reinforced apartment buildings with frame-type, ranging 30 to 40 stories, have become popular in Japan among leading construction companies. Therefore, this paper presents to a comprehensive review of high strength concrete with kinds of test specimens (model test specimen, molded cylinder test specimen), coarse aggregates (crushed stone for concrete, artificial light- weight aggregate), water cement ratios (30, 35, 40, 45, 50%) and curings (standard curings, water curings, sealed curings, air-dry curings). The cement was used a normal Portland cement and the water cement per cubic was 170 kg. The concrete was 21cm slump were prepared by using superplasticizer and high-range water reducing agent. Effect of compressive strength, Young's modulus, tensile strength, pulse velocity, rebound number by core test specimen (model test specimen) and cylinder test specimen were chiefly studied. (author abst.)

16. Using Concrete Technology to Improve the Performance of Lightweight Cements. Eric Moulin (Schlumberger Dowell); Philippe Revil, Bipin Jain. Proceedings of the 1997 SPE/IADC Middle East Drilling Technology Conference. Proceedings of the IADC/SPE Asia Pacific Drilling Technology Conference, APDT 1997. Soc Pet Eng (SPE), Richardson, TX, USA.p 243-248 SPE/IADC 39276

To successfully cement across and isolate formations with low fracture gradients requires the use of lightweight cement slurries. Conventional lightweight slurries usually have a high water-to-solid ratio, which results in long waiting-on-cement times, limited compressive strength development, and a relatively permeable cement sheath subject to acid and brine attack. A new approach to designing cement slurries effectively decouples the physical properties of set cement from the slurry properties and density, resulting in high performance lightweight cement slurries that reduce rig time and the logistics and costs associated with using conventional slurry designs. This has been clearly demonstrated in the cases of completing in reservoirs with a low fracture gradient (eliminating the risk of block squeeze), replacement of two-stage cement jobs by a single stage, and the use of a single slurry to replace lead/tail cement and sidetrack plugs. Results are described from various field applications where the technology has been used. (Author abstract) 8 References.

17. Basic Cementing-2. Specialty Cements Can Solve Special Problems. Pat N Parker, Oil Gas J v 75 n 9 Feb 28 1977 p 128-131

Part 2 of this article reviews a number of specialty cements formulated by service companies and cement manufacturers to solve special problems encountered in oil wells. These cements, which are essentially modified Portland cements or cements manufactured from limestone, can handle both pressure and temperature extremes. Among the specialty cements discussed are pozzolan slurries, lightweight cements, thixotropic cement, and quick-setting cements.

18. Next-Generation Cementing Systems to Control Shallow Water Flow. Ronnie Faul, B. R. Reddy, James Griffith, Rocky Fitzgerald, Bryan Waugh. 32nd Annual Offshore Technology Conference - OTC 2000; Proceedings of the Annual Offshore 19. Technology Conference v 1 2000. Offshore Technol Conf, USA.p 117-122

As documented in industry literature, shallow hazards, especially shallow water flows (SWF's), pose a challenge in deepwater Gulf of Mexico operations. Cement systems that successfully solved SWF's were first used in 1992. The first of these special systems was a lightweight nonfoamed system. In 1994, special foamed lightweight systems were implemented and were proven superior both in large-scale laboratory models and in field use. Several special foamed-cement blends have been used to cement over 300 conductor casings where SWF's were a threat. These formulations consisted of highly activated cements that required special blending at the shore base before being transported to the offshore rig. Because dry additives were used, the cement slurry could not be redesigned or modified, so any unused blend had to be discarded. To address these challenges, the industry developed a lightweight foamed-cement (LFC) slurry system. This system uses only liquid additives in conjunction with the dry Portland cement on board the rig. The LFC system provides a low-density slurry with short transition times to help prevent SWF's while maintaining zonal isolation, adequate placement time, and shorter waiting-on-cement (WOC) time.

20. Foamed Cement for Squeeze Cementing Low-Pressure Highly Permeable Reservoirs. Design and Evaluation. W. Chmilowski, L.B. Kondratoff. Drilling Proceedings - SPE Annual Technical Conference and Exhibition v Delta. Publ by Soc of Petroleum Engineers of AIME, Richardson, TX, USA.p 231-245

Squeeze cementing is a highly used remedial technique that relies on controlled slurry placement as the key to success. Typically, competent low-permeability reservoirs with normal bottomhole pressures are routinely cement squeezed with little difficulty, as long as the established techniques for conventional cement squeezing are properly followed. Formations with low reservoir pore pressure and high permeability can create severe challenges for proper placement, especially if the high permeability is due to naturally occurring formation vugs and fractures. Recently, a new technique using low-density foamed cement proved to be successful in providing a squeeze cementing method offering a much higher probability of success. In this paper, a number of key aspects that are critical to the success of squeeze treatments in these difficult reservoirs are discussed. Candidate selection, slurry design, treatment design, operational considerations, and an evaluation of squeeze treatment results are included. The evaluation focuses primarily on foamed and conventional cement squeeze treatments on wells producing from the Keg River formation in the Rainbow Lake area of northwestern Alberta, Canada. Ninety-six individual well case histories involving 151 remedial cementing operations were evaluated to determine their success. (Author abstract) 16 References

21. New Generation Foam Cement - A Universal System for Cementing A. Ruch. Oil Gas European Magazine 26/3 16,17-22 (September 2000) ISSN: 0342-5622

A discussion on nitrogen foamed cement slurries, known as foamed cement, which have been used for cementing operations in the petroleum industry for more than a decade, covers the single components of the system. Foam-Cement; various applications for foamed cement, including lightweight cement slurries, avoidance of fluid-migration, optimization of cement sheath properties; steam-injection and geothermal projects, and squeeze-applications; prerequisites and selection process for the foamed cement system; preparation, planning, and simulation for a cement job; foamed cementing equipment and job site layout; foamed cement job execution; case histories of recent foamed cement jobs, including 9.625-in. gas storage production casing across formations with different pore pressure; and limitations on economics. 3 photomicrographs, 10 graphs, flow diagram, and 7 references.

22. Bond Of Lightweight Aggregate Concrete Incorporating Condensed Silica Fume P.J Robins. Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Proceedings Second International Conference, Madrid, Spain, Volume 2, Aci Special Publication, 1986., No. Sp91. P. 941-58. 27 Refs., American Concrete Institute

Condensed silica fume, at up to 30% by weight, was used as a partial cement replacement in lightweight aggregate concrete. The results of round and deformed bar cube pullout tests, with and without applied lateral stress, show that condensed silica fume increases ultimate bond strength and affects the mechanism of failure. The influence of condensed silica fume on bond stress of round bars was similar at all lateral stresses, producing a 50% increase at 20% by Weight replacement of cement. For deformed bars the increase in bond strength was more pronounced at higher levels of lateral stress, Producing increases approaching 70% at 20% silica fume content. The improvements in ultimate bond strength with condensed silica fume are shown to only partly result from the associated increases in compressive strength, the greater part resulting from the modified properties of the concrete matrix.

23. A Novel Lightweight Cement Slurry And Placement Technique For Covering Weak Shale In Appalachian Basin S V Kulkarni; D S Hina, Spe East Reg Mtg (Charleston, Wv, 10/20-22/1999) Proc 1999 (Spe-57449)

24. Successful Primary Cementing Can Be A Reality R C Smith, Amoco Prod. Co, J. Pet.

Technol. V36 N.12 1851-58 (Nov. 1984) Successful Primary Cementing Can Be a Reality.

A review of primary cementing includes planning and slurry design; blending of additives and cement, and mixing of the slurry; slurry displacement; the adequate strength of ultralight-weight cements containing new additives such as hollow glass (borosilicate or sodium silicate) or ceramic microspheres, in well-completion situations requiring cement densities lower than those attainable with conventional lightweight cement containing additives such as bentonite, diatomaceous earth, or sodium silicate; spacers and preflushes; and free fall of cements.

25. Preventing Shallow Gas Migration In Offshore Wells: The Performance Of Lead Cements. O. D Coker, K.L Harris,T.A. Williams; Proc Eur Pet Conf.Publ By Society Of Petroleum Engineers (SPE), P.O.Box 833836, Richardson, TX, USA, 24978.P 159-169

Offshore drilling operations that encounter shallow gas formations must consider the potential annular gas flow that may occur following primary cementing. Many specialized cements and procedures have been developed to combat gas migration, but the complexities of gas migration control still challenge operators worldwide. In offshore shallow environments, additional complications can arise with the presence of weak formations and cold temperatures. In such conditions, lightweight lead cements are employed to avoid fracturing the wellbore. Although lead cements are often viewed simply as ‘filler’ materials, shallow gas control slurries must far exceed that role as they become the mechanism to help isolate the movement of gas up the annulus. Presented in this paper is a review of the properties of gas control cementing systems specifically related to lightweight lead slurries. The importance of fluid loss control, rapid gelation, and compressive strength at the time of drillout is stressed. Silica fume cement and newer cementing additives such as colloidal silica and small particle cement are highlighted as means of helping prevent shallow gas migration. Several offshore cementing operations are documented which confirm the success of applying the prescribed designs and methods.(Author abstract) 8 References

26. Pulverised-Fuel Ash J.B. Cripwell, (Natl Power Plc, Uk) The Use Of Pfa In Construction. Proceedings Of The National Seminar, Held At University Of Dundee On 25-27 February 1992 (1992) p.

This paper is intended to provide a brief introduction to pulverised fuel ash (PFA). It describes its production and properties, comments on handling and uses, makes references to health and safety requirements, and concludes with a review of research and development. PFA consists predominantly of finely divided spherical particles mainly in the size range of 1 to 150 microns. Chemically, it is an alumino-silicate glass containing some iron, calcium, magnesium and alkali metals together with carbonaceous particles resulting from incomplete combustion. Uses for PFA include: load bearing fill, aerated concrete blocks, lightweight aggregate, cement manufacture, grouting, fillers and stabilization in road bases and sub-bases.

27. Preventing Shallow Gas Migration In Offshore Wells: The Performance Of Lead [(Primary)] Cements. O. D. Coker, K.L Harris,T.A. Williams; SPE European Petroleum Conference (Cannes, France 11/16-18/92) Proceedings V1 159-69 (1992)

Preventing shallow gas migration in offshore wells: The performance of lead [(primary)] cements. A discussion covers the need for a primary cement which can prevent gas migration in shallow wells, especially in the North Sea; the importance of complete removal of drilling fluid prior to cementing; density requirements for such cements; the other required properties of such cements, including low fluid loss, rapid gelation, zero free water, low permeability, high early compressive strength, and adequate waiting-on-cement time; the additives which provide these properties, i.e., Portland cement, silica flour, an acrylamide copolymer to minimize fluid loss, a polymeric sulfonate dispersant, and a lignosulfonate retarder; and a case history of using light-weight cement in a well drilled in 236 ft of water in the North Sea to a depth of 2109 ft. Tables, diagram, well logs, and 18 references.

28. New Generation Foam-Cement - System For A Wide Range Of Cementing Operations. A Ruch,. Erdoel Erdgas Kohle/EKEP V 116 N 5 2000.P 267-272

LANGUAGE: German

In recent years the use of Foam-Cement for cementing casing or liner during drilling operations has undergone a major development. Used successful as lightweight cement in the last decades Foam-Cement is seen today more as a system for a wide range of cementing operations than a cement slurry alone. This is mainly due to the fact that optimized computer simulation programs and automated cementing equipment is available for accurate job planning and execution. This article explains the single components of the system Foam-Cement and lists reasons for its use to cement a casing or liner, especially in critical well situations or in wells demanding technically high standards.(Author abstract) 7 References

29. Cementing The Conductor Casing Annulus In An Overpressured Water Formation. James Griffith, Proceedings Of The 1997 29th Annual Offshore Technology Conference, OTC.Part 1 (Of 4).

The technique for cementing a 20- or 24-in. outside diameter conductor pipe offshore, in deep water, in the presence of pressurized water flow, which constantly threatens to wash cement away from the wellbore are described. The conductor pipe is cemented with a lightweight, foamed slurry with good compressive strength that helps control the water flow. Three key fluids are used such as foamed drilling fluid sweeps, settable spotting fluids and foamed cement slurries. The foamed sweeps are used to brings cuttings out of the wellbore. The settable fluids have low gel strength and are composed to provide fluid-loss control. The combination of settable spotting fluid and cement slurry provides good zonal isolation of the water-flow interval.5 References

30. Mud Management, Special Slurries Improve Deepwater Cementing Operations. James Griffith, (Oil And Gas Journal V 95 N 42) Oct 20 1997. P 49-51

Deepwater cementing requires improved mud-management techniques. In the Gulf of Mexico (GOM), new mud-management techniques and specially designed cement mixtures are being used to effectively set conductor casing in deepwater conditions and to improve the success rate in cementing deepwater wells. Recent case histories in the GOM describe these new techniques and the advantages of using a specially formulated, lightweight, foamed cement slurry to avoid cement-sheath damage caused shallow-water flow. 4 References

31. Alkali-Aggregate Reactivity In Canada C. A. Rogers, Cem. Concr. Compos. (1993), 15(1-2), 13-9

A review and discussion with 23 references. In Canada, three types of alkali-aggregate reaction in Portland cement concrete are recognized. Each type is evaluated using different tests. Corrective measures such as the use of low-alkali cement, lower cement contents, or pozzolans are seldom used with reactive aggregates. Beneficiation or selective extn. is used with some reactive aggre-gates. Work is being conducted on multiple. study of existing tests and new, rapid tests.

32. Experimental Methods For Determining The Residual Alkali Silica Reactivity Potential In Concrete Structures Sharma, V.M.; Suri, S.B.; Chandrasekaran, N. Proc. - Int. Symp. Innovative World Concr. (1993), Volume 1, 2/193-2/203. Oxford & IBH: New Delhi, India.

A review with no references. It is essential to identify alkali reactive aggregates and their potential for deleterious expansion before their use in concrete. However, in the absence of the above evaluation, if the alkali silica reaction gets triggered in a concrete structure, determination of the residual alkali silica reactivity potential in the structure becomes inevitable for assessing its safety and durability. Laboratory testing can often be difficult, complex, time consuming and even inconclusive. Still, it is the best method to assess and evaluate the potential reactivity of aggregates prior to their use in concrete construction. While there are several established standard test methods available for determining the potential reactivity of cement-aggregate combinations and new and rapid test methods have been proposed, there are no standard test methods available for assessing the magnitude of the residual alkali-silica reactivity potential existing in a structure, for establishing its future damage potential.

33. Does Silica Fume Merely Postpone Expansion Due To Alkali-Aggregate Reactivity Berube, M. A.; Duchesne, J., Int. Conf. Alkali-Aggregate React. Concr., 9th (1992), Volume 1 71-80. Concr. Soc.: Slough, UK.

A review and discussion with 25 references. Condensed silica fume (CSF) is considered effective in suppressing concrete expansion due to alkali-silica reaction (ASR), provided it is used in sufficient amts. Various mechanisms can be proposed to explain this: higher strength, lower permeability, alkali diln., portlandite consumption in the cement paste and alkali depletion in the pore soln. due to pozzolanic reaction. The most crit. mechanism appears to be alkali depletion in the pore soln. and consequent pH decrease. However, the long-term effectiveness of CSF against ASR is presently questioned by a no. of workers. The proposed explanation is the recycling of alkalis which were entrapped early in low Ca/Si and high-alkali pozzolanic CSH. This hypothesis is based on expansion tests on concrete contg. CSF and reactive aggregates, and on chem. of pore soln. extd. at different time intervals from equiv. cement-admixt. pastes.

34. Pore Solution Chemistry And Alkali Aggregate Reaction Christopher Page And Philip Norman, Am. Concr. Inst., SP (1987), SP-100(Concr. Durability, Vol2, 1833-62

A review, with 39 references, of the progress in explaining the phenomena associated with alkali-aggregate reactions in terms of pore solution comparison. In particular, consideration is given to the effects of alkali level and water content of the concrete on the severity of reaction, the role of alkalis in pulverized fuel ashes, granulated blast-furnace slags, and other cement replacement materials in determining their effectiveness in preventing damage, and the contribution to pore solution alky. made by salt contamination of aggregates and deicing salts.

35. Some Opportunities To Offset Poor Quality Characteristics Of High-Alkali Cement Louis U. Spellman, Cem., Concr. Aggregates (1983), 5(1), 73-6

A review, with 18 references, concluding that inclusion of a substantial percentage of ground blast-furnace slag in cement manuf. minimizes the alkali-aggregate reactivity and the decreased rates of strength gain at later ages.

36. Reducing Expansion Due To Alkali- Silica Reactivity Fournier, B.; Malhotra, V. M. Concr. Int. (1996), 18(3), 55-9

A review with no references, including general objectives and scope of the research program, petrog. of the aggregates, portland cement and supplementary cementing materials, mixuture, proportioning, lab. and field testing of specimens, and general observations on test results.

Review Of Alkali-Silica Reaction And Expansion Mechanisms. Alkalies In Cements And In Concrete Pore Solutions Diamond, Sidney Cem. Concr. Res. (1975), 5(4), 329-45 A review with 35 references.

37. Alkali-Aggregate Reactions And The Middle East. French, W. J.; Poole, A. B. Concrete (London) (1976), 10(1), 18-20

A review with 16 references is given on the chem. and phys. mechanisms associated with reactions between alkalis derived from cement pastes and aggregates of SiO2 minerals or carbonate rocks to explain the causes for the rapid deterioration of some concrete structures.

38. Durable Concrete Containing Three Or Four Cementitious Materials Butler, W. Barry, Am. Concr. Inst., SP (1997), SP-170(Vol. 1, Durability Of Concrete), 309-330

A review with 25 references In most concrete markets these days, there are several varieties of pozzolans and ground slag available for use in regular and high-performance concretes. Each one has its strong points when blended with portland cement in concrete and, properly used, will provide concrete of enhanced durability. Recently, concrete contg. more than one such material has become common, even to the point of being available as ternary or quaternary blend. This paper reviews the data available on durability of concrete produced from multiple blends and discusses some of the potential benefits to specifiers and users. The blending materials covered include silica fume, fly ash, metakaolin, and ground granulated slag.

39. High-Alkali Cements For 21st Century Concretes, Davidovits, J., Am. Concr. Inst., SP (1994), SP-144(Concrete Technology), 383-97

A review with 27 references Recent literature suggests that there is considerable potential for redn. in the emission of CO_2 to the environment through the manuf. of new types of cement which do not rely on the calcination of limestone (and accompanying release of CO_2). The 1988 one billion metric tons world-wide production of cement accounted for one billion metric tons of CO_2 release, i.e. 5% of the 1988 world CO_2 emission (human activity only). This is equiv. to the CO_2 emission by the entire Japanese activity. The use of lesser amounts of calcium-based cements could be achieved through their partial replacement by alkali-activated aluminosilicate materials, which do not release large quantities of CO_2 in their manuf. The fostering of low-CO_2high-alkali-based cements will mean a dramatic change in the research and development presCO_2ently carried out in USA and other countries. Alkalis are generally thought of as the cause of deleterious alkali-aggregate-reaction. As a consequence, the tendency has been to avoid any addn. of alkali portland cement products, and often require the cement manufacturers to supply low-alkali cements. The use of MASNMR spectrog. for the detns. of compounds of alkali-activated cements, in combination with std. ASTM C 227 bar expansion, allows us to predict the potential for alkali-aggregate reaction. Our preliminary study involving 27Al and 29Si MASNMR spectroscopy revealed that the alkali-activated aluminosilicate cements are the synthetic analogs of natural pozzolans that are known to effectively suppress the alkali-aggregate reaction. These cements, even with alkali contents as high as 9.2% do not generate any deleterious alkali-aggregate reaction, according to ASTM C 227 bar expansion test. Industrial experience based on the use of alkali-activated slags in Eastern Europe since 1964, associated with the com. produced alkali-activated cements in the US since 1988, suggest that high-alkali cements will ultimately improve the concrete used in buildings and highways, and also serve our global need by a) reducing the emission of CO2 b) reducing the energy consumption during cement manufacturing in terms of a 5% growth scenario, the predicted Business as Usual (BaU) world cement production for the year 2015 equals 3500 million metric tons. Based on an amt. of blended Portland cement production in the order of 1850 million metric tons (1000 Mt. Portland + 560 Mt. slag + 290 Mt. fly ash), in the 21st century, the need for novel alkali-activated cementitious materials could be in the range of 1650 million metric tons.

40. The Alkali-Silica Reaction In Concrete. Chapter 1 - Introduction To Alkali-Aggregate Reaction In Concrete Swamy, R.N. [Editor] (Sheffield Univ, Uk); Poole, A.B. (London Univ, Queen Mary And Westfield College, Uk) 1992. P. 1-29. 43 Refs., Blackie And Sons Ltd

This chapter introduces and defines the nature of alkali-aggregate reactions in concretes. Alkali-silica reactivity in concrete is a particular variety of chemical reaction within the fabric of a concrete involving alkali hydroxides, usually derived from the alkalis present in the cement used, and reactive forms of silica present within aggregate particles. This chemical reaction also requires water for it to produce the alkali-silica gel reaction product which swells with the absorption of moisture. The amount of gel and the swelling pressures exerted are very variable depending on reaction temperature, type and proportions of reacting materials, gel composition, and other factors, but they are often sufficiently high to induce the development and propagation of microfractures in the concrete which, in turn, lead to expansion and disruption of the affected concrete structure or element. Typical deleterious features of alkali-silica reaction in concrete structures include cracking, expansion and consequent misalignment of structural elements, spalling of fragments of surface concrete as ‘pop-outs’, and the presence of gel in fractures or associated with aggregate particles within the concrete. The reaction typically takes between 5 and 12 years to develop, though there are many exceptions, and it is most severe where alkali concentrations in the concrete pore fluids are high. A very wide variety of aggregate rock types in structures from many parts of the world have been reported as being alkali-silica reactive. This is consequent on the reactive forms of silica often only forming a minor mineral component of the aggregate such as the cement between mineral grains. This silicious material must be amorphous or cryptocrystalline with a large surface area if it is to react sufficiently to produce deleterious effects in the concrete. (A) For the covering abstract of the BOOK see IRRD 844648.

41. Concrete Durability And Alkali Reactions. Figg, John Concrete (London) (1981), 15(8), 18-22

A review, with 14 references, discussing equiv. alkalinities of alkali metals, adverse effects of alky., cement compounds and hydration, concrete performance, alkali-aggregate reactivities, the reaction mechanism and symptoms, parameters affecting the reaction, and preventive and remedial measures.

42. Proceedings Of The 1996 10th International Conferenceon Alkali-Aggregate Reaction, AAR. Cement & Concrete Composites V 19 N 5-6 Oct 1997.Elsevier Sci Ltd, Exeter, Engl.P 391-480

The proceedings contains 6 papers on cement and concrete composites. Topics discussed include: cements; concrete aggregates; alkali-silica reaction; alkali-aggregates reactivity; ultra-accelerated tests; fracture mechanics; crack initiation; crack propagation; nondestructive techniques; mortar bar tests; and petrographic evaluation.

43. Possibility Of Enhanced Silica Dissolution In Concrete As In Diagenetically Altered Sandstone. Broekmans, Maarten A. T. M.; Jansen, J. Ben. H. Bull. - Nor. Geol. Unders. (1997), 433, 42-43

A review and discussion, with 13 references, of the alkali-silica reaction in concrete and the need for tests predicting the reactivity of aggregates. Sandstone as an aggregate is theoretically less prone to silica dissoln. compared with chert. Study of thirty-year-old concrete showed that fine-grained sandstone with detrital mica and diagenetic clay minerals is extremely alkali-reactive, whereas chert in the same samples reacts only slightly. Recent studies have demonstrated the catalytic interaction of phyllosilicates like mica and clay minerals in silica dissoln. and diagenetic sandstone compaction and cementation.

44. ASR Testing Remains In Technology Spotlight.(Test Methods For Alkali-Silica Reactivity). Kuennen, Tom Concrete Products, (May 1999) Vol. 102, No. 5, Pp. 6(4).

Editor’s note: Test methods for alkali-silica reactivity (ASR) were among concrete program highlights at the Transportation Research Board’s (TRB) 78th annual meeting in Washington, D.C. ASR testing shared the stage with new research on admixtures and fibers, freeze-thaw durability, and D-cracking prediction. Separately, an eight-member panel discussed High-Performance Concrete (HPC) pavements (note Concrete Products’ March 1999 report, “FHWA to Inject $30 Million into HPC Pavement Studies.”). THIS IS THE FULL TEXT:

45. Durability of cement pastes, mortars, and concretes Struble, Leslie, Cem. Res. Prog. (1989), Volume Date 1987 157-238

A review, with 638 references, including discussions of general durability (effects of concrete parameters, quant. studies), permeability, aggressive environments (sulfates, chlorides, seawater, CO2, other), alkali-aggregate reactions (mechanisms, reactivity tests, constituent effects, practical aspects), freeze-thaw (mechanisms, test methods, constituent effects, air entrainment), reinforcement corrosion (glass, steel, other), drying shrinkage, thermal degrdn., efflorescence, and abrasion.

46. A Critical Review Of The Recent Danish Literature On Alkali-Silica Reaction. Chatterji, S. (Teknol Inst, Taastrup, Denmark) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 37-42. 14 Refs.

In Denmark researches on alkali-silica reaction have been carried out in two distinct phases. In the first phase the problem was identified as a national one. Opaline limestone, and flint of varying degree of crystallinites and porosities were identified as the main reactive aggregates. At this stage the use of a low alkali Portland cement was suggested as the effective preventive measure against alkali-silica reaction. The second phase of research started with an investigation of the breakdown of concrete roads, which indicated that NaCl, a de-icing agent, accelerates alkali-silica reaction and that the presence of free Ca(OH)2 is a pre-requisite for expansive alkali-silica reaction. At the same time the electron-probe micro-analytical technique was adapted for the analysis of the reaction products still within expanding structures. In subsequent investigations the above observations and the analytical technique were utilized to explore the reaction mechanisms, in the development of an accelerated mortar bar method for alkali-silica reactivity with its acceptance criterion, in the development of a simple chemical method for the identification of reactive aggregates. Independently of the above researches a method has been proposed to monitor continuously the dissolution of reactive silica in 10N NaOH solution as a means of evaluating alkali- silica reactivity. In this report the literature of this second phase of research has been critically evaluated. (A) For the covering abstract of the conference see IRRD 857024.

47. Alkali-Silica Reactions And Silica Fume: 20 Years Of Experience In Iceland. Gudmundsson, Gisli (Icelandic Building Research Inst, Reykjavik, UK); Olafsson, Hakon Cement and Concrete Research v 29 n 8 1999.p 1289-1297

In Iceland, silica fume has been blended with all Icelandic cement since 1979.Icelandic cement is unique in many ways. Common raw material for cement production is not found; therefore, less appropriate material is utilized for production. As a result, the alkali content of the cement clinker is relatively high. Because alkali-silica reactive aggregates are relatively common and favorable environmental conditions for alkali-silica reaction (ASR) prevail, ASR became a serious problem in Iceland during the 1970s.At that time research began in Iceland to look for pozzolanic material to counteract ASR reactions in Icelandic concrete. Since the opening of a ferrosilicium plant in Iceland in 1979, silica fume has been utilized as pozzolanic material in all concrete. After 20 years of service there are no signs of ASR in this concrete in Iceland. These findings are supported by scientific research, standardized alkali-silica test methods, and field observations. (Author abstract) 22 References

48. State-Of-The-Art Report On The Mechanism Of Alkali-Aggregate Reaction In Concrete Containing Fly Ash. Interim Report Schumann, D.C.; Carrasquillo, R.L.; Farbiarz, J. Published By: Texas State Department Of Highways & Public Transp (01 Feb 1988), No. 884502. P. 108. 115 Refs. Published by: Federal Highway Administration

Although aggregates were once thought to be inert, it is now known that all aggregates are chemically reactive. The chemical reactions between the aggregates and the cement paste are responsible for beneficial effects such as enhanced bond, but also for other effects that can be deleterious to the durability of the concrete. Alkali- aggregate reaction is one of such chemical reactions. its chemistry and mechanism are not yet very well known but several hypotheses have been presented over the years and are reported herein. The prevention of expansion in concrete due to alkali-aggregate reaction has been widely investigated by many researchers around the world. It is now known that the proper use of mineral admixtures in concrete can reduce the cost of concrete, improve many material properties, and inhibit alkali-silica reaction. The effect of fly ash and silica fume and a summary of the probable mechanisms in which pozzolans affect the expansion caused by alkali-aggregate reaction in concrete is also reviewed, as well as the different methods of predicting the Reactivity of aggregates and a discussion of their relative accuracy and validity. Research study title: alkali-aggregate reaction in concrete containing fly ash.

49. Use Of Cement Kiln Dust In Blended Cements - Alkali-Aggregate Reaction Expansion. Bhatty, Muhammad S.Y. (Pca, Skokie, Il, Usa) World Cem V 16 N 10 Dec 1985 P 386, 388-390, 392

Blended cements made from Portland cement, cement kiln dust and fly ash (ASTM Class F) or granulated blast furnace slag were studied for alkali-aggregate reactivity using the mortar bar expansion test. Beltane opal was used as a reactive aggregate in mortar bars. Blended cements made from cement and kiln dust showed higher expansions at 6 months than cement alone. Expansion increased even more as the level of kiln dust in blends was increased. Cement-kiln dust-fly ash blends produced lower expansion than corresponding cement-kiln dust blends with the same amount of kiln dust, and an increase in fly ash in blends further reduced expansion. Fly ash was a much better expansion inhibitor than slag in comparable blends. (Edited author abstract) 3 references

50. Alkali-Silica Reaction In Australian Concrete Structures Carse, A. (Main Roads Dept, Brisbane, Australia); Dux, (Queensland Univ, Australia) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 25-30. 4 Refs., Document Type Book

This research investigation has placed significant emphasis on collecting field information of alkali-silica distressed structures and using this data to calibrate laboratory tests for predicting safe cement/aggregate combinations. It was determined that alkali- silica reaction has occurred in concrete bridges, a wharf structure and an off shore bulk loading facility. The age of the structures investigated ranges from 8 to 29 years with a corresponding period of construction from 1959 to 1980. Documentation is provided showing that the occurrence of alkali-silica reaction may not always cause destructive expansion in the associated concrete matrix. Two structures were analyzed and shown to exhibit alkali-silica reaction without any associated destructive cracking of the concrete structures. Four additional structures were shown to display similar alkali- silica reaction, however, in these cases associated destructive cracking of the concrete matrix had occurred. The reactive aggregates in the structures examined were identified as an extrusive volcanic source and a river gravel. It has been concluded from this project that the degree of alkali-silica reaction within a structure is dependent on environmental factors and can be magnified by an inadequate design concept. Details of an accelerated test for alkali-silica reaction on concrete samples are provided for use in determining safe cement/aggregate combinations.

51. Chemistry And Structure Of Hydration Products Christensen, Bruce J.; Garci, Maria C.; Olson, Rudy A.; Jennings, Hamlin M. Cem. Res. Prog. (1996), Volume Date 1994 25-50

A review, with 133 references, including discussions of pure compounds, cement hydration, effects of admixtures, creep and shrinkage thermodn., nanostructure, and reaction kinetics, alkali -aggregate reactions, composites, hydration processes of portland and high-alumina cements, hydration of other cement types, stabilization/solidification and utilization of waste materials, effects of minerals on the hydration process, and decomposition, and carbonation.

52. Effect And Mechanism Of Natural Zeolite On Suppressing Alkali-Silica Reaction (Asr) In Concrete. Feng, N.; Jia, H.; Hao, T.; Malhotra, V.M. [Editor] Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Location: Bangkok, Thailand. Held: 31 May - 5th June 1998, 1998., Vol. 2 P. 797-820. - Refs., American Concrete Institute

Effect and mechanism of natural zeolite (NZ) on preventing expansion due to alkali-silica reaction (ASR) are studied in this paper. The reduction of deleterious expansion by NZ is compared with that of three other cementitious materials: silica fume (SF), fly ash (FA), and blast-furnace slag (BFS). The order of effectiveness is SF>NZ>FA>BFS. When 30% zeolite blended cement with an alkali content of 1.82% Na2O equivalent is used in concrete, there will be no damage from ASR even if all the aggregates are reactive. The suppression of ASR by NZ is related to its fineness. The required dosage of NZ is about 20% at a surface area of 7000 cm squared/g with the same effect. Pre-heating of NZ at 500 degrees C increases the preventive effectiveness. The suppressing mechanism of NZ on ASR is decreasing the alkali ion concentration in the pore solution in concrete through ion exchange, adsorption, and pozzolanic reaction of NZ. So the formation of alkali silicate is prevented and the interface is improved.

54. Before Using Fly Ash. Barringer, William L. (New Mexico State Highway & Transportation Dep, NM, USA) Concrete International V 19 N 4 Apr 1997.P 39-40

Provided it is properly used, fly ash can be an excellent material for use in concrete. Aside from its price and its availability, the strength-gaining ability of the fly ash should be considered in proportioning. The spherical geometry of fly ash particles can aid in placing concrete; however, good quality mixes require consistent fly ash fineness. Moreover, the proportions of fly ash to be used depends on the concrete quality desired. Fly ash may lower the heat of hydration and mitigate the resultant thermal strain, provide strength gains that are not delayed, or lessen the effect of alkali-silica reactions or alkali-aggregate reactions depending on its proportion. Tests are suggested to determine the reaction of brands of fly ash with cement type. 2 References

55. The Alkali-Silica Reaction In Concrete (This Looks Like A Good Book To Order). Swamy, R.N. [Editor] (Sheffield Univ, Uk) 1992. P. Xv+333. + Refs., Blackie And Sons Ltd. Isbn: 0-216-92691-2 Publisher Blackie And Sons Ltd, Bishopbriggs, G64 2nz, Glasgow, United Kingdom, Country United Kingdom, Language English

The first four chapters of this BOOK are devoted to the basics of the alkali silica reaction (ASR) while the remaining chapters describe the experience gained globally in tackling the problem. Chapter 1 traces the history of ASR and describes in detail the nature of alkali aggregate reactions in concrete, the basic requirements for the reaction to initiate and propagate, the factors controlling the reaction and the observed effects of the reaction. Chapter 2 presents an analysis of the chemistry of the alkali-aggregate reactions and relates this to the chemistry of cements, mineral admixtures, and the mineralogy of aggregates. A critical review of the various test methods used to detect ASR is provided in Chapter 3. Experiences of ASR in the United Kingdom, Denmark, Iceland, Canada, New Zealand, Japan and India are then presented. For abstracts of some of the individual papers see IRRD 844649-844658.

56. Use Of Dynamic Nondestructive Test Methods To Monitor Concrete Deterioration Due To Alkali-Silica Reaction. Narayan Swamy, R.; Wan, Wmr. Cement, Concrete And Aggregates (1993), Vol. 15, No. 1. P. 32-49. - Refs.,

Dynamic nondestructive tests such as pulse velocity and dynamic modulus to monitor the initiation and progress of concrete deterioration due to alkali silica reactions (ASR) are reviewed. The study found that both pulse velocity and dynamic modulus are sensitive to material and structural changes arising from ASR and that they can respond reliably to changes prior to first crack, at first crack, and the progress of deterioration with time in concrete both with and without cementitious materials other than portland cement. It is noted, that with good engineering judgments, pulse velocity measurements can be used to assess structural deterioration due to ASR.

57. Expansive Reactions In Concrete Odler, Ivan; Jawed, Inam Mater. Sci. Concr. (1991), Volume 2, 221-47. Editor(S): Skalny, Jan P.; Mindess, Sidney. Am. Ceram. Soc.: Westerville, Ohio.

A review, with 60 references, of chem. reactions (other than alkali-aggregate reactions) that cause expansion in concrete and may lead to its deterioration. The most notable of these reactions are those involving sulfates of Ca, Mg, and alkali metals that form expansive products, essentially ettringite, in the concrete matrix. These sulfates may already be present in cement or may come from outside sources (sulfate attack). Various hypotheses on the mechanism of these reactions and the associated. vol. expansions are critically examined. The vol. expansion is harmful when allowed to proceed uncontrolled. However, if carefully controlled, it may, in fact, prove to be beneficial. This is the case with expansive cements that are used to produce pre-stressed concrete or to prevent cracking due to drying shrinkage.

58. Alkali-Silica Reaction In Concrete Hobbs, D.W. (British Concrete Association) 1988. P. 183. + Refs., Thomas Telford Books Isbn: 0 7277 1317 5 Publisher Thomas Telford Books, Thomas Telford House, 1 Heron; Quay, E14 9xf, London, United Kingdom; Document Type Book, United Kingdom, Language English

This book will give users and producers of cement, aggregate and concrete a better understanding of the alkali silica reaction (asr) and its effects upon concrete performance, and how the risks of damage occurring from the reaction can be minimized. Topics covered in the book include the reaction, alkalis in portland cement, alkalis from other sources, reactive silica, cracking and expansion, the diagnosis of the alkali silica reaction, its effects upon the properties of concrete and its structural performance, and remedial actions to counteract the damage caused. The effectiveness of various cement replacement materials in reducing the risk of asr is examined, and methods of testing aggregates and aggregate combinations with cement for their reactivity are explained. Finally, the procedures that are being adapted to minimize the risks of cracking in new construction are given.

59. The Inhibiting Effect Of Lithium Compounds On Alkali-Silica Reaction Sakaguchi, Y. (Nissan Chem Ind Ltd, Japan); Takakura, M. (Nissan Chem Ind Ltd, Japan); Kitagawa, A. (Nissan Chem Ind Ltd, Japan); Hori, T. (Nissan Chem Ind Ltd, Japan); Tomosawa, F. (Tokyo Univ, Japan); Abe, M. (Min Of Construction, Japan); Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 229-34. 4 Refs.; Document Type Book, Japan, Language English

Expansion of mortar bars, which contained Pyrex glass, due to alkali-silica reaction (ASR) was inhibited by addition of lithium compounds (lithium carbonate, lithium nitrite and lithium hydroxide). Lithium hydroxide was found also effective in inhibiting the expansion of mortar bars containing reactive aggregates. The inhibiting effect increased in proportion to the amount of its addition. Expansion was inhibited by impregnating the solution of lithium nitrite to both mortar bars and concrete prisms that had been subjected to accelerated expansion. The effects of lithium compounds were examined by observing the boundary face between Pyrex glass and hardened cement paste by means of energy dispersive X-ray spectrometer and by analyzing the extracted pore solution from the mortars. It was confirmed that the alkali-silica gel, the reaction product of Pyrex glass and hardened cement paste, was not observed at the boundary face, and that the concentration of lithium ion in pore solution decreased and that of sodium and potassium ion in it was nearly constant with the passage of time. In conclusion, these results suggest that the inhibiting effect of lithium compounds is attributed to the production of a kind of lithium silicate, which hardly swells and dissolves, at the surface of the aggregate. (A) For the covering abstract of the conference see IRRD.

60. Canmet Investigations Of Supplementary Cementing Materials For Reducing Alkali-Aggregate Reactions; Part 1 Granulated/Pelletized Blast Furnace Slags Soles, J.A. (Canmet, Ottowa, Canada); Malhotra, V.M. (Canmet, Ottowa, Canada); Chen, H. (La Farge Canada Inc); Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Proceedings Of The Third International Conference, Trondheim, Norway, 1989. Volume 2 (Aci Sp-114), 1989. P. 1637-56. 15 Refs., American Concrete Institute; Document Type Book, United States, Language English

The use of supplementary cementing materials for reducing harmful alkali-aggregate reactions (AAR) in concrete is being studied at the Canada Centre for Mineral and Energy Technology (CANMET). One investigation involves the use of three types of reactive aggregate and supplementary cementing materials that include fly ash, slag, silica fume and natural pozzolans. This report covers the part in which ground, granulated blast-furnace slags from one US and two Canadian sources were used to partially replace cement in concrete containing the three reactive aggregates. Test data include characterization of the materials used, their proportions in mixtures, concrete strengths, and 2-year expansion measurements of mortar bars and concrete prisms containing them. The test results indicate the effectiveness of the slags in reducing deleterious AAR, and their optimum replacement levels. These slags are all effective in controlling such reactions, particularly with the highly reactive Kingston dolostone. (A) For the covering abstract of the conference see IRRD 829586.

61. Comparison Of The Effectiveness Of Four Mineral Admixtures To Counteract Alkali-Aggregate Reaction. Durand, B. (Ecole Polytechnique, Montreal Canada); Berard, J. (Ecole Polytechnique, Montreal Canada); Soles, J.A. (Canmet, Ottawa, Canada) Proceedings Of The 7th International Conference On Concrete Alkali-Aggregate Reactions, Ottawa, Canada, 1986, 1987. P. 30-5. 7 Refs., Noyes Publications Isbn: 0-8155-1142-6; Document Type Book, United States, Language English

Two fly ashes, one silica fume and one granulated slag were used as admixtures to test the effectiveness of these pozzolans in reducing expansion of concrete due to alkali-aggregate reaction. Standard mortar bar (astm c-227) and concrete prism (csa.a23.2-14a) expansion tests were used to show the effects. Three types of aggregate were used, to represent the best known alkali - aggregate reactions: (1) trois-rivieres siliceous limestone—alkali-silica reactive; (2) kingston dolomitic limestone—alkali-carbonate reactive; (3) lady evelyn lake argillite—alkali-silica/ silicate reactive. Other experimental work included the measurement of ca(oh)2 content in the cement pastes, and microstructural examination of the pastes by scanning electron microscopy. The effectiveness of the mineral admixtures in reducing expansion was different for each of the three aggregates. Ca(oh)2 measurements and scanning electron microscopy revealed important differences related to the type of mineral admixture used and its replacement levels.(a) for the covering abstract of the conference see IRRD 811982.

62. Alkali-Silica-Reaction - A Risk For The Long-Term Stability?. Wieker, Wolfgang (Universitaet Berlin, Berlin, Ger); Betonwerk Und Fertigteil-Technik V 60 N 11 Nov 1994.P; LANGUAGE: English; German

The alkali-silica-reaction (ASR) is a concrete-damaging reaction that is brought about by a high alkali presence in the concrete, which can come from cement, additions or aggregates. These reactions lead to the formation of alkali silicates that, under moist conditions, lead to crack formation as a result of expansion phenomena. For the purpose of clarification of the reaction mechanism and finding ways of avoiding these concrete-damaging reactions, pore solutions from appropriate test specimens were pressed out and their composition analyzed. It was established that it is possible to suppress an ASR when the alkali concentration in the pore solutions is reduced by finely divided alkali binding additions (such as filter fly ashes, silica fume, etc.). 4 References

63. Mechanisms Affecting The Development Of Alkali-Silica Reaction In Hardened Concretes Exposed To Saline Environments. Sibbick, R.G. (Aston Univ, Birmingham, UK); Page, C.L.; Magazine Of Concrete Research V 50 N 2 Jun 1998.P 147-159

In circumstances where concretes containing UK aggregates with reactive siliceous components are exposed to high concentrations of NaCl there is conflicting evidence as to whether salt ingress enhances susceptibility to alkali-silica reaction (ASR).There is also uncertainty over the mechanisms involved. The research undertaken was intended to elucidate these issues. Expansion tests with concrete prisms and cores immersed in 2 and 7 M NaCl solutions at 20 and 38°C showed that significant ASR expansion and cracking could be induced in specimens containing the more highly reactive UK aggregates at alkali levels well below 3 kg/m3 Na2Oeq, which is the present recommended UK limit for minimizing the risk of ASR. Even concretes containing aggregates of lower reactivity (chert-bearing gravels, etc.) were found to exhibit significant ASR expansion when exposed to NaCl solution in specimens of 3 to 4 kg/m^3 Na_2Oeq. The role of NaCl ingress in exacerbating the development of ASR in concretes of varied composition was studied by thermoanalytical techniques and petrography combined with electron probe microanalysis. The mechanisms were found to depend on several features of the environment (NaCl concentration, temperature, etc.) and the composition of the concrete (type of reactive aggregate, alkali content, cement mineralogy, etc.). A simplified reaction scheme was proposed to account for the results obtained. (Author abstract) 18 References

64. Manufacture Of Supplementary Cementitious Materials From Cement Kiln Dust. Mishulovich, Alex (Construction Technology Lab, IL, USA); Hansen, Eric R. World Cement v 27 n 3 Mar 1996.p 116-120

The formulation and production of supplementary cementitious materials (SCM) based on cement kiln dust (CKD) was studied with the dual objective of waste reduction and inhibition of alkali-silica reactivity (ASR) in concrete. The SCM's were produced by melting and vitrification of mixes containing CKD with additives, such as clay, shale, and some industrial wastes, including power plant and incinerator ashes. The product chemical composition was close to low-melting eutectics in the ternary system CaO-SiO2-Al2O3 prime and most melts were produced at temperatures below 1200°C. Vitrification provided the necessary hydraulic reactivity of the product and prevented leaching of the trace elements present in source materials. Blended cements incorporating SCMs proved to be competitive with ordinary Portland cement in strength. Adding SCM to cement reduced the ASR-related expansion by 85 to 90% in the standard test with highly reactive aggregates.(Author abstract) 10 References

65. Effectiveness Of Silica Fume In Reducing Damage Due To Alkali-Silica Reaction Kojima, T. (Ritsumeikan Univ, Kyoto, Japan); Amamsuki, S. (Ritsumeikan Univ, Kyoto, Japan); Takagi, N. (Ritsumeikan Univ, Kyoto, Japan) Proceedings Of 66. The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 265-70. 3 Refs.; Document Type Book, Japan, Language English

In the early 1980s, many cases of concrete structures deteriorated as a result of alkali-silica reaction (ASR) have been reported in Japan, including T-shaped piers of the Hanshin Expressway. It has been suggested that a suitable method of reducing the risk of cracking due to ASR is to replace a part of Portland cement by pozzolanic materials such as pulverized fuel ash (FA), ground granulated blast-furnace slag (BFS) or condensed silica fume (SF). A recent report by Hobbs, DW (see IRRD 814132) states that use of pozzolanic materials is not necessarily a good method to prevent the damage due to ASR. It is necessary to ascertain that the adequate usage of pozzolanic materials can prevent the damage due to ASR. In this study, firstly in order to compare the effectiveness of three kinds of pozzolanic materials used in Japan in reducing the deterioration due to ASR, mortar bars in which a part of cement was replaced by pulverized fuel ash, ground granulated blast-furnace slag and condensed silica fume were made by using the same aggregate as that in the deteriorated structure of the Hanshin Expressway, and expansive strain was measured. Secondly in order to investigate the availability of SF, which was considered most effective in reducing the deterioration due to ASR, non-destructive tests such as ultrasonic pulse velocity, dynamic modulus of elasticity and the spectral analysis of ultrasonic pulse, were carried out on SF mortar and concrete specimens. For the covering abstract of the conference see IRRD 857024.

67. Alkali-Silica Reactivity Mechanisms and Management. Leming, M.L. (North Carolina State Univ., Raleigh, NC, USA) Mining Engineering (Littleton, Colorado) Vol 48N, 12 December 1996. P 61-64

In the decades since silica gel was first identified in material exuding from cracked concrete, a great deal of research has been conducted regarding the chemical reactions between the alkalis found in portland cement and silica found in aggregates. This paper reviews the research findings attempts to provide a simplified review of the mechanisms of the alkali-silica reaction (ASR), so that one can better understand the implications of the specifications, test results and effects on structures. In addition, the contractual relationships between the aggregate supplier and one of their major clients, the concrete supplier, examined with regard to the ASR.

68. Alkali-Aggregate Reaction In Concrete: A Review Of Basic Concepts And Engineering Implications. Fournier B (Reprint); Berube M A CANADIAN JOURNAL OF CIVIL ENGINEERING, (APR 2000) Vol. 27, No. 2, Pp. 167-191.

This paper presents theoretical and applied state-of-the-art information in the field of alkali-aggregate reactivity (AAR) in concrete. The aspects discussed include basic concepts of the reaction and expansion mechanisms, conditions conducive to the development and the sustainability of AAR in concrete, field and laboratory investigation programs for evaluating the potential alkali-reactivity of concrete aggregates, selection of preventive measures against AAR, and the management of structures affected by AAR. The management section includes the diagnosis of AAR in existing concrete structures, evaluation of the potential for future distress due to AAR, and mitigation and repair approaches used on such structures. This is an introductory paper and sets the stage for a special review of the current AAR situation in the various regions of Canada that is presented in seven papers as part of this issue.

69. Deleterious Expansion Of Concrete Due To Alkali-Silica Reaction: Influence Of Pfa And Slag. Hobbs, D.W. (Cement & Concrete Assoc, Slough, Engl) Mag Concr Res V 38 N 137 Dec 1986 P 191-205

The literature dealing with the effectiveness of partial replacement of a high-alkali cement by pulverized-fuel ash (pfa) and ground granulated blast furnace slag (slag) in preventing deleterious expansion due to the alkali-silica reaction (ASR) when a reactive aggregate is used is reviewed, and results are reported of recent tests carried out on concrete at C&CA. It is shown that the effectiveness of pfa's and slags in preventing deleterious expansion due to ASR varies widely and that the use of some pfa's and slags may not reduce the risk of deleterious expansion.(Author abstract) 48 references

70. Effectiveness Of Mineral Admixtures In Controlling Asr Expansion Swamy, R.N. (Sheffield Univ, Uk); Al-Asali, M.M. (Canmet, Ottawa, Canada) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 205-10. 3 Refs; Document Type Book, Japan, Language English

Alkali silica reaction (ASR) is now known to be capable of causing considerable damage to concrete structures, which might sometimes even lead to their failure. Although the occurrence of such reaction is limited when one considers the large number of concrete structures built, the reaction can cause serious problems of serviceability when it does occur. It is therefore important to consider at the design stage the possible damages arising from ASR, and to minimize the risk of its occurrence by choice of suitable materials, and appropriate design. The most practical and beneficial means of controlling ASR expansion is probably through part replacement of cement by mineral admixtures such as fly ash, ground granulated blast furnace slag and silica fume. A number of studies on the use of these and other natural and artificial pozzolans to control ASR expansion have been reported in literature. In spite of much detailed research, there are several aspects of the role of mineral admixtures in ASR that are not yet fully understood. For example, there appears to be no single explanation on the mechanism of pozzolanic reactions and control of ASR expansion. Further, the effect of pozzolanic additions on ASR is highly variable, and the effectiveness very much depends on the type of reactive aggregate, the type of mineral admixture, the method of replacement, etc. Whilst there is a lot of evidence on mortar bar tests to show that pozzolans can reduce or even eliminate ASR expansion, there is also test data to show that materials judged as effective pozzolans by ASTM tests, sometimes even increase ASR expansion. In this paper, some test data are presented to evaluate the effectiveness of fly ash, slag and silica fume in controlling and/or reducing ASR expansion in concrete. (A) For the covering abstract of the conference see IRRD 857024.

71. Alkali-Silica Reactivity In Concrete - Importance Of Cement Content And Alkali Equivalent Johnston, C.D. (Univ Calgary, Canada) Proceedings Of The 7th International Conference On Concrete Alkali-Aggregate Reactions, Ottawa, Canada, 1986, 1987. P. 477-82. 2 Refs., Noyes Publications; Document Type Book

The effect of cement content and alkali equivalent on alkali-silica reactivity is evaluated in terms of expansion up to age 5 years for concrete prisms made with crushed glass as the coarse aggregate. What happens with each cement-aggregate combination depends strongly on the amount of alkali in the concrete available to fuel the reaction, which in turn is related to the product of cement content and alkali equivalent. three categories of reactivity can be identified: apparently innocuous for alkali contents in concrete less than about 0.05%, rapid and highly deleterious for alkali contents more than 0.10%, and slowly expansive, potentially dangerous, and classifiable as deleterious only after 1 year or more of testing for alkali contents of 0.05-0.10%.(a) for the covering abstract of the conference see irrd 811982.

72. A Discussion Of The Paper ''The Alkali-Silica Reaction. The Surface Charge Density Of Silica And Its Effect On Expansive Pressure" By F.A. Rodrigues, P.J.M. Monteiro, G. Sposito Chatterji S (Reprint) Cement And Concrete Research, (Mar 2000) Vol. 30, No. 3, Pp. 501-502.

73. Effects Of Silica Fume And Steel Fibers On Some Mechanical Properties Of High-Strength Fiber-Reinforced Concrete Eren O (Reprint); Marar K; Celik T Journal Of Testing And Evaluation, (Nov 1999) Vol. 27, No. 6, Pp. 380-387.

There are many test methods to measure the impact resistance of fiber-reinforced concrete that are complicated, time consuming, and expensive. A practical test method has been developed to measure the impact resistance of high-strength fiber-reinforced concrete (HSFRC). The equipment developed can also be used for testing aggregate impact values by simply changing the base plate of the machine. A machine was developed to measure the surface abrasion resistance of HSFRC. Testing fiber-reinforced concrete for surface abrasion resistance was found to be extremely difficult if realistic and practical results were desired. In this study the influence of silica fume on the properties of HSFRC was investigated by using silica fume at two different percentages and with three different hooked-end fibers, namely, 30/0.50, 60/0.80, and 50/0.60 length/diameter (mm/mm). Fibers were added to concrete in three different percentages of 0.5, 1.0, and 2.0% by volume of concrete. The results show that including fibers in high-strength concrete improves impact resistance, surface abrasion, and splitting tensile strength.

74. A Critical Review Of Ultra-Accelerated Tests For Alkali-Silica Reactivity Grattanbellew P E Cement & Concrete Composites, (Oct 1997) Vol. 19, No. 5-6, Pp. 403-414.

A large number of ultra-accelerated test procedures, for determining the potential alkali reactivity of aggregates, have been developed, particularly in the past 15 years. An ultra-accelerated test method is defined as one which yields results within a few days or, at most, a few weeks. A number of ultra-accelerated test methods have been adopted as 'standard tests', but few have been adequately evaluated. The rapid globalization of the construction industry will require the harmonization of National Standard Test Methods. The major requirement of ultra-accelerated test methods is that they should correctly predict the potential reactivity of aggregates in greater than 95% of the cases. Due to the complexity and variability in the composition and grain size of aggregates, it is improbable that a single test method will be developed which would be appropriate for evaluating all types of aggregates. Another major requirement for ultra-accelerated test methods is that the inter-laboratory coefficient of variation should be low, preferably less than 12%. At present, only the NBRI accelerated mortar bar method has been subject to adequate inter-laboratory evaluation. However, a more limited inter-laboratory investigation showed that the autoclave mortar bar test also shows considerable potential, as a satisfactory ultra-accelerated test method. Further refinement of the NBRI and autoclave methods is required to improve their performance with a wide variety of aggregates.

75. Effect Of Silica Fume And Steel Fibers On Some Properties Of High-Strength Concrete Eren O (Reprint); Celik T Construction And Building Materials, (Oct-Dec 1997) Vol. 11, No. 7-8, Pp. 373-382.

The main disadvantage of high-strength concrete is its highly brittle behavior and this can be overcome by adding fibers to the concrete. This would also improve some other mechanical properties of high-strength concrete such as tensile strength and compressive strength. These properties are not very well established for high-strength steel-fiber reinforced concrete (HSFRC) yet. In this study the influence of silica fume on the properties of HSFRC were investigated by using silica fume of two different percentages and three different hooked-end fibers namely, 30/0.50, 60/0.80 and 50/0.60 length/diameter (mm/mm). Fibers were added to concrete in three different volume percentages of 0.5, 1.0 and 2.0 by volume of concrete. The results indicated that there is a linear function between splitting tensile strength (F-splt) and volume percentage of fibers (V-f) [i.e. F-splt = A(V-f) + B, where A and B are correlation coefficients] as well as between splitting tensile strength (F) and compressive strength (F-c) of plain series A concrete [i.e. F-splt = C(root F-c) + D, where C and D are correlation coefficients]. These relations can describe the development of splitting tensile strength of HSFRC containing no silica fume, 5% silica fume and 10% silica fume by weight of cement. On the other hand, although silica fume has an effect on compressive strength, volume percentage and aspect ratio of steel fibers has little effect.

76. The Effect of Grinding On the Physical Properties Of Fly Ashes and a Portland Cement Clinker Bouzoubaa N; Zhang M H (Reprint); Bilodeau A; Malhotra V M Cement And Concrete Research, (Dec 1997) Vol. 27, No. 12, Pp. 1861-1874.

The effect of the grinding on the physical properties of three ASTM Class F fly ashes and a Portland cement clinker were investigated. The specific gravity and the fineness of the Ay ashes increased with an increase in the grinding time. However, this increase was less significant beyond 2 hours. The morphology of the fly ashes was changed by grinding. Most of the plerospheres and large, irregular-shaped particles were crushed after 2 hours of grinding. However, the number of the spherical particles reduced with increased grinding. There appears to be an optimum grinding time of approximately 4 hours for the Ay ashes beyond which the water requirement increased and the strength activity indices either decreased or did not increase significantly. (C) 1997 Elsevier Science Ltd.

77. L34 Answer 46 Of 60 Scisearch Copyright 2000 Isi (R) Performance Of Concrete Under Different Curing Conditions Tan K F (Reprint); Gjorv O E Cement And Concrete Research, (Mar 1996) Vol. 26, No. 3, Pp. 355-361.

The effect of curing conditions on strength and permeability of concrete was studied. Test results showed that after 3 and 7 days moist curing only the concretes with w/c ratios equal to or less than 0.4 were accepted, while after 28 days of moist curing however, even the concrete with w/c of 0.6 could be accepted. Silica fume has a significant effect on the resistance to water penetration. For the concretes both with and without silica fume and with w/c + s of 0.5, the 28-day compressive strengths of 3 and 7 days moist curing were higher than those of 28 days moist curing, and the silica fume concrete seemed to be less sensitive to early drying. The curing temperatures did not affect the water penetration of concrete, but affected the chloride penetration and compressive strength of concrete significantly.

78. Effectiveness Of Fly-Ash In Preventing Deleterious Expansion Due To Alkali-Aggregate Reaction In Normal And Steam-Cured Concrete Shayan A (Reprint); Diggins R; Ivanusec I Cement And Concrete Research, (Jan 1996) Vol. 26, No. 1, Pp. 153-164.

A non-reactive and several reactive aggregates were used in concrete specimens with and without two fly ashes (varying in total alkali content) at binder (cement + fly ash) alkali levels ranging from 0.46 to 2.5% and a binder content of 500 kg/m(3) and fly ash/binder ratio of 0.25. The specimens were stored either at 23 degrees C (fog room) or 40 degrees C, 100% RH. Some specimens were steam cured at 75 degrees C for eight hours, and then transferred to 40 degrees C, 100% RH. The expansion behavior of the specimens was monitored over nearly six years, and showed that the effectiveness of the fly ash in preventing deleterious AAR expansion depended on the alkali content of the concrete. At the highest alkali content of 12.5 kg Na_2O equiv./m(3), the fly ashes only had a delaying effect (one to several years), whereas at 6.9 kg Na_2O equiv./m(3) they eliminated deleterious AAR expansions. Generally, for more highly reactive aggregates, and at the 2.5% alkali level, fly ash was less effective at 40°C than 23°C because the rate of AAR expansion was much higher at 40°C. At lower alkali levels and for less reactive aggregates, the temperature was not important. Fly ashes were also effective under steam-curing conditions. A measurable amount of chemical shrinkage occurred in the first few months in concretes containing fly ash and with high alkali contents, although some of these concretes later expanded and cracked as a result of aggregate reactivity. Fly ash was used in mortar specimens prepared for the expression and analysis of the pore solution and was found to be very effective in reducing the alkalinity of the pore solution, a factor contributing to its preventive effects on AAR. It is concluded (based on six-year results and the shapes of expansion curves) that the two fly ashes can be used to prevent deleterious AAR expansions in practical situations.

79. Effectiveness Of Supplementary Cementing Materials In Suppressing Expansion Due To Asr .1. Concrete Expansion And Portlandite Depletion – Discussion Chatterji S (Reprint) Cement And Concrete Research, (1994) Vol. 24, No. 8, Pp. 1572-1573.

80. Comparative-Study Of Various Silica Fumes As Additives In High-Performance Cementitious Materials. Delarrard F (Reprint); Gorse J F; Puch C Materials And Structures, (Jun 1992) Vol. 25, No. 149, Pp. 265-272.

This article concerns marginal variations in the functional properties of very-high-strength mortars and concretes resulting from the type of silica fume used. Twenty silica fumes were tested, in the presence of two cement-superplasticizer pairs. All of the results are analyzed into main components and regressions. The action of carbon on the workability of the mixtures has been verified. Finally, within the limits of the scattering of the results, it has been possible to establish an empirical law, fitted to previous results, showing the influence of the alkali content of the silica fume on its pozzolanic activity.

81. Mechanism Of Alkali-Silica Reaction And The Significance Of Calcium Hydroxide - Reply. Wang H (Reprint); Gillott J E Cement And Concrete Research, (Jan 1992) Vol. 22, No. 1, Pp. 193-194.

On The Long-Term Strength Losses Of Silica-Fume High-Strength Concretes. Delarrard F (Reprint); Bostvironnois J L Magazine Of Concrete Research, (1991) Vol. 43, No. 155, Pp. 109-119.

This Paper presents studies and tests performed at the Laboratoire Central des Ponts et Chaussees with a view to a better understanding of the long-term mechanical properties of silica-fume high-strength concretes (HSC) and very-high-strength (VHSC) concretes. After noting the discrepancies among the various references in the literature, we propose to explain the drop in strength observed by some authors after three months by the hypothesis of drying-related effects. To check the soundness of this hypothesis, mechanical tests were carried out on three different concretes, their drying was investigated by gammadensimetry, and accelerated tests were performed on mortars. The homogeneous drying to which the specimens are subjected has no negative effect on their mechanical strengths. The losses of strength observed on some concretes are therefore probably not caused by a local effect of the drying. Examination of the water content fields of VHSC specimens four years old shows that the drying occurs with a high gradient and affects only a small thickness. Mechanical tests in this case show a non-negligible drop in compressive strength. Calculation of the self-stress field due to drying shrinkage indicates that the compression at the core of the specimen is of the same order as the drop in strength observed. To conclude, it is shown that, given some hypotheses concerning the water content field, the drop in strength linked to the structural effects of drying can be not more than twice the tensile strength.

82. A New Test Method For Fiber-Reinforced Concrete Zollo R F (Reprint); Hays C D; Zellers R Cement Concrete And Aggregates, (Dec 1999) Vol. 21, No. 2, Pp. 111-116.

It has long been recognized that the principal benefit gained by using fiber reinforcement in portland cement concrete is a conversion of the material from brittle to relatively ductile behavior. The apparent ductility, or toughness, is primarily related to the improved tensile strength of fiber-reinforced concrete (FRC) especially and even after significant matrix cracking has occurred. However, the methods used to measure tensile strength and toughness of FRC have been, at best, elaborate and controversial. A practical and much needed testing methodology for fiber-reinforced concrete has been developed and adopted as an ASTM standard. It was conceived from the need to have a test that is relatively simple and inexpensive to conduct and is yet capable of assessing the tensile strength of cracked FRC. The test method, ASTM C 1399, and an interlaboratory testing program conducted to help formulate a precision statement for the new methodology is discussed.

83. Surface Modified Polypropylene Fibers For Use In Concrete Tu L (Reprint); Kruger D; Wagener J B; Carstens P A B Magazine Of Concrete Research, (Sep 1998) Vol. 50, No. 3, Pp. 209-217.

The research project reported on is concerned with the effect of modification of the surface of polypropylene fiber by a new chemical treatment process, oxyfluorination, on the properties of polypropylene fiber reinforced concrete. As a world first, the interfacial bond of polypropylene fibers with the cementitious matrix is improved by increasing the surface free energy of the fiber surface. The reasons for the poor bonding between untreated polypropylene fiber and cementitious matrix are discussed, using the fiber surface free energy and Lewis acid-base interaction concept. The contact angle of water on the polypropylene fiber surface as well as fiber surface free energy components were measured. This showed reduced contact angles, as well as increased acid-base components of the surface free energy because of oxyfluorination. Mechanical properties such as compressive strength, flexural properties and impact resistance of the fibrous concrete, reinforced with different types of oxyfluorinated polypropylene fibers, were determined and compared with those of untreated polypropylene fiber reinforced concrete. The results confirmed that the surface modification largely improves the mechanical performance of the fibrous concretes. Restrained plastic and drying shrinkage cracking tests, using restrained slab specimens and steel ring restrained specimens, indicated that the surface oxyfluorinated fibers possess a higher shrinkage cracking resistance than do unmodified fibers. The effect of surface oxyfluorination on the concrete/concrete matrix interfacial bondings was investigated using a fiber pull-out test. A mechanism for this interfacial bonding improvement is proposed. Oxyfluorinated polypropylene fiber surfaces and their interfaces with concrete matrix compared with that of unmodified fiber, were observed using scanning electronic microscopy. Some field application tests were conducted and the good results that were achieved are presented.

Appendix 3

Quarterly Report 3

Ultra-Lightweight Cement

Third Quarterly Technical Progress Report

April 1 to June 30, 2001

Fred Sabins

Issued July 18, 2001

DOE Award Number
DE-FC26-00NT40919, Tasks 1, 2, 3, and 8

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). Work reported herein addresses Task 1: Assess Ultra-Lightweight Cementing Issues, Task 2: Review Russian Ultra-Lightweight Cement Literature, Task 3: Test Ultra-Lightweight Cements, and Task 8: Develop Field ULHS Cement Blending and Mixing Techniques. Results reported this quarter include:

- preliminary findings from a literature review focusing on problems associated with ultra-lightweight cements
- summary of pertinent information from Russian ultra-lightweight cement literature review
- laboratory tests comparing ULHS slurries to foamed slurries and sodium silicate slurries for two different applications
- initial laboratory studies with ULHS in preparation for a field job

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List of Graphical Materials

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, to isolate various formations from one another, and to control fluid movement within the well.

Typical cement fluid density ranges from 14 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitate application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, named lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections: surface casings and intermediate casings. Since formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are relatively low.

The minimum practical density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength. Lower temperature further delays strength development. Achieving density requirements lower than this or strength requirements greater than minimum necessitate use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent as candidate material for producing ultra-lightweight cements. These small, hollow, glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS. The development will be achieved through a carefully designed program of modeling, design, laboratory testing, and field testing.

The phase of the project documented in this report involves review of previous investigations conducted in Russia; review of literature about potential alkali-silica reactivity; laboratory testing of cements made with ULHS, foamed cements, and cements made with sodium silicate; and preliminary laboratory testing in preparation for field testing.

Executive Summary

The third quarter of this investigation focused on laboratory testing that compared slurries containing ULHS to two other lightweight cement systems: foamed and sodium silicate slurries. In addition, literature reviews also revealed pertinent information about lightweight cement systems and some of their potential problems. Further studies examined ULHS characteristics and performance.

A review of literature dealing with potential problems of lightweight cement systems revealed a phenomenon known as alkali-silica reactivity (ASR). This is a potential problem since silica is a large component of ULHS. Reaction mechanisms, prevention techniques, and test methods for ASR are presented.

A review of Russian literature reveals some of the lightweight cement systems that are used in Russia and its neighboring countries. The review presents some performance characteristics that are common to some of the lightweight hollow spheres used in that area. In addition, the review offers information on ASR and some prevention methods.

Because of the large volume of cement required for this project, a quality-control process has been implemented. Information and data gathered for the program are presented.

Further testing evaluated the performance of ULHS. Studies investigated the effect of shear on the breakage of ULHS and the resulting change in density. A simple series of tests was also performed to confirm density measurements of slurries made with ULHS.

To test the performance of slurries made with ULHS and compare them with two other lightweight cement systems (foamed and sodium silicate slurries), the project will employ a battery of tests to simulate three cementing applications:

- deepwater conductor pipe
- land-based surface pipe
- land-based intermediate casing

This phase of the project tested six slurries on two of the three cementing scenarios/applications. The six different slurries are the three lightweight cement systems (ULHS, foamed, and sodium silicate) prepared using two different cement types (Class A and TXI Lightweight). Preliminary data indicates that the slurries made with ULHS performed as well as or better than the sodium silicate and foamed slurries based on performance criteria established thus far. Mechanical testing in the next quarter will help establish performance qualities of cement slurries made with ULHS.

Preliminary laboratory data has also been gathered in preparation for a field test that is tentatively scheduled for July.

Literature Review

Task 1 of this project is to Assess Ultra-Lightweight Cementing Issues. A portion of that task includes a literature review of lightweight cement systems. The literature review also covers the potential alkali-silica reaction that could occur with ULHS.

Siliceous admixtures combined with cement create a potential for a phenomenon known as alkali-silica reactivity (ASR). Whether this detrimental reaction occurs depends on several factors including cement chemistry and available moisture.

An aqueous liquid pore solution is present in all cements. This pore solution is alkaline (pH typically greater than 12.5) and can contain calcium cations (Ca^{++}) and alkali cations (Na^{+}, K^{+}). The hydroxyl ions in the alkaline pore solution chemically attack silica (SiO_2) creating SiO^{-} species that are susceptible to reaction with the cations (Ca++, Na+, and K+). If large concentrations of calcium cations are in the pore solution, a calcium silicate hydrate (C-S-H) gel is formed. C-S-H gel is considered one of the safe reactions that can occur; it is not prone to swelling.[1]

When the alkali concentration in pore solutions is high as compared to the calcium ion concentration, a deleterious high alkali-silica gel will be formed. The high-alkali gel has a greater capacity to swell with absorption of moisture. This swelling can lead to detrimental cracking of the cement. As might be expected, if available moisture remains low (below 80% relative humidity referenced to 70 to 75°F), there will not be enough moisture available for detrimental swelling. [2]

There are several methods available to limit or avoid this detrimental expansion due to ASR. One of the ways to avoid this detrimental reaction is to avoid using siliceous materials that are known to be reactive. Decreasing the alkali level of the cement (less than 0.60% equivalent Na_2O) can also limit the detrimental ASR gel formation. Another method includes the addition of specific admixtures. These admixtures impede normal ASR by reducing the steady state concentration of alkali and hydroxyl ions in concrete, or by altering diffusion rates of alkali and lime to reactions sites. Common admixtures that are used to limit ASR are fly ash, blast-furnace slag, and even silica fume.[2]

Because of the siliceous components of ULHS, it is important to determine if ULHS leads to ASR. There are several ASTM methods that aim to identify reactive materials that lead to ASR in cements[2]:

1. ASTM C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method)
2. ASTM C 289 Test Method for Potential Reactivity of Aggregates (Chemical Method)
3. ASTM C 295 Guide for Petrographic Examination of Aggregates for Concrete

There are pros and cons to each method. As suggested by their titles, these methods are used to identify potentially reactive aggregates that are generally used in construction cement. Methods C 227 and C 289 are effective in identifying rapidly reactive materials, but fail to identify slowly reactive materials. ASTM C 295 is a rapid way to identify potentially reactive aggregates, but is highly subjective and dependent on the capability of the petrographer examining the aggregate.[2]

If ULHS is affected by ASR, there is a possibility that the glass wall of the ULHS will be chemically attacked. This could in turn increase the permeability of cements made with ULHS. Hence, long-term permeability testing could reveal if ASR negatively affects cements made with ULHS.

The project steering committee agreed to test for ASR by testing ULHS as outlined by ASTM C 289 as well as testing for long-term permeability of cements made with ULHS.

Review of Russian Lightweight Cement Literature

Task 2 of this project is to Review Russian Lightweight Cement Literature. The first quarterly progress report for this project contained an appendix with a report of the Russian literature review conducted by Dr. Vladimir Sledkov. This review reveals that there are several types of hollow microspheres used in Russia. A group of microspheres with the trade name Plaminol is made from phenol-formaldehyde and carbamide formaldehyde tars and filled with nitrogen. These Plaminol microspheres are generally expensive and have limited hydrostatic collapse strength (less than 2,900 psi).[3,4]

Most of the hollow glass microspheres from Russia have low hydrostatic collapse strengths (less than 1,500 psi). However, there are Russian companies that produce aluminum sodium borosilicate glass hollow microspheres with collapse strengths of 1,450 to 2,900 psi. The collapse strength of 2,900 psi is still below most of the ULHS under study in this project.

This literature review also points out that sodium glass is susceptible to attack by alkaline medium. To counteract the effects of lime, it is recommended that materials such as pozzolan or slag be added to the cement slurry.[5] Protective materials, such as boron and aluminum silicates, are effective in boosting the chemical resistance of glass microspheres. Some of the products from initial reaction with these materials help to create a protective barrier that slows silicate glass destruction.[6] Boron and aluminum silicate glass microspheres generally have hydrostatic collapse strengths in excess of 4,000 psi.

Cement Quality-Control Program

An extensive quality-control program was initiated because of the large quantity of cement used over the course of this project. Each bucket of cement is labeled with a materials log number and date upon receipt. When a bucket is first opened for use, the date of opening is recorded in the materials log. This log number will be referenced on the laboratory sheets for each test performed. Where applicable, tests according to API Specification 10A are conducted. Additionally, several other tests tailored specifically for the test conditions and materials (rheology and low-temperature compressive-strength development) are included in this QC Program.

The Class A and Class H cement performance requirements are presented in API Specification 10A. Because the Lightweight Oilwell cement is not an API cement, it is tested according to QC procedures developed by the manufacturer.
Initially, the testing lab received five 5-gallon buckets of API Class A cement (analogous to ASTM Type I cement), ten 5-gallon buckets of API Class H cement, and nineteen 3-gallon buckets of Lightweight Oilwell cement from TXI. Both API Specification tests and tests recommended by advisory board members are being performed for the cement quality-control program. The physical requirements used for testing each of the cements are listed in Table 1. To accelerate the rate of compressive-strength development at low temperatures, calcium chloride ($CaCl_2$) is being used with the cements according to Table 2. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 1—Cement Slurry Compositions for Quality-Control Testing Program

Cement	Mix Water (%)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Class A	46	15.6	772	355	API
TXI LW	75	13.2	541	406	TT and CS
TXI LW	105	12.1	426	447	FW
Class H	38	16.4	860	327	API

Table 2—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (%)
80	0.0
60	1.0
45	2.0

All of these tests have been run to provide a baseline for each type of cement. This QC data will provide a comparison when examining other data for this project. The complete set of tests will be conducted periodically throughout the DOE project.

Appendix A shows the data gathered for the quality-control program through the third project quarter. These data track well with performance data that were provided by the vendors and presented in the previous report. The test results exceeded the required specifications, and this process will be repeated when new cement supplies are received. Data will also be presented in the appendices of future reports.

Tests of Lightweight Cements

Task 3 of the project encompasses testing of ultra-lightweight cement slurries made with ULHS. In the second quarterly progress report, the specific gravity of the different kinds of ULHS were investigated. One part of the investigation studied the specific gravity of the beads at different applied pressures.

The preliminary comparisons found that the 5K beads (supplied in November, 2000) did not perform as well as expected. In the third project quarter, a new sample of 5K beads was tested; these tests showed similar performance results. The 5K bead sample sent to the principal investigator in November, 2000 was typical production material. The bead manufacturer analyzed that specific lot for survival strength and found it to be a statistical normal lot and to fall within a normal distribution curve, albeit slightly below the targeted mean. The strength testing that is performed by the bead manufacturer is very similar to the way that the principal investigator tests the slurries with the beads at different applied pressures. The results observed with the 5K beads may be related to the lower-than-average strength of the specific lot tested. The bead manufacturer plans to submit to the principal investigator a new lot of 5K beads for re-evaluation in lightweight cement slurries. The bead manufacturer anticipates that the new lot will fall in line with the expected strengths of the 4K and 6K beads.

Additional studies have been performed on the ULHS slurries to determine the effect of blending shear on bead breakage. One way to analyze possible breakage is by monitoring slurry density changes after shearing ULHS slurries. The slurries for these shear effect studies were first prepared as follows.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry according to Section 5.3.5 of API RP 10B.[8]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

The density of this (unsheared) slurry is then measured with a pressurized mud balance and recorded. This same slurry is then placed in a Waring blender and mixed at 4,000 RPM for 35 seconds. The density of the slurry is again measured and recorded. The slurry is again transferred to the Waring blender and mixed at 4,000 RPM for an additional 15 seconds (50 seconds total). The density of the slurry is again measured and recorded. Table 3 shows the results from these experiments.

Table 3—Effect of Shear on Slurry Density

Measurements for 10.0 lb/gal Slurry Design				
	ULHS Type			
	3K	4K	5K	6K
ULHS Concentration (%bwoc)	20.89	21.71	21.71	29.13
Water Concentration (gal/sk)	8.5	8.5	8.5	8.5
Density Before Shear (lb/gal)	10.0†	10.0	10.0	10.0
Density After 35 Seconds of Shear (lb/gal)	10.3†	10.2	10.5	10.1
Density After 50 Seconds of Shear (lb/gal)	10.4†	10.3	10.5	10.1
Measurements for 11.0 lb/gal Slurry Design				
	ULHS Type			
	3K	4K	5K	6K
ULHS Concentration (%bwoc)	13.24	13.74	13.74	18.18
Water Concentration (gal/sk)	8.5	8.5	8.5	8.5
Density Before Shear (lb/gal)	11.0†	11.0	11.0	11.0
Density After 35 Seconds of Shear (lb/gal)	11.3	11.2	11.4	11.0
Density After 50 Seconds of Shear (lb/gal)	11.4	11.3	11.4	11.1

†Density confirmed with three samples.

As evidenced by an increase in slurry density, the 3K, 4K, and 5K beads were distinctly damaged by the shear. The 6K beads suffered the least from shearing.

The cross (†) in Table 3 marks four slurries for which the density was checked three times. Of these slurries, the slurry was divided into three different samples and the density for each sample was measured with a pressurized mud balance. For each slurry, the measured density for all three samples was the same. These additional density measurements were performed to confirm that the density measurements are repeatable.

The shear effects studied to this point have focused on laboratory mixing procedures. Future work will investigate the effect that field mixing equipment and procedures have on bead breakage.

Application Scenarios

One way to gauge the performance of cements made with ULHS is to compare them to other ultra-lightweight cements. Members of the project steering committee decided to compare ULHS cements with a foamed cement and with a conventional sodium silicate slurry.

Three different application scenarios were chosen to test the performance of the lightweight cements. Application 1 simulates deepwater cementing. Application 2 simulates a typical land-based surface pipe cementing job. Application 3 simulates a typical land-based cementing job for intermediate casing.

Table 4 shows the pressure and temperatures associated with the three different applications. The conditions for Application 1 (deepwater cementing) came from typical applications as experienced by the principal investigator. The values for the surface pipe and intermediate casing applications (2 and 3) came from average values attained from *Worldwide Cementing Practices*[7] as detailed in the first quarterly progress report. For the three different applications, the slurries were designed to try to achieve certain performance standards (although they could not always be achieved). These standards are also listed in Table 4.

Table 4—Simulation Conditions for Comparison of Lightweight Slurries

Application	BHCT (°F)	BHST (°F)	Pressure (psi)	Desired Thickening Time	Desired Free Fluid	Desired Fluid Loss
1	65	45	5,300	4 to 6 hours	<1%	NA
2	78	96	1,000	4 to 6 hours	<1%	NA
3	128	174	5,000	4 to 6 hours	<0.5%	250cc/30min

Of the different classes of ULHS being studied in this project, the 6K beads were chosen because of their ability to withstand the hydrostatic pressures associated with the applications.

Most of the tests were performed as specified in API RP 10B[8]. Some preparation and testing methods were modified to adapt for the ULHS and foamed slurries. The mixing procedures were modified for the ULHS slurries to minimize bead breakage that can occur due to high shear from API blending procedures. The following blending procedure was used for the ULHS slurries.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry according to Section 5.3.5 of API RP 10B.[8]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

4. Pour this slurry back into the Waring blender and mix at 4,000 RPM for 35 seconds to mix and evenly distribute the contents.

Testing methods for foamed slurries were also modified. For example, thickening time is performed on unfoamed slurries only. Because the air in the foam will not affect the thickening rate, the slurry is prepared as usual per API RP 10B[8] and then the foaming surfactants are mixed into the slurry by hand without foaming the slurry. This and the other non-standard procedures for testing foamed cement are presented in Appendix B.

Stability of foamed slurries has recently been getting more attention and discussion. The foamed slurries in these laboratory tests appear thus far to be durable and stable. After the slurries were mixed and foamed in the blender, the foam did not expand while opening the container; many people in the industry have experienced foam expansion once the container is opened. The densities of the foamed slurries were measured using a volumetric container and a scale and were found to be within 0.1 lb/gal of the designed foamed density.

Also, cubes that have were cured for compressive strength testing showed no visual volumetric change. The cubes were the same size after curing as they were when they were poured into the molds. Other indications of foamed cement stability will be examined and presented as the project progresses.

Table 5 presents the slurry compositions for Applications 1 and 2. Additives (slurry extenders, accelerators, and foaming agents) were added to the different slurries in order to adapt each slurry to the application's testing conditions as specified in Table 4. The additives are widely available, generic additives, and are not specific to any particular service company.

Table 6 presents rheology data for the slurry designs specified in Table 5. The data was taken using a Chandler Chan 35 direct indicating viscometer.

Table 5—Slurry Compositions for Applications 1 and 2

Cement Type	Slurry System	Measured Density (lb/gal)	Water Content (gal/sk)	Additive Concentrations
Application 1				
Class A	ULHS	11.7	8.00	2.0%bwoc $CaCl_2$; 14.9%bwoc (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	1.0%bwoc $CaCl_2$; 0.03 gal/sk Witcolate; 0.01 gal/sk Aromox C-12
	Sodium Silicate	11.5	16.87	3.0%bwoc Sodium Silicate
TXI Lightweight	ULHS	11.5	6.65	2.0%bwoc $CaCl_2$; 11.5%bwoc (6K) ULHS
	Foamed	13.1† (11.4‡)	7.00	2.0%bwoc $CaCl_2$; 0.03 gal/sk Witcolate; 0.01 gal/sk Aromox C-12
	Sodium Silicate	11.6	12.11	3.0%bwoc Sodium Silicate
Application 2				
Cement Type	**Slurry System**	**Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.5	7.09	16.2%bwoc (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	0.03 gal/sk Witcolate; 0.02 gal/sk Aromox C-12
	Sodium Silicate	11.5	16.87	3.0%bwoc Sodium Silicate
TXI Lightweight	ULHS	11.5	6.50	2.0%bwoc $CaCl_2$; 11.9%bwoc (6K) ULHS
	Foamed	13.0† (11.5‡)	7.00	0.03 gal/sk Witcolate; 0.02 gal/sk Aromox C-12
	Sodium Silicate	11.5	12.11	3.0%bwoc Sodium Silicate

†Unfoamed slurry density

‡Foamed slurry density

Table 6—Rheology Data for Applications 1 and 2

Cement Type	Slurry System	Temperature (°F)	Dial Reading (RPM)								
Application 1											
			300	200	100	60	30	20	10	6	3
Class A	ULHS	80	59	48	24	29	25	23	19	14	10
		65	72	57	40	32	26	24	20	16	11
	Foamed†	80	96	82	65	56	49	45	33	23	15
		65	80	68	54	47	41	37	28	18	12
	Sodium Silicate	80	31	28	24	23	21	20	19	17	14
		65	31	27	23	21	19	19	18	17	11
TXI Lightweight	ULHS	80	92	80	65	58	50	46	33	25	17
		65	112	94	74	64	55	50	38	26	18
	Foamed†	80	40	35	29	26	23	22	19	16	11
		65	54	47	38	34	29	27	23	19	12
	Sodium Silicate	80	43	38	33	30	27	25	23	20	11
		65	40	36	31	28	26	23	22	20	12
Application 2											
Cement Type	Slurry System	Temperature (°F)	Dial Reading (RPM)								
			300	200	100	60	30	20	10	6	3
Class A	ULHS	78	107	87	64	53	40	33	20	14	9
		96	122	102	79	67	47	36	22	14	9
	Foamed†	78	80	68	53	47	39	36	24	16	9
		96	102	90	74	67	56	48	28	19	10
	Sodium Silicate	78	34	30	27	25	23	22	20	19	10
		96	29	26	23	21	19	18	17	13	8
TXI Lightweight	ULHS	78	115	98	78	69	58	52	35	26	17
		96	144	124	101	88	72	59	38	29	19
	Foamed†	78	42	37	30	26	23	21	19	16	9
		96	61	54	46	41	35	31	25	18	10
	Sodium Silicate	78	40	35	32	29	26	25	24	20	12
		96	45	39	33	30	27	25	23	18	12

†Rheology data from unfoamed slurry

Table 7 shows an overview comparison of the performances of each of the slurries in Applications 1 and 2. The thickening time for each slurry is recorded as the time that the consistency reached 70 Bc. Table 7 also presents the point of departure for the sodium silicate slurries. The point of departure indicates when the slurry consistency begins to noticeably increase. This is sometimes taken as the thickening time for highly extended slurries such as sodium silicate because the mechanical agitation of the thickening time test may “break” hydrates that are forming but which have low consistency (Bc) because of the large amount of mix water. The values for the crush compressive strengths in Table 7 are the averages of three cube samples that were crushed.

Table 7—Summary of Data for Applications 1and 2

Cement Type	Slurry System	Thickening Time to 70Bc (Hr:Min)	Point of Departure (Hr:Min)	Percent Free Fluid	Crush Compressive Strength 24-Hour (psi)	Crush Compressive Strength 7-Day (psi)
Application 1						
Class A	ULHS	7:00+	---	0.0	215	995
	Foamed	3:55*	---	0.6*	170	1,125
	Sodium Silicate	6:40+	4:40	1.1	Not Set	240
TXI Lightweight	ULHS	6:40	---	0.0	155	450
	Foamed	5:35*	---	0.4*	85	280
	Sodium Silicate	7:00+	4:35	0.4	65	175
Application 2						
Class A	ULHS	5:05	---	0.8	975	2140
	Foamed	5:29*	---	1.0*	780	1,180
	Sodium Silicate	5:30+	3:50	0.0	235	350
TXI Lightweight	ULHS	5:12	---	0.0	935	3,075
	Foamed	5:53*	---	0.2*	385	1615
	Sodium Silicate	7:00+	2:55	0.0	200	605

*Thickening time and free fluid tests performed on unfoamed slurry
+Thickening time tests with (+) were terminated at indicated time

Because of the low temperatures associated with Applications 1 and 2, calcium chloride ($CaCl_2$) was used with the foamed and ULHS slurries to accelerate hydration. Calcium chloride was not used with the sodium silicate slurries due to viscosity issues specific to this slurry. The only viable accelerators for sodium silicate slurries are company-specific and not widely available in a generic form.

Application 1. At low temperatures, thickening times for cements can be quite long. In Application 1 (see Table 7), the Class A cement with ULHS was still below 40 Bc when the thickening time test was taken off after seven hours, even though it contained $CaCl_2$. The Class A cement with the foaming surfactants had a thickening time of 3 hours and 55 minutes. The Class A cement with sodium silicate was below 40 Bc when its test was taken off after 6 hours and 40 minutes, but it had a point of departure of 4 hours and 40 minutes. Even with the differences in thickening times for the ULHS and foamed slurries, the 24-hour and 7-day compressive strengths for the two slurries were comparable.

With the TXI Lightweight cement, the thickening time for the ULHS slurry was longer than that for the foamed slurry. However, the compressive strengths of the ULHS slurry were higher than those for the foamed slurry.

Application 2. In this application, the compressive strengths of the sodium silicate slurries were lower than those of the foamed or ULHS slurries. At this temperature (78°F), the thickening times for the foamed and ULHS slurries are relatively close. The compressive strengths for the ULHS slurry were above those for the other slurries.

Comparison of Compressive Strengths Using Ultrasonic and Crush Methods

In the previous quarterly technical report, a comparison study was presented of six slurries using 3K ULHS. The study compared compressive strengths determined using ultrasonic cement analyzer (UCA) with those using the traditional crush method. There were varying degrees of agreement between the UCA and crush values.

The two slurries that showed the least agreement between UCA and crush were tested again. Table 8 shows the results obtained from the previous project quarter along with the results from this quarter. The difference between the UCA and crush values are presented in Table 8 as a percent difference between the UCA and crush value while using the crush value as the reference value. In other words, $\%Difference = \frac{(UCA - crush)}{crush}$.

Table 8—Comparison of Ultrasonic and Crush Compressive Strengths

		2				3			
Project Quarter		2				3			
Cement Type		TXI LW		TXI LW		TXI LW		TXI LW	
3K ULHS (%bwoc)		27.6		6.1		27.6		6.1	
Density (lb/gal)		9.0		11.5		9.0		11.5	
		UCA	Crush	UCA	Crush	UCA	Crush	UCA	Crush
12 Hours		900	500	1,220	830	616	590	1,118	968
18 Hours		1,300	850	1,700	1,280	970	1,088	1,776	1,563
24 Hours		1,400	1,050	2,000	1,600	1,038	1,228	1,973	2,048
48 Hours		1,470	1,250	2,150	2,000	1,132	1,475	2,169	2,116
		Percent Difference=(UCA - Crush)/Crush							
% Difference	**12 Hours**	80%		47%		4%		15%	
	18 Hours	53%		33%		-11%		14%	
	24 Hours	33%		25%		-15%		-4%	
	48 Hours	18%		8%		-23%		3%	
	Average	46%		28%		-11%		7%	

(-) Indicates that the crush value is higher than the UCA value

Table 9 compares the values of Table 8 in a different way. Table 9 presents differences between readings from the two different project quarters. This is one way to look at the repeatability of the tests. In Table 9 the percent difference is presented as the difference between second quarter and third quarter values divided by the third quarter value. The 2 and 3 used as subscripts indicate the project quarter that the value came from.

Table 9—Comparison of UCA and Crush Strengths by Quarter

Cement Type		TXI LW		TXI LW		TXI LW		TXI LW	
3K ULHS (%bwoc)		27.6		6.1		27.6		6.1	
Density (lb/gal)		9.0		11.5		9.0		11.5	
UCA or Crush		UCA	UCA	UCA	UCA	Crush	Crush	Crush	Crush
Project Quarter		2	3	2	3	2	3	2	3
12 Hours		900	616	1,220	1,118	500	590	830	968
18 Hours		1,300	970	1,700	1,776	850	1,088	1,280	1,563
24 Hours		1,400	1,038	2,000	1,973	1,050	1,228	1,600	2,048
48 Hours		1,470	1,132	2,150	2,169	1,250	1,475	2,000	2,116
% Difference =		$(UCA_2-UCA_3)/UCA_3$				$(Crush_2-Crush_3)/Crush_3$			
% Difference	12 Hours	46%		9%		-15%		-14%	
	18 Hours	34%		-4%		-22%		-18%	
	24 Hours	35%		1%		-14%		-22%	
	48 Hours	30%		-1%		-15%		-5%	
	Average	36%		1%		-17%		-15%	

(-) Indicates that the UCA or crush value from the 3rd quarter is higher than the UCA or crush value from the 2nd quarter.

In general, for the 48 hour time period examined in these studies the agreement between the UCA and crush values tends to improve with time and with strength development as seen in Table 8. The same general trend can be seen in Table 9 when comparing UCA strengths to each other or crush strengths to each other. The agreement of these compressive strength values is relatively close considering that such differences are not uncommon even when crushing three samples of the same slurry within the same test.

Preliminary Data for Field Job

Tasks 8 and 9 of this project focus on preparing and testing ULHS slurries for possible field applications. A potential candidate well has been identified in Webb County, Texas. The cementing application is for intermediate casing with a total depth of 6,100 feet, BHCT of 135°F, and BHST of 178°F. The cement that will be used is TXI Class A. The slurry design will also consist of 22.9% bwoc ULHS (4K), 0.6% bwoc proprietary retarder, and 8.5 gal/sk water for a design density of 10.0 lb/gal. Table 10 presents the preliminary laboratory tests that have been completed for this candidate well. The field job is scheduled for July.

Table 10—Preliminary Laboratory Data for Field Job

<table>
<tr><th colspan="6">Slurry Density (lb/gal)</th></tr>
<tr><td colspan="6">Surface/Atmospheric: 9.9</td></tr>
<tr><td colspan="6">Pressurized at 3,200 psi: 10.1</td></tr>
<tr><th colspan="6">Rheology</th></tr>
<tr><td colspan="6">Fann Readings</td></tr>
<tr><td>RPM</td><td>300</td><td>200</td><td>100</td><td>60</td><td>30</td></tr>
<tr><td>80°F</td><td>158</td><td>120</td><td>67</td><td>45</td><td>27</td></tr>
<tr><td>135°F</td><td>95</td><td>70</td><td>40</td><td>27</td><td>19</td></tr>
<tr><th colspan="6">Thickening Time (Hr:Min)</th></tr>
<tr><td colspan="2">40 Bc</td><td colspan="2">70 Bc</td><td colspan="2">100 Bc</td></tr>
<tr><td colspan="2">2:56</td><td colspan="2">3:06</td><td colspan="2">3:29</td></tr>
<tr><th colspan="6">Free Fluid</th></tr>
<tr><td colspan="6">4.6 mL (1.8%) after 2 hr at 135°F</td></tr>
<tr><th colspan="6">Crush Compressive Strength (psi)</th></tr>
<tr><td colspan="3">Cure Temperature (°F)</td><td>80</td><td>127</td><td>178</td></tr>
<tr><td colspan="3">Strength - 24 Hours</td><td>310</td><td>490</td><td>945</td></tr>
<tr><td colspan="3">Strength - 48 Hours</td><td>1,075</td><td>1,550</td><td>1,630</td></tr>
<tr><th colspan="6">UCA Compressive Strength (psi)</th></tr>
<tr><td colspan="3">Cure Temperature (°F)</td><td>80</td><td>127</td><td>178</td></tr>
<tr><td colspan="3">Hours to 500 psi</td><td>18</td><td>7</td><td>6</td></tr>
<tr><td colspan="3">Strength - 24 Hours</td><td>730</td><td>1,490</td><td>1,630</td></tr>
<tr><td colspan="3">Strength - 48 Hours</td><td>1,260</td><td>1,970</td><td>1,740</td></tr>
</table>

Conclusions

- Laboratory mixing procedures for 6K ULHS have been established and are acceptable.
- Field versus laboratory mixing will be verified with large-scale testing.
- Short-term laboratory testing shows mixable, pumpable slurries are possible. However, mechanical testing will help verify long-term viability.
- Testing for possible alkali-silica reactivity will be performed using tests outlined in ASTM C 289 as well as testing for long-term permeability of cements made with ULHS.
- Conventional testing data has been generated and acceptable test variabilities established.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
avg—average
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
bwoc—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
gal/sk—gallon(s) per sack of cement
H_2O—chemical formula for water
lb/gal—pound(s) per gallon
POD—point of departure
psi—pound(s) per square inch
QC—quality control
RPM—revolution(s) per minute
TXI—Texas Industries
TXI LW—lightweight cement available from TXI
UCA—ultrasonic cement analyzer
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
4K—4,000-psi designation
5K—5,000-psi designation
6K—6,000-psi designation

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8. API Recommended Practice 10B: "Recommended Practice for Testing Well Cements," 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

TXI Information			CSI Information			Free Fluid			Rheology										
Cmt Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date	Temp (°F)	mL	% by volume	H_2O (%)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
LW	09/18/00	11/06/00	C-108 B-1	11/07/00	11/15/00	105	2	0.8	75	80	57	50	42	38	33	22	12	13	120
LW	09/18/00	11/06/00	C-108 B-2	12/05/00	01/04/01	105	2	0.8	75	80	58	52	45	38	32	21	13	13	125
LW	09/18/00	11/06/00	C-108 B-11	06/24/01	06/26/01	105	2	0.8	75	80	60	55	47	39	21	20	15	15	127

CSI Information			Water	45°F Strengths			60°F Strengths			80°F Strengths		120°F Strengths		Thickening Time			
Cmt Type	CSI Log #	Test Date	Conc. (%)	Time (Hr)	$CaCl_2$ (%)	CS (psi)	Time (Hr)	$CaCl_2$ (%)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 70 Bc	Time to 100 Bc
LW	C-108 B-1	11/15/00	75.0	24	2.0	166	24	1.0	254	24	523	24	1579	5	6	2:02	2:20
LW	C-108 B-2	01/04/01	75.0	24	2.0	161	24	1.0	221	24	441	24	1225	5	5	2:00	2:17
LW	C-108 B-11	06/26/01	75.0	24	2.0	158	---	---	---	24	501	---	---	5	9	1:57	2:18

TXI Information		CSI Information				Free Fluid		Rheology									
Cmt Type	Prod. Date	Date Received	CSI Log #	Bucket Opened	Test Date	mL	% by volume	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	1.9	0.8	80	89	72	53	45	37	16	10	---	---
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	3	1.2	80	85	70	53	45	38	14	8	9	19
Class H	09/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	3	1.2	80	95	80	60	51	42	20	12	15	26
Class H	09/27/00	11/06/00	C-108 A-3	02/22/01	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-4	06/26/01	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths		140°F Strengths		Thickening Time		
Cement Type	CSI Log#	Test Date	Conc. (%)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 100 Bc
Class H	C-108 A-1	11/07/00	38.0	8	524	8	2088	---	---	---
Class H	C-108 A-1	11/29/00	38.0	8	480	8	2249	5	12	2:03
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1617	---	---	---
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1550	---	---	---
Class H	C-108 A-2	01/11/01	38.0	8	1201	8	1964	5	7	1:54
Class H	C-108 A-2	01/12/01	38.0	8	1039	8	1756	---	---	---
Class H	C-108 A-2	02/12/01	38.0	8	424	8	1717	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1567	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1580	---	---	---
Class H	C-108 A-4	06/29/01	38.0	---	---	---	---	5	17	2:00

TXI Information		CSI Information				Rheology									
Cmt Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class A	09/27/00	11/06/00	C-113 A-1	11/09/00	11/17/00	80	75	62	48	40	33	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-2	11/20/00	11/20/00	80	80	65	49	40	34	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-3	12/04/00	12/05/00	80	78	64	50	40	32	16	10	10	19
Class A	09/27/00	11/06/00	C-113 A-4	01/09/01	01/09/01	80	80	65	52	40	33	17	11	10	20
Class A	09/27/00	11/06/00	C-113 A-5	11/09/00	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-1	03/20/01	03/20/01	80	77	63	51	39	32	17	10	10	20
Class A	03/10/01	03/19/01	C-189 A-5	06/01/01	06/29/01	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths				45°F Strengths			60°F Strengths			80°F Strengths		Thickening Time			
Cmt Type	CSI Log #	Test Date	Conc. (%)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	$CaCl_2$ (%)	CS (psi)	Time (Hr)	$CaCl_2$ (%)	CS (psi)	Time (Hr)	CS (psi)	Test Date	Sch #	Int. Bc	Time to 100 Bc
Class A	C-113 A-1	11/17/00	46.0	---	---	---	---	---	---	---	---	---	---	24	1646	11/15/00	4	9	2:17
Class A	C-113 A-2	11/27/00	46.0	8	754	24	2607	24	2	737	24	1	1194	24	1689	01/05/01	4	8	2:21
Class A	C-113 A-2	02/12/01	46.0	---	---	---	---	---	---	---	---	---	---	24	2022	---	---	---	---
Class A	C-113 A-3	12/05/00	46.0	---	---	24	2585	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-4	01/17/01	46.0	8	729	24	2527	24	2	1042	---	---	---	---	---	01/17/01	4	4	2:09
Class A	C-113 A-5	02/15/01	46.0	8	931	24	2568	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2334	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2590	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2250	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-189 A-1	03/20/01	46.0	8	916	24	2364	---	---	---	24	1	1238	24	1737	03/20/01	4	12	1:42
Class A	C-189 A-5	06/29/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/29/01	4	10	1:37

Appendix B—Laboratory Mixing, Testing Procedures, and Testing Scope for Foamed Cement

The working draft of ISO 10426-4[1] outlines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries. The procedures discussed in this appendix and used for this project were borrowed from ISO 10426-4.

B.1 Preparing Unfoamed Base Slurry

B.1.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density	=	14.5 lb/gal	
Surfactant weight	=	10 lb/gal	

Base Slurry Calculations:		Weight	Volume
	Cement	94 lb	3.59 gal
	Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
	Water	55.39 lb	6.65 gal
	Total	151.39 lb	10.44 gal

Calculation of True Weight % Contributions:			
	Cement	62.1 %	(94/151.39)
	Surfactant	1.3 %	(2/151.39)
	Water	36.6 %	(55.39/151.39)

Slurry without Surfactants:		Weight	Volume
	Cement	94 lb	3.59 gal
	Water	55.39 lb	6.65 gal
	Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

B.2 Equipment

B.2.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure B.1) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

B.2.2 Multi-Blade Assembly

The multi-blade assembly is what is used during this project. The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO 10426-2[2], clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure B.1.

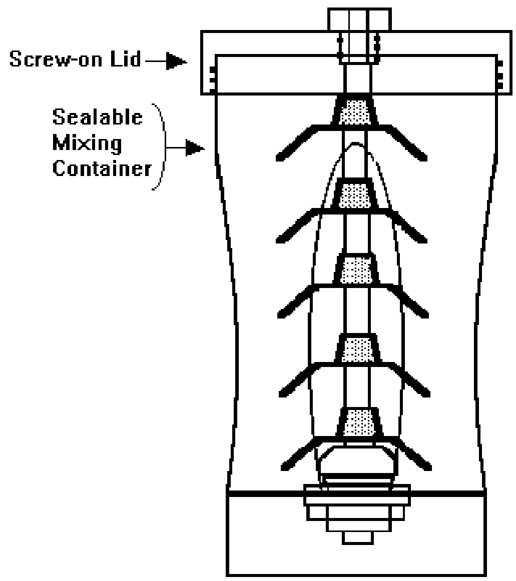

Fig. B.1—Example of a typical blending container

B.3 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

B.4 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section B.1.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section B.2.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Base slurries containing all additives except foaming surfactant(s) should be prepared according to ISO 10426-2[2],clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3.3 rev/s (200 rpm) at 66.7 rev/s (4,000 rpm) and ± 8.3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO 10426-2[2], clause 6.

B.5 Determining Slurry Volumes and Weights

B.5.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times FD \qquad (2)$$

Where:	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	FD	=	Foamed density of the slurry (g/mL)

Example:	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Unfoamed slurry weight	=	1170 mL × 1.2 g/mL = 1404 g

B.5.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 4.

$$GS = GUFS \times (\%Surfactant/100) \quad (3)$$

Where:	GS	=	Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)
	GUFS	=	Total grams unfoamed slurry prepared in B.1

$$GUSM = GUFS - GS \quad (4)$$

Where:	GUSM	=	Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example:	Unfoamed slurry weight	=	1404.1 g
	Percent by weight of surfactant	=	1.3 %

Surfactant weight	=	1404.1 × 0.013	=	18.5 g
Slurry weight	=	1404.1 - 18.5	=	1385.6 g

B.6 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section B.5.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section B.5.2.

B.6.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section B.2.2, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port or container lid, and verify that the slurry completely fills the slurry-mixing container. If the slurry does not fill the mixing container at the end of the 15-second

mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

B.7 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

B.7.1 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weigh the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry. The density of the foamed slurry in the container is determined by dividing the slurry mass by the container volume and converting to the appropriate density units.

B.7.2 Determining Slurry Stability

B.7.2.1 Unset Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder cannot be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

B.7.2.2 Set Slurry Stability

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 50.8-mm (2-in.) diameter, 101.6-mm (4-in.) tall cylinders or any appropriate covered container. Use of grease or other mold-release agents should be avoided as these materials may affect the stability of the foamed cement.

Cut or break the samples into sections, mark them from the top to the bottom, and

measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined by dividing the weight, W (in grams) by volume, V (in mL). The slurry density can also be determined (SG × 8.33 = lb/gal).

Signs of foam instability include the following:
- More than a trace of free fluid.
- Bubble breakout noted by bubbles appearing on the surface of the sample.
- Excessive gap at the top of the specimen. Minor meniscus effects are normal.
- Visual signs of density segregation as indicated by streaking or light to dark color change from top to bottom.
- Large variations in density from sample top to bottom.

B.7.3 Determining Compressive Strength
The foamed cement slurry is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated. This expansion can result in an undesired density decrease. The mold can be a standard 50.8-mm (2-in.) cube mold with a cover clamped to the top.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is sufficient seal to prevent the slurry from expanding out of the curing mold.

B.7.4 Determining Permeability
For determination of the permeability foamed cement slurry is poured into permeability test molds. These test specimens are then cured and tested for permeability while still in the permeability mold. If the foamed cement slurry is poured into a mold in which the specimen must be removed, cored, cut, or sealed in the permeability testing apparatus, the specimen may be damaged. Curing should be conducted under atmospheric pressure as for the compressive strengths in Section B.7.3.

The permeability testing of the cured specimens will be performed using the procedures in ISO 10426-2[2], clause 11.

B.8 Determining Other Tests on Base Unfoamed Slurry

A slurry that is foamed at atmospheric pressure should not be tested under pressure. Applying pressure to a foamed slurry prepared at atmospheric pressure will compress the foam, changing the density and gas ratio. This can also allow contamination when tested in a HPHT consistometer for thickening time.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO 10426-2[2], clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

B.8.1 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO 10426-2[2], clause 9.

B.8.2 Determining Fluid Loss

Fluid-loss tests performed with a foamed cement prepared at atmospheric pressure will not yield reliable results. The fluid loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry.

The static fluid-loss test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 10.

B.8.3 Determining Rheological Properties

With the concentration of gas in a foamed slurry changing continuously during pumping of the job, it is impractical to perform rheological testing at all the foam quality concentrations that are needed to model the frictional pressures during pumping of a foamed slurry. Use of a rotational viscometer will result in separation of the gas from the slurry, causing erroneous results. Correlations can be used to convert the rheological properties of the base unfoamed slurry to that of a foamed cement with varying foam qualities to simulate the job.

The rheological test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 12.

References

[1] ISO 10426-4: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 4: Recommended Practice for Atmospheric Foam Cement Slurry Preparation," working draft 2001.

[2] ISO 10426-2: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements," 1998.

Appendix 4

Quarterly Report 4

Ultra-Lightweight Cement

Fourth Quarterly Technical Progress Report

July 1 to September 30, 2001

Fred Sabins

Issued October 23, 2001

DOE Award Number
DE-FC26-00NT40919

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). Work reported herein addresses tasks performed in the fourth quarter as well as the other three quarters of the past year.

The subjects that were covered in previous reports and that are also discussed in this report include:

- Analysis of field laboratory data of active cement applications from three oilwell service companies
- Preliminary findings from a literature review focusing on problems associated with ultra-lightweight cements
- Summary of pertinent information from Russian ultra-lightweight cement literature review
- Comparison of compressive strengths of ULHS systems using ultrasonic and crush methods

Results reported from the fourth quarter include laboratory testing of ULHS systems along with other lightweight cement systems—foamed and sodium silicate slurries. These comparison studies were completed for two different densities (10.0 and 11.5 lb/gal) and three different field application scenarios. Additional testing included the mechanical properties of ULHS systems and other lightweight systems. Studies were also performed to examine the effect that circulation by centrifugal pump during mixing has on breakage of ULHS.

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List of Graphical Materials

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, to isolate various formations from one another, and to control fluid movement within the well.

Typical cement fluid density ranges from 12 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitate application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, named lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Sections of a well in which lost circulation occurs include the upper sections: surface casings and intermediate casings. Since formations covered by these casings are relatively close to the Earth’s surface, application temperatures for these low-density cements are relatively low.

The minimum practical density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength. Lower temperature further delays strength development. Achieving density requirements lower than 11 lb/gal with acceptable strengths necessitates use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are being evaluated in this project as a candidate material for producing ultra-lightweight cements. These small, hollow, glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS. The development will be achieved through a carefully designed program of modeling, design, laboratory testing, and field testing.

This quarterly report gives an account of the activities that occurred during the project’s fourth quarter from July 1 to September 30, 2001. Since this is the fourth quarterly report, the report also summarizes the events of the other three quarters of the past year.

Executive Summary

The fourth quarter of this investigation focused on laboratory testing that compared slurries containing ULHS to two other lightweight cement systems: foamed and sodium silicate slurries. The project employs a battery of tests to simulate three field cementing applications:

- conductor casing in deep water
- surface casing on land
- intermediate casing on land

These tests include thickening time, compressive strengths, rheology, free fluid, and fluid loss (where applicable). Preliminary data indicate that the slurries made with ULHS performed as well as or better than the sodium silicate and foamed slurries based on established performance criteria.

For selective slurries, tests were also performed to determine additional mechanical properties of the cement systems. These other mechanical tests include tensile strength, Young's modulus at various confining pressures, and effective compressive strength at various confining pressures.

Work from previous quarters that is also included in this report consists of a review of literature dealing with potential problems of lightweight cement systems including a phenomenon known as alkali-silica reactivity (ASR). This is a potential problem because silica is a large component of ULHS. Reaction mechanisms, prevention techniques, and test methods for ASR are presented.

A review of Russian literature reveals some of the lightweight cement systems that are used in Russia and its neighboring countries. The review presents performance characteristics that are common to some of the lightweight hollow spheres used in that area. In addition, the review offers information on ASR and prevention methods.

Because of the large volume required for this project, a quality-control process has been implemented for the cement. Information and data gathered for the program are presented.

Further testing evaluated the performance of ULHS. Studies investigated the effect of blending shear and circulation by centrifugal pumps during mixing on the breakage of ULHS and the resulting change in density.

Literature Review

Task 1 of this project is to Assess Ultra-Lightweight Cementing Issues. A portion of that task includes a literature review of lightweight cement systems. The literature review also covers the potential alkali-silica reaction that could occur with ULHS. The results of an extensive literature review can be seen in Appendix A, which lists over eighty papers with brief summaries. Findings from the literature follow.

Siliceous admixtures combined with cement create a potential for a phenomenon known as alkali-silica reactivity (ASR). Whether this detrimental reaction occurs depends on several factors including cement chemistry and available moisture.

An aqueous liquid pore solution is present in all cements. This pore solution is alkaline (pH typically greater than 12.5) and can contain calcium cations (Ca^{++}) and alkali cations (Na^{+}, K^{+}). The hydroxyl ions in the alkaline pore solution chemically attack silica (SiO_2) creating SiO^{-} species that are susceptible to reaction with the cations (Ca^{++}, Na^{+}, and K^{+}). If large concentrations of calcium cations are in the pore solution, a calcium silicate hydrate (C-S-H) gel is formed. C-S-H gel is considered one of the safe reactions that can occur; it is not prone to swelling.[1]

When the alkali concentration in pore solutions is high as compared to the calcium ion concentration, a deleterious high alkali-silica gel will be formed. The high-alkali gel has a greater capacity to swell with absorption of moisture. This swelling can lead to detrimental cracking of the cement. As might be expected, if available moisture remains low (below 80% relative humidity referenced to 70 to 75°F), there will not be enough moisture available for detrimental swelling. [2]

There are several methods available to limit or prevent this detrimental expansion caused by ASR. One of the ways to avoid this reaction is to avoid using siliceous materials that are known to be reactive. Decreasing the alkali level of the cement (less than 0.60% equivalent Na_2O) can also limit the ASR gel formation. Another method includes the addition of specific admixtures. These admixtures impede normal ASR by reducing the steady state concentration of alkali and hydroxyl ions in concrete, or by altering diffusion rates of alkali and lime to reaction sites. Common admixtures that are used to limit ASR are fly ash, blast-furnace slag, and silica fume.[2]

Because of the siliceous components of ULHS, it is important to determine if ULHS is susceptible to ASR. There are several ASTM methods that aim to identify reactive materials that lead to ASR in cements[2]:

1. ASTM C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
2. ASTM C 289 Test Method for Potential Reactivity of Aggregates (Chemical Method)
3. ASTM C 295 Guide for Petrographic Examination of Aggregates for Concrete
4. ASTM C 1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

There are pros and cons to each method. As suggested by their titles, these methods are used to identify potentially reactive aggregates that are generally used in construction cement. Methods C 227 and C 289 are effective in identifying rapidly reactive materials, but fail to identify slowly reactive materials. ASTM C 1260 is an accelerated mortar-bar method that helps to identify some of the longer-term reactions. ASTM C 295 is a rapid way to identify potentially reactive aggregates, but is highly subjective and dependent on the capability of the petrographer examining the aggregate.[2] All of these test methods are also geared toward aggregates, which are different from the admixtures that are used in oilwell cementing. Compared to oilwell cement admixtures, aggregates in concrete are used in a much larger concentration in the cement blend and aggregates are also much larger with less surface area.

If ULHS is affected by ASR, there is a possibility that the glass wall of the ULHS will be chemically attacked. This could in turn increase the permeability of cements made with ULHS. Hence, long-term permeability testing could reveal if ASR negatively affects cements made with ULHS.

This project is pursuing several methods for detecting ASR. Permeability data of different cement systems including ULHS systems are presented in another section of this report. The permeability data is short-term (24 hours of cement curing) and will be compared with long-term permeability data that will be collected in the following project quarter. An outside laboratory is also performing tests using a modified version of ASTM C1260, the accelerated mortar-bar method. The modified ASTM C 1260 test method makes adjustments for smaller admixture concentrations that are typical of the concentrations used in oilwell cementing. This project will also test for ASR as outlined by ASTM C 289.

Review of Russian Lightweight Cement Literature

Task 2 of this project is to Review Russian Lightweight Cement Literature. Appendix B contains a report of a Russian literature review conducted by Dr. Vladimir Sledkov. This review reveals that there are several types of hollow microspheres used in Russia. A group of microspheres with the trade name Plaminol is made from phenol-formaldehyde and carbamide formaldehyde tars and filled with nitrogen. These Plaminol microspheres are generally expensive and have limited collapse strength (less than 2,900 psi).[3,4]

Most of the hollow glass microspheres from Russia have low collapse strengths (less than 1,500 psi). However, there are Russian companies that produce aluminum sodium borosilicate glass hollow microspheres with collapse strengths of 1,450 to 2,900 psi. The collapse strength of 2,900 psi is still below most of the ULHS under study in this project.

This literature review also points out that sodium glass is susceptible to attack by alkaline medium. To counteract the effects of lime, it is recommended that materials such as pozzolan or slag be added to the cement slurry.[5] Protective materials, such as boron and aluminum silicates, are effective in boosting the chemical resistance of glass microspheres. Some of the products from initial reaction with these materials help to create a protective barrier that slows silicate glass destruction.[6] Boron and aluminum silicate glass microspheres generally have collapse strengths in excess of 4,000 psi.

Data from Service Companies

Project members Schlumberger, Halliburton Energy Services (HES), and BJ Services contributed historical data that they generated on lightweight cement systems. Data was compiled from laboratory tests for field cement applications. These data represent a significant population of actual lightweight cement applications. Exact compositions of the different cement systems were not specified because of the proprietary nature of these formulations. However, density, 24-hour compressive strength, bottomhole circulating temperature (BHCT), and other data were shared and are presented in Appendix C. A summary of the data received to date is presented in Tables 1 through 3.

Table 1—Summary of Data Sets from Service Companies

Type of Cement	No. of Tests in Data Set	Type of Applications and Compositions							
		Offshore	Land-Based	With Bentonite	With Sodium Silicate	With Calcium Sulfate	With Micro-spheres	With HEC	With Blast-Furnace Slag
Halliburton Unfoamed	3,778	3,042	736	1,097 (29%)	1,077 (29%)	787 (21%)	137 (4%)	286 (8%)	20 (0.5%)
Halliburton Foamed	294	294†	0	unspecified	unspecified	unspecified	unspecified	unspecified	unspecified
BJ Services Unfoamed	177	50	127	28 (16%)	55 (31%)	unspecified	48 (27%)	unspecified	unspecified
Schlumberger Unfoamed	149	24	125	56 (38%)	52 (35%)	unspecified	unspecified	unspecified	unspecified

†Water depth ranged from 113 ft to 7,600 ft, with a large majority between 2,000 and 5,000 ft.

Table 2—Summary of Density Data

Type of Cement	Percentage of Tests within a Density Range (%)		
	9.0 to 10.9 lb/gal	11.0 to 11.9 lb/gal	12.0 to 13.0 lb/gal
Halliburton Unfoamed	0.7	26.6	72.7
Halliburton Foamed	11.0	22.0	67.0
BJ Unfoamed	16.0	32.0	55.0
Schlumberger Unfoamed	7.4	33.6	59.7

Table 3—Types of Cement Used in Historical Test Data

Type of Cement	Percent of Data within Classification of Base Cement (%)									
	Class A	Class C	Class G	Class H	TXI LW	Microfine	Fly Ash/ Class A	Fly Ash/ Class H	Slag	Others
HES Unfoamed	19.0	0	0	35.0	20.0	7.0	6.0	11.0	2.0	0
HES Foamed	47.0	0	0	9.4	0	43.0†	0	< 1.0	< 1.0	0
BJ Unfoamed	12.0	33.0	12.0	42.0	0	0	0	0	0	1.0

†All tests between 10.0 & 11.9 lb/gal were run using an unspecified percentage of Microfine cement. Only 33 (19%) of the 12.0 to 12.9 lb/gal were run using Microfine cement. All remaining tests were either Class A (a large majority) or Class H.

This study investigates 24-hour compressive-strength information for lightweight cement systems. All of the compressive strength data from BJ Services and Schlumberger was derived from crushing 2-in. cube samples. The majority (approximately 60%) of the Halliburton compressive strength data was derived from physical crushing; the remainder of the Halliburton compressive strength data was derived using non-destructive ultrasonic analysis. The compressive strength data is organized into three practical categories:

- 500 psi and above
- 200 to 499 psi
- Below 200 psi

500 psi was chosen as a milestone compressive strength because it is the WOC (waiting on cement) strength that is required before drilling further. 200 psi was arbitrarily chosen as another cutoff to ease data analysis and further break the data down into more-finite categories.

This data analysis focuses on the 24-hour compressive strength of the two general categories of lightweight cements: foamed and unfoamed. Because of insufficient information regarding composition, further analysis by composition is impractical.

Figure 1 depicts the data distribution for the two different categories of lightweight cements (foamed and unfoamed). The data for the unfoamed cements combines 149 data sets from Schlumberger; 3,777 data sets from Halliburton; and approximately 177 data sets from BJ. Halliburton also provided approximately 294 data sets for foamed slurries. No foamed cement data was provided by BJ or Schlumberger.

The data is based on a variety of traditional lightweight cement systems, some of which contain or are extended by bentonite, microfine cement, hollow spheres, sodium silicate, and fumed silica.

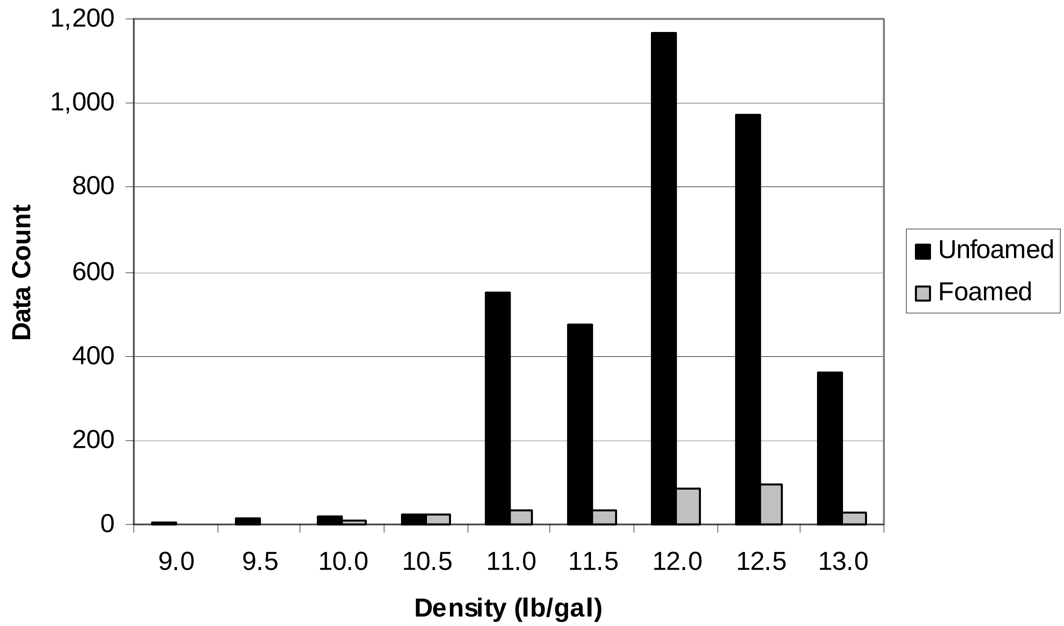

Figure 1—Data distribution for foamed and unfoamed cements

The database contains limited temperature data for a large percentage of the unfoamed slurries. BHCT is chosen as one way to differentiate the data because it is the temperature parameter common to most of the data sets. Most (97%) of the foamed cement data collected was for BHCT of 100°F or below. Forty-eight percent (48%) of the unfoamed cement data is for BHCT of 100°F or below. The data analysis is divided into three broad temperature categories: 1) all temperatures, 2) BHCT of 100°F and below, and 3) BHCT of 101°F and above.

This study examines lightweight cement systems with a density of 13.0 lb/gal or less. To better trace the trends of slurry density versus compressive strength, the density values are divided into ranges with 0.5 lb/gal increments. For example, the density range of 11.0 lb/gal covers all densities from 11.0 to 11.4 lb/gal, and the 11.5-lb/gal density range covers all densities from 11.5 to 11.9 lb/gal.

Most of the slurry densities are 11.0 lb/gal or greater (see Figure 1). Ninety-nine percent (99%) of the unfoamed cements and 90% of the foamed cements have densities of 11.0 lb/gal or greater.

Figures 2 through 4 present data for conventional unfoamed cements. Figure 2 shows the percentage of all cements that fall into the three compressive-strength categories. Figures 3 and 4 display the data for temperatures 100°F and below (Figure 3) and 101°F and above (Figure 4). These charts show the percentage of the data that falls within the three different compressive-strength categories for each density division. Note the general trend of low strength at low density.

Figure 3 depicts the data count associated with each of the different densities. The small number of data points below 11.0 lb/gal came mostly from BJ slurries that contained hollow ceramic or glass spheres. The small amount of data from these specialized slurries tends to contradict the general trend of an increase in compressive strength with an increase in density. This same anomaly can also be seen in Figure 4. The fact that these data points are for cements with hollow spheres strengthens the theory that ULHS can extend the practical lower density limit of cement.

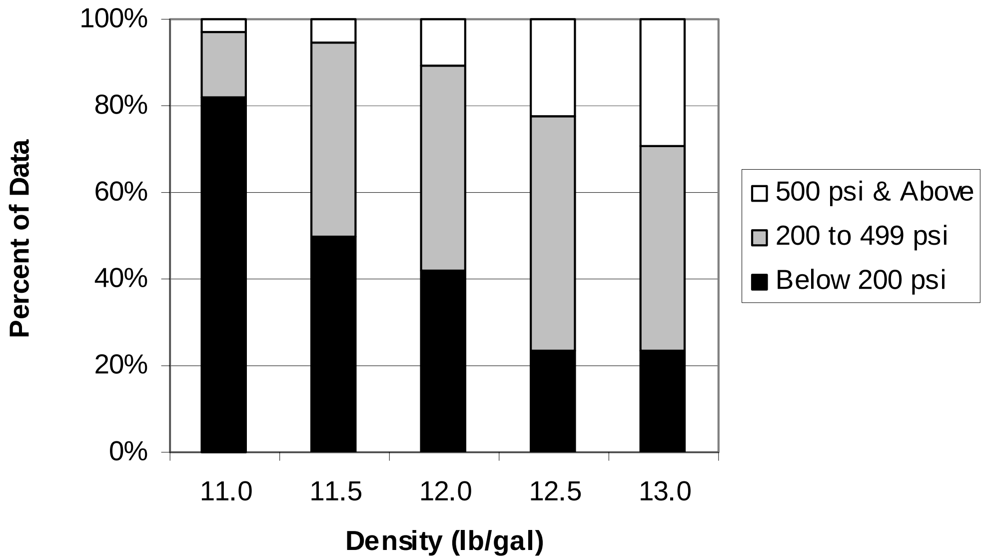

Figure 2—24-hour compressive strength for all temperature categories of unfoamed cements

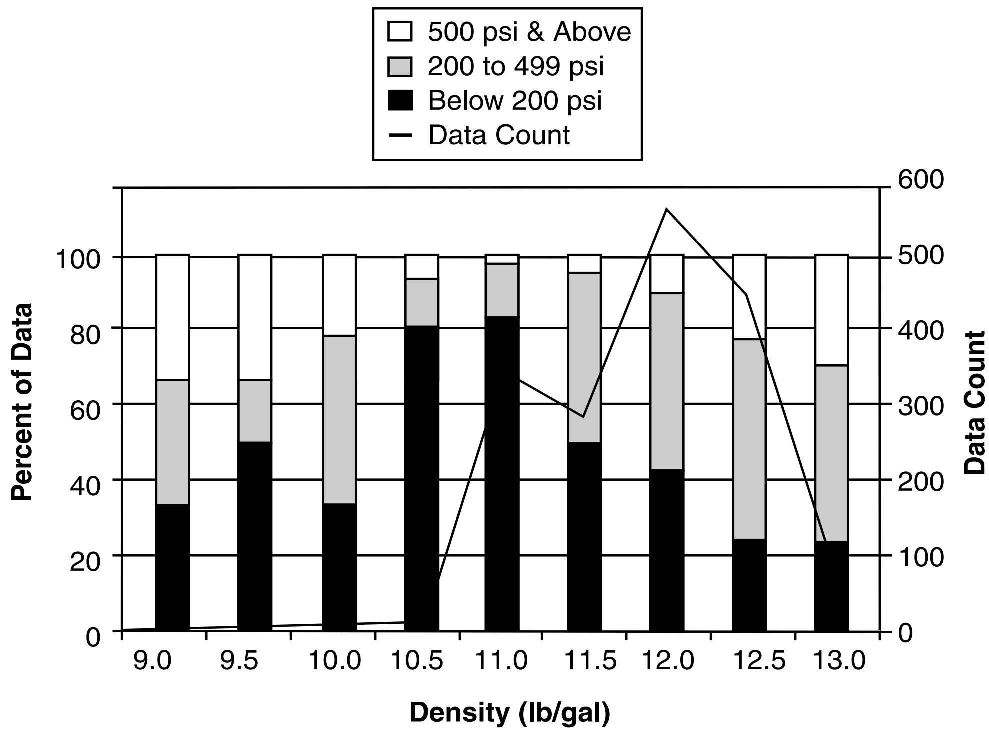

Figure 3—24-hour compressive strength for unfoamed cement at 100°F and below

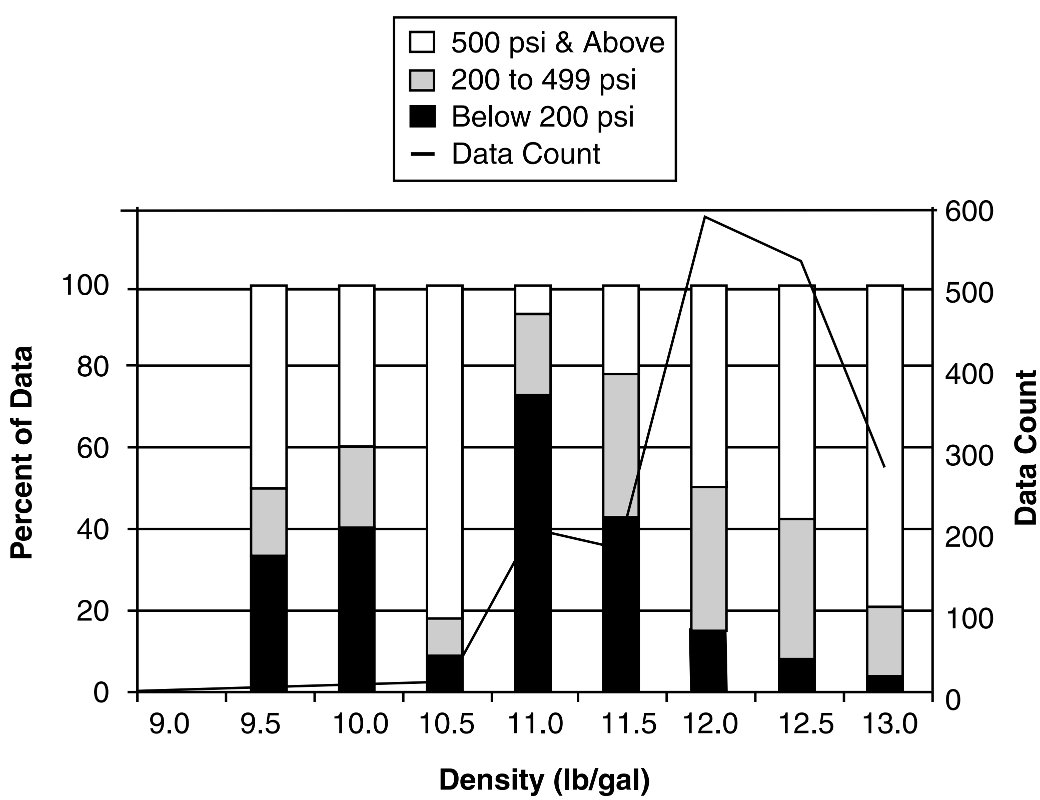

Figure 4—24-hour compressive strength for unfoamed cement at 101°F and above

Figures 5 presents foamed cement data from the Halliburton data. Note that the trend identified for unfoamed cements also applies to the foamed cements. The majority of the foamed slurries in the historical data set have a BHCT between 60 and 65°F, which could account for the lower compressive strength.

Lightweight cement systems that are currently available rarely develop substantial compressive strength at densities below 12.5 lb/gal. Strong lightweight cements are particularly scarce for low-temperature applications.

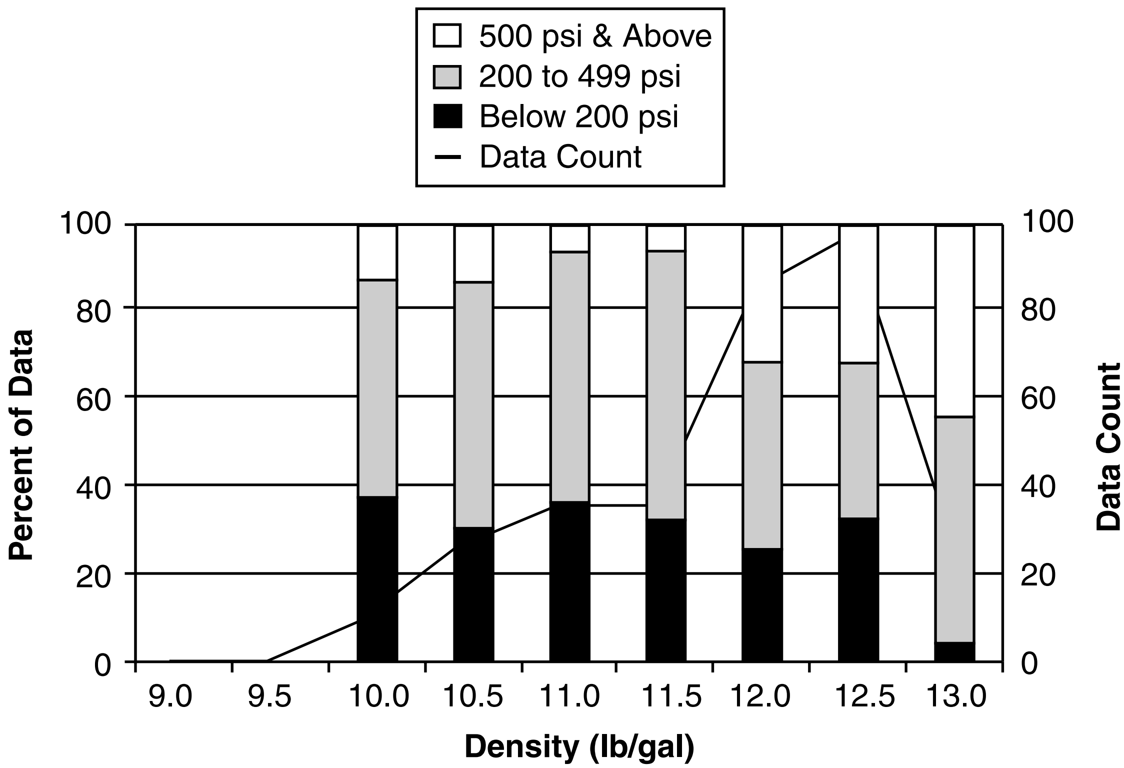

Figure 5—24-hour compressive strength for foamed cement at 100°F and below

Cement Quality-Control Program

An extensive quality-control program was initiated because of the large quantity of cement used over the course of this project. Each bucket of cement is labeled with a materials log number and date upon receipt. When a bucket is first opened for use, the date of opening is recorded in the materials log. This log number will be referenced on the laboratory sheets for each test performed. Where applicable, tests according to API Specification 10A[7] are conducted. Additionally, several other tests tailored specifically for the test conditions and materials (rheology and low-temperature compressive-strength development) are included in this QC Program.

The Class A and Class H cement performance requirements are presented in API Specification 10A. Because the Lightweight Oilwell cement is not an API cement, it is tested according to QC procedures developed by the manufacturer.

Both API Specification tests and tests recommended by advisory board members were performed for the cement quality-control program. The physical requirements used for testing each of the cements are listed in Table 4. To accelerate the rate of compressive-strength development at low temperatures, calcium chloride ($CaCl_2$) is being used with the cements according to Table 5. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 4—Cement Slurry Compositions for Quality-Control Testing Program

Cement	Mix Water (% bwoc)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Class A	46	15.6	772	355	API Series of Tests
TXI Lightweight	75	13.2	541	406	Thickening Time & Compressive Strength
TXI Lightweight	105	12.1	426	447	Free Fluid
Class H	38	16.4	860	327	API Series of Tests

Table 5—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (% bwoc)
80	0.0
60	1.0
45	2.0

These quality-control tests have been run to provide a baseline for each type of cement. This QC data will provide a comparison when examining other data for this project. After several cycles of the complete QC program had been performed on the cements, the data showed no significant variations and remained within the vendors’ specifications. It was then decided to proceed with a less-stringent program of scheduled thickening-time tests. Each time that a new bucket is opened, a thickening-time test is run. In addition, once a month, a thickening-time test is performed on all opened buckets (for all three cement types). The thickening-time test was chosen as a gauge to detect abnormal cement performance. Appendix D shows the data gathered for the quality-control program through the fourth project quarter.

Effect of Laboratory Blender Shear on Bead Breakage

Studies have been performed on the ULHS slurries to determine the effect of blending shear on bead breakage. One way to analyze possible breakage is by monitoring slurry density changes after shearing ULHS slurries. The slurries for these shear effect studies were prepared as follows.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry (without ULHS) according to Section 5.3.5 of API RP 10B.[9]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

The density of this (unsheared) slurry is then measured with a pressurized mud balance and recorded. This same slurry is then placed in a Waring blender and mixed at 4,000 RPM for 35 seconds. The density of the slurry is again measured and recorded. The slurry is again transferred to the Waring blender and mixed at 4,000 RPM for an additional 15 seconds (50 seconds total). The density of the slurry is again measured and recorded. Table 6 shows the results from these experiments.

Table 6—Effect of Shear on Slurry Density

Measurements for 10.0 lb/gal Slurry Design				
	ULHS Type			
	3K	4K	5K	6K
ULHS Concentration (% bwoc)	20.89	21.71	21.71	29.13
Water Concentration (gal/sk)	8.5	8.5	8.5	8.5
Density Before Shear (lb/gal)	10.0†	10.0	10.0	10.0
Density After 35 Seconds of Shear (lb/gal)	10.3†	10.2	10.5	10.1
Density After 50 Seconds of Shear (lb/gal)	10.4†	10.3	10.5	10.1
Measurements for 11.0 lb/gal Slurry Design				
	ULHS Type			
	3K	4K	5K	6K
ULHS Concentration (% bwoc)	13.24	13.74	13.74	18.18
Water Concentration (gal/sk)	8.5	8.5	8.5	8.5
Density Before Shear (lb/gal)	11.0†	11.0	11.0	11.0
Density After 35 Seconds of Shear (lb/gal)	11.3	11.2	11.4	11.0
Density After 50 Seconds of Shear (lb/gal)	11.4	11.3	11.4	11.1

†Density confirmed with three samples.

As evidenced by an increase in slurry density, the 3K, 4K, and 5K beads were distinctly damaged by the shear. The 6K beads suffered the least from shearing.

The cross (†) in Table 6 marks four slurries for which the density was checked three times. Of these slurries, the slurry was divided into three different samples and the density for each sample was measured with a pressurized mud balance. For each slurry, the measured density for all three samples was the same. These additional density measurements were performed to confirm that the density measurements are repeatable.

Effect of Centrifugal Pump Circulation on Bead Breakage

Another investigation in this project examined the effect that centrifugal pump circulation during mixing has on bead breakage. Two different ULHS systems were studied—3K and 6K. The slurry density for both of the systems was 10.0 lb/gal. The formulation for the two slurries is as follows.

3K ULHS System
Class H Cement + 20.49% bwoc 3K ULHS + 9.0 gal of fresh water/sk of cement.
Yield: 2.52 ft^3/sk.

6K ULHS System
Class H Cement + 26.50% bwoc 6K ULHS + 11.0 gal of fresh water/sk of cement.
Yield: 2.80 ft^3/sk.

A slurry volume based on two sacks of cement was tested for each slurry. The slurry was placed in a container and recirculated through a semi-open impeller, self-priming centrifugal pump (Gorman-Rupp Model 83E1-GX140). The 3K ULHS system was circulated at a rate of 68 gallons per minute. The 6K ULHS system was circulated at a rate of 98 gallons per minute. Both systems were circulated for one hour.

The results of these tests are presented in Tables 7 through 10. Slurry density and temperature were measured throughout the tests. Slurry rheology was also measured at the beginning and end of each test. The data is presented based on the number of times that the slurry volume is circulated (assuming 100% circulation efficiency). In Tables 7 and 9, the measured slurry density is used to deduce the effective specific gravity of the ULHS.

Table 7—Data for Circulation Test of 3K ULHS System

Time (minutes)	Number of Times Volume is Circulated	Slurry Density (lb/gal)	ULHS Specific Gravity	Temperature (°F)
0	0	10.00	0.370	92.9
8	14	10.00	0.370	97.0
18	32	10.10	0.381	102.6
24	43	10.20	0.393	105.8
34	61	10.25	0.399	109.0
40	72	10.30	0.406	112.2
48	87	10.30	0.406	114.8
54	97	10.35	0.412	116.7
60	108	10.40	0.418	118.6

Table 8—Rheology for Circulation Test of 3K ULHS System

Rheology		
RPM	**Beginning**	**End**
300	55	56
200	41	44
100	27	32
60	21	25
30	16	20.0
20	14	16
10	10	11
6	8	7
3	6	6
Temp (°F)	92.9	118.6

Table 9—Data for Circulation Test of 6K ULHS System

Time (minutes)	Number of Times Volume is Circulated	Slurry Density (lb/gal)	ULHS Specific Gravity	Temperature (°F)
0	0	10.05	0.460	100.3
8	19	10.05	0.460	107.0
16	37	10.10	0.468	110.4
24	56	10.10	0.468	112.6
32	75	10.10	0.468	115.5
40	94	10.10	0.468	118.0
48	112	10.10	0.468	120.1
54	126	10.10	0.468	120.6
60	140	10.10	0.468	121.1

Table 10—Rheology for Circulation Test of 6K ULHS System

Rheology		
RPM	**Beginning**	**End**
300	30	32
200	28	26
100	21	19
60	15	16
30	11	13.0
20	8	12
10	6	9
6	5	6
3	4	4
Temp (°F)	100.3	121.1

Figure 6 shows the change of slurry density with respect to the number of times that the volume is circulated. Figure 7 shows the effect that the circulation and mixing energy of the pump has on the effective specific gravity of ULHS. As seen in Figures 6 and 7, the 6K ULHS system experienced less bead breakage and retained its specific gravity and slurry density better than the 3K ULHS system; however, considering the number of cycles that the ULHS systems went through, both systems held up rather well. Future studies will analyze the data further and compare the mixing energy delivered by cementing units and the mixing energy delivered by the centrifugal pump used in this study.

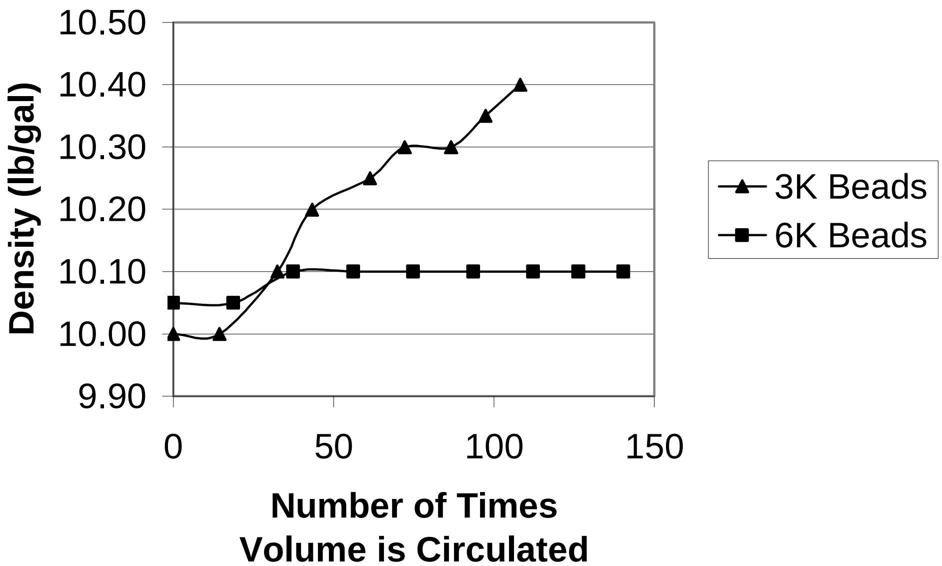

Figure 6—Effect of pump circulation on slurry density

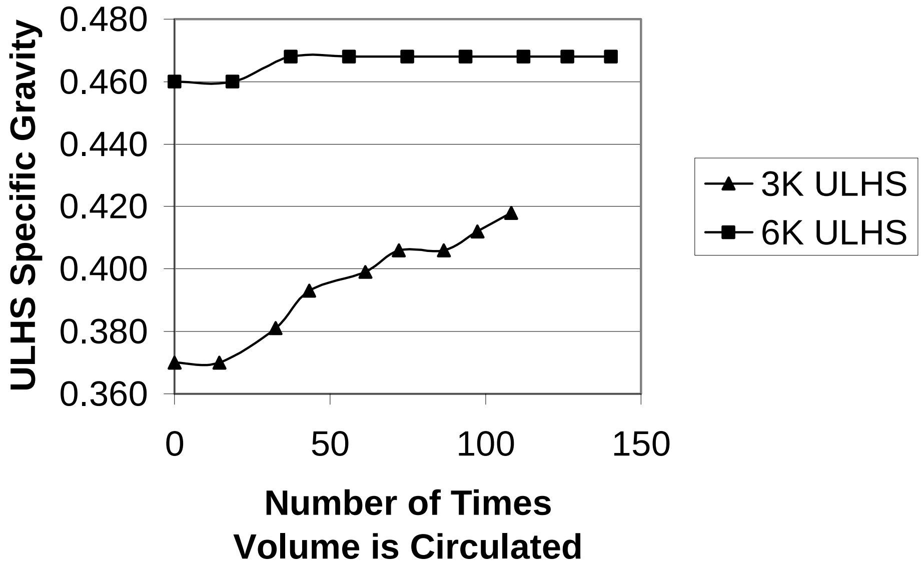

Figure 7—Effect of pump circulation on ULHS specific gravity

Application Scenarios

One way to gauge the performance of cements made with ULHS is to compare them to other ultra-lightweight cements. Members of the project steering committee decided to compare ULHS cements with a foamed cement and with a conventional sodium-silicate slurry.

Three different application scenarios were chosen to test the performance of the lightweight cements. Application 1 simulates deepwater cementing. Application 2 simulates a typical land-based surface pipe cementing job. Application 3 simulates a typical land-based cementing job for intermediate casing.

To determine typical well parameters associated with surface and intermediate casing jobs, a historical review was conducted using data from Appendix C of *Worldwide Cementing Practices*[8]. This review looked at casing sizes, hole depths, bottomhole static temperature (BHST), and BHCT. Table 11 presents a summary of the findings of the review. This analysis indicates that the most common surface casing size in the US is 8 5/8 in. The most common intermediate casing size is 9 5/8 in.

Table 11—Summary of Casing Conditions in the United States

Number of Data Samplings						Avg. Depth (ft)	Avg. BHST (°F)	Avg. BHCT (°F)
Casing	8 5/8 inches	9 5/8 inches	13 3/8 inches	Other	Total			
Surface	64†	37	29	24	182	1,660	96	78
Intermediate	17	34‡	0	26	77	8,300	174	128

† The average weight was 24 lb/ft.

‡ The average weight was 53.5 lb/ft.

Table 12 shows the pressure and temperatures associated with the three different applications. The conditions for Application 1 (deepwater) came from typical applications as experienced by the principal investigator. The values for the surface pipe and intermediate casing applications (2 and 3) came from the average values indicated in Table 11. For the three applications, the slurries were designed to try to achieve certain performance standards (although they could not always be achieved). These standards are also listed in Table 12.

Table 12—Simulation Conditions for Comparison of Lightweight Slurries

Application	BHCT (°F)	BHST (°F)	Pressure (psi)	Desired Thickening Time	Desired Free Fluid	Desired Fluid Loss
1	65	45	5,300	4 to 6 hours	≤1%	NA
2	78	96	1,000	4 to 6 hours	≤1%	NA
3	128	174	5,000	4 to 6 hours	≤0.5%	250cc/30min

Of the different classes of ULHS being studied in this project, the 6K beads were chosen because of their ability to withstand the hydrostatic pressures associated with the applications.

Most of the tests were performed as specified in API RP 10B[9]. Some preparation and testing methods were modified for the ULHS and foamed slurries. The mixing procedures were modified for the ULHS slurries to minimize bead breakage that can occur because of high shear from API blending procedures. The following blending procedure was used for the ULHS slurries.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry (without ULHS) according to Section 5.3.5 of API RP 10B.[9]

3. Pour the slurry into a mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

4. Pour this slurry back into the Waring blender and mix at 4,000 RPM for 35 seconds to mix and evenly distribute the contents.

Testing methods for foamed slurries were also modified. For example, thickening-time tests are performed on unfoamed slurries only. Because the air in the foam will not affect the thickening rate, the slurry is prepared as usual per API RP 10B[9] and then the foaming surfactants are mixed into the slurry by hand without foaming the slurry. This and the other non-standard procedures for testing foamed cement are presented in Appendix E.

Attention was given to the foamed slurries as they were being prepared and tested. After the slurries were mixed and foamed in the blender, the foamed slurry did not expand when the container was opened; many people in the industry have experienced foam expansion once the container is opened. The densities of the foamed slurries were measured using a volumetric container and a scale and were found to be within 0.1 lb/gal of the designed foamed density.

Also, cubes that were cured for compressive-strength testing showed no visual volumetric change. The cubes were the same size after curing as when they were poured into the molds.

Table 13 presents the slurry compositions for the 11.5-lb/gal slurries. Table 14 presents the slurry compositions for the 10.0-lb/gal slurries. Additives (slurry extenders, accelerators, foaming agents, etc.) were added to the slurries in order to adapt each slurry to the application's testing conditions as specified in Table 12. The additives are widely available, generic additives, and are not specific to any particular service company. These additives include Witcolate® 7093 (a foaming agent), Aromox® C/12 (a foam stabilizer), Natrosol® 250 GXR (a fluid-loss control additive), Melcret® (a dispersant), and Diacel® FL (a fluid-loss control additive).

Testing of the 10.0-lb/gal slurries does not include sodium-silicate slurries. That is because the density of 10.0 lb/gal is outside of the typical working range for sodium-silicate slurries.

Tables 15 and 16 present rheology data for the slurries specified in Tables 13 and 14 respectively. The data was taken using a Chandler Chan 35 direct-indicating viscometer. Each slurry was first conditioned in an atmospheric consistometer for twenty minutes at the specified temperature and then rheology readings were taken.

Table 13—Compositions for 11.5-lb/gal Slurries

Application 1				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.7	8.00	2.0% bwoc $CaCl_2$; 14.9% bwoc (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	1.0% bwoc $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% bwoc Sodium Silicate
TXI Lightweight	ULHS	11.5	6.65	2.0% bwoc $CaCl_2$; 11.5%bwoc (6K) ULHS
	Foamed	13.1† (11.4‡)	7.00	2.0% bwoc $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.6	12.11	3.0% bwoc Sodium Silicate
Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.5	7.09	16.2% bwoc (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% bwoc Sodium Silicate
TXI Lightweight	ULHS	11.5	6.50	2.0% bwoc $CaCl_2$; 11.9% bwoc (6K) ULHS
	Foamed	13.0† (11.5‡)	7.00	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	12.11	3.0% bwoc Sodium Silicate

†Unfoamed slurry density
‡Foamed slurry density

Table 13—Compositions for 11.5-lb/gal Slurries (Continued)

Application 3				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class H	ULHS	11.5	8.20	1.1% bwoc Natrosol® 250 GXR; 0.3% bwoc Melcret®; 13.4% bwoc (6K) ULHS
	Foamed	15.6† (11.5‡)	4.97	0.6% bwoc Natrosol® 250 GXR; 0.11 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.42	0.65% bwoc Natrosol® 250 GXR; 0.5% bwoc Melcret®; 2.0% bwoc Sodium Silicate
TXI Lightweight	ULHS	11.5	6.53	0.16% bwoc Marabond® 21; 0.75% bwoc Natrosol® 250 GXR; 0.25% bwoc Melcret®; 10.8% bwoc (6K) ULHS
	Foamed	13.0† (11.5‡)	6.76	0.2% bwoc Marabond® 21; 0.8% bwoc Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	11.60	0.75% bwoc Marabond® 21; 1.0% bwoc Natrosol® 250 GXR; 0.5% bwoc Melcret®; 2.0% bwoc Sodium Silicate

†Unfoamed slurry density

‡Foamed slurry density

Table 14—Compositions for 10.0-lb/gal Slurries

Cement Type	Slurry System	Measured Density (lb/gal)	Water Content (gal/sk)	Additive Concentrations
Application 1				
Class A	ULHS	10.0	8.53	2.0% bwoc $CaCl_2$; 29.6% bwoc (6K) ULHS
	Foamed	15.6† (10.0‡)	5.24	2.0% bwoc $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	7.17	2.0% bwoc $CaCl_2$; 26.0% bwoc (6K) ULHS
	Foamed	13.5† (10.0‡)	6.09	2.0% bwoc $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	10.0	8.50	29.1% bwoc (6K) ULHS
	Foamed	15.6† (10.0‡)	5.19	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	7.23	2.0% bwoc $CaCl_2$; 26.0% bwoc (6K) ULHS
	Foamed	13.5† (10.0‡)	6.10	2.0% bwoc $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
Application 3				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class H	ULHS	10.0	8.48	0.2% bwoc Marabond® 21; 0.50 gal/sk Diacel® FL; 30.0% bwoc (6K) ULHS
	Foamed	15.6† (10.0‡)	5.01	0.6% bwoc Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	8.08	0.15% bwoc Marabond® 21; 1.0% bwoc Natrosol® 250 GXR; 1.0% bwoc Melcret®; 23.6% bwoc (6K) ULHS
	Foamed	13.5† (10.0‡)	5.82	0.3% bwoc Marabond® 21; 0.8% bwoc Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12

†Unfoamed slurry density
‡Foamed slurry density

Table 15—Rheology Data for 11.5-lb/gal Slurries

Cement Type	Slurry System	Temperature (°F)	Dial Reading (RPM)								
Application 1											
Cement Type	**Slurry System**	**Temperature (°F)**	**300**	**200**	**100**	**60**	**30**	**20**	**10**	**6**	**3**
Class A	ULHS	80	59	48	24	29	25	23	19	14	10
	Foamed†	80	96	82	65	56	49	45	33	23	15
	Sodium Silicate	80	31	28	24	23	21	20	19	17	14
TXI Lightweight	ULHS	80	92	80	65	58	50	46	33	25	17
	Foamed†	80	40	35	29	26	23	22	19	16	11
	Sodium Silicate	80	43	38	33	30	27	25	23	20	11
Class A	ULHS	65	72	57	40	32	26	24	20	16	11
	Foamed†	65	80	68	54	47	41	37	28	18	12
	Sodium Silicate	65	31	27	23	21	19	19	18	17	11
TXI Lightweight	ULHS	65	112	94	74	64	55	50	38	26	18
	Foamed†	65	54	47	38	34	29	27	23	19	12
	Sodium Silicate	65	40	36	31	28	26	23	22	20	12
Application 2											
Cement Type	**Slurry System**	**Temperature (°F)**	**300**	**200**	**100**	**60**	**30**	**20**	**10**	**6**	**3**
Class A	ULHS	78	107	87	64	53	40	33	20	14	9
	Foamed†	78	80	68	53	47	39	36	24	16	9
	Sodium Silicate	78	34	30	27	25	23	22	20	19	10
TXI Lightweight	ULHS	78	115	98	78	69	58	52	35	26	17
	Foamed†	78	42	37	30	26	23	21	19	16	9
	Sodium Silicate	78	40	35	32	29	26	25	24	20	12
Class A	ULHS	96	122	102	79	67	47	36	22	14	9
	Foamed†	96	102	90	74	67	56	48	28	19	10
	Sodium Silicate	96	29	26	23	21	19	18	17	13	8
TXI Lightweight	ULHS	96	144	124	101	88	72	59	38	29	19
	Foamed†	96	61	54	46	41	35	31	25	18	10
	Sodium Silicate	96	45	39	33	30	27	25	23	18	12
Application 3											
Cement Type	**Slurry System**	**Temperature (°F)**	**300**	**200**	**100**	**60**	**30**	**20**	**10**	**6**	**3**
Class H	ULHS	80	300+	300+	192	130	74	53	29	19	9
	Foamed†	80	300+	253	152	104	61	45	26	18	11
	Sodium Silicate	80	35	28	19	16	14	12	11	11	10
TXI Lightweight	ULHS	80	300+	256	156	109	68	54	38	31	26
	Foamed†	80	152	111	64	42	24	17	10	7	4
	Sodium Silicate	80	70	53	35	28	22	20	18	18	17
Class H	ULHS	128	243	176	101	66	37	25	14	9	5
	Foamed†	128	282	218	140	110	78	66	51	44	37
	Sodium Silicate	128	18	14	9	8	6	5	5	5	5
TXI Lightweight	ULHS	128	251	188	119	87	60	50	39	34	30
	Foamed†	128	132	103	70	54	41	36	30	27	24
	Sodium Silicate	128	66	51	37	30	24	23	21	20	20

†Rheology data from unfoamed slurry

Table 16—Rheology Data for 10.0-lb/gal Slurries

Cement Type	Slurry System	Temperature (°F)	Dial Reading (RPM)								
Application 1											
			300	200	100	60	30	20	10	6	3
Class A	ULHS	80	180	135	87	66	47	38	27	22	16
	Foamed†	80	96	82	65	56	49	45	33	23	15
TXI Lightweight	ULHS	80	219	177	126	105	77	62	46	35	26
	Foamed†	80	40	35	29	26	23	22	19	16	11
Class A	ULHS	65	200	156	97	81	62	50	32	28	24
	Foamed†	65	80	68	54	47	41	37	28	18	12
TXI Lightweight	ULHS	65	231	190	141	112	84	70	56	44	40
	Foamed†	65	54	47	38	34	29	27	23	19	12
Application 2											
Cement Type	**Slurry System**	**Temperature (°F)**	**Dial Reading (RPM)**								
			300	200	100	60	30	20	10	6	3
Class A	ULHS	78	167	129	88	68	46	37	27	20	13
	Foamed†	78	80	68	53	47	39	36	24	16	9
TXI Lightweight	ULHS	78	210	169	125	105	74	60	45	35	23
	Foamed†	78	42	37	30	26	23	21	19	16	9
Class A	ULHS	96	209	187	104	80	62	48	39	27	20
	Foamed†	96	102	90	74	67	56	48	28	19	10
TXI Lightweight	ULHS	96	236	215	141	112	81	72	53	38	34
	Foamed†	96	61	54	46	41	35	31	25	18	10
Application 3											
Cement Type	**Slurry System**	**Temperature (°F)**	**Dial Reading (RPM)**								
			300	200	100	60	30	20	10	6	3
Class H	ULHS	80	294	215	120	81	45	31	16	9	4
	Foamed†	80	300+	277	181	135	93	80	62	55	48
TXI Lightweight	ULHS	80	300+	280	183	127	77	58	36	28	20
	Foamed†	80	264	197	120	84	53	42	29	24	18
Class H	ULHS	128	138	95	52	33	17	11	5	3	1
	Foamed†	128	274	212	140	106	75	64	48	42	35
TXI Lightweight	ULHS	128	270	200	121	85	55	43	31	25	20
	Foamed†	128	220	168	109	81	57	48	28	33	29

†Rheology data from unfoamed slurry

Table 17 shows an overview of the performances of each of the 11.5-lb/gal slurries. Table 18 gives a performance overview for the 10.0-lb/gal slurries. The thickening time for each slurry is recorded as the time that the consistency reached 70 Bc. Table 17 also presents the point of departure for the sodium-silicate slurries. The point of departure indicates when the slurry consistency begins to noticeably increase. This is sometimes taken as the thickening time for highly extended slurries such as those extended with sodium silicate. In such slurries, the point of departure is used because the mechanical agitation of the thickening time test may "break" hydrates that are forming but which have low consistency (Bc) because of the large amount of mix water. The values for the crush compressive strengths in Tables 17 and 18 are the averages of three 2-inch×2-inch×2-inch cube samples that were crushed. The samples were cured in a water bath at atmospheric pressure and at the BHST specified for each application. The free-fluid tests were performed at the BHCT for each application.

Because of the low temperatures associated with Applications 1 and 2, calcium chloride ($CaCl_2$) was used with some of the foamed and ULHS slurries to accelerate thickening time. Calcium chloride was not used with the sodium-silicate slurries because of viscosity issues specific to this slurry. The only viable accelerators for sodium-silicate slurries are company-specific and not widely available in a generic form.

Table 17—Summary of Laboratory Tests for 11.5-lb/gal Slurries

Cement Type	Slurry System	Thickening Time to 70Bc (Hr:Min)	Point of Departure (Hr:Min)	Percent Free Fluid	Crush Compressive Strength 24 Hours (psi)	Crush Compressive Strength 7 Days (psi)	API Fluid Loss (mL/30min)
Application 1							
Class A	ULHS	7:00+	—	0.0	220	1,000	—
	Foamed	3:55*	—	0.6*	170	1,120	—
	Sodium Silicate	6:40+	4:40	1.1	Not Set	240	—
TXI Lightweight	ULHS	6:40	—	0.0	160	450	—
	Foamed	5:35*	—	0.4*	80	280	—
	Sodium Silicate	7:00+	4:35	0.4	60	170	—
Application 2							
Cement Type	**Slurry System**	**Thickening Time to 70Bc (Hr:Min)**	**Point of Departure (Hr:Min)**	**Percent Free Fluid**	**Crush Compressive Strength 24 Hours (psi)**	**Crush Compressive Strength 7 Days (psi)**	**API Fluid Loss (mL/30min)**
Class A	ULHS	5:05	—	0.8	980	2,140	—
	Foamed	5:29*	—	1.0*	780	1,180	—
	Sodium Silicate	5:30+	3:50	0.0	230	350	—
TXI Lightweight	ULHS	5:12	—	0.0	940	3070	—
	Foamed	5:53*	—	0.2*	390	1,620	—
	Sodium Silicate	7:00+	2:55	0.0	200	610	—
Application 3							
Cement Type	**Slurry System**	**Thickening Time to 70Bc (Hr:Min)**	**Point of Departure (Hr:Min)**	**Percent Free Fluid**	**Crush Compressive Strength 24 Hours (psi)**	**Crush Compressive Strength 14 Days (psi)**	**API Fluid Loss (mL/30min)**
Class H	ULHS	4:59	—	0.0	620	1,220	211
	Foamed	6:04*	—	0.0*	590	1,700	216*
	Sodium Silicate	6:00+	3:15	0.0	250	350	213
TXI Lightweight	ULHS	3:55	—	0.0	2,070	2,390	186
	Foamed	4:19*	—	0.0*	1,510	1,610	211*
	Sodium Silicate	4:33	3:25	0.0	1,040	1,090	120

*Thickening-time, free-fluid, and fluid-loss tests performed on unfoamed slurry
+Thickening-time tests with (+) were terminated at indicated time

Table 18—Summary of Laboratory Tests for 10.0-lb/gal Slurries

Cement Type	Slurry System	Thickening Time to 70Bc (Hr:Min)	Percent Free Fluid	Crush Compressive Strength 24 Hours (psi)	Crush Compressive Strength 14 Days (psi)	API Fluid Loss (mL/30min)
Application 1						
Class A	ULHS	3:50	0.0	210	1,250	—
	Foamed	3:55*	0.6*	390	1,100	—
TXI Lightweight	ULHS	5:22	0.0	120	570	—
	Foamed	5:35*	0.4*	120	350	—
Application 2						
Class A	ULHS	4:10	0.0	780	2,330	—
	Foamed	5:29*	0.5*	580	990	—
TXI Lightweight	ULHS	4:01	0.0	680	3,250	—
	Foamed	5:53*	0.5*	480	2,020	—
Application 3						
Class H	ULHS	4:13	0.0	700	1,530	209
	Foamed	4:50*	0.0*	590	1,070	220*
TXI Lightweight	ULHS	4:12	0.0	1,560	2,060	214
	Foamed	4:05*	0.0*	1,290	1,590	132*

*Thickening-time, free-fluid, and fluid-loss tests performed on unfoamed slurry

<u>Tests on 11.5-lb/gal Slurries</u> At low temperatures, thickening times for cements can be quite long. In Application 1 (Table 17), where BHCT is 65°F, the Class A cement with ULHS was still below 40 Bc when the thickening-time test was taken off after seven hours, even though it contained $CaCl_2$. The Class A cement with the foaming surfactants had a thickening time of 3 hours and 55 minutes. The Class A cement with sodium silicate was below 40 Bc when its test was taken off after 6 hours and 40 minutes, but it had a point of departure of 4 hours and 40 minutes. Even with the differences in thickening times for the ULHS and foamed slurries, the 24-hour and 7-day compressive strengths for the two slurries were comparable.

In Application 1, with the TXI Lightweight cement, the thickening time for the ULHS slurry was longer than that for the foamed slurry. However, the compressive strengths of the ULHS slurry were higher than those for the foamed slurry.

In Application 2, the compressive strengths of the sodium silicate slurries were lower than those of the foamed or ULHS slurries. At this temperature (78°F), the thickening times for the foamed and ULHS slurries are relatively close. The compressive strengths for the ULHS slurry were above those for the other slurries.

The higher temperatures of Application 3 made it possible to get most of the thickening times within the window of four to six hours. The only exception was the Class H sodium silicate slurry. The ULHS slurries once again showed higher compressive strengths than the other two systems.

Tests on 10.0-lb/gal Slurries As stated earlier, sodium silicate slurries were not tested at 10.0 lb/gal density because 10.0 lb/gal is out of the working density range for sodium silicate. For the data available, theULHS system performed as well as or better than the foamed system in Applications 2 and 3.

Mechanical Properties

The mechanical properties of the different cement systems were also tested. Table 19 shows the 14-day tensile strength of the slurries used in Application 2. Tensile strength was tested using two methods. Conventional oilfield tensile-strength testing was performed using ASTM C109 on "dog-bone" shaped samples. The samples for the ASTM C109 testing measured 3 inches long, 1 inch thick, and 1 inch wide at the waistline of the sample. Some testing was also performed using ASTM C 496 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For the ASTM C496 testing, the specimen dimensions were 1.5 inches in diameter by 2 inches long. Figure 8 shows a general schematic of how each specimen is oriented on its side when tested. For each of the ASTM C496 tests, only one sample was tested.

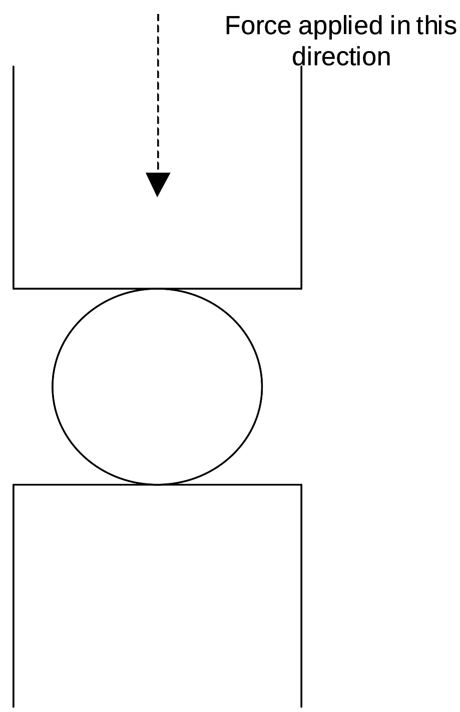

Figure 8—Specimen orientation for ASTM C496 testing

Table 19—Tensile-Strength Data of Cements

Cement Type	Slurry System	Tensile Strength (psi) per ASTM C109				Tensile Strength (psi) per ASTM C496
Density: 11.5 lb/gal, Application 2						
		Sample 1	Sample 2	Sample 3	Average	
Class A	ULHS	324	371	241	312	158
	Sodium Silicate	57	48	66	57	80
	Foamed	224	247	174	215	227
TXI Lightweight	ULHS	365	245	268	293	261
	Sodium Silicate	118	141	154	138	145
	Foamed	177	278	230	228	156
Density: 10.0 lb/gal, Application 2						
Cement Type	**Slurry System**	**Tensile Strength (psi) per ASTM C109**				**Tensile Strength (psi) per ASTM C496**
		Sample 1	**Sample 2**	**Sample 3**	**Average**	
Class A	ULHS	220	244	465	310	—
	Foamed	180	121	163	155	—
TXI Lightweight	ULHS	154	228	214	199	—
	Foamed	162	227	197	195	—

Table 20 presents Young's modulus data and effective compressive-strength data for the cements used in Application 2. ASTM C469, Standard Test Method for Static Modulus of Elasticity (Young's Modulus) and Poisson's Ratio of Concrete in Compression, was followed for the Young's modulus testing. The diameter of each test specimens was 1.5 inches and varied in length from 2.5 to 3 inches. The tests that were performed on the 11.5-lb/gal samples at zero confining pressure were done on cement samples that were cured in water, but were stored out of water approximately 24 hours before testing (as noted in Table 20). The other samples were stored in water up to the moment of testing. In the next project quarter, new samples will be made of the 11.5-lb/gal slurries and testing will again be done for the zero-confining load samples so that the same preparation (stored in water up to the moment of testing) will be done for all samples.

Table 20—Mechanical Properties of 11.5-lb/gal & 10.0-lb/gal Cements (Application 2)

Density: 11.5 lb/gal									
Cement Type	Slurry System	Young's Modulus ($x10^5$ psi) at Confining Pressure (psi)				Effective Compressive Strength (psi) at Confining Pressure (psi)			
		0	500	1000	1500	0	500	1000	1500
Class A	ULHS	3.46*	3.40	3.37	2.83	5,000*	4,508	4,773	5,006
	Sodium Silicate	0.24*	0.10	0.22	0.52	320*	651	777	1,450
	Foamed	1.42*	0.83	1.21	1.21	1,300*	1,669	2,041	1,956
TXI Lightweight	ULHS	3.29*	1.79	2.21	3.87	4,652*	6,198	6,372	6,349
	Sodium Silicate	0.73*	0.31	0.45	1.10	752*	1,066	1,078	1,134
	Foamed	1.94*	2.41	1.75	1.70	1,550*	2,907	2,910	3,168
Density: 10.0 lb/gal									
Cement Type	Slurry System	Young's Modulus ($x10^5$ psi) at Confining Pressure (psi)				Effective Compressive Strength (psi) at Confining Pressure (psi)			
		0	500	1000	1500	0	500	1000	1500
Class A	ULHS	1.94	2.46	2.69	3.00	1,950	3,141	3,291	3,575
	Foamed	1.84	1.07	1.69	2.59	1,193	1,248	1,253	1,250
TXI Lightweight	ULHS	2.47	2.42	3.01	2.84	3,150	4,850	5,470	5,502

* Samples were not stored in water approximately 24 hours prior to testing.

Comparison of Strengths Using Ultrasonic and Crush Methods

In the second quarterly technical report (January 1 to March 31, 2001), a comparison study was presented of six slurries using 3K ULHS. The study compared compressive strengths determined using non-destructive, ultrasonic methods with those using the traditional 2-in. cube crush method. The cements were cured at 140°F for both the crush and ultrasonic methods. The crush samples were cured in a water bath at atmospheric pressure and the ultrasonic samples were cured at 100 psi (minimum pressure for proper ultrasonic transmission). There were varying degrees of agreement between the ultrasonic and crush values.

The two slurries that showed the least agreement between ultrasonic and crush were tested again. Table 21 shows the results obtained from the previous project quarter along with the results from this quarter. The difference between the ultrasonic and crush values are presented in Table 21 as a percent difference between the ultrasonic and crush value while using the crush value as the reference value. In other words, $\%Difference = \frac{(ultrasonic - crush)}{crush}$. It should be noted that, in general, as time progresses, the ultrasonic and crush values converge. For example, the data in Table 21 for the 11.5 lb/gal TXI LW cement system in the second project quarter, the percent difference between ultrasonic and crush at 12 hours is 47% whereas the percent difference at 48 hours is 8%.

Table 22 compares the values of Table 21 in a different way. Table 22 presents differences between readings from the two different project quarters. This is one way to examine the repeatability of the tests. In Table 22, the percent difference is presented as the difference between second-quarter and third-quarter values divided by the third-quarter value. The 2 and 3 used as subscripts indicate the project quarter that the value came from.

Table 21—Comparison of Ultrasonic and Crush Compressive Strengths

Project Quarter	**2**				**3**			
Cement Type	TXI LW		TXI LW		TXI LW		TXI LW	
3K ULHS (%bwoc)	27.6		6.1		27.6		6.1	
Density (lb/gal)	9.0		11.5		9.0		11.5	
	Ultra-sonic	Crush	Ultra-sonic	Crush	Ultra-sonic	Crush	Ultra-sonic	Crush
12 Hours	900	500	1,220	830	616	590	1,118	968
18 Hours	1,300	850	1,700	1,280	970	1,088	1,776	1,563
24 Hours	1,400	1,050	2,000	1,600	1,038	1,228	1,973	2,048
48 Hours	1,470	1,250	2,150	2,000	1,132	1,475	2,169	2,116
	Percent Difference=(Ultrasonic - Crush)/Crush							
% Difference 12 Hours	80%		47%		4%		15%	
% Difference 18 Hours	53%		33%		-11%		14%	
% Difference 24 Hours	33%		25%		-15%		-4%	
% Difference 48 Hours	18%		8%		-23%		3%	
% Difference Average	46%		28%		-11%		7%	

(-) Indicates that the crush value is higher than the ultrasonic value

Table 22—Additional Comparisons of Ultrasonic and Crush Values

Cement Type	TXI LW		TXI LW		TXI LW		TXI LW	
3K ULHS (%bwoc)	27.6		6.1		27.6		6.1	
Density (lb/gal)	9.0		11.5		9.0		11.5	
Ultrasonic or Crush	Ultra-sonic	Ultra-sonic	Ultra-sonic	Ultra-sonic	Crush	Crush	Crush	Crush
Project Quarter	2	3	2	3	2	3	2	3
12 Hours	900	616	1,220	1,118	500	590	830	968
18 Hours	1,300	970	1,700	1,776	850	1,088	1,280	1,563
24 Hours	1,400	1,038	2,000	1,973	1,050	1,228	1,600	2,048
48 Hours	1,470	1,132	2,150	2,169	1,250	1,475	2,000	2,116
% Difference =	$(Ultrasonic_2 - Ultrasonic_3)/Ultrasonic_3$				$(Crush_2 - Crush_3)/Crush_3$			
% Difference 12 Hours	46%		9%		-15%		-14%	
% Difference 18 Hours	34%		-4%		-22%		-18%	
% Difference 24 Hours	35%		1%		-14%		-22%	
% Difference 48 Hours	30%		-1%		-15%		-5%	
% Difference Average	36%		1%		-17%		-15%	

(-) Indicates that the ultrasonic or crush value from the 3rd quarter is higher than the ultrasonic or crush value from the 2nd quarter.

In general, for the 48-hour time period examined in these studies, the agreement between the ultrasonic and crush values tends to improve with time and with strength development, as seen in Table 21. The same general trend can be seen in Table 22 when comparing ultrasonic strengths to each other or crush strengths to each other. The agreement of these compressive-strength values is relatively close, considering that such differences are not uncommon even when crushing three samples of the same slurry within the same test.

Specific Gravity vs. Applied Pressure

The different bead classes within the ULHS family are defined in this project by their general pressure limitations. For example, the 6K ULHS maintains a density that is close to its original density up to a pressure of about 6,000 psi. After 6,000 psi, a portion of the 6K ULHS begins to break and the overall density of the beads increases. The same general trend applies to the other class of beads. The effect that pressure has on ULHS breakage and density can be used to predict how the density of ULHS-cement slurries will change at downhole pressures. Figure 9 illustrates the change of specific gravity of the beads at different applied pressures.

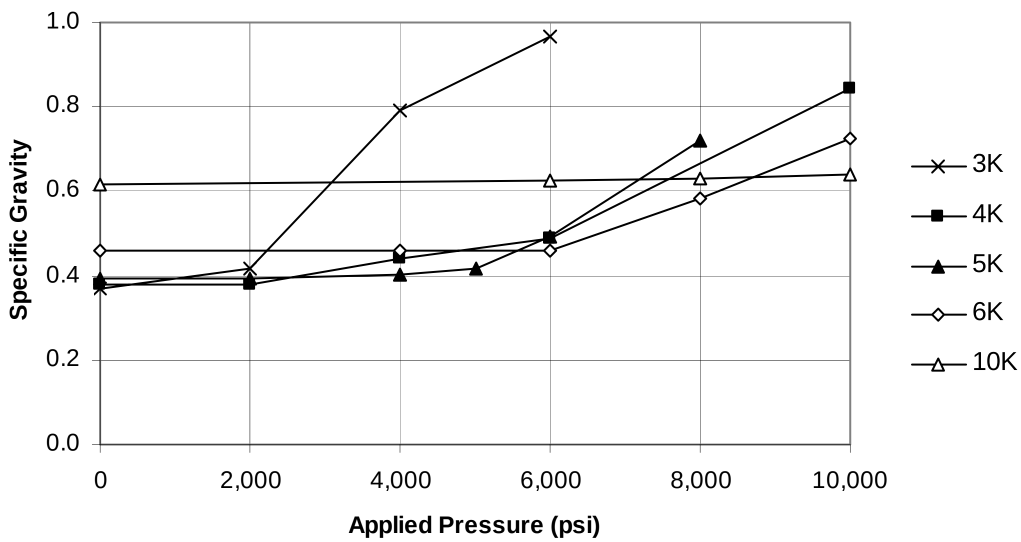

Figure 9—Specific gravity vs. applied pressure for ULHS

Plans for the Fifth Project Quarter

- A cement field job is scheduled for the fifth quarter. This field application will use a 10.4-lb/gal cement slurry made with 6K ULHS.
- Data analysis and additional testing will be done for Young's modulus data of the different cement systems.
- Further testing of mechanical properties will investigate Poisson's ratio of the cement systems.
- Permeability testing will be performed. The cements' permeability to air and to water will be studied.
- Testing for potential alkali silica reaction will also take place in the fifth quarter. The different test methods include: ASTM C1260 (accelerated mortar-bar method), ASTM C289 (chemical method), and long-term permeability studies.
- Shear-bond testing will also be performed. This testing will investigate the effect of temperature and pressure cycling conditions that are associated with well production.

Conclusions

- Schlumberger has contributed lightweight cement data. That data has been combined and presented with the data from the other service companies.
- Laboratory testing for the field-application scenarios has been completed.
- Centrifugal pump testing revealed that the 3K ULHS is subject to significant breakage, whereas the 6K ULHS held up better to the circulation and mixing energy delivered by the centrifugal pump. Further investigations will compare the mixing energy delivered by cementing units and the mixing energy delivered by the centrifugal pump used in this study.
- Test procedures are being developed and adjusted for testing air and water permeability of cements. Initial permeability data has been gathered and analysis will be presented in the next quarter.
- Test protocol for Young’s modulus has been established and data has been presented.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
avg—average
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
bwoc—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
gal/sk—gallon(s) per sack of cement
H_2O—chemical formula for water
lb/gal—pound(s) per gallon
POD—point of departure
psi—pound(s) per square inch
QC—quality control
RPM—revolution(s) per minute
TXI—Texas Industries
TXI LW—lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
10K—10,000-psi designation
3K—3,000-psi designation
4K—4,000-psi designation
5K—5,000-psi designation
6K—6,000-psi designation

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Appendix A— Technical Literature Review of Lightweight Cement Performance

1. Light Weight Cement Systems, What They Are - How They Are Used. L. H. Eilers, Dowell Div., Dow Chem, Proc. Annu. Southwest. Pet. Short Course (1980), 27th

A review, with 10 references, on lightweight cement systems and the role of water and extenders.

2. Low-Density Foamed Portland Cements Fill Variety of Needs R. Montman, D. L. Sutton, W. M. Harms, B. G. Mody Halliburton Serv. Oil Gas J. (1982), 80(30), 209-16

A review, with 9 references, on the properties and uses of foamed cement in oil fields.

3. Cement Encapsulated Lightweight Fine Aggregate T. Yamamoto. Tohoku Denryoku K. K., Japan. Gypsum Lime (1989), 222, 304-10

A review, with 7 references, of the use of coal ash for granulation with cement-encapsulated sand and the manufacturing, physical properties, and uses of the cured material.

4. Lightweight Cement Additives W. Manns, W. Zem. Taschenbuch (1974), Meeting Date 1974-1975, 155-71. Bauverlag GmbH: Wiesbaden, Ger.

A review, with 22 references, is given on lightweight cement additives (bulk d. <1.5 kg/dm3).

5. Real-Time Quality Control of Foamed Cement Fobs: A Case Study. R.D. Thayer, D.G. Ford, S. Holekamp, D.J. Pferdehirt Proceedings of the SPE Annual Technical Conference and Exhibition. Part 3 (of 5). 03 Oct 1993-06 Oct 1993

Foamed cement is a low density cement system prepared by mixing nitrogen gas and surfactants with API portland cement. The lower density limit for conventionally extended slurries is between 11.0 and 12.0 lb/gal. Foaming permits cement slurry densities lower than water (8.33 lb/gal) while maintaining relatively high compressive strengths. These advantages and others have been well documented. Actual field mixing procedures and additive rates are critical and must be monitored to assure a competent foamed cement. Slight variations in base slurry density, base slurry rate, foamer and stabilizer rate, or nitrogen rate can significantly alter the final foam density. Formerly, foam density was measured by a radioactive densometer. This allowed for significant error when densities were less than 8.33 lb/gal. There was no physical means to collect and weigh an actual foamed cement sample.

This paper explains methods to improve the accuracy of the additive rates. It also defines a method for real-time measurement of foamed cement density. The paper describes the use of a high-pressure device downstream of the nitrogen addition that can weigh a pressurized foamed cement sample during the job. It discusses the use of concrete technology to improve the performance of lightweight cements.

6. E. Moulin (Schlumberger Dowell), P. Revil, B. Jain. Proceedings of the 1997 SPE/IADC Middle East Drilling

To successfully cement across and isolate formations with low fracture gradients requires the use of lightweight cement slurries. Conventional lightweight slurries usually have a high water-to-solid ratio, which results in long waiting-on-cement times, limited compressive strength development, and a relatively permeable cement sheath subject to acid and brine attack. A new approach to designing cement slurries effectively decouples the physical properties of set cement from the slurry properties and density, resulting in high performance lightweight cement slurries that reduce rig time and the logistics and costs associated with using conventional slurry designs. This has been clearly demonstrated in the cases of completing in reservoirs with a low fracture gradient (eliminating the risk of block squeeze), replacement of two-stage cement jobs by a single stage, and the use of a single slurry to replace lead/tail cement and side-track plugs. Results are described from various field applications where the technology has been used.

7. Sodium Metasilicate-Modified Lightweight High Alumina Cements For Use as Geothermal Well-Cementing Materials. T. Sugama, N. Carciello. Advanced Cement Based Materials v 3 n 2 Mar 1996.p 45-53

In studying the use of sodium metasilicate- (SMS) modified high alumina cements containing mullite-shelled microspheres as light-weight geothermal cementitious materials, we found that the following were the most advantageous characteristics of the slurries and of the 200 and 300°C autoclaved cements: (1) the slurries have a low density of less than 1.25 glcc, (2) the incorporation of SMS retarded the setting of the cements, (3) sodium calcium silicate hydrate and boehmite were formed in the matrix phase by hydrothermal reactions between the cement and SMS, and (4) there was a favorable reaction between the mullite shell layer in the hollow microspheres and the SMS to form analcime and boehmite phases. For characteristics (3) and (4), the pronounced development of these phases at 300°C generated a dense microstructure in the cements and was reflected by a reduced water permeability and a low rate of porosity.

8. Use of 1.6/1.7 kg/l Slurry For Cementing Production Casings. P. Macculi (AGIP). Proceedings of the 1997 SPE/IADC Middle East DrillingTechnology Conference.

A major concern in drilling operations is the problem of carrying out cementing jobs for production casings where no fracture margin during the slurry displacement exists. In general, a double stage cement job, the use of a liner with a subsequent tie-back or one more casing string is required to resolve this problem.

9. In the Adriatic Offshore we have experimented with the use of lightweight high mechanical resistance slurry (SG equals 1.6/1.7 kg/l) in 7-in. production casing cement jobs in order to complete the operation in a single stage. These cement jobs have been carried out, with positive results, in six of the fourteen Angela platform wells, in three of the four Antonella platform wells, in one Anemone cluster well (double-stage cementing to avoid one more casing string), in the Antares 1 s.t. and the Agostino 11 s.t. wells.

The wells, where the 1.6/1.7 Kg/l lightweight slurry has been used, have an average total depth of 3600 m VD, their intermediate casing shoes are set at an average depth of 1800 m VD. The use of lightweight slurry, composed of 10/30% microsilica by cement, has led to a reduction in the hydrostatic load, an optimization of rheology and filtration control (maximum differential pressure of 400 atm exist at the end of displacement) while guaranteeing the necessary high mechanical resistance. According to field data, we can conclude that the use of lightweight slurry has the following advantages: a single stage cement job can be used instead of the more complex double stage one with the consequent improvement in well and rig safety; in particular cases, a lightweight slurry can avoid setting one more casing string; improved quality of the cement job in comparison with the not always reliable results of a double-stage cementing; operational time and cost reduction.

10. Increasing Well Life by Eliminating the Multistage Cementer and Utilizing a Light Weight High Performance Slurry. T. Mukhalalaty, A . Al Suwaidi, M. Shaheen. Schlumberger Dowell. SPE 11th Middle East Oil Conference (Bahrain 2/20-23/99) Proceedings 425-37 (1999) (SPE Paper #53283)

Increasing well life by eliminating the multistage cementer and utilizing a lightweight high performance slurry. A discussion covers the annulus pressure problem; losses during cementation; poor set cement mechanical properties; different casing schemes; lightweight cement slurries, including those with ceramic hollow spheres; a reduced water slurry system; set cement properties, including compressive strength and permeability; and four case histories. Tables, diagrams, graphs, and references.

11. Application of Foam Cements in Alberta. Olanson, M. T. J Can Pet Technol v 24 n 5 Sep-Oct 1985 p 49-57.

The demand for lightweight cement in areas of low-strength formation has led to the increased use of foamed cement in PanCanadian's wells. Foamed cementing involves mixing surfactant upstream of the cement pumper and injecting nitrogen into the pumper discharge line, with a foam generator installed downstream. The 'constant foam density method' was used. Recent field tests by PanCanadian confirmed that foamed cementing is only slightly more expensive than conventional cement jobs but less costly and involving less mechanical risk than multi-stage jobs. At the same time, it can be considerably less expensive than glass or ceramic microspheres cementing.

12. Foamed Cement a Second Generation N. R. Loeffler, Dow Chem. U.S.A., Dowell Div. Spe (Soc. Pet. Eng. Aime) Permian Basin Oil Gas Recovery Conf. (Midland, Tex. 3/8-9/84) Proc. N.12592, 153-59 (Mar. 1984)

A survey of new applications for foamed cement shows that lightweight nitrified cement systems placed across weak and washed-out zones have been successfully perforated and fractured. For example, an 8.0- to 8.5-lb/gal nitrified cement replaced costly and time-inefficient cement staging in air-drilled holes with fracture gradients in the 0.4- to 0.6-psi/ft range; cost savings for one such treated well was more than $12,000 compared with cementing by staging methods. To meet the special needs of steam flood wells, low-density (> 12 lb/gal) extended cement systems such as bentonite/sodium silicate, perlite, fly ash, hollow glass spheres, etc., are suggested.

Performance data for a 9-lb/gal cement containing glass spheres vs. a 9-lb/gal high-temperature foamed system show major losses of compressive strength; although the foamed system maintains an adequate level of strength (700 psi), the cement containing the microspheres undergoes an immediate severe loss (to < 200 psi). The three general criteria for successful oilfield foamed cement performance are also discussed.

13. ACI Manual of Concrete Practice 1999: Volume 1 Materials and General Properties of Concrete

Part 1 of the American Concrete Institute (ACI) Manual of Concrete Practice contains current committee reports and standards concerned with materials and general properties of concrete. The contents include information on the following topics: concrete notation; cement and concrete terminology; concrete construction and materials tolerances; recommended format for concrete identification in a materials property database; concrete condition survey; concrete durability; mass concrete; cracking of mass concrete; roller compacted mass concrete; prediction of creep, shrinkage and temperature effects in concrete structures; concrete erosion and repair in hydraulic structures; selecting proportions for normal, heavyweight, and mass concrete, structural lightweight concrete, no-slump concrete, and high strength concrete; concrete admixtures; superplasticizers; lightweight aggregate concrete; design of concrete structures subjected to fatigue loading; fire endurance of concrete; use of normal and heavyweight aggregates in concrete; alkali-aggregate reactivity; corrosion of metals in concrete; shrinkage-compensating concrete; selection and use of hydraulic cements; controlled low strength materials; soil cement; pozzolans, fly ash, blast-furnace slag, and silica fume in concrete; high-strength concrete; and high-strength concrete columns.

14. Improved Performance of Lightweight Cement Slurries. JPT, Journal of Petroleum Technology v 49 n 8 Aug 1997.p 852-853

Lightweight slurries are used for cementing across formations with low fracture gradients. Conventional lightweight slurries have a high water-to-cement ratio that results in long waiting periods during cementing, slow development strength, and a relatively permeable cement sheath that is subject to acid and brine attack. However, a new engineering approach has eliminated these characteristics. The resulting high-performance lightweight slurries reduce the rig time, logistics, and costs associated with conventional designs. The new approach considers the quality of the granular mixture in terms of its water demand and optimizes particle size distributions.

15. Fundamental Study on the Properties of High Strength Lightweight Concrete (Part 5).

Tsuiba Hiroyuki; Honda Satoru; Araki Aya, Fukuoka Univ. (Fukuoka University Review Of Technological Sciences), (1993) No. 50, Pp. 137-147. Journal Code:

S0905A (Fig. 11, Tbl. 6, Ref. 9) ISSN: 0285-2799

PUB. COUNTRY: Japan

DOCUMENT TYPE: Journal; Article

LANGUAGE: Japanese

AB Super high-rise reinforced apartment buildings with frame-type, ranging 30 to 40 stories, have become popular in Japan among leading construction companies. Therefore, this paper presents to a comprehensive review of high strength concrete with kinds of test specimens (model test specimen, molded cylinder test specimen), coarse aggregates (crushed stone for concrete, artificial light- weight aggregate), water cement ratios (30, 35, 40, 45, 50%) and curings (standard curings, water curings, sealed curings, air-dry curings). The cement was used a normal Portland cement and the water cement per cubic was 170 kg. The concrete was 21cm slump were prepared by using superplasticizer and high-range water reducing agent. Effect of compressive strength, Young's modulus, tensile strength, pulse velocity, rebound number by core test specimen (model test specimen) and cylinder test specimen were chiefly studied. (author abst.)

16. Using Concrete Technology to Improve the Performance of Lightweight Cements. Eric Moulin (Schlumberger Dowell); Philippe Revil, Bipin Jain. Proceedings of the 1997 SPE/IADC Middle East Drilling Technology Conference. Proceedings of the IADC/SPE Asia Pacific Drilling Technology Conference, APDT 1997. Soc Pet Eng (SPE), Richardson, TX, USA.p 243-248 SPE/IADC 39276

To successfully cement across and isolate formations with low fracture gradients requires the use of lightweight cement slurries. Conventional lightweight slurries usually have a high water-to-solid ratio, which results in long waiting-on-cement times, limited compressive strength development, and a relatively permeable cement sheath subject to acid and brine attack. A new approach to designing cement slurries effectively decouples the physical properties of set cement from the slurry properties and density, resulting in high performance lightweight cement slurries that reduce rig time and the logistics and costs associated with using conventional slurry designs. This has been clearly demonstrated in the cases of completing in reservoirs with a low fracture gradient (eliminating the risk of block squeeze), replacement of two-stage cement jobs by a single stage, and the use of a single slurry to replace lead/tail cement and sidetrack plugs. Results are described from various field applications where the technology has been used. (Author abstract) 8 References.

17. Basic Cementing-2. Specialty Cements Can Solve Special Problems. Pat N Parker, Oil Gas J v 75 n 9 Feb 28 1977 p 128-131

Part 2 of this article reviews a number of specialty cements formulated by service companies and cement manufacturers to solve special problems encountered in oil wells. These cements, which are essentially modified Portland cements or cements manufactured from limestone, can handle both pressure and temperature extremes. Among the specialty cements discussed are pozzolan slurries, lightweight cements, thixotropic cement, and quick-setting cements.

18. Next-Generation Cementing Systems to Control Shallow Water Flow. Ronnie

Faul, B. R. Reddy, James Griffith, Rocky Fitzgerald, Bryan Waugh. 32nd Annual Offshore Technology Conference - OTC 2000; Proceedings of the Annual Offshore 19. Technology Conference v 1 2000. Offshore Technol Conf, USA.p 117-122

As documented in industry literature, shallow hazards, especially shallow water flows (SWF's), pose a challenge in deepwater Gulf of Mexico operations. Cement systems that successfully solved SWF's were first used in 1992. The first of these special systems was a lightweight nonfoamed system. In 1994, special foamed lightweight systems were implemented and were proven superior both in large-scale laboratory models and in field use. Several special foamed-cement blends have been used to cement over 300 conductor casings where SWF's were a threat. These formulations consisted of highly activated cements that required special blending at the shore base before being transported to the offshore rig. Because dry additives were used, the cement slurry could not be redesigned or modified, so any unused blend had to be discarded. To address these challenges, the industry developed a lightweight foamed-cement (LFC) slurry system. This system uses only liquid additives in conjunction with the dry Portland cement on board the rig. The LFC system provides a low-density slurry with short transition times to help prevent SWF's while maintaining zonal isolation, adequate placement time, and shorter waiting-on-cement (WOC) time.

20. Foamed Cement for Squeeze Cementing Low-Pressure Highly Permeable Reservoirs. Design and Evaluation. W. Chmilowski, L.B. Kondratoff. Drilling Proceedings - SPE Annual Technical Conference and Exhibition v Delta. Publ by Soc of Petroleum Engineers of AIME, Richardson, TX, USA.p 231-245

Squeeze cementing is a highly used remedial technique that relies on controlled slurry placement as the key to success. Typically, competent low-permeability reservoirs with normal bottomhole pressures are routinely cement squeezed with little difficulty, as long as the established techniques for conventional cement squeezing are properly followed. Formations with low reservoir pore pressure and high permeability can create severe challenges for proper placement, especially if the high permeability is due to naturally occurring formation vugs and fractures. Recently, a new technique using low-density foamed cement proved to be successful in providing a squeeze cementing method offering a much higher probability of success. In this paper, a number of key aspects that are critical to the success of squeeze treatments in these difficult reservoirs are discussed. Candidate selection, slurry design, treatment design, operational considerations, and an evaluation of squeeze treatment results are included. The evaluation focuses primarily on foamed and conventional cement squeeze treatments on wells producing from the Keg River formation in the Rainbow Lake area of northwestern Alberta, Canada. Ninety-six individual well case histories involving 151 remedial cementing operations were evaluated to determine their success. (Author abstract) 16 References

21. New Generation Foam Cement - A Universal System for Cementing A. Ruch. Oil Gas European Magazine 26/3 16,17-22 (September 2000) ISSN: 0342-5622

A discussion on nitrogen foamed cement slurries, known as foamed cement, which have been used for cementing operations in the petroleum industry for more than a decade, covers the single components of the system. Foam-Cement; various applications for foamed cement, including lightweight cement slurries, avoidance of fluid-migration, optimization of cement sheath properties; steam-injection and geothermal projects, and squeeze-applications; prerequisites and selection process for the foamed cement system; preparation, planning, and simulation for a cement job; foamed cementing equipment and job site layout; foamed cement job execution; case histories of recent foamed cement jobs, including 9.625-in. gas storage production casing across formations with different pore pressure; and limitations on economics. 3 photomicrographs, 10 graphs, flow diagram, and 7 references.

22. Bond Of Lightweight Aggregate Concrete Incorporating Condensed Silica Fume P.J Robins. Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Proceedings Second International Conference, Madrid, Spain, Volume 2, Aci Special Publication, 1986., No. Sp91. P. 941-58. 27 Refs., American Concrete Institute

Condensed silica fume, at up to 30% by weight, was used as a partial cement replacement in lightweight aggregate concrete. The results of round and deformed bar cube pullout tests, with and without applied lateral stress, show that condensed silica fume increases ultimate bond strength and affects the mechanism of failure. The influence of condensed silica fume on bond stress of round bars was similar at all lateral stresses, producing a 50% increase at 20% by Weight replacement of cement. For deformed bars the increase in bond strength was more pronounced at higher levels of lateral stress, Producing increases approaching 70% at 20% silica fume content. The improvements in ultimate bond strength with condensed silica fume are shown to only partly result from the associated increases in compressive strength, the greater part resulting from the modified properties of the concrete matrix.

23. A Novel Lightweight Cement Slurry And Placement Technique For Covering Weak Shale In Appalachian Basin S V Kulkarni; D S Hina, Spe East Reg Mtg (Charleston, Wv, 10/20-22/1999) Proc 1999 (Spe-57449)

24. Successful Primary Cementing Can Be A Reality R C Smith, Amoco Prod. Co, J. Pet. Technol. V36 N.12 1851-58 (Nov. 1984) Successful Primary Cementing Can Be a Reality.

A review of primary cementing includes planning and slurry design; blending of additives and cement, and mixing of the slurry; slurry displacement; the adequate strength of ultralight-weight cements containing new additives such as hollow glass (borosilicate or sodium silicate) or ceramic microspheres, in well-completion situations requiring cement densities lower than those attainable with conventional lightweight cement containing additives such as bentonite, diatomaceous earth, or sodium silicate; spacers and preflushes; and free fall of cements.

25. Preventing Shallow Gas Migration In Offshore Wells: The Performance Of Lead Cements. O. D Coker, K.L Harris,T.A. Williams; Proc Eur Pet Conf.Publ By Society Of Petroleum Engineers (SPE), P.O.Box 833836, Richardson, TX, USA, 24978.P 159-

169

Offshore drilling operations that encounter shallow gas formations must consider the potential annular gas flow that may occur following primary cementing. Many specialized cements and procedures have been developed to combat gas migration, but the complexities of gas migration control still challenge operators worldwide. In offshore shallow environments, additional complications can arise with the presence of weak formations and cold temperatures. In such conditions, lightweight lead cements are employed to avoid fracturing the wellbore. Although lead cements are often viewed simply as 'filler' materials, shallow gas control slurries must far exceed that role as they become the mechanism to help isolate the movement of gas up the annulus. Presented in this paper is a review of the properties of gas control cementing systems specifically related to lightweight lead slurries. The importance of fluid loss control, rapid gelation, and compressive strength at the time of drillout is stressed. Silica fume cement and newer cementing additives such as colloidal silica and small particle cement are highlighted as means of helping prevent shallow gas migration. Several offshore cementing operations are documented which confirm the success of applying the prescribed designs and methods.(Author abstract) 8 References

26. Pulverised-Fuel Ash J.B. Cripwell, (Natl Power Plc, Uk) The Use Of Pfa In Construction. Proceedings Of The National Seminar, Held At University Of Dundee On 25-27 February 1992 (1992) p.

This paper is intended to provide a brief introduction to pulverised fuel ash (PFA). It describes its production and properties, comments on handling and uses, makes references to health and safety requirements, and concludes with a review of research and development. PFA consists predominantly of finely divided spherical particles mainly in the size range of 1 to 150 microns. Chemically, it is an alumino-silicate glass containing some iron, calcium, magnesium and alkali metals together with carbonaceous particles resulting from incomplete combustion. Uses for PFA include: load bearing fill, aerated concrete blocks, lightweight aggregate, cement manufacture, grouting, fillers and stabilization in road bases and sub-bases.

27. Preventing Shallow Gas Migration In Offshore Wells: The Performance Of Lead [(Primary)] Cements. O. D. Coker, K.L Harris,T.A. Williams; SPE European Petroleum Conference (Cannes, France 11/16-18/92) Proceedings V1 159-69 (1992)

Preventing shallow gas migration in offshore wells: The performance of lead [(primary)] cements. A discussion covers the need for a primary cement which can prevent gas migration in shallow wells, especially in the North Sea; the importance of complete removal of drilling fluid prior to cementing; density requirements for such cements; the other required properties of such cements, including low fluid loss, rapid gelation, zero free water, low permeability, high early compressive strength, and adequate waiting-on-cement time; the additives which provide these properties, i.e., Portland cement, silica flour, an acrylamide copolymer to minimize fluid loss, a polymeric sulfonate dispersant, and a lignosulfonate retarder; and a case history of using lightweight cement in a well drilled in 236 ft of water in the North Sea to a depth of 2109 ft. Tables, diagram, well logs, and 18 references.

28. New Generation Foam-Cement - System For A Wide Range Of Cementing Operations. A Ruch,. Erdoel Erdgas Kohle/EKEP V 116 N 5 2000.P 267-272

LANGUAGE: German

In recent years the use of Foam-Cement for cementing casing or liner during drilling operations has undergone a major development. Used successful as lightweight cement in the last decades Foam-Cement is seen today more as a system for a wide range of cementing operations than a cement slurry alone. This is mainly due to the fact that optimized computer simulation programs and automated cementing equipment is available for accurate job planning and execution. This article explains the single components of the system Foam-Cement and lists reasons for its use to cement a casing or liner, especially in critical well situations or in wells demanding technically high standards.(Author abstract) 7 References

29. Cementing The Conductor Casing Annulus In An Overpressured Water Formation. James Griffith, Proceedings Of The 1997 29th Annual Offshore Technology Conference, OTC.Part 1 (Of 4).

The technique for cementing a 20- or 24-in. outside diameter conductor pipe offshore, in deep water, in the presence of pressurized water flow, which constantly threatens to wash cement away from the wellbore are described. The conductor pipe is cemented with a lightweight, foamed slurry with good compressive strength that helps control the water flow. Three key fluids are used such as foamed drilling fluid sweeps, settable spotting fluids and foamed cement slurries. The foamed sweeps are used to brings cuttings out of the wellbore. The settable fluids have low gel strength and are composed to provide fluid-loss control. The combination of settable spotting fluid and cement slurry provides good zonal isolation of the water-flow interval.5 References

30. Mud Management, Special Slurries Improve Deepwater Cementing Operations. James Griffith, (Oil And Gas Journal V 95 N 42) Oct 20 1997. P 49-51

Deepwater cementing requires improved mud-management techniques. In the Gulf of Mexico (GOM), new mud-management techniques and specially designed cement mixtures are being used to effectively set conductor casing in deepwater conditions and to improve the success rate in cementing deepwater wells. Recent case histories in the GOM describe these new techniques and the advantages of using a specially formulated, lightweight, foamed cement slurry to avoid cement-sheath damage caused shallow-water flow. 4 References

31. Alkali-Aggregate Reactivity In Canada C. A. Rogers, Cem. Concr. Compos. (1993), 15(1-2), 13-9

A review and discussion with 23 references. In Canada, three types of alkali-aggregate reaction in Portland cement concrete are recognized. Each type is evaluated using different tests. Corrective measures such as the use of low-alkali cement, lower cement contents, or pozzolans are seldom used with reactive aggregates. Beneficiation or selective extn. is used with some reactive aggregates. Work is being conducted on multiple. study of existing tests and new, rapid tests.

32. Experimental Methods For Determining The Residual Alkali Silica Reactivity Potential In Concrete Structures Sharma, V.M.; Suri, S.B.; Chandrasekaran, N. Proc. - Int. Symp. Innovative World Concr. (1993), Volume 1, 2/193-2/203. Oxford & IBH: New Delhi, India.

A review with no references. It is essential to identify alkali reactive aggregates and their potential for deleterious expansion before their use in concrete. However, in the absence of the above evaluation, if the alkali silica reaction gets triggered in a concrete structure, determination of the residual alkali silica reactivity potential in the structure becomes inevitable for assessing its safety and durability. Laboratory testing can often be difficult, complex, time consuming and even inconclusive. Still, it is the best method to assess and evaluate the potential reactivity of aggregates prior to their use in concrete construction. While there are several established standard test methods available for determining the potential reactivity of cement-aggregate combinations and new and rapid test methods have been proposed, there are no standard test methods available for assessing the magnitude of the residual alkali-silica reactivity potential existing in a structure, for establishing its future damage potential.

33. Does Silica Fume Merely Postpone Expansion Due To Alkali-Aggregate Reactivity Berube, M. A.; Duchesne, J., Int. Conf. Alkali-Aggregate React. Concr., 9th (1992), Volume 1 71-80. Concr. Soc.: Slough, UK.

A review and discussion with 25 references. Condensed silica fume (CSF) is considered effective in suppressing concrete expansion due to alkali-silica reaction (ASR), provided it is used in sufficient amts. Various mechanisms can be proposed to explain this: higher strength, lower permeability, alkali diln., portlandite consumption in the cement paste and alkali depletion in the pore soln. due to pozzolanic reaction. The most crit. mechanism appears to be alkali depletion in the pore soln. and consequent pH decrease. However, the long-term effectiveness of CSF against ASR is presently questioned by a no. of workers. The proposed explanation is the recycling of alkalis which were entrapped early in low Ca/Si and high-alkali pozzolanic CSH. This hypothesis is based on expansion tests on concrete contg. CSF and reactive aggregates, and on chem. of pore soln. extd. at different time intervals from equiv. cement-admixt. pastes.

34. Pore Solution Chemistry And Alkali Aggregate Reaction Christopher Page And Philip Norman, Am. Concr. Inst., SP (1987), SP-100(Concr. Durability, Vol2, 1833-62

A review, with 39 references, of the progress in explaining the phenomena associated with alkali-aggregate reactions in terms of pore solution comparison. In particular, consideration is given to the effects of alkali level and water content of the concrete on the severity of reaction, the role of alkalis in pulverized fuel ashes, granulated blast-furnace slags, and other cement replacement materials in determining their effectiveness in preventing damage, and the contribution to pore solution alky. made by salt contamination of aggregates and deicing salts.

35. Some Opportunities To Offset Poor Quality Characteristics Of High-Alkali Cement Louis U. Spellman, Cem., Concr. Aggregates (1983), 5(1), 73-6

A review, with 18 references, concluding that inclusion of a substantial percentage of ground blast-furnace slag in cement manuf. minimizes the alkali-aggregate reactivity and the decreased rates of strength gain at later ages.

36. Reducing Expansion Due To Alkali- Silica Reactivity Fournier, B.; Malhotra, V. M. Concr. Int. (1996), 18(3), 55-9

A review with no references, including general objectives and scope of the research program, petrog. of the aggregates, portland cement and supplementary cementing materials, mixuture, proportioning, lab. and field testing of specimens, and general observations on test results.

Review Of Alkali-Silica Reaction And Expansion Mechanisms. Alkalies In Cements And In Concrete Pore Solutions Diamond, Sidney Cem. Concr. Res. (1975), 5(4), 329-45 A review with 35 references.

37. Alkali-Aggregate Reactions And The Middle East. French, W. J.; Poole, A. B. Concrete (London) (1976), 10(1), 18-20

A review with 16 references is given on the chem. and phys. mechanisms associated with reactions between alkalis derived from cement pastes and aggregates of SiO2 minerals or carbonate rocks to explain the causes for the rapid deterioration of some concrete structures.

38. Durable Concrete Containing Three Or Four Cementitious Materials Butler, W. Barry, Am. Concr. Inst., SP (1997), SP-170(Vol. 1, Durability Of Concrete), 309-330

A review with 25 references In most concrete markets these days, there are several varieties of pozzolans and ground slag available for use in regular and high-performance concretes. Each one has its strong points when blended with portland cement in concrete and, properly used, will provide concrete of enhanced durability. Recently, concrete contg. more than one such material has become common, even to the point of being available as ternary or quaternary blend. This paper reviews the data available on durability of concrete produced from multiple blends and discusses some of the potential benefits to specifiers and users. The blending materials covered include silica fume, fly ash, metakaolin, and ground granulated slag.

39. High-Alkali Cements For 21st Century Concretes, Davidovits, J., Am. Concr. Inst., SP (1994), SP-144(Concrete Technology), 383-97

A review with 27 references Recent literature suggests that there is considerable potential for redn. in the emission of CO_2 to the environment through the manuf. of new types of cement which do not rely on the calcination of limestone (and accompanying release of CO_2). The 1988 one billion metric tons world-wide production of cement accounted for one billion metric tons of CO_2 release, i.e. 5% of the 1988 world CO_2 emission (human activity only). This is equiv. to the CO_2 emission by the entire Japanese activity. The use of lesser amounts of calcium-based cements could be achieved through their partial replacement by alkali-activated aluminosilicate materials, which do not release large quantities of CO_2 in their manuf. The fostering of low-CO_2high-alkali-based cements will mean a dramatic change in the research and development presCO_2ently carried out in USA and other countries. Alkalis are generally thought of as the cause of deleterious alkali-aggregate-reaction. As a consequence, the tendency has been to avoid any addn. of alkali portland cement products, and often require the cement manufacturers to supply low-alkali cements. The use of MASNMR spectrog. for the detns. of compounds of alkali-activated cements, in combination with std. ASTM C 227 bar expansion, allows us to predict the potential for alkali-aggregate reaction. Our preliminary study involving 27Al and 29Si MASNMR spectroscopy revealed that the alkali-activated aluminosilicate cements are the synthetic analogs of natural pozzolans that are known to effectively suppress the alkali-aggregate reaction. These cements, even with alkali contents as high as 9.2% do not generate any deleterious alkali-aggregate reaction, according to ASTM C 227 bar expansion test. Industrial experience based on the use of alkali-activated slags in Eastern Europe since 1964, associated with the com. produced alkali-activated cements in the US since 1988, suggest that high-alkali cements will ultimately improve the concrete used in buildings and highways, and also serve our global need by a) reducing the emission of CO2 b) reducing the energy consumption during cement manufacturing in terms of a 5% growth scenario, the predicted Business as Usual (BaU) world cement production for the year 2015 equals 3500 million metric tons. Based on an amt. of blended Portland cement production in the order of 1850 million metric tons (1000 Mt. Portland + 560 Mt. slag + 290 Mt. fly ash), in the 21st century, the need for novel alkali-activated cementitious materials could be in the range of 1650 million metric tons.

40. The Alkali-Silica Reaction In Concrete. Chapter 1 - Introduction To Alkali-Aggregate Reaction In Concrete Swamy, R.N. [Editor] (Sheffield Univ, Uk); Poole, A.B. (London Univ, Queen Mary And Westfield College, Uk) 1992. P. 1-29. 43 Refs., Blackie And Sons Ltd

This chapter introduces and defines the nature of alkali-aggregate reactions in concretes. Alkali-silica reactivity in concrete is a particular variety of chemical reaction within the fabric of a concrete involving alkali hydroxides, usually derived from the alkalis present in the cement used, and reactive forms of silica present within aggregate particles. This chemical reaction also requires water for it to produce the alkali-silica gel reaction product which swells with the absorption of moisture. The amount of gel and the swelling pressures exerted are very variable depending on reaction temperature, type and proportions of reacting materials, gel composition, and other factors, but they are often sufficiently high to induce the development and propagation of microfractures in the concrete which, in turn, lead to expansion and disruption of the affected concrete structure or element. Typical deleterious features of alkali-silica reaction in concrete structures include cracking, expansion and consequent misalignment of structural elements, spalling of fragments of surface concrete as ‘pop-outs’, and the presence of gel in fractures or associated with aggregate particles within the concrete. The reaction typically takes between 5 and 12 years to develop, though there are many exceptions, and it is most severe where alkali concentrations in the concrete pore fluids are high. A very wide variety of aggregate rock types in structures from many parts of the world have been reported as being alkali-silica reactive. This is consequent on the reactive forms of silica often only forming a minor mineral component of the aggregate such as the cement between mineral grains. This silicious material must be amorphous or cryptocrystalline with a large surface area if it is to react sufficiently to produce deleterious effects in the concrete. (A) For the covering abstract of the BOOK see IRRD 844648.

41. Concrete Durability And Alkali Reactions. Figg, John Concrete (London) (1981), 15(8), 18-22

A review, with 14 references, discussing equiv. alkalinities of alkali metals, adverse effects of alky., cement compounds and hydration, concrete performance, alkali-aggregate reactivities, the reaction mechanism and symptoms, parameters affecting the reaction, and preventive and remedial measures.

42. Proceedings Of The 1996 10th International Conferenceon Alkali-Aggregate Reaction, AAR. Cement & Concrete Composites V 19 N 5-6 Oct 1997.Elsevier Sci Ltd, Exeter, Engl.P 391-480

The proceedings contains 6 papers on cement and concrete composites. Topics discussed include: cements; concrete aggregates; alkali-silica reaction; alkali-aggregates reactivity; ultra-accelerated tests; fracture mechanics; crack initiation; crack propagation; nondestructive techniques; mortar bar tests; and petrographic evaluation.

43. Possibility Of Enhanced Silica Dissolution In Concrete As In Diagenetically Altered Sandstone. Broekmans, Maarten A. T. M.; Jansen, J. Ben. H. Bull. - Nor. Geol. Unders. (1997), 433, 42-43

A review and discussion, with 13 references, of the alkali-silica reaction in concrete and the need for tests predicting the reactivity of aggregates. Sandstone as an aggregate is theoretically less prone to silica dissoln. compared with chert. Study of thirty-year-old concrete showed that fine-grained sandstone with detrital mica and diagenetic clay minerals is extremely alkali-reactive, whereas chert in the same samples reacts only slightly. Recent studies have demonstrated the catalytic interaction of phyllosilicates like mica and clay minerals in silica dissoln. and diagenetic sandstone compaction and cementation.

44. ASR Testing Remains In Technology Spotlight.(Test Methods For Alkali-Silica Reactivity). Kuennen, Tom Concrete Products, (May 1999) Vol. 102, No. 5, Pp. 6(4).

Editor’s note: Test methods for alkali-silica reactivity (ASR) were among concrete program highlights at the Transportation Research Board’s (TRB) 78th annual meeting in Washington, D.C. ASR testing shared the stage with new research on admixtures and fibers, freeze-thaw durability, and D-cracking prediction. Separately, an eight-member panel discussed High-Performance Concrete (HPC) pavements (note Concrete Products’ March 1999 report, “FHWA to Inject $30 Million into HPC Pavement Studies.”). THIS IS THE FULL TEXT:

45. Durability of cement pastes, mortars, and concretes Struble, Leslie, Cem. Res. Prog. (1989), Volume Date 1987 157-238

A review, with 638 references, including discussions of general durability (effects of concrete parameters, quant. studies), permeability, aggressive environments (sulfates, chlorides, seawater, CO2, other), alkali-aggregate reactions (mechanisms, reactivity tests, constituent effects, practical aspects), freeze-thaw (mechanisms, test methods, constituent effects, air entrainment), reinforcement corrosion (glass, steel, other), drying shrinkage, thermal degrdn., efflorescence, and abrasion.

46. A Critical Review Of The Recent Danish Literature On Alkali-Silica Reaction. Chatterji, S. (Teknol Inst, Taastrup, Denmark) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 37-42. 14 Refs.

In Denmark researches on alkali-silica reaction have been carried out in two distinct phases. In the first phase the problem was identified as a national one. Opaline limestone, and flint of varying degree of crystallinites and porosities were identified as the main reactive aggregates. At this stage the use of a low alkali Portland cement was suggested as the effective preventive measure against alkali-silica reaction. The second phase of research started with an investigation of the breakdown of concrete roads, which indicated that NaCl, a de-icing agent, accelerates alkali-silica reaction and that the presence of free Ca(OH)2 is a pre-requisite for expansive alkali-silica reaction. At the same time the electron-probe micro-analytical technique was adapted for the analysis of the reaction products still within expanding structures. In subsequent investigations the above observations and the analytical technique were utilized to explore the reaction mechanisms, in the development of an accelerated mortar bar method for alkali-silica reactivity with its acceptance criterion, in the development of a simple chemical method for the identification of reactive aggregates. Independently of the above researches a method has been proposed to monitor continuously the dissolution of reactive silica in 10N NaOH solution as a means of evaluating alkali- silica reactivity. In this report the literature of this second phase of research has been critically evaluated. (A) For the covering abstract of the conference see IRRD 857024.

47. Alkali-Silica Reactions And Silica Fume: 20 Years Of Experience In Iceland. Gudmundsson, Gisli (Icelandic Building Research Inst, Reykjavik, UK); Olafsson, Hakon Cement and Concrete Research v 29 n 8 1999.p 1289-1297

In Iceland, silica fume has been blended with all Icelandic cement since 1979.Icelandic cement is unique in many ways. Common raw material for cement production is not found; therefore, less appropriate material is utilized for production. As a result, the alkali content of the cement clinker is relatively high. Because alkali-silica reactive aggregates are relatively common and favorable environmental conditions for alkali-silica reaction (ASR) prevail, ASR became a serious problem in Iceland during the 1970s.At that time research began in Iceland to look for pozzolanic material to counteract ASR reactions in Icelandic concrete. Since the opening of a ferrosilicium plant in Iceland in 1979, silica fume has been utilized as pozzolanic material in all concrete. After 20 years of service there are no signs of ASR in this concrete in Iceland. These findings are supported by scientific research, standardized alkali-silica test methods, and field observations. (Author abstract) 22 References

48. State-Of-The-Art Report On The Mechanism Of Alkali-Aggregate Reaction In Concrete Containing Fly Ash. Interim Report Schumann, D.C.; Carrasquillo, R.L.; Farbiarz, J. Published By: Texas State Department Of Highways & Public Transp (01 Feb 1988), No. 884502. P. 108. 115 Refs. Published by: Federal Highway Administration

Although aggregates were once thought to be inert, it is now known that all aggregates are chemically reactive. The chemical reactions between the aggregates and the cement paste are responsible for beneficial effects such as enhanced bond, but also for other effects that can be deleterious to the durability of the concrete. Alkali- aggregate reaction is one of such chemical reactions. its chemistry and mechanism are not yet very well known but several hypotheses have been presented over the years and are reported herein. The prevention of expansion in concrete due to alkali-aggregate reaction has been widely investigated by many researchers around the world. It is now known that the proper use of mineral admixtures in concrete can reduce the cost of concrete, improve many material properties, and inhibit alkali-silica reaction. The effect of fly ash and silica fume and a summary of the probable mechanisms in which pozzolans affect the expansion caused by alkali-aggregate reaction in concrete is also reviewed, as well as the different methods of predicting the Reactivity of aggregates and a discussion of their relative accuracy and validity. Research study title: alkali-aggregate reaction in concrete containing fly ash.

49. Use Of Cement Kiln Dust In Blended Cements - Alkali-Aggregate Reaction Expansion. Bhatty, Muhammad S.Y. (Pca, Skokie, Il, Usa) World Cem V 16 N 10 Dec 1985 P 386, 388-390, 392

Blended cements made from Portland cement, cement kiln dust and fly ash (ASTM Class F) or granulated blast furnace slag were studied for alkali-aggregate reactivity using the mortar bar expansion test. Beltane opal was used as a reactive aggregate in mortar bars. Blended cements made from cement and kiln dust showed higher expansions at 6 months than cement alone. Expansion increased even more as the level of kiln dust in blends was increased. Cement-kiln dust-fly ash blends produced lower expansion than corresponding cement-kiln dust blends with the same amount of kiln dust, and an increase in fly ash in blends further reduced expansion. Fly ash was a much better expansion inhibitor than slag in comparable blends. (Edited author abstract) 3 references

50. Alkali-Silica Reaction In Australian Concrete Structures Carse, A. (Main Roads Dept, Brisbane, Australia); Dux, (Queensland Univ, Australia) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 25-30. 4 Refs., Document Type Book

This research investigation has placed significant emphasis on collecting field information of alkali-silica distressed structures and using this data to calibrate laboratory tests for predicting safe cement/aggregate combinations. It was determined that alkali- silica reaction has occurred in concrete bridges, a wharf structure and an off shore bulk loading facility. The age of the structures investigated ranges from 8 to 29 years with a corresponding period of construction from 1959 to 1980. Documentation is provided showing that the occurrence of alkali-silica reaction may not always cause destructive expansion in the associated concrete matrix. Two structures were analyzed and shown to exhibit alkali-silica reaction without any associated destructive cracking of the concrete structures. Four additional structures were shown to display similar alkali- silica reaction, however, in these cases associated destructive cracking of the concrete matrix had occurred. The reactive aggregates in the structures examined were identified as an extrusive volcanic source and a river gravel. It has been concluded from this project that the degree of alkali-silica reaction within a structure is dependent on environmental factors and can be magnified by an inadequate design concept. Details of an accelerated test for alkali-silica reaction on concrete samples are provided for use in determining safe cement/aggregate combinations.

51. Chemistry And Structure Of Hydration Products Christensen, Bruce J.; Garci, Maria C.; Olson, Rudy A.; Jennings, Hamlin M. Cem. Res. Prog. (1996), Volume Date 1994 25-50

A review, with 133 references, including discussions of pure compounds, cement hydration, effects of admixtures, creep and shrinkage thermodn., nanostructure, and reaction kinetics, alkali -aggregate reactions, composites, hydration processes of portland and high-alumina cements, hydration of other cement types, stabilization/solidification and utilization of waste materials, effects of minerals on the hydration process, and decomposition, and carbonation.

52. Effect And Mechanism Of Natural Zeolite On Suppressing Alkali-Silica Reaction (Asr) In Concrete. Feng, N.; Jia, H.; Hao, T.; Malhotra, V.M. [Editor] Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Location: Bangkok, Thailand. Held: 31 May - 5th June 1998, 1998., Vol. 2 P. 797-820. - Refs., American Concrete Institute

Effect and mechanism of natural zeolite (NZ) on preventing expansion due to alkali-silica reaction (ASR) are studied in this paper. The reduction of deleterious expansion by NZ is compared with that of three other cementitious materials: silica fume (SF), fly ash (FA), and blast-furnace slag (BFS). The order of effectiveness is SF>NZ>FA>BFS. When 30% zeolite blended cement with an alkali content of 1.82% Na2O equivalent is used in concrete, there will be no damage from ASR even if all the aggregates are reactive. The suppression of ASR by NZ is related to its fineness. The required dosage of NZ is about 20% at a surface area of 7000 cm squared/g with the same effect. Pre-heating of NZ at 500 degrees C increases the preventive effectiveness. The suppressing mechanism of NZ on ASR is decreasing the alkali ion concentration in the pore solution in concrete through ion exchange, adsorption, and pozzolanic reaction of NZ. So the formation of alkali silicate is prevented and the interface is improved.

54. Before Using Fly Ash. Barringer, William L. (New Mexico State Highway & Transportation Dep, NM, USA) Concrete International V 19 N 4 Apr 1997.P 39-40

Provided it is properly used, fly ash can be an excellent material for use in concrete. Aside from its price and its availability, the strength-gaining ability of the fly ash should be considered in proportioning. The spherical geometry of fly ash particles can aid in placing concrete; however, good quality mixes require consistent fly ash fineness. Moreover, the proportions of fly ash to be used depends on the concrete quality desired. Fly ash may lower the heat of hydration and mitigate the resultant thermal strain, provide strength gains that are not delayed, or lessen the effect of alkali-silica reactions or alkali-aggregate reactions depending on its proportion. Tests are suggested to determine the reaction of brands of fly ash with cement type. 2 References

55. The Alkali-Silica Reaction In Concrete (This Looks Like A Good Book To Order). Swamy, R.N. [Editor] (Sheffield Univ, Uk) 1992. P. Xv+333. + Refs., Blackie And Sons Ltd. Isbn: 0-216-92691-2 Publisher Blackie And Sons Ltd, Bishopbriggs, G64 2nz, Glasgow, United Kingdom, Country United Kingdom, Language English

The first four chapters of this BOOK are devoted to the basics of the alkali silica reaction (ASR) while the remaining chapters describe the experience gained globally in tackling the problem. Chapter 1 traces the history of ASR and describes in detail the nature of alkali aggregate reactions in concrete, the basic requirements for the reaction to initiate and propagate, the factors controlling the reaction and the observed effects of the reaction. Chapter 2 presents an analysis of the chemistry of the alkali-aggregate reactions and relates this to the chemistry of cements, mineral admixtures, and the mineralogy of aggregates. A critical review of the various test methods used to detect ASR is provided in Chapter 3. Experiences of ASR in the United Kingdom, Denmark, Iceland, Canada, New Zealand, Japan and India are then presented. For abstracts of some of the individual papers see IRRD 844649-844658.

56. Use Of Dynamic Nondestructive Test Methods To Monitor Concrete Deterioration Due To Alkali-Silica Reaction. Narayan Swamy, R.; Wan, Wmr. Cement, Concrete And Aggregates (1993), Vol. 15, No. 1. P. 32-49. - Refs.,

Dynamic nondestructive tests such as pulse velocity and dynamic modulus to monitor the initiation and progress of concrete deterioration due to alkali silica reactions (ASR) are reviewed. The study found that both pulse velocity and dynamic modulus are sensitive to material and structural changes arising from ASR and that they can respond reliably to changes prior to first crack, at first crack, and the progress of deterioration with time in concrete both with and without cementitious materials other than portland cement. It is noted, that with good engineering judgments, pulse velocity measurements can be used to assess structural deterioration due to ASR.

57. Expansive Reactions In Concrete Odler, Ivan; Jawed, Inam Mater. Sci. Concr. (1991), Volume 2, 221-47. Editor(S): Skalny, Jan P.; Mindess, Sidney. Am. Ceram. Soc.: Westerville, Ohio.

A review, with 60 references, of chem. reactions (other than alkali-aggregate reactions) that cause expansion in concrete and may lead to its deterioration. The most notable of these reactions are those involving sulfates of Ca, Mg, and alkali metals that form expansive products, essentially ettringite, in the concrete matrix. These sulfates may already be present in cement or may come from outside sources (sulfate attack). Various hypotheses on the mechanism of these reactions and the associated. vol. expansions are critically examined. The vol. expansion is harmful when allowed to proceed uncontrolled. However, if carefully controlled, it may, in fact, prove to be beneficial. This is the case with expansive cements that are used to produce pre-stressed concrete or to prevent cracking due to drying shrinkage.

58. Alkali-Silica Reaction In Concrete Hobbs, D.W. (British Concrete Association) 1988. P. 183. + Refs., Thomas Telford Books Isbn: 0 7277 1317 5 Publisher Thomas Telford Books, Thomas Telford House, 1 Heron; Quay, E14 9xf, London, United Kingdom; Document Type Book, United Kingdom, Language English

This book will give users and producers of cement, aggregate and concrete a better understanding of the alkali silica reaction (asr) and its effects upon concrete performance, and how the risks of damage occurring from the reaction can be minimized. Topics covered in the book include the reaction, alkalis in portland cement, alkalis from other sources, reactive silica, cracking and expansion, the diagnosis of the alkali silica reaction, its effects upon the properties of concrete and its structural performance, and remedial actions to counteract the damage caused. The effectiveness of various cement replacement materials in reducing the risk of asr is examined, and methods of testing aggregates and aggregate combinations with cement for their reactivity are explained. Finally, the procedures that are being adapted to minimize the risks of cracking in new construction are given.

59. The Inhibiting Effect Of Lithium Compounds On Alkali-Silica Reaction Sakaguchi, Y. (Nissan Chem Ind Ltd, Japan); Takakura, M. (Nissan Chem Ind Ltd, Japan); Kitagawa, A. (Nissan Chem Ind Ltd, Japan); Hori, T. (Nissan Chem Ind Ltd, Japan); Tomosawa, F. (Tokyo Univ, Japan); Abe, M. (Min Of Construction, Japan); Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 229-34. 4 Refs.; Document Type Book, Japan, Language English

Expansion of mortar bars, which contained Pyrex glass, due to alkali-silica reaction (ASR) was inhibited by addition of lithium compounds (lithium carbonate, lithium nitrite and lithium hydroxide). Lithium hydroxide was found also effective in inhibiting the expansion of mortar bars containing reactive aggregates. The inhibiting effect increased in proportion to the amount of its addition. Expansion was inhibited by impregnating the solution of lithium nitrite to both mortar bars and concrete prisms that had been subjected to accelerated expansion. The effects of lithium compounds were examined by observing the boundary face between Pyrex glass and hardened cement paste by means of energy dispersive X-ray spectrometer and by analyzing the extracted pore solution from the mortars. It was confirmed that the alkali-silica gel, the reaction product of Pyrex glass and hardened cement paste, was not observed at the boundary face, and that the concentration of lithium ion in pore solution decreased and that of sodium and potassium ion in it was nearly constant with the passage of time. In conclusion, these results suggest that the inhibiting effect of lithium compounds is attributed to the production of a kind of lithium silicate, which hardly swells and dissolves, at the surface of the aggregate. (A) For the covering abstract of the conference see IRRD.

60. Canmet Investigations Of Supplementary Cementing Materials For Reducing Alkali-Aggregate Reactions; Part 1 Granulated/Pelletized Blast Furnace Slags Soles, J.A. (Canmet, Ottowa, Canada); Malhotra, V.M. (Canmet, Ottowa, Canada); Chen, H. (La Farge Canada Inc); Fly Ash, Silica Fume, Slag And Natural Pozzolans In Concrete. Proceedings Of The Third International Conference, Trondheim, Norway, 1989. Volume 2 (Aci Sp-114), 1989. P. 1637-56. 15 Refs., American Concrete Institute; Document Type Book, United States, Language English

The use of supplementary cementing materials for reducing harmful alkali-aggregate reactions (AAR) in concrete is being studied at the Canada Centre for Mineral and Energy Technology (CANMET). One investigation involves the use of three types of reactive aggregate and supplementary cementing materials that include fly ash, slag, silica fume and natural pozzolans. This report covers the part in which ground, granulated blast-furnace slags from one US and two Canadian sources were used to partially replace cement in concrete containing the three reactive aggregates. Test data include characterization of the materials used, their proportions in mixtures, concrete strengths, and 2-year expansion measurements of mortar bars and concrete prisms containing them. The test results indicate the effectiveness of the slags in reducing deleterious AAR, and their optimum replacement levels. These slags are all effective in controlling such reactions, particularly with the highly reactive Kingston dolostone. (A) For the covering abstract of the conference see IRRD 829586.

61. Comparison Of The Effectiveness Of Four Mineral Admixtures To Counteract Alkali-Aggregate Reaction. Durand, B. (Ecole Polytechnique, Montreal Canada); Berard, J. (Ecole Polytechnique, Montreal Canada); Soles, J.A. (Canmet, Ottawa, Canada) Proceedings Of The 7th International Conference On Concrete Alkali-Aggregate Reactions, Ottawa, Canada, 1986, 1987. P. 30-5. 7 Refs., Noyes Publications Isbn: 0-8155-1142-6; Document Type Book, United States, Language English

Two fly ashes, one silica fume and one granulated slag were used as admixtures to test the effectiveness of these pozzolans in reducing expansion of concrete due to alkali-aggregate reaction. Standard mortar bar (astm c-227) and concrete prism (csa.a23.2-14a) expansion tests were used to show the effects. Three types of aggregate were used, to represent the best known alkali -aggregate reactions: (1) trois-rivieres siliceous limestone—alkali-silica reactive; (2) kingston dolomitic limestone—alkali-carbonate reactive; (3) lady evelyn lake argillite—alkali-silica/silicate reactive. Other experimental work included the measurement of ca(oh)2 content in the cement pastes, and microstructural examination of the pastes by scanning electron microscopy. The effectiveness of the mineral admixtures in reducing expansion was different for each of the three aggregates. Ca(oh)2 measurements and scanning electron microscopy revealed important differences related to the type of mineral admixture used and its replacement levels.(a) for the covering abstract of the conference see IRRD 811982.

62. Alkali-Silica-Reaction - A Risk For The Long-Term Stability?. Wieker, Wolfgang (Universitaet Berlin, Berlin, Ger); Betonwerk Und Fertigteil-Technik V 60 N 11 Nov 1994.P; LANGUAGE: English; German

The alkali-silica-reaction (ASR) is a concrete-damaging reaction that is brought about by a high alkali presence in the concrete, which can come from cement, additions or aggregates. These reactions lead to the formation of alkali silicates that, under moist conditions, lead to crack formation as a result of expansion phenomena. For the purpose of clarification of the reaction mechanism and finding ways of avoiding these concrete-damaging reactions, pore solutions from appropriate test specimens were pressed out and their composition analyzed. It was established that it is possible to suppress an ASR when the alkali concentration in the pore solutions is reduced by finely divided alkali binding additions (such as filter fly ashes, silica fume, etc.). 4 References

63. Mechanisms Affecting The Development Of Alkali-Silica Reaction In Hardened Concretes Exposed To Saline Environments. Sibbick, R.G. (Aston Univ, Birmingham, UK); Page, C.L.; Magazine Of Concrete Research V 50 N 2 Jun 1998.P 147-159

In circumstances where concretes containing UK aggregates with reactive siliceous components are exposed to high concentrations of NaCl there is conflicting evidence as to whether salt ingress enhances susceptibility to alkali-silica reaction (ASR).There is also uncertainty over the mechanisms involved. The research undertaken was intended to elucidate these issues. Expansion tests with concrete prisms and cores immersed in 2 and 7 M NaCl solutions at 20 and 38°C showed that significant ASR expansion and cracking could be induced in specimens containing the more highly reactive UK aggregates at alkali levels well below 3 kg/m3 Na2Oeq, which is the present recommended UK limit for minimizing the risk of ASR. Even concretes containing aggregates of lower reactivity (chert-bearing gravels, etc.) were found to exhibit significant ASR expansion when exposed to NaCl solution in specimens of 3 to 4 kg/m^3 Na_2Oeq. The role of NaCl ingress in exacerbating the development of ASR in concretes of varied composition was studied by thermoanalytical techniques and petrography combined with electron probe microanalysis. The mechanisms were found to depend on several features of the environment (NaCl concentration, temperature, etc.) and the composition of the concrete (type of reactive aggregate, alkali content, cement mineralogy, etc.). A simplified reaction scheme was proposed to account for the results obtained. (Author abstract) 18 References

64. Manufacture Of Supplementary Cementitious Materials From Cement Kiln Dust. Mishulovich, Alex (Construction Technology Lab, IL, USA); Hansen, Eric R. World Cement v 27 n 3 Mar 1996.p 116-120

The formulation and production of supplementary cementitious materials (SCM) based on cement kiln dust (CKD) was studied with the dual objective of waste reduction and inhibition of alkali-silica reactivity (ASR) in concrete. The SCM's were produced by melting and vitrification of mixes containing CKD with additives, such as clay, shale, and some industrial wastes, including power plant and incinerator ashes. The product chemical composition was close to low-melting eutectics in the ternary system CaO-SiO2-Al2O3 prime and most melts were produced at temperatures below 1200°C. Vitrification provided the necessary hydraulic reactivity of the product and prevented leaching of the trace elements present in source materials. Blended cements incorporating SCMs proved to be competitive with ordinary Portland cement in strength. Adding SCM to cement reduced the ASR-related expansion by 85 to 90% in the standard test with highly reactive aggregates.(Author abstract) 10 References

65. Effectiveness Of Silica Fume In Reducing Damage Due To Alkali-Silica Reaction Kojima, T. (Ritsumeikan Univ, Kyoto, Japan); Amamsuki, S. (Ritsumeikan Univ, Kyoto, Japan); Takagi, N. (Ritsumeikan Univ, Kyoto, Japan) Proceedings Of 66. The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 265-70. 3 Refs.; Document Type Book, Japan, Language English

In the early 1980s, many cases of concrete structures deteriorated as a result of alkali-silica reaction (ASR) have been reported in Japan, including T-shaped piers of the Hanshin Expressway. It has been suggested that a suitable method of reducing the risk of cracking due to ASR is to replace a part of Portland cement by pozzolanic materials such as pulverized fuel ash (FA), ground granulated blast-furnace slag (BFS) or condensed silica fume (SF). A recent report by Hobbs, DW (see IRRD 814132) states that use of pozzolanic materials is not necessarily a good method to prevent the damage due to ASR. It is necessary to ascertain that the adequate usage of pozzolanic materials can prevent the damage due to ASR. In this study, firstly in order to compare the effectiveness of three kinds of pozzolanic materials used in Japan in reducing the deterioration due to ASR, mortar bars in which a part of cement was replaced by pulverized fuel ash, ground granulated blast-furnace slag and condensed silica fume were made by using the same aggregate as that in the deteriorated structure of the Hanshin Expressway, and expansive strain was measured. Secondly in order to investigate the availability of SF, which was considered most

effective in reducing the deterioration due to ASR, non-destructive tests such as ultrasonic pulse velocity, dynamic modulus of elasticity and the spectral analysis of ultrasonic pulse, were carried out on SF mortar and concrete specimens. For the covering abstract of the conference see IRRD 857024.

67. Alkali-Silica Reactivity Mechanisms and Management. Leming, M.L. (North Carolina State Univ., Raleigh, NC, USA) Mining Engineering (Littleton, Colorado) Vol 48N, 12 December 1996. P 61-64

In the decades since silica gel was first identified in material exuding from cracked concrete, a great deal of research has been conducted regarding the chemical reactions between the alkalis found in portland cement and silica found in aggregates. This paper reviews the research findings attempts to provide a simplified review of the mechanisms of the alkali-silica reaction (ASR), so that one can better understand the implications of the specifications, test results and effects on structures. In addition, the contractual relationships between the aggregate supplier and one of their major clients, the concrete supplier, examined with regard to the ASR.

68. Alkali-Aggregate Reaction In Concrete: A Review Of Basic Concepts And Engineering Implications. Fournier B (Reprint); Berube M A CANADIAN JOURNAL OF CIVIL ENGINEERING, (APR 2000) Vol. 27, No. 2, Pp. 167-191.

This paper presents theoretical and applied state-of-the-art information in the field of alkali-aggregate reactivity (AAR) in concrete. The aspects discussed include basic concepts of the reaction and expansion mechanisms, conditions conducive to the development and the sustainability of AAR in concrete, field and laboratory investigation programs for evaluating the potential alkali-reactivity of concrete aggregates, selection of preventive measures against AAR, and the management of structures affected by AAR. The management section includes the diagnosis of AAR in existing concrete structures, evaluation of the potential for future distress due to AAR, and mitigation and repair approaches used on such structures. This is an introductory paper and sets the stage for a special review of the current AAR situation in the various regions of Canada that is presented in seven papers as part of this issue.

69. Deleterious Expansion Of Concrete Due To Alkali-Silica Reaction: Influence Of Pfa And Slag. Hobbs, D.W. (Cement & Concrete Assoc, Slough, Engl) Mag Concr Res V 38 N 137 Dec 1986 P 191-205

The literature dealing with the effectiveness of partial replacement of a high-alkali cement by pulverized-fuel ash (pfa) and ground granulated blast furnace slag (slag) in preventing deleterious expansion due to the alkali-silica reaction (ASR) when a reactive aggregate is used is reviewed, and results are reported of recent tests carried out on concrete at C&CA. It is shown that the effectiveness of pfa’s and slags in preventing deleterious expansion due to ASR varies widely and that the use of some pfa’s and slags may not reduce the risk of deleterious expansion.(Author abstract) 48 references

70. Effectiveness Of Mineral Admixtures In Controlling Asr Expansion Swamy, R.N. (Sheffield Univ, Uk); Al-Asali, M.M. (Canmet, Ottawa, Canada) Proceedings Of The 8th (July 17-20, 1989) International Conference On Alkali-Aggregate Reaction, Held Kyoto, Japan, 1989. P. 205-10. 3 Refs; Document Type Book, Japan, Language English

Alkali silica reaction (ASR) is now known to be capable of causing considerable damage to concrete structures, which might sometimes even lead to their failure. Although the occurrence of such reaction is limited when one considers the large number of concrete structures built, the reaction can cause serious problems of serviceability when it does occur. It is therefore important to consider at the design stage the possible damages arising from ASR, and to minimize the risk of its occurrence by choice of suitable materials, and appropriate design. The most practical and beneficial means of controlling ASR expansion is probably through part replacement of cement by mineral admixtures such as fly ash, ground granulated blast furnace slag and silica fume. A number of studies on the use of these and other natural and artificial pozzolans to control ASR expansion have been reported in literature. In spite of much detailed research, there are several aspects of the role of mineral admixtures in ASR that are not yet fully understood. For example, there appears to be no single explanation on the mechanism of pozzolanic reactions and control of ASR expansion. Further, the effect of pozzolanic additions on ASR is highly variable, and the effectiveness very much depends on the type of reactive aggregate, the type of mineral admixture, the method of replacement, etc. Whilst there is a lot of evidence on mortar bar tests to show that pozzolans can reduce or even eliminate ASR expansion, there is also test data to show that materials judged as effective pozzolans by ASTM tests, sometimes even increase ASR expansion. In this paper, some test data are presented to evaluate the effectiveness of fly ash, slag and silica fume in controlling and/or reducing ASR expansion in concrete. (A) For the covering abstract of the conference see IRRD

857024.

71. Alkali-Silica Reactivity In Concrete - Importance Of Cement Content And Alkali Equivalent Johnston, C.D. (Univ Calgary, Canada) Proceedings Of The 7th International Conference On Concrete Alkali-Aggregate Reactions, Ottawa, Canada, 1986, 1987. P. 477-82. 2 Refs., Noyes Publications; Document Type Book

The effect of cement content and alkali equivalent on alkali-silica reactivity is evaluated in terms of expansion up to age 5 years for concrete prisms made with crushed glass as the coarse aggregate. What happens with each cement-aggregate combination depends strongly on the amount of alkali in the concrete available to fuel the reaction, which in turn is related to the product of cement content and alkali equivalent. three categories of reactivity can be identified: apparently innocuous for alkali contents in concrete less than about 0.05%, rapid and highly deleterious for alkali contents more than 0.10%, and slowly expansive, potentially dangerous, and classifiable as deleterious only after 1 year or more of testing for alkali contents of 0.05-0.10%.(a) for the covering abstract of the conference see irrd 811982.

72. A Discussion Of The Paper ''The Alkali-Silica Reaction. The Surface Charge Density Of Silica And Its Effect On Expansive Pressure" By F.A. Rodrigues, P.J.M. Monteiro, G. Sposito Chatterji S (Reprint) Cement And Concrete Research, (Mar 2000) Vol. 30, No. 3, Pp. 501-502.

73. Effects Of Silica Fume And Steel Fibers On Some Mechanical Properties Of High-Strength Fiber-Reinforced Concrete Eren O (Reprint); Marar K; Celik T Journal Of Testing And Evaluation, (Nov 1999) Vol. 27, No. 6, Pp. 380-387.

There are many test methods to measure the impact resistance of fiber-reinforced concrete that are complicated, time consuming, and expensive. A practical test method has been developed to measure the impact resistance of high-strength fiber-reinforced concrete (HSFRC). The equipment developed can also be used for testing aggregate impact values by simply changing the base plate of the machine. A machine was developed to measure the surface abrasion resistance of HSFRC. Testing fiber-reinforced concrete for surface abrasion resistance was found to be extremely difficult if realistic and practical results were desired. In this study the influence of silica fume on the properties of HSFRC was investigated by using silica fume at two different percentages and with three different hooked-end fibers, namely, 30/0.50, 60/0.80, and 50/0.60 length/diameter (mm/mm). Fibers were added to concrete in three different percentages of 0.5, 1.0, and 2.0% by volume of concrete. The results show that including fibers in high-strength concrete improves impact resistance, surface abrasion, and splitting tensile strength.

74. A Critical Review Of Ultra-Accelerated Tests For Alkali-Silica Reactivity Grattanbellew P E Cement & Concrete Composites, (Oct 1997) Vol. 19, No. 5-6, Pp. 403-414.

A large number of ultra-accelerated test procedures, for determining the potential alkali reactivity of aggregates, have been developed, particularly in the past 15 years. An ultra-accelerated test method is defined as one which yields results within a few days or, at most, a few weeks. A number of ultra-accelerated test methods have been adopted as 'standard tests', but few have been adequately evaluated. The rapid globalization of the construction industry will require the harmonization of National Standard Test Methods. The major requirement of ultra-accelerated test methods is that they should correctly predict the potential reactivity of aggregates in greater than 95% of the cases. Due to the complexity and variability in the composition and grain size of aggregates, it is improbable that a single test method will be developed which would be appropriate for evaluating all types of aggregates. Another major requirement for ultra-accelerated test methods is that the inter-laboratory coefficient of variation should be low, preferably less than 12%. At present, only the NBRI accelerated mortar bar method has been subject to adequate inter-laboratory evaluation. However, a more limited inter-laboratory investigation showed that the autoclave mortar bar test also shows considerable potential, as a satisfactory ultra-accelerated test method. Further refinement of the NBRI and autoclave methods is required to improve their performance with a wide variety of aggregates.

75. Effect Of Silica Fume And Steel Fibers On Some Properties Of High-Strength Concrete Eren O (Reprint); Celik T Construction And Building Materials, (Oct-Dec 1997) Vol. 11, No. 7-8, Pp. 373-382.

The main disadvantage of high-strength concrete is its highly brittle behavior and this can be overcome by adding fibers to the concrete. This would also improve some other mechanical properties of high-strength concrete such as tensile strength and compressive strength. These properties are not very well established for high-strength steel-fiber reinforced concrete (HSFRC) yet. In this study the influence of silica fume on the properties of HSFRC were investigated by using silica fume of two different percentages and three different hooked-end fibers namely, 30/0.50, 60/0.80 and 50/0.60 length/diameter (mm/mm). Fibers were added to concrete in three different volume percentages of 0.5, 1.0 and 2.0 by volume of concrete. The results indicated that there is a linear function between splitting tensile strength (F-splt) and volume percentage of fibers (V-f) [i.e. F-splt = A(V-f) + B, where A and B are correlation coefficients] as well as between splitting tensile strength (F) and compressive strength (F-c) of plain series A concrete [i.e. F-splt = C(root F-c) + D, where C and D are correlation coefficients]. These relations can describe the development of splitting tensile strength of HSFRC containing no silica fume, 5% silica fume and 10% silica fume by weight of cement. On the other hand, although silica fume has an effect on compressive strength, volume percentage and aspect ratio of steel fibers has little effect.

76. The Effect of Grinding On the Physical Properties Of Fly Ashes and a Portland Cement Clinker Bouzoubaa N; Zhang M H (Reprint); Bilodeau A; Malhotra V M Cement And Concrete Research, (Dec 1997) Vol. 27, No. 12, Pp. 1861-1874.

The effect of the grinding on the physical properties of three ASTM Class F fly ashes and a Portland cement clinker were investigated. The specific gravity and the fineness of the Ay ashes increased with an increase in the grinding time. However, this increase was less significant beyond 2 hours. The morphology of the fly ashes was changed by grinding. Most of the plerospheres and large, irregular-shaped particles were crushed after 2 hours of grinding. However, the number of the spherical particles reduced with increased grinding. There appears to be an optimum grinding time of approximately 4 hours for the Ay ashes beyond which the water requirement increased and the strength activity indices either decreased or did not increase significantly. (C) 1997 Elsevier Science Ltd.

77. L34 Answer 46 Of 60 Scisearch Copyright 2000 Isi (R) Performance Of Concrete Under Different Curing Conditions Tan K F (Reprint); Gjorv O E Cement And Concrete Research, (Mar 1996) Vol. 26, No. 3, Pp. 355-361.

The effect of curing conditions on strength and permeability of concrete was studied. Test results showed that after 3 and 7 days moist curing only the concretes with w/c ratios equal to or less than 0.4 were accepted, while after 28 days of moist curing however, even the concrete with w/c of 0.6 could be accepted. Silica fume has a significant effect on the resistance to water penetration. For the concretes both with and without silica fume and with w/c + s of 0.5, the 28-day compressive strengths of 3 and 7 days moist curing were higher than those of 28 days moist curing, and the silica fume concrete seemed to be less sensitive to early drying. The curing temperatures did not affect the water penetration of concrete, but affected the chloride penetration and compressive strength of concrete significantly.

78. Effectiveness Of Fly-Ash In Preventing Deleterious Expansion Due To Alkali-Aggregate Reaction In Normal And Steam-Cured Concrete Shayan A (Reprint); Diggins R; Ivanusec I Cement And Concrete Research, (Jan 1996) Vol. 26, No. 1, Pp. 153-164.

A non-reactive and several reactive aggregates were used in concrete specimens with and without two fly ashes (varying in total alkali content) at binder (cement + fly ash) alkali levels ranging from 0.46 to 2.5% and a binder content of 500 kg/m(3) and fly ash/binder ratio of 0.25. The specimens were stored either at 23 degrees C (fog room) or 40 degrees C, 100% RH. Some specimens were steam cured at 75 degrees C for eight hours, and then transferred to 40 degrees C, 100% RH. The expansion behavior of the specimens was monitored over nearly six years, and showed that the effectiveness of the fly ash in preventing deleterious AAR expansion depended on the alkali content of the concrete. At the highest alkali content of 12.5 kg Na_2O equiv./m(3), the fly ashes only had a delaying effect (one to several years), whereas at 6.9 kg Na_2O equiv./m(3) they eliminated deleterious AAR expansions. Generally, for more highly reactive aggregates, and at the 2.5% alkali level, fly ash was less effective at 40°C than 23°C because the rate of AAR expansion was much higher at 40°C. At lower alkali levels and for less reactive aggregates, the temperature was not important. Fly ashes were also effective under steam-curing conditions. A measurable amount of chemical shrinkage occurred in the first few months in concretes containing fly ash and with high alkali contents, although some of these concretes later expanded and cracked as a result of aggregate reactivity. Fly ash was used in mortar specimens prepared for the expression and analysis of the pore solution and was found to be very effective in reducing the alkalinity of the pore solution, a factor contributing to its preventive effects on AAR. It is concluded (based on six-year results and the shapes of expansion curves) that the two fly ashes can be used to prevent deleterious AAR expansions in practical situations.

79. Effectiveness Of Supplementary Cementing Materials In Suppressing Expansion Due To Asr .1. Concrete Expansion And Portlandite Depletion – Discussion Chatterji S (Reprint) Cement And Concrete Research, (1994) Vol. 24, No. 8, Pp. 1572-1573.

80. Comparative-Study Of Various Silica Fumes As Additives In High-Performance Cementitious Materials. Delarrard F (Reprint); Gorse J F; Puch C Materials And Structures, (Jun 1992) Vol. 25, No. 149, Pp. 265-272.

This article concerns marginal variations in the functional properties of very-high-strength mortars and concretes resulting from the type of silica fume used. Twenty silica fumes were tested, in the presence of two cement-superplasticizer pairs. All of the results are analyzed into main components and regressions. The action of carbon on the workability of the mixtures has been verified. Finally, within the limits of the scattering of the results, it has been possible to establish an empirical law, fitted to previous results, showing the influence of the alkali content of the silica fume on its pozzolanic activity.

81. Mechanism Of Alkali-Silica Reaction And The Significance Of Calcium Hydroxide - Reply. Wang H (Reprint); Gillott J E Cement And Concrete Research, (Jan 1992) Vol. 22, No. 1, Pp. 193-194.

On The Long-Term Strength Losses Of Silica-Fume High-Strength Concretes. Delarrard F (Reprint); Bostvironnois J L Magazine Of Concrete Research, (1991) Vol. 43, No. 155, Pp. 109-119.

This Paper presents studies and tests performed at the Laboratoire Central des Ponts et Chaussees with a view to a better understanding of the long-term mechanical properties of silica-fume high-strength concretes (HSC) and very-high-strength (VHSC) concretes. After noting the discrepancies among the various references in the literature, we propose to explain the drop in strength observed by some authors after three months by the hypothesis of drying-related effects. To check the soundness of this hypothesis, mechanical tests were carried out on three different concretes, their drying was investigated by gammadensimetry, and accelerated tests were performed on mortars. The homogeneous drying to which the specimens are subjected has no negative effect on their mechanical strengths. The losses of strength observed on some concretes are therefore probably not caused by a local effect of the drying. Examination of the water content fields of VHSC specimens four years old shows that the drying occurs with a high gradient and affects only a small thickness. Mechanical tests in this case show a non-negligible drop in compressive strength. Calculation of the self-stress field due to drying shrinkage indicates that the compression at the core of the specimen is of the same order as the drop in strength observed. To conclude, it is shown that, given some hypotheses concerning the water content field, the drop in strength linked to the structural effects of drying can be not more than twice the tensile strength.

82. A New Test Method For Fiber-Reinforced Concrete Zollo R F (Reprint); Hays C D; Zellers R Cement Concrete And Aggregates, (Dec 1999) Vol. 21, No. 2, Pp. 111-

116.

It has long been recognized that the principal benefit gained by using fiber reinforcement in portland cement concrete is a conversion of the material from brittle to relatively ductile behavior. The apparent ductility, or toughness, is primarily related to the improved tensile strength of fiber-reinforced concrete (FRC) especially and even after significant matrix cracking has occurred. However, the methods used to measure tensile strength and toughness of FRC have been, at best, elaborate and controversial. A practical and much needed testing methodology for fiber-reinforced concrete has been developed and adopted as an ASTM standard. It was conceived from the need to have a test that is relatively simple and inexpensive to conduct and is yet capable of assessing the tensile strength of cracked FRC. The test method, ASTM C 1399, and an interlaboratory testing program conducted to help formulate a precision statement for the new methodology is discussed.

83. Surface Modified Polypropylene Fibers For Use In Concrete Tu L (Reprint); Kruger D; Wagener J B; Carstens P A B Magazine Of Concrete Research, (Sep 1998) Vol. 50, No. 3, Pp. 209-217.

The research project reported on is concerned with the effect of modification of the surface of polypropylene fiber by a new chemical treatment process, oxyfluorination, on the properties of polypropylene fiber reinforced concrete. As a world first, the interfacial bond of polypropylene fibers with the cementitious matrix is improved by increasing the surface free energy of the fiber surface. The reasons for the poor bonding between untreated polypropylene fiber and cementitious matrix are discussed, using the fiber surface free energy and Lewis acid-base interaction concept. The contact angle of water on the polypropylene fiber surface as well as fiber surface free energy components were measured. This showed reduced contact angles, as well as increased acid-base components of the surface free energy because of oxyfluorination. Mechanical properties such as compressive strength, flexural properties and impact resistance of the fibrous concrete, reinforced with different types of oxyfluorinated polypropylene fibers, were determined and compared with those of untreated polypropylene fiber reinforced concrete. The results confirmed that the surface modification largely improves the mechanical performance of the fibrous concretes. Restrained plastic and drying shrinkage cracking tests, using restrained slab specimens and steel ring restrained specimens, indicated that the surface oxyfluorinated fibers possess a higher shrinkage cracking resistance than do unmodified fibers. The effect of surface oxyfluorination on the concrete/concrete matrix interfacial bondings was investigated using a fiber pull-out test. A mechanism for this interfacial bonding improvement is proposed. Oxyfluorinated polypropylene fiber surfaces and their interfaces with concrete matrix compared with that of unmodified fiber, were observed using scanning electronic microscopy. Some field application tests were conducted and the good results that were achieved are presented.

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-1	y		3907	9.2		95	9800	5:49	676	1800	Slag
HES-11	y		120	9.2	82	80	165	8:00+	80	80	TLW
HES-11	y		1100	9.8		85	3361	5:00+			TLW
HES-3		n		10.0		60	7600	4:45			A
HES-4	y		210	10.0		91	2100		183	271	A
HES-11	y		210	10.0		91	2100		155	244	TLW
HES-4	y		210	10.0		91	2100		126	185	Micro-fine
HES-11		n		10.0		119	6100	4:16			TLW
HES-11		n		10.0		119	6100	5:18		176	TLW
HES-11	y		2945	10.0		47	6200	5:00+		0	TLW
HES-5	y		142	10.0	120	103	2500	5:00+	85	156	H
HES-6		n		10.1	130	111	2752	4:38	4900		
HES-3	y		1605	10.5		75	2600	7:31	83	226	A
HES-2				10.5	181	145	7200	2:30	423	982	H
HES-11	y		250	10.5	92	80	1000	7:00+	FIRM	72	TLW
HES-11	y		250	10.5	92	80	1000	7:00+	50	70	TLW
HES-11	y		722	10.5	0	85	1305	6:00+	0	0	TLW
HES-11	y		220	10.5	97	83	1308	5:00+	FIRM	50	TLW
HES-4	y		2945	10.6		47	6200	5:00+		64	A
HES-3	y		1605	10.8		75	2600	2:21			A
HES-3	y		1605	10.8		75	2600	3:15			A
HES-3	y		2100	10.8		60	3650		0	54	A
HES-3	y		2100	10.8		60	3650		57	64	A
A	y		148	10.8	94	82	1200	4:00+	SET	110	H
HES-3	y		167	10.9		87	1732	2:57			A
HES-11	y		100	11.0	130	103	4500		184		TLW
HES-3	y		1711	11.0		80	2600	3:42			A
HES-4	y		210	11.0		91	2100		436	863	A
A	y		210	11.0		91	2100		89	128	Micro-fine
F		n		11.0	220	182	12055	4:20	238	286	Micro-fine
HES-2		n		11.0	181	145	7200	2:17	526	581	H
HES-3	y		1490	11.0		80	2505	2:29	377	487	A
A	y		1000	11.0		60	14085	7:00+		102	H
HES-11	y		31	11.0	86	80	555	6:00+	0	0	TLW
HES-11	y		31	11.0	86	80	555	6:00+	31	113	TLW
HES-3		n		11.0		60	7600	5:18			A
A	y		150	11.0	92	80	1000	4:00+	112	274	A
HES-3	y		100	11.0	130	103	4500	4:35	247	642	A
HES-4	y		100	11.0	130	100	4500	4:27	404	564	A
HES-11	y		100	11.0	130	103	4500	4:02	0	95	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	75	129	TLW
A	y		50	11.0	136	104	4799	6:00+	111	188	H
HES-11	y		100	11.0	130	103	4500		107	159	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	53	95	TLW
HES-11	y		100	11.0	130	103	4500	6:00+	87	92	TLW
HES-3	y		1736	11.0		60	2450	4:19	105	175	A
A	y		480	11.0	97	84	1400	6:00+	126	345	A
A	y		174	11.0	95	80	1000	6:00+	115	205	A
HES-2	y		110	11.0	94	83	1300	5:00+	80	490	A
HES-11	y		80	11.0	160	116	6425	4:43			TLW
HES-11	y		1120	11.0	140	112	7990	2:53	30	90	TLW
HES-11	y		253	11.0	122	97	3862	7:00+	40	150	TLW
A	y		238	11.0	102	86	1894	6:00+	40	70	H
A	y		153	11.0	90	80	800	5:00+	FIRM	30	H
A	y		180	11.0	146	111	5555	7:00+	170	220	A
A	y		37	11.0	139	105	4500	6:00+	175	185	A
F	y		210	11.0		135	1868	2:00	172	180	Micro-fine
A	y		50	11.0	133	103	4400	2:04	270	280	A
HES-7	y		2841	11.0	0	72	5600	7:00+	0	0	A
A	y		193	11.0	96	83	1300	5:00+	120	190	A
A	y		300	11.0	125	98	3897	4:00+	130	200	H
HES-1	y		3214	11.0		80	6350	6:00+	115	160	Slag
F		n		11.0		228	12402	7:50	250	300	Micro-fine
HES-11		n		11.0	240	192	13000	5:55			TLW
HES-11		n		11.0	240	192	13000	6:00	90	324	TLW
A	y		180	11.0	128	102	4200	6:30+	76	103	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F		n		11.0	213	172	9713	5:00+	307	334	Micro-fine
A	y		385	11.0	118	102	4500	6:00+			A
A	y		50	11.0	133	103	4400	2:55	150	160	A
HES-3	y		1470	11.1		70	2600	5:03			A
A	y		50	11.1	161	122	7000	7:00+	37	50	H
HES-11	y		100	11.2	96	83	1300	6:00+	0	89	TLW
HES-11	y		380	11.2		95	6000	5:30+	32	86	TLW
HES-11	y		380	11.2		95	6000	4:30+	75	139	TLW
HES-11	y		380	11.2	154	115	6000	6:53	225	436	TLW
HES-11	y		380	11.2		70	1450	6:00+	38	67	TLW
HES-11	y		100	11.2	96	83	1300	7:00+	0	0	TLW
A	y		148	11.2	128	101	4863	5:00+	0	150	H
HES-7	y		100	11.2	96	83	1300	7:00+	0	74	H
HES-11	y		76	11.2	145	110	8174	4:00+	374	531	TLW
HES-11	y		100	11.2	171	125	7000	5:50	184	305	TLW
HES-11	y		76	11.2	211	163	12182	3:45	460	500	TLW
HES-7	y		2100	11.2		65	2500	6:00+	0	0	A
HES-11	y		76	11.2	211	163	12182	3:40	450	570	TLW
HES-11	y		380	11.2	154	115	6000	6:47	191	614	TLW
B	y		200	11.3	120	98	4000	4:30	86	128	H
F		n		11.3	194	156	8625	2:08	285	341	Micro-fine
A	y		123	11.3	113	94	3200	5:00+	130	200	H
A	y		280	11.4	102	89	3223	5:00+	75	127	H
A	y		110	11.4	95	80	1000	4:30+	95	120	H
A	y		420	11.4	115	99	4334	6:00+	138	201	A
A	y		420	11.4		102	4500	6:00+	187	257	A
A	y		420	11.4		102	4500		56	99	H
A	y		385	11.4		98	4094	5:00+	69	175	A
A	y		113	11.4	90	80	753	4:00+	50	100	H
A	y		164	11.4	93	81	1100	4:30+	101	163	A
A	y		113	11.4	95	84	2000	4:00+	60	110	H
A	y		113	11.4	101	89	6460		80	160	H
A	y		113	11.4	101	89	6460	4:00+	70	130	H
A	y		222	11.4	125	100	3850	5:00+	50	110	H
A	y		164	11.4	93	81	1100	4:00+			A
A	y		260	11.4	120	96	4820	5:00+	60	120	H
A	y		164	11.4	125	100	4084	4:00+	178	193	A
A	y		127	11.4	136	105	4700	7:00+	120	210	A
A	y		45	11.4	128	101	4000	5:00+	88	170	H
A	y		225	11.4	139	106	4853	5:00+	130	180	H
A	y		324	11.4	92	80	900	5:30+	70	121	H
A	y		80	11.4		84	2295	6:00+			H
A	y		108	11.4	91	80	1000	4:00+	50	110	H
A	y		108	11.4	108	92	2500	4:00+	60	120	H
A	y		90	11.4	92	80	1000	4:00+	52	140	A
A	y		228	11.4	92	80	1000	4:00+	60	152	A
A	y		181	11.4	92	80	1000	4:00+	130	150	H
A	y		181	11.4	110	93	3768	4:00+	140	155	H
A	y		236	11.4	118	97	4112	5:00+	78	130	H
A	y		47	11.4	119	96	3000	5:00+	90	173	A
A	y		245	11.4	126	100	4398	4:30	129	212	A
A	y		148	11.4	128	101	4000	4:00+	120	135	H
A	y		68	11.4	89	80	820	4:20	250	320	A
A	y		68	11.4	136	105	4700	2:20	230	390	A
A		n		11.4		80	50			70	A
A		n		11.4	80	80	270	4:00+		86	A
HES-11	y		20	11.4	97	84	1450	4:00+	87	113	TLW
HES-11	y		20	11.4	150	116	6400	3:45	255	419	TLW
A	y		43	11.4	152	115	6000	6:30+	142	155	H
A	y		236	11.4	95	83	1300	6:00+	83	107	A
A	y		420	11.4		100	3538	6:00+	98	147	A
A	y		427	11.4	100	89	2000	5:30+	75	140	H
A	y		165	11.4	118	96	3120	7:00+	140	220	A
A	y		236	11.4	118	97	4112	5:00+	70	130	H
A	y		427	11.4	117	99	4200	5:00+	85	158	H
A	y		420	11.4		84	1502	6:30+	90	171	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		372	11.4		82	1200	8:20	111	193	A
A	y		372	11.4		82	1200	8:20	111	193	A
A	y		260	11.4	95	83	1300	5:00+			H
A	y		260	11.4	95	83	1340	5:00+			H
A	y		420	11.4		85	1600	7:16	103	206	A
A	y		420	11.4		83	1200	5:30+	98		A
A	y		199	11.4	92	80	1050	5:00+	110	140	H
A	y		372	11.4	116	97	3500	6:03	274	348	A
A	y		260	11.4	125	99	3600	5:00+	50	110	H
A	y		236	11.4	95	83	1300	6:00+	89	112	A
HES-11	y		38	11.4	95	80	1000		36	229	TLW
A	y		120	11.4	197	147	9000		0	SET	H
A	y		25	11.4	88	80	700	2:00+	90	140	A
A	y		80	11.4	100	87	1700	5:00+	99	145	H
A	y		43	11.4	120	98	3500	3:30+	60	110	H
A	y		25	11.4	116	96	3000	3:00+	79	125	A
A	y		890	11.4	121	103	4500	6:00+	57	113	H
A	y		800	11.4	146	114	6000	6:30+	0	115	H
A	y		150	11.4	90	80	800	7:00+	0	51	H
A	y		30	11.4	92	80	1000	6:00+	0	60	H
HES-11	y		385	11.4		74	1450	4:00+	70	137	TLW
A		n		11.4	92	80	1000		60	120	H
HES-11	y		160	11.4		80	1000	6:00+	79	106	TLW
A	y		100	11.4	120	96	3100	5:00+	170	290	A
A	y		160	11.4	96	83	1300	6:00+			H
A	y		118	11.4	148	106	4500	5:00+	66	147	H
HES-11	y		57	11.4	92	80	1000	4:00+	92	109	TLW
A	y		150	11.4	115	94	2700	7:00+	0	52	H
A	y		8	11.4	108	92	2500	5:00+	65	116	H
A	y		8	11.4	108	92	2500	5:00+	58	81	H
HES-11	y		220	11.4	104	90	2180	4:00+	133	388	TLW
A	y		220	11.4	115	96	3525	3:00+	199	251	A
HES-11	y		78	11.4	116	96	3710	4:48	310	600	TLW
HES-11	y		160	11.4	119	98	3902	6:44	122	583	TLW
HES-11	y		40	11.4	119	98	3500	4:00+	168	601	TLW
HES-11	y		10	11.4	125	100	3800	5:00+	350	558	TLW
A	y		180	11.4	124	100	4000	4:00+	105	153	A
HES-11	y		25	11.4	124	100	4000	3:28	325	384	TLW
HES-11		n		11.4		80	1000	4:00+	79	110	TLW
B	y		100	11.4	92	80	1000	4:00+	300	310	A
A	y		52	11.4	117	96	3892	4:30+	50	130	H
A	y		238	11.4	126	100	4173	4:30+	70	120	H
A	y		90	11.4	125	98	3500	4:00+	85	125	A
A	y		90	11.4	120	98	3500	5:00+	145	216	A
A	y		210	11.4	114	98	3800	4:13	144	216	A
A	y		228	11.4	120	98	4275	5:00+	120	195	A
A	y		12	11.4	128	101	4000	4:30+	90	135	A
A	y		107	11.4	138	106	4800	4:30+			H
A	y		226	11.4	125	100	4000	4:30+	109	122	H
A	y		238	11.4	128	101	4600	4:36	160	206	A
A	y		245	11.4	143	109	5200	4:30+	78	116	A
A	y		90	11.4	140	107	5000	5:00+			H
A	y		9	11.4	140	108	5200	4:30			A
A	y		12	11.4	156	118	6350	7:00+	130	160	H
A	y		9	11.4	140	108	5200	7:30+	105	115	H
A		n		11.4	96	83	1300	5:00+	120	170	A
A	y		645	11.4		80	2500	4:00+	50	110	A
A	y		25	11.4	128	101	4000	5:00+	116	143	H
A	y		50	11.4	128	101	4000	4:00+	170	290	A
A	y		180	11.4	136	105	4700	6:00+	125	141	H
A	y		100	11.4	140	107	5000	5:00+	130	240	A
A		n		11.4	142	108	5200	6:30+	0	60	H
A	y		170	11.4	95	84	1400	4:00+	74	117	H
B	y		50	11.4	115	96	3000	4:00+	95	110	H
A	y		38	11.4	133	103	4937	8:00+	99	120	H
A	y		61	11.4	125	102	4300	4:00+	78	134	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		220	11.4	139	105	4677	7:00+	190	230	H
A	y		181	11.4	121	98	3500	4:00+	70	110	H
A	y		80	11.4	140	107	5000	7:00+	130	155	H
A	y		250	11.4		80	1000	6:30+	123	132	A
A	y		90	11.4	140	108	5350	4:00+	170	250	H
A	y		55	11.4	152	115	6345	4:00+	130	150	H
A	y		200	11.4		80	900	5:00+	0	102	H
A	y		35	11.4	95	81	1150	4:00+	50	121	H
A	y		358	11.4	102	89	2000	4:30+	69	157	A
A	y		365	11.4	122	98	3450	6:05	140	190	A
A	y		261	11.4	130	103	4500	5:00+	107	122	H
A	y		261	11.4	130	103	4500	4:30+	164	167	A
HES-3	y		6224	11.4		79	10000	6:49	0	160	A
A	y		155	11.4	90	80	900	5:00+	87	106	H
A	y		151	11.4	90	80	1000	4:00+	69	197	A
A	y		35	11.4	94	81	1100	6:00+	83	124	H
A	y		218	11.4	115	96	3150	4:00+	160	179	A
A	y		50	11.4	91	81	1100	5:00+	78	121	H
A	y		160	11.4	150	114	7150	5:00+	140	160	H
A	y		54	11.4	91	80	1050	4:30+	191	240	A
HES-11	y		80	11.4	103	88	1800	4:00+	88	108	TLW
A	y		45	11.4	98	84	1400	5:30+			H
A	y		151	11.4	90	80	1000	4:00+	119	205	A
A	y		151	11.4	93	81	1147	5:00+	130	150	H
A	y		35	11.4	113	93	2500	5:00+	94	197	H
A	y		35	11.4	117	95	3175	5:00+	87	116	H
A	y		126	11.4	103	89	2000	5:30+	83	131	H
A	y		126	11.4	103	89	2000	5:30+	93	119	H
A	y		20	11.4	118	93	2500	4:00+	184	243	A
A	y		151	11.4	120	98	3500	4:30+	86	99	H
A	y		107	11.4	95	82	1200	9:35	118	159	A
A	y		151	11.4	90	80	1000	4:00+	60	155	A
A	y		185	11.4	128	101	4000	4:00+	90	160	A
A	y		206	11.4	92	80	1000	4:00+	70	105	H
A	y		280	11.4	105	90	2000	6:30+	79	139	H
A	y		40	11.4	110	93	2500	4:00+	90	130	H
A	y		390	11.4	108	92	2630	6:00+	75	219	A
A	y		1430	11.4		75	2600	5:00+	50	110	A
A	y		38	11.4	118	97	3500	4:00+	88	164	H
A	y		293	11.4	109	96	3500	5:00+	95	165	H
A	y		340	11.4	115	97	3800	7:00+	58	79	H
A	y		206	11.4	124	99	4211	4:00+	75	115	H
HES-11	y		2000	11.4		90	4505	7:00+	55	215	TLW
A	y		35	11.4	135	105	4800	4:00+	102	133	H
A	y		35	11.4	135	105	4800	4:00+	111	192	A
A	y		110	11.4	140	107	5000	4:00+	103	110	H
A	y		130	11.4	128	101	4000	7:00+	60	120	H
A	y		90	11.4	142	108	5372	4:00+	130	160	H
A	y		200	11.4	128	101	5986	6:00+	28	79	H
A	y		60	11.4	130	103	4500	5:00+	90	129	H
HES-11	y		50	11.4	130	103	4500		0	111	TLW
HES-11	y		50	11.4	130	103	4500	5:23	97	173	TLW
A	y		162	11.4	138	104	4500	4:00+	120	150	H
A	y		68	11.4	135	104	4854	4:00+	140	280	H
A	y		21	11.4	124	100	4000	4:00+	125	155	H
HES-11	y		2000	11.4		92	4500	6:00	42	179	TLW
A	y		60	11.4	128	101	4000	4:00+	127	139	A
A	y		150	11.4	142	107	5080	6:00+	89	142	H
A	y		150	11.4	153	113	5600	7:30+	90	121	H
A	y		9	11.4	143	109	5200	6:00+	120	148	H
A	y		52	11.4	119	97	3400	7:00+	80	176	H
A	y		110	11.4	135	105	4600	4:00+	102	134	H
A	y		42	11.4	140	108	8020	6:00+	0	157	H
A	y		53	11.4	99	86	1921	4:00+	195	208	A
A	y		85	11.4	92	80	1000	4:00+	110	140	A
A	y		108	11.4	94	82	1200	4:00+	25	140	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		42	11.4	106	92	2794	6:00+	101	155	H
A	y		85	11.4	110	93	2500	4:00+	120	180	A
A	y		194	11.4	138	104	5525	5:00+	102	133	H
HES-11	y		2000	11.4	90	80	5000	6:00+	0	80	TLW
HES-11	y		722	11.4	130	103	4500	5:00+	217	497	TLW
A	y		157	11.4	143	105	4500	4:00+	130	160	H
A	y		90	11.4	146	110	5250	5:30+	0	172	H
A	y		160	11.4	140	108	5200	6:00+	78	135	H
A	y		42	11.4	140	108	6883	6:00+	122	130	H
A	y		168	11.4	115	97	3500	4:00+	162	185	A
A	y		42	11.4	140	108	7132	6:00+	80	120	H
A	y		87	11.4	145	114	6000	5:00+	136	164	H
A	y		42	11.4	140	108	7487	6:00+	0	125	H
A	y		42	11.4	140	108	8423	6:00+	0	110	H
A	y		60	11.4	145	108	6350	5:00+	125	132	H
A	y		154	11.4	155	112	5400	2:14	206	397	A
A	y		154	11.4	158	112	5200	6:30+	110	160	H
A	y		68	11.4	92	80	1000	3:00+			A
A	y		167	11.4	94	82	1200	4:00+	110	140	H
A	y		68	11.4	91	80	1000	3:00+	109	171	A
A	y		50	11.4	105	91	2200	5:00+	106	130	H
A	y		68	11.4	105	90	2100	3:00+			A
A	y		68	11.4	105	90	2100	3:00+	115	175	A
A	y		160	11.4	135	104	4500	6:00+			H
A	y		180	11.4	155	110	5000	5:00+	61	158	H
A	y		45	11.4	152	112	5500	5:30+	101	118	H
A	y		151	11.4	115	97	3500	5:00+	83	158	H
A	y		151	11.4	115	97	3500	5:00+	75	165	H
A	y		155	11.4	120	98	3635	5:00+	92	125	H
A	y		54	11.4	118	97	3500	4:00+	100	149	H
A	y		150	11.4	115	96	3000	5:00+	105	178	H
A	y		151	11.4	115	97	3500	4:00+	95	125	H
A	y		58	11.4	139	105	4500	5:00+	116	131	H
A	y		35	11.4	136	103	4300	5:00+	105	150	H
A	y		100	11.4	128	102	4400	5:00+	120	128	H
A	y		250	11.4	134	104	4550	9:30+	68	120	H
A	y		54	11.4	124	100	4000	4:00+	115	146	H
A	y		50	11.4	130	101	4000	5:30+			H
A	y		194	11.4	92	80	1000	5:00+	88	155	H
A	y		65	11.4	141	108	5100	5:00+			H
A	y		154	11.4	92	80	800	4:00+	100	130	H
A	y		95	11.4	90	80	998	3:00+	110	140	H
A	y		164	11.4	90	80	1000	3:00+	SET	130	H
A		n		11.4	90	80	1000	3:00+	55	125	A
A	y		300	11.4	98	86	1630	5:00+	70	140	A
A	y		500	11.4		80	1600	5:00+	108	376	A
A	y		294	11.4	93	82	1175	5:30+			H
A	y		95	11.4	94	83	1856	3:00+	100	145	H
A	y		121	11.4	125	100	3800	4:00+	65	140	H
A	y		294	11.4	120	97	3200	5:00+	98	168	H
A	y		70	11.4	135	106	5000	5:30+			A
A	y		70	11.4	135	106	5000	4:30+	60	110	H
A	y		110	11.4	138	107	5000	5:00+	95	121	H
A	y		148	11.4	90	80	800	4:00+	83	143	H
A	y		65	11.4	141	108	5100	5:00+	93	128	H
A	y		41	11.4	128	99	3670	5:00+	100	120	H
A	y		100	11.4	132	104	5100	6:00+	80	100	H
A	y		100	11.4	126	101	4200	7:00+	60	100	H
A	y		220	11.4	120	98	4636	6:30+	60	75	H
A	y		100	11.4	150	109	6488	5:30+	100	110	H
A	y		100	11.4	150	109	5078	8:00+	110	170	H
A	y		220	11.4	134	104	4500	7:00+	80	100	A
A	y		204	11.4	92	80	1000	5:00+	40	77	H
A	y		204	11.4	120	97	3300	5:00+	45	100	H
A	y		45	11.4	138	104	4948	6:00+	80	120	H
A	y		22	11.4	152	115	6000	7:00+	50	72	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		42	11.4	136	104	4500	6:00+	40	100	H
A	y		55	11.4	130	104	4630	5:00+	50	100	H
A	y		220	11.4	91	80	1000	4:00+	FIRM	70	H
A	y		35	11.4	126	99	4378	7:00+	80	110	H
A	y		14	11.4	132	104	4500	5:30+	40	110	H
A	y		60	11.4	92	82	1000	5:39	160	200	A
A	y		61	11.4	130	100	4000	2:40			A
A	y		90	11.4	0	91	1000	4:30+	40	60	H
A	y		90	11.4	132	104	4500	5:00+	90	130	H
A	y		23	11.4	134	104	4500	7:00+	60	120	A
A	y		300	11.4	98	84	1400	5:00+	20	80	A
A	y		16	11.4	110	92	2500	7:00+	20	80	A
A	y		41	11.4	95	80	1000	3:00+	50	80	H
A	y		48	11.4	90	80	800	3:00+	FIRM	80	H
A	y		36	11.4	92	80	1000	5:00+	50	100	H
A	y		36	11.4	128	100	4000	5:30+	90	120	H
A	y		73	11.4	125	96	3000	4:27	80	100	A
A	y		55	11.4	90	80	800	4:00+	50	70	H
A	y		90	11.4	134	104	4500	9:00+	50	160	H
A	y		25	11.4	124	100	4000	4:00+	88	165	H
A	y		750	11.4		80	1825		15	40	H
B	y		65	11.4	145	107	5016	7:30+	40	60	H
A	y		68	11.4	132	103	6022	4:30+	225	250	H
A	y		1550	11.4		80	5000	6:00+	20	65	H
A	y		87	11.4	93	80	800	5:00+	40	80	A
A	y		87	11.4	138	106	4800	5:00+	40	60	A
A	y		110	11.4	140	107	5000	5:00+	110	130	A
A	y		80	11.4	133	99	3771	5:00+	50	60	H
A	y		1061	11.4		70	2800	10:00+	0	FIRM	H
A	y		100	11.4	146	117	6500	5:00+	40	60	H
A	y		227	11.4	104	90	2000	5:00+	50	110	A
A	y		1050	11.4		77	2800		0	65	H
A	y		245	11.4	94	82	1200	4:00+	FIRM	100	H
A	y		200	11.4	134	104	4585	5:30+	50	170	H
A	y		45	11.4	140	107	5000	7:00+	40	60	H
A	y		131	11.4	145	106	4500	6:00+	60	170	H
A	y		131	11.4	95	80	1000	5:00+	30	60	H
A	y		46	11.4		75	1000	5:00+	35	80	H
A	y		143	11.4	115	99	4790	6:00+	60	80	A
A	y		55	11.4	140	107	5000	6:00+	70	90	H
A	y		256	11.4	90	80	1000	4:30+	30	60	H
A	y		82	11.4	140	107	5000	5:00+	30	80	H
A	y		82	11.4	140	107	5000	5:00+	60	100	H
A	y		650	11.4		120	5155	1:15			A
A	y		650	11.4	122	106	5155	2:34	170	280	A
HES-9	y		98	11.4		130	4500	4:03	60	280	77.5/22.5 TLW/MM
A	y		120	11.4	92	80	1000	5:00+	30	70	H
A	y		245	11.4	124	101	4205	5:00+	60	90	H
A	y		191	11.4	114	94	3030	5:00+	FIRM	40	H
A	y		296	11.4	125	102	4500	5:00+	0	70	H
A	y		80	11.4	160	116	6425	8:00+			H
A	y		50	11.4	104	86	1600	6:00+	30	80	H
A	y		258	11.4	95	82	1200	5:00+	40	70	H
A	y		258	11.4	131	102	4329	5:00+	60	100	H
A	y		50	11.4	162	114	5500	8:00+	60	100	H
A	y		50	11.4	162	114	5500	5:00+			H
A	y		50	11.4	112	93	2500	5:00+	40	70	H
A	y		221	11.4	132	101	4000	6:45+	70	110	H
A	y		100	11.4	140	106	4700	5:00+	35	55	H
A	y		50	11.4	90	80	800	5:00+	0	50	H
A	y		100	11.4	94	80	1000	5:00+	30	50	H
A	y		61	11.4	135	104	4500	5:00+	60	100	H
A	y		191	11.4	92	80	1000	4:00+	0	50	H
A	y		58	11.4	105	92	2617	6:00+	80	140	H
A	y		191	11.4	132	103	4772	6:00+	90	130	H
A	y		180	11.4	90	80	800	5:00+	40	80	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		100	11.4	116	97	3500	7:00+	110	160	H
A		n		11.4	134	104	4550	5:00+	100	110	H
A	y		180	11.4	124	100	4540	6:00+	50	90	H
HES-7	y		2841	11.4	0	75	5600	5:00+	0	0	A
A	y		6500	11.4	0	68	11000	6:00+	0	0	H
A	y		180	11.4	111	93	2710	5:00+	FIRM	40	H
A	y		227	11.4	91	80	1000	5:00+	70	120	H
A	y		120	11.4	92	80	1000	4:00+	FIRM	20	H
A	y		120	11.4	116	95	3000	5:00+	70	110	H
A	y		120	11.4	122	97	3500	5:00+	40	60	H
A	y		191	11.4	92	80	1000	5:00+	80	120	H
A	y		300	11.4	98	84	1500	4:00+	150	180	A
A	y		34	11.4	122	97	3500	4:00+	70	110	H
A	y		120	11.4	138	108	5000	7:30+	100	140	H
A	y		30	11.4	130	104	4500	8:00+	70	110	H
A	y		84	11.4	122	97	3300	6:00+	70	80	H
B	y		372	11.4	95	84	1500	4:00+	0	100	H
A	y		50	11.4	160	120	6500	5:00+	190	210	H
A	y		100	11.4	90	80	800	4:00+	FIRM	70	H
A	y		202	11.4	95	80	800	5:00+	70	90	H
A	y		25	11.4	100	91	2500	8:00+	70	130	H
A	y		60	11.4	120	96	3500	4:00+	60	100	H
A	y		180	11.4	92	80	1000	3:00+	70	110	A
A	y		180	11.4	141	108	5100	4:00+	90	140	A
A	y		210	11.4	122	99	4000	6:00+	55	110	H
A	y		55	11.4	0	105	4600	6:00+	110	160	H
A	y		163	11.4	120	102	4500	5:00+	60	105	H
A	y		314	11.4	128	100	4000	6:00+	80	130	H
A	y		155	11.4	98	84	1500	6:00+	90	130	H
A	y		155	11.4	148	113	5747	6:00+	110	140	H
A	y		241	11.4	115	96	5047	9:00+	60	90	H
A	y		100	11.4	143	108	4900	7:00+	30	60	H
A	y		50	11.4	92	80	950	4:00+	80	140	A
A	y		50	11.4	125	98	3500	2:43	271	410	A
A	y		100	11.4	117	96	3180	6:00+	FIRM	110	H
A	y		100	11.4	134	104	4500	7:00+	60	110	H
A	y		40	11.4	128	100	4063	6:00+	60	170	H
A	y		50	11.4	92	80	1000	3:00+	0	50	H
A	y		58	11.4	90	80	700	5:00+	FIRM	50	H
A	y		73	11.4	95	80	1000	4:30+	40	70	A
A	y		77	11.4	98	82	1200	6:00+	90	140	H
A	y		300	11.4	115	95	2900	4:00+	110	180	A
A	y		199	11.4	96	83	1300	5:00+	120	210	A
A	y		517	11.4	103	90	2100	7:00+	82	127	A
A	y		184	11.4	97	80	1000	4:00+	50	110	H
A	y		184	11.4	122	98	3758	4:00+	80	130	H
A	y		100	11.4	88	80	750	3:00+	0	50	H
A	y		100	11.4	115	97	3500	4:00+	0	50	H
A	y		104	11.4	118	97	3500	4:30+	120	140	H
A	y		45	11.4	93	80	1000	4:00+	0	60	H
A	y		45	11.4	138	104	4500	7:30+	192	386	H
A	y		82	11.4	92	80	1000	4:00+	80	130	H
A	y		95	11.4	109	93	2786	4:00+	175	290	H
A	y		38	11.4	122	98	3500	4:00+	130	160	H
A	y		175	11.4	122	98	3500	7:00+	110	130	H
A	y		134	11.4	98	85	1500	5:00+	100	150	H
A	y		126	11.4	98	85	1659	5:00+	100	140	H
A	y		79	11.4		95	4927	6:00+	120	290	H
A	y		79	11.4		95	4927	4:00+	100	180	H
A	y		79	11.4	134	106	4927	5:00+	130	160	H
A		n		11.4	171	128	7600	4:48	170	270	H
A	y		48	11.4	130	102	4200	5:00+	50	190	A
A	y		370	11.4		95	4904	5:00+	115	135	H
A	y		78	11.4	90	80	800	5:00+	110	210	A
A	y		78	11.4	110	93	2500	5:00+	120	190	A
A	y		250	11.4	127	100	3915	4:00+	130	200	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
A	y		40	11.4	94	82	1200	3:00+	50	95	H
A	y		40	11.4	94	82	1200	4:00+	0	120	H
A	y		202	11.4	90	80	800	6:00+	40	55	H
A	y		82	11.4	128	101	4043	4:00+	110	180	H
A	y		183	11.4	92	80	1000	5:00+	120	240	A
A	y		227	11.4	135	104	4516	5:00+	50	70	A
HES-11	y		38	11.4	134	104	4500	6:00+	244	1247	TLW
HES-11	y		385	11.4	130	106	5000	5:30+	164	433	TLW
A	y		180	11.4	92	80	1000	6:00+	95	130	A
A	y		30	11.4	114	93	2500	5:00+	280	289	A
A	y		124	11.4	129	99	3500	7:00+	110	160	H
A	y		18	11.4	135	102	4000	4:30+	85	109	H
A	y		85	11.4	134	104	4528	7:00+	60	120	H
A	y		55	11.4	140	105	4635	7:00+	130	160	H
A	y		102	11.4	143	108	5000	7:00+	138	175	H
A	y		142	11.4	158	110	5175	5:00+	122	132	H
A	y		150	11.4	155	110	5000	5:00+	107	137	H
A	y		25	11.4	116	96	3000	3:53	276	391	A
A	y		22	11.4	95	82	1200	4:30+	0	125	H
A	y		50	11.4	93	80	1000	4:00+	105	120	H
A	y		340	11.4	100	89	2000	5:00+	140	150	A
A	y		22	11.4	135	105	4660	6:00+	90	160	H
A	y		152	11.4	140	107	5000	6:00+			A
A	y		120	11.4	143	109	5300	4:00+	124	163	H
A	y		176	11.4	140	107	5000	7:00+	190	270	A
A	y		175	11.4	90	80	800	6:00+	87	112	H
A	y		175	11.4	114	95	2943	5:30+	0	155	H
A	y		120	11.4	110	93	2500	6:17	262	376	A
A	y		175	11.4	111	93	2500	5:00+			H
A	y		175	11.4	90	80	900	6:30+	70	120	H
A	y		689	11.4		87	2000	4:00+	50	120	A
A	y		689	11.4	138	108	5300	5:00+	90	159	A
A	y		40	11.4	134	104	4500	5:00+	50	100	H
A	y		100	11.4	115	100	2500		98	151	H
A	y		65	11.4	126	100	4000	4:00+	40	110	H
A	y		303	11.4	126	103	4889	5:30+	130	180	A
A	y		124	11.4	124	98	4044	4:00+	50	85	H
A	y		80	11.4	92	80	1000	4:00+	90	140	H
A	y		45	11.4	95	80	900	6:53	110	150	A
A	y		107	11.4	125	96	3000	3:53	150	200	A
A	y		45	11.4	116	96	3000	3:39	130	160	A
A	y		222	11.4	110	93	2905	6:00+	140	170	H
A	y		240	11.4	115	97	3500		0	50	H
A	y		240	11.4	115	97	3500	13:26	0	100	A
A	y		44	11.4	127	100	3900	4:00+	130	180	H
A	y		334	11.4	103	89	2000	5:00+	160	180	A
A	y		232	11.4	110	93	2500	4:43	120	145	A
A	y		152	11.4	112	93	2600	4:00+	120	160	H
A	y		65	11.4	110	93	2500	4:00+	30	70	H
A	y		200	11.4	92	80	1000	4:00+	SET	140	H
A	y		106	11.4	95	80	1000	5:00+	30	42	H
A	y		72	11.4	117	96	3316	5:00+	40	110	H
A	y		25	11.4	108	92	2500	5:00+	30	60	A
A	y		1163	11.4		70	3100	4:00+	FIRM	60	H
A	y		87	11.4	140	107	5190	4:00+	40	80	H
A	y		58	11.4	132	103	4300	5:00+	80	100	A
A	y		233	11.4	120	100	4000	6:00+	50	65	A
A	y		75	11.4	128	101	4000	5:30+	130	180	H
A	y		160	11.4	120	100	4000	4:00+	35	60	H
A	y		100	11.4	129	99	3500	6:00+	50	65	H
A	y		80	11.4	140	106	4700	6:00+	60	140	H
B	y		67	11.4	91	80	1000	5:00+	30	70	H
A	y		334	11.4	138	107	5186	5:00+			A
A	y		58	11.4	122	98	3850	4:30+	130	180	H
A	y		222	11.4	98	85	1881	5:00+	125	195	A
A	y		200	11.4	108	90	2000	5:00+	120	130	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		225	11.4	116	96	3089	4:00	110	180	A
A	y		220	11.4	125	100	4000	4:00+	160	180	A
A	y		220	11.4	125	100	4000	4:00+	120	140	H
A	y		89	11.4	140	107	5143	4:00+	110	160	H
A	y		30	11.4	140	105	4500	6:00+	50	101	H
A	y		212	11.4	138	106	4839	4:00+	170	180	A
A	y		79	11.4		80	3000		0	130	H
A	y		517	11.4	123	101	4643	4:00+	0	90	A
A	y		50	11.4	133	103	4400	5:00+	120	170	H
A	y		40	11.4	92	80	1000	4:04	250	310	A
A	y		340	11.4	104	90	2129	5:00	110	150	A
A	y		48	11.4	124	98	3500	4:00+	150	200	H
A	y		38	11.4	105	90	2000	4:00+	170	220	A
A	y		63	11.4	124	98	3500	7:00+	130	190	H
A	y		63	11.4	130	101	4000	4:00+	150	190	H
A	y		40	11.4	140	107	5133	4:00+	140	210	A
A	y		220	11.4	96	83	1500	5:00+	0	60	H
A	y		220	11.4	102	88	3189	5:00+	0	60	H
A	y		9	11.4	126	100	3800	5:30+	170	215	A
A	y		72	11.4	122	98	4082	4:00+	110	150	H
A	y		40	11.4	115	96	3000	4:00+	120	190	H
A	y		80	11.4	140	106	4800	4:00+	150	190	H
A	y		80	11.4	138	105	4700	4:00+			H
A	y		37	11.4	143	105	4500	6:30+	165	195	H
A	y		38	11.4	88	80	800	4:00+	180	210	A
A	y		58	11.4	126	103	4500	4:00+	277	347	TLW
A	y		114	11.4	152	115	6000	8:09	150	170	H
A		n		11.5	128	101	4000		142	229	Micro-fine
HES-11	y		3200	11.5		73	7000	7:00+	0	0	TLW
HES-3	y		6220	11.5		79	10000	4:20			A
F		n		11.5	192	157	9394	3:40	46	255	Micro-fine
HES-11	y		17	11.5	150	116	6400	2:50			TLW
HES-11	y		3000	11.5		65	4500	8:00+			TLW
A	y		80	11.5	116	96	3000	4:00	142	233	H
HES-11	y		50	11.5	114	95	2850	6:30	0	122	TLW
HES-11	y		50	11.5	98	85	1500	7:00+	73	175	TLW
HES-11	y		107	11.5	210	163	12227	4:06	460	890	TLW
A	y		241	11.5	135	107	5075	5:00+	158	288	H
HES-11	y			11.5	142	109	6708	7:12	40	150	TLW
HES-11	y			11.5	142	109	6708		75	230	TLW
HES-11	y			11.5	142	109	6708	6:48	200	530	TLW
HES-11	y			11.5	142	109	6708		75	230	TLW
HES-11	y			11.5	142	109	6708		170	450	TLW
HES-11	y			11.5	145	111	7040	5:30	53	94	TLW
F	y			11.5		90	1600	3:37	94	230	Micro-fine
HES-11	y			11.5		90	1600	6:00+	62	157	TLW
B	y			11.5	99	90	2300	4:38	54	114	A
HES-3	y			11.5		60	4085	4:00+		296	A
HES-3	y			11.5		60	4085			89	A
A	y			11.5	120	96	3080	5:00+	94	134	H
B	y			11.5		91	2400			122	A
HES-7	y			11.5		91	2400			82	A
HES-11	y			11.5		86	1900	5:00+	107	132	TLW
HES-3	y			11.5		100	4600	6:24			FLOSTOP-I
HES-3	y			11.5		75	2600	6:00+			A
HES-3		n		11.5		80	4085	5:30+			A
A	y			11.5		60	4085	5:00+		40	A
A	y			11.5	91	80	900	4:00+	110	140	H
HES-11	y			11.5	122	97	3200	5:00+	133	414	TLW
A	y			11.5	96	84	1500	4:00+	140	175	H
A	y			11.5	96	84	1500	4:00+	135	210	H
B	y			11.5	105	90	2100		36	44	50/50 H/POZ
HES-11		n		11.5		80	80	5:00+	132	341	TLW
B	y			11.5	210	159	11295	6:30+	120	180	65/35 H/POZ
B	y			11.5	210	159	11295	6:30+	120	130	65/35 H/POZ
HES-3	y			11.5		70	3950	4:00+	96	347	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-7	y			11.5	0	65	4550	4:30+	0	0	A
HES-7	y			11.5	0	63	7000	5:30+			A
HES-7	y			11.5	200	151	9800	9:00+			50/50 H/POZ
HES-7	y			11.5	200	151	9800	9:00+			50/50 H/POZ
HES-11	y			11.5	96	83	1300	6:00+	102	222	TLW
A	y			11.5	130	103	4500	7:00+	120	150	H
A	y			11.5	134	106	5010	6:00+	95	107	H
F	y			11.5	122	104	3800	3:05	333	494	Micro-fine
F	y			11.5	170	138	7400	3:51	439	519	Micro-fine
F	y			11.5	230	194	13900	4:00+	346	379	Micro-fine
F		n		11.5	195	159	9522	0:43			Micro-fine
F		n		11.5	164	134	7000	3:27	381	477	Micro-fine
A	y			11.5	128	101	4000	4:30+	99	118	H
HES-11	y			11.5	94	83	1300	4:00+	87	184	TLW
HES-11	y			11.5	117	98	4000	5:00+	194	386	TLW
HES-11	y			11.5	106	93	2600	5:00+			TLW
HES-11	y			11.5	94	84	1420	5:00+			TLW
B	y			11.5	257	198	11800	8:30+	180	340	65/35 H/POZ
A	y			11.5	185	136	8100	6:00+	54	71	H
HES-7	y			11.5	0	70	7200	5:00+	0	0	A
HES-11	y			11.5	135	106	5000	4:00+	144	409	TLW
F	y			11.5		92	2900	3:45+	323	347	Micro-fine
B	y			11.5	90	80	1050	6:00+	FIRM	20	50/50 H/POZ
F	y			11.5	225	186	11795	5:00+	625	705	Micro-fine
A	y			11.5	100	83	1300	6:00+		147	A
B		n		11.5		83	1500	6:30+	39	150	A
A	y		320	11.6	102	89	3223	5:00+	99	137	H
A	y		57	11.6	128	101	4000	5:00+			H
HES-3	y		2920	11.6		75	6500	5:20	115	334	A
A		n		11.6		80	50		0	0	A
A		n		11.6	90	80	1000		170	346	A
A	y		126	11.6	140	105	4500	3:00			A
A	y		110	11.6	90	80	760	5:00+	117	143	H
A	y		80	11.6	126	96	4000	4:47	289	416	A
A	y		250	11.6	90	80	880	6:00+	68	131	H
A	y		110	11.6	127	101	4071	5:00+	125	155	H
A	y		320	11.6	102	89	2690	4:00+		142	H
A	y		250	11.6	120	100	3952	6:00+	81	101	H
A	y		250	11.6	120	98	3429	6:00+	75	140	H
A	y		250	11.6	110	95	3100	6:00+	98	126	H
A	y		250	11.6	111	95	3100	6:00+	785	1424	H
A	y		182	11.6	128	103	4500	7:00+	102	152	H
A	y		250	11.6	96	80	800	6:00+	94	121	H
HES-3	y		1450	11.7		100	4600	4:47	191	340	FLOSTOP-I
A	y		320	11.7	164	117	6000	6:55	120	140	H
HES-3	y		6220	11.7		70	8016	6:00+			FLOSTOP-I
HES-3	y		6220	11.7		60	8016		104	327	FLOSTOP-I
B	y		200	11.7	172	132	11000	3:54	66	211	H
HES-11	y		100	11.7	98	85	1500	6:00+	96	273	TLW
A	y		3822	11.7		106	7450	2:30			A
A	y		1420	11.7		95	6600	6:30+	173	315	A
HES-11	y		20	11.7	134	102	4200	5:00+	210	760	TLW
F		n		11.7	166	136	7550	3:55	557	698	Micro-fine
A	y		358	11.7	120	98	3700	4:33	131	181	A
HES-3	y		2649	11.7		80	7234	6:07	141	313	A
A	y		363	11.7	120	98	3657	7:12	110	200	H
A		n		11.8		110	4000	8:00+			H
A		n		11.8		60	100		50	110	A
A		n		11.8		93	2500		0	57	
A		n		11.8		110	4000	9:00+			H
A		n		11.8		110	4000	9:00+			H
A		n		11.8		110	4000	9:58			H
A		n		11.8		80	1000		110	250	A
A		n		11.8		110	4000	8:00+			H
HES-11		n		11.8	80	80	1000	5:58	157	200	TXI
A		n		11.8		96	3000	5:25	232	325	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F		n		11.8	140	140	6278	4:40	140	580	Micro-matrix
A	y		10	11.8	114	95	3015	4:17	211	273	A
HES-11		n		11.8	118	93	2500	4:45		166	TXI
HES-11		n		11.8	103	86	1630	4:07		280	TXI
B		n		11.8	95	80	1000	4:00+	160	200	H
A	y		50	11.8	120	96	3100	5:00+	40	80	H
B	y		75	11.8	145	107	4700	4:52	100	130	H
A	y		60	11.8	130	101	4000	4:00+	110	160	H
B	y		75	11.8	145	108	5131	4:02	70	100	H
B	y		75	11.8	116	94	2831	5:00+	160	200	H
A	y		122	11.8	128	101	4000	5:30+	140	240	H
A	y		122	11.8	95	82	1250	5:00+	130	220	H
A	y		75	11.8	91	80	750	5:00+	56	97	H
A	y		20	11.8	93	82	1200	6:00+	65	115	H
A	y		20	11.8	102	82	1200	5:00+	142	206	H
A	y		20	11.8	93	82	1200	4:00+	100	130	H
A	y		120	11.8	130	102	6226	4:00+	50	139	H
A		n		11.8	98	82	1250	5:00+	170	220	A
A		n		11.8	132	102	4200	5:00+	40	90	A
HES-11	y		1500	11.8		70	5200	7:00+	32	50	TLW
A	y		35	11.8	134	104	4500	5:30+	227	328	H
A	y		80	11.8	114	95	3100	5:00+	155	190	H
A	y		80	11.8	126	96	4000	5:00+	299	426	A
A	y		80	11.8	124	95	4000	4:00+	167	325	A
A	y		85	11.8	126	96	4000	10:00+	211	296	A
A	y		100	11.8	95	80	1000	8:00+	30	80	H
A	y		100	11.8	144	108	5386	8:00+	80	115	H
A	y		100	11.8	115	95	3000	6:00+	40	90	H
A	y		100	11.8	90	80	800	6:00+	0	56	H
A	y		100	11.8	116	96	3500	6:00+	50	100	H
A	y		30	11.8	141	108	5100	5:00+	142	163	H
B	y		180	11.8	134	104	4535	4:17	122	178	H
B	y		180	11.8	130	102	4216	4:21	168	205	H
A	y		200	11.8	145	109	5200	7:30+	0	63	H
A	y		220	11.8	125	99	3950	6:30+	145	175	H
A	y		250	11.8	132	101	5400	7:00+	135	155	H
HES-11	y		300	11.8	112	99	3800	6:30+	81	193	TLW
HES-11	y		300	11.8		80	1000	6:00+	47	55	TLW
A	y		365	11.8	112	92	2414	4:00+	159	228	A
A	y		45	11.8	128	104	4985	6:00+	94	106	H
A	y		360	11.8	92	80	1000	4:00+	120	200	H
A	y		30	11.8	129	103	4500	5:00+	143	169	H
B	y		35	11.8	112	95	3000	5:00+	40	100	H
B	y		35	11.8	112	95	3000	5:00+	40	100	H
B	y		35	11.8	92	80	1000	5:00+	0	FIRM	H
B	y		35	11.8	92	80	1000	5:00+	0	60	H
B	y		35	11.8	140	108	5000	6:00	50	90	H
B	y		35	11.8	140	108	5000	5:00	50	130	H
B	y		75	11.8	89	80	750	5:00+	70	80	H
B	y		75	11.8	90	80	800	3:30+	30	110	H
B	y		75	11.8	126	100	4000	4:00+	60	140	H
A	y		90	11.8	130	102	4200	6:00+	50	130	H
A	y		10	11.8	140	107	5000	5:30+	128	194	H
B	y		110	11.8	135	105	4800	5:41	120	140	H
A	y		100	11.8	134	104	4693	4:30+	180	230	H
A	y		100	11.8	121	98	3600	5:00+	115	190	H
A	y		100	11.8	115	93	2500	5:00+	155	210	H
A	y		120	11.8	140	116	5200	5:00+	164	188	H
A	y		145	11.8	128	101	4000	4:00+	98	138	H
A	y		145	11.8	92	80	1000		0	169	H
A	y		140	11.8	132	101	4323	10:00+	80	100	H
A	y		15	11.8	140	107	5000	6:30+	105	140	H
A	y		265	11.8	109	93	4431	5:00+	110	255	H
A	y		350	11.8	115	97	3500	3:37	258	372	A
A	y		333	11.8	120	97	5000	5:00+	95	280	A
A	y		25	11.8	130	104	4700	6:30+	215	250	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		22	11.8	125	100	4000	5:00+	130	200	H
A	y		20	11.8	135	106	5000	5:00+	162	222	H
B		n		11.8	122	98	3500	5:00+	50	103	65/35 A/POZ
B		n		11.8	115	93	2550	5:00+	130	160	65/35 A/POZ
A		n		11.8	147	110	5250	5:00+	90	100	H
A	y		800	11.8	130	102	4200	4:32		262	A
HES-11	y		800	11.8	125	103	4500	6:00+	235	365	TLW
HES-11	y		800	11.8	103	91	2300	6:00+	149	374	TLW
A		n		11.8	85	80	300		108	140	A
A		n		11.8	85	80	300		190	205	A
A	y		100	11.8	92	80	1000	5:00+	130	300	A
B	y		218	11.8	134	104	4500	4:00+	70	150	H
HES-11	y		50	11.8	139	106	4900	3:00+	820	1680	TLW
HES-11	y		850	11.8	105	91	2575	4:06	70	160	TLW
A	y		75	11.8	127	99	4200	8:00+	163	260	H
A	y		50	11.8	122	99	3540	2:39	150	355	A
B	y		75	11.8	120	98	3500	5:05	90	170	H
B	y		75	11.8	90	80	750	5:00+	43	80	H
B	y		75	11.8	140	106	5016	3:30	150	250	H
B	y		65	11.8	116	96	3000	4:00+	125	190	H
B	y		65	11.8	90	80	750	4:00+	50	150	H
B	y		95	11.8	90	80	753	4:19	150	170	A
B	y		95	11.8	125	100	3751	4:00+	0	140	H
B	y		97	11.8	135	102	4600	3:15	160	220	H
B	y		97	11.8	125	100	4080	4:22	140	180	H
B	y		97	11.8	90	80	750	4:00+	110	150	H
HES-11	y		925	11.8	121	103	4610	4:33			TLW
HES-3	y		925	11.8		80	2050	5:00+			A
A	y		625	11.8	100	87	1707	4:00+	125	175	H
A	y		1420	11.8		98	6000	5:00+	120	160	A
A	y		700	11.8	130	101	4000	7:00+	75	127	H
HES-7	y		3778	11.8		70	6100	4:00+	0	120	H
E	y		3778	11.8		70	6100	5:30+	140	210	H
A	y		4000	11.8	0	90	6000	4:00+	90	220	A
A	y		520	11.8	125	101	4148	4:00+	220	235	A
A	y		520	11.8	0	80	2085	4:00+	80	210	H
B		n		11.8	156	114	5800	5:30+			65/35 A/POZ
HES-11		n		11.8	140	102	4500	3:55	0	187	TXI
A	y		1120	11.8		110	4950	8:00+	50	138	H
A	y		1120	11.8		85	1850	6:00+			H
A	y		1120	11.8		99	5149	4:00+	160	350	A
A	y		1120	11.8		79	2018	3:30+	139	305	A
HES-3	y		1560	11.8		65	4100	7:00+	89	124	FLOSTOP-I
HES-3	y		2760	11.8		93	6300	4:13	111	426	A
HES-3	y		4243	11.8		80	6321	6:00			A
HES-3	y		4243	11.8		90	8321	3:00			A
HES-3	y		4243	11.8		90	8321	5:31	140	261	A
HES-11	y		340	11.8	125	101	4342	8:14	26	325	TLW
A	y		350	11.8	103	90	2100	6:20	239	292	A
A	y		350	11.8	103	90	2100	4:38	140	290	A
A	y		50	11.8		80	3000			320	A
A	y		50	11.8		80	3000			250	A
HES-7	y		40	11.8	100	85	1500	5:30+	85	100	H
A	y		160	11.8	114	94	3314	6:00+	80	110	H
A	y		200	11.8	122	97	5518	8:00+	110	160	H
A	y		200	11.8	95	80	1012	8:00+	60	148	H
HES-11	y		340	11.8	125	101	4342	8:28	26	365	TLW
B	y		280	11.8	180	132	8929	4:58	140	360	65/35 H/POZ
F	y		340	11.8	182	150	9231	2:38			FLOSTOP-I
F	y		340	11.8	182	150	9231	4:45	690	704	FLOSTOP-I
A	y		160	11.8	145	108	5387	5:00+	230	270	H
A	y		160	11.8	109	92	2683	5:00+	75	100	H
A	y		160	11.8	90	80	825	5:00+	80	100	H
A	y		210	11.8	112	93	5284	7:00+	80	200	H
A	y		350	11.8	135	106	5000	6:00+	126	194	H
A	y		220	11.8	97	85	2797	4:00+	190	210	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		280	11.8		90	1500	6:00+	27	66	TLW
B		n		11.8		99	3500	3:01			A
B		n		11.8	287	243	15500	3:40	294	560	65/35 H/POZ
A	y		160	11.8	92	80	1000	4:00+	122	218	A
A	y		160	11.8	120	98	3500	4:30+	75	221	H
A	y		160	11.8	92	80	1000	4:00+	100	157	H
A	y		260	11.8	133	104	4500	4:30+	211	308	A
A	y		225	11.8	118	98	6800	6:00+	0	FIRM	H
A	y		225	11.8	146	107	9310	6:00+			H
A	y		225	11.8	114	95	4480	6:00+	80	110	H
A	y		225	11.8	146	110	9777	6:00+	0	0	H
A	y		225	11.8	146	110	9777	5:27	150	188	H
HES-11	y		40	11.8	115	95	2950	5:12	0	280	TLW
A	y		50	11.8	102	89	2000	5:30+	120	189	H
A	y		50	11.8	89	80	800	5:00+	88	124	H
B	y		150	11.8	112	94	3000	8:45	190	230	H
A		n		11.8	140	105	4600	8:15	100	140	A
HES-11	y		2266	11.8		95	5100	4:15	107	276	TLW
HES-3	y		6417	11.8		75	8100	4:20	SET	151	A
HES-3	y		6417	11.8		75	8900	4:20	466	1109	A
A	y		2100	11.8		65	2500	6:00+		57	A
HES-11	y		1970	11.8		80	3500	4:00+	0	83	TLW
HES-11	y		63	11.8	97	82	1200	4:30+		193	TLW
A	y		50	11.8		115	6000	10:00+	90	100	H
HES-7	y		50	11.8	152	115	6000	9:30+	60	100	H
HES-11	y		50	11.8		115	6000	7:03	190	270	TLW
A	y		50	11.8		115	6000	10:00+	104	127	H
HES-7	y		65	11.8	171	125	7000	7:00+	151	189	H
HES-11	y		65	11.8	171	125	7000	5:12	230	682	TLW
A	y		45	11.8	94	81	1100	4:00+	100	170	A
HES-11	y		65	11.8	170	128	7500	8:05	160	260	TLW
HES-11	y		65	11.8	170	127	7400	5:10	480	600	TLW
HES-11	y		65	11.8	170	127	7400	7:03	0	490	TLW
HES-11	y		65	11.8	170	128	7500	7:56	140	300	TLW
HES-11	y		70	11.8	146	114	6000	7:00+	333	572	TLW
HES-11	y		70	11.8	133	112	6000		336	550	TLW
A	y		50	11.8	96	84	1702	6:00+			A
A	y		50	11.8	95	84	1698	6:00+	231	273	A
A	y		50	11.8	95	84	1698	4:00+	231	273	A
A		n		11.8	119	96	3000	2:43			A
A	y		50	11.8		80	1000			229	A
A	y		50	11.8	118	97	3200	5:00+	90	155	H
B	y		202	11.8	150	107	4500	8:00+	60	110	H
B	y		202	11.8	90	80	800	4:45+	30	50	H
A		n		11.8	127	101	3920	5:00+	60	125	A
HES-11		n		11.8	150	109	5000	2:19			TXI
HES-11		n		11.8	150	109	5000	3:38	299	391	TXI
B		n		11.8	134	105	4700	6:00+	60	111	65/35 A/POZ
A		n		11.8	250	205	12200	1:12			H
A		n		11.8	250	205	12200	1:40			H
A		n		11.8	132	104	4500	5:00+	55	125	A
B		n		11.8	116	96	3000	5:00+			65/35 A/POZ
A	y		246	11.8	95	82	1200	4:30+	112	371	A
A	y		246	11.8	132	104	4500	6:00+	130	185	H
A	y		10	11.8	128	101	4000	4:00+	140	260	A
A	y		10	11.8	128	101	4000	4:00+	120	170	H
A	y		10	11.8	92	80	1000	4:00+	155	225	A
HES-11	y		10	11.8	92	80	1000	6:30+	210	360	TLW
A	y		95	11.8		90	2000	5:00+	120	150	A
A	y		200	11.8	97	85	1500	7:00+	155	240	H
HES-11	y		182	11.8	96	83	1300	4:00+	120	240	TLW
A		n		11.8	145	108	4900	2:26			A
HES-7		n		11.8	196	149	13661	5:00+	150	180	H
HES-11	y		25	11.8	105	91	2200	5:30+	94	249	TLW
HES-7	y		25	11.8	114	95	3011	4:00+	SET	150	H
B	y		25	11.8	94	82	1160	4:00+	110	170	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-7	y		25	11.8	116	96	4370	4:00+	75	230	H
HES-11	y		40	11.8	108	92	2300	5:00+	355	421	TLW
HES-11	y		40	11.8	108	92	2300	5:00+	121	346	TLW
HES-11	y		40	11.8	108	92	2300	5:00+	90	189	TLW
HES-11	y		30	11.8	124	98	5500	4:00	240	650	TLW
HES-11	y		30	11.8	92	80	1000	5:00+	160	230	TLW
B	y		75	11.8	191	144	10415	3:36	390	470	H
B	y		75	11.8	99	89	1950	7:00+	140	240	H
B	y		75	11.8	102	89	1950	4:00+	150	165	H
HES-11	y		50	11.8	109	93	2673	5:00+	140	520	TLW
HES-7	y		186	11.8	160	122	9263	4:00+	90	140	H
HES-7	y		186	11.8	160	122	9400	4:00+	130	1520	H
HES-7	y		186	11.8	200	152	13912	5:30+	165	199	H
HES-7	y		186	11.8	173	130	11700	4:30+	125	230	H
A	y		200	11.8	105	91	2900	5:00+	140	184	H
B	y		200	11.8	175	140	13500	3:15	74	165	H
A	y		200	11.8	119	98	4077	5:30+	130	220	H
A	y		200	11.8	105	92	2500	6:00+		180	H
A	y		200	11.8	153	117	6508	4:30	140	290	H
A	y		200	11.8	112	95	4000	5:00+	190	375	H
A	y		200	11.8	134	104	5978	5:00+		80	H
HES-7	y		200	11.8	199	151	13800	5:43	67	96	H
HES-7	y		200	11.8	199	151	13800	5:43	67	96	H
A	y		200	11.8	105	91	2500	5:00+		175	H
B	y		200	11.8	135	104	5000	5:00+	78	178	H
A	y		200	11.8	134	105	7427	5:00+	100	115	H
A	y		200	11.8	0	103	6000	7:00+	80	110	H
HES-7	y		200	11.8	175	134	14075	6:00+	130	180	H
HES-7	y		200	11.8	175	134	14075	5:00+	120	220	H
A	y		200	11.8	100	89	2000	5:00+	61	92	H
A	y		200	11.8	119	98	4224	4:00+	108	132	H
HES-7	y		250	11.8	188	142	13652	5:30+	230	450	H
HES-7	y		250	11.8	188	142	13652	5:00+	210	415	H
A	y		200	11.8	140	107	5369	6:00+	350	730	H
HES-11	y		300	11.8	75	75	647	5:00+	32	70	TLW
A	y		200	11.8	132	106	5500	6:00+	70	120	H
HES-11	y		35	11.8		85	1500	6:30			TLW
A	y		60	11.8	140	105	4500	4:30+	151	210	H
A	y		60	11.8	128	103	4500	6:00+		120	H
A	y		60	11.8	92	80	800	4:00+	190	210	H
A	y		60	11.8	92	80	800	3:30+	128	200	H
A	y		35	11.8	135	105	4800	4:00+	144	183	H
A	y		175	11.8	92	80	1000	5:00+	35	134	H
A	y		175	11.8	134	104	4500	5:00+	60	115	H
B	y		50	11.8	90	80	750	4:00+	130	175	A
A	y		20	11.8	134	104	4500	7:00+	110	140	H
A	y		65	11.8	131	103	4660	7:00+	310	690	H
A	y		90	11.8	140	106	4860	6:00+	135	165	H
HES-11	y		180	11.8		91	2300	6:00+	50	64	TLW
HES-7	y		20	11.8	151	114	5900	8:30+	109	152	H
A	y		20	11.8	124	100	4000	5:30+	98	130	H
A	y		20	11.8	90	80	800	5:00+	76	103	H
A	y		20	11.8	90	80	800	6:00+	78	106	H
A	y		326	11.8	95	85	2060	6:00+	75	137	H
A	y		326	11.8	122	99	3995	6:00+	99		H
A	y		326	11.8	92	81	1100	6:00+	72		H
A	y		385	11.8	95	84	1500	6:00+	91	176	H
A	y		450	11.8	115	97	3500	4:30	117		A
A	y		20	11.8	124	100	4000	5:30+	57	95	H
B	y		25	11.8	127	101	4200	5:56	220	250	H
HES-11	y		35	11.8		85	1500	6:15	56	177	TLW
HES-11	y		35	11.8		80	1200	8:00	50	625	TLW
A	y		12	11.8	93	81	1509	4:00+	180	230	A
HES-11	y		60	11.8	242	195	14978	7:34	770	800	TLW
HES-11	y		60	11.8	212	167	12680	7:40	0	860	TLW
HES-11	y		60	11.8	128	101	4000			280	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		160	11.8	126	100	3800	4:56	165	221	A
HES-11		n		11.8		93	2500	3:36	151	268	TXI
F		n		11.8	216	174	9685	3:47	669	728	F
F		n		11.8	216	174	9685	5:00+			F
B		n		11.8	119	96	3000	8:49	120	150	65/35 A/POZ
F		n		11.8	179	145	8002	3:13	324	526	F
B		n		11.8	123	94	2530	5:26	130	295	A
B		n		11.8	150	104	4200	4:52			A
A	y		55	11.8	142	107	5000	7:00+	170	220	A
A	y		60	11.8	92	80	1000	6:00+	80	210	H
A	y		60	11.8	92	80	1000	4:00+	80	210	H
A	y		10	11.8	113	95	3000	3:00+	120	175	H
A	y		190	11.8	87	80	750		188	382	A
B	y		190	11.8	88	80	800	5:00+	20	80	H
A	y		260	11.8	135	105	4750	6:00+	253	407	A
A	y		260	11.8		93	1100	4:00+	162	324	A
A	y		365	11.8	112	91	3243	4:00+	149	174	A
A	y		365	11.8	90	82	1200	5:30+			A
HES-11	y		365	11.8	112	96	3476	7:00+	246	429	TLW
B	y		30	11.8	116	95	2800	5:50	100	200	H
B	y		25	11.8	90	80	750	6:00+	120	210	H
A		n		11.8	120	96	3000	4:15	290	330	A
A		n		11.8	120	96	3000	4:12	280	320	A
A		n		11.8	110	95	3000	6:00+	190	300	A
A	y		1100	11.8		90	6000	3:50	172	285	A
HES-11	y		1932	11.8		80	3400	5:00+	102	173	TLW
HES-11	y		1932	11.8		90	4500	4:30+	183	647	TLW
HES-3	y		2649	11.8		80	7234	3:23			A
HES-3	y		2920	11.8		70	5000	6:00+			A
HES-3	y		2920	11.8		75	6500	2:54			A
HES-11	y		75	11.8		80	1000	7:30	29	63	TLW
HES-11	y		75	11.8		104	4500	6:02	209	318	TLW
A	y		40	11.8	94	82	1200	5:00+	140	200	H
HES-11	y		70	11.8	117	96	3000	7:00+	150	447	TLW
A	y		90	11.8	128	101	4200	6:00+	57	102	H
A	y		160	11.8	132	100	3943	5:00+	110	180	H
A	y		160	11.8	92	80	1000	4:00+	30	140	H
A	y		150	11.8	160	121	9900	6:00+	40	80	H
A	y		150	11.8	160	119	8681	5:00+	70	150	H
A	y		150	11.8	165	122	8750	5:00+	190	210	H
A	y		175	11.8	96	86	3190	5:00+	130	190	A
A	y		290	11.8		108	5000	5:30+	72	155	H
HES-11	y		290	11.8		108	5000	5:53	119	485	TLW
B	y		180	11.8	116	96	3000	4:00+	160	220	H
B	y		180	11.8	116	96	3000	5:00+	180	220	H
B	y		180	11.8	92	80	850	4:00+	50	150	H
A	y		354	11.8	102	87	1967	5:00+			H
F	y		30	11.8		213	11410	2:30	341	478	F
HES-11	y		30	11.8		83	1000	6:30	0	103	TLW
A	y		220	11.8	135	106	5000	5:00+	128	475	H
HES-11	y		220	11.8	230	183	14043	3:00			TLW
A	y		250	11.8	135	106	5000	5:00+	143	674	H
A	y		40	11.8	118	97	3500	4:00+	85	130	A
A	y		200	11.8	140	107	5000	5:30+	125	170	H
A		n		11.8	100	85	1500	6:00+	164	330	A
HES-11		n		11.9	135	105	4700	5:54	361		TLW
F		n		11.9	255	215	14600	3:36	870	1040	Micro-fine
HES-11		n		11.9	203	156	11060	2:40	1030	1380	TLW
HES-11		n		11.9	203	156	11060	2:44	1190	1230	TLW
HES-11	y		110	11.9	90	80	1000	6:30+	109	240	TLW
HES-11	y		110	11.9	125	100	4000	7:00+	360	763	TLW
HES-11	y		110	11.9	132	101	4700	5:57			TLW
HES-11	y		110	11.9	143	107	4800	4:28			TLW
F	y		85	11.9		223	12905	4:18	250	430	Micro-fine
HES-11	y		90	11.9	144	109	5300	6:28	127	280	TLW
F	y		140	11.9	300	252	15278	3:08	440	460	Micro-fine

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		260	11.9	95	82	1250	6:30+	28	65	TLW
HES-11	y		265	11.9	106	91	6350	6:00+	66	179	TLW
HES-11	y		265	11.9		86	3050	6:00+	50	138	TLW
HES-11	y		265	11.9	105	93	2900	7:00+	50	178	TLW
HES-11	y		265	11.9	92	80	1000	6:00+	200	250	TLW
HES-11	y		252	11.9	118	98	3708	6:00+	195	753	TLW
HES-11	y		252	11.9	118	98	3600	6:00+	139	841	TLW
HES-11	y		252	11.9	118	97	3542	4:27	222	414	TLW
HES-11	y		25	11.9	116	96	3300	6:30+	158	565	TLW
HES-11	y		25	11.9	92	80	1000	5:00+	114	214	TLW
HES-11		n		11.9		129	6200	5:26	62	415	TLW
A	y		1419	11.9		95	6600	3:34			A
HES-3	y		2761	11.9		93	6300	3:24			A
F	y		40	11.9	242	208	12091	3:00	510	830	Micro-fine
B	y		200	11.9	130	102	4200	6:00+	121	227	65/35 A/POZ
HES-11	y		75	11.9	164	123	7000	5:46	123	841	TLW
HES-11	y		75	11.9	164	123	7000	9:14	520	999	TLW
F	y		200	11.9		255	12170	4:06	390	620	Micro-fine
HES-11	y		220	11.9	120	97	3789	5:00+	46	220	TLW
HES-11	y		95	11.9	115	96	3200	7:16	79	354	TLW
A	y		220	11.9		129	9485	5:00+	135	160	H
F	y		380	11.9	235	205	15531	3:41	450	610	Micro-fine
F	y		35	11.9		238	13482	5:28	430	630	Micro-fine
HES-11	y		220	11.9	106	92	3235	7:18	81	217	TLW
HES-11	y		220	11.9	111	95	3300	5:00+	250	818	TLW
HES-11	y		125	11.9	91	81	1100		81	166	TLW
HES-11	y		125	11.9	92	81	1100		107	217	TLW
HES-11	y		115	11.9	93	80	1050	6:00+	88	460	TLW
HES-11	y		115	11.9	130	101	4050	5:00+	150	233	TLW
F	y		55	11.9	227	190	12824	3:10	360	690	Micro-fine
F	y		55	11.9	247	204	12824	3:36	770	820	Micro-fine
HES-11	y		1750	11.9		71	2825		89	301	TLW
HES-11	y		40	11.9	90	80	1000	4:00+	116	340	TLW
HES-11	y		40	11.9	120	98	3500	5:00+	240	450	TLW
B	y		135	11.9	92	80	1000	6:00+	60	140	H
HES-11	y		225	11.9	120	98	3400	6:02	171	291	TLW
HES-11	y		40	11.9		77	650	5:00+	28	56	TLW
HES-11	y		155	11.9	92	80	1000	3:30+	147	219	TLW
HES-11	y		150	11.9	110	91	2200	5:30+	79	263	TLW
HES-11	y		220	11.9		93	3373	6:00+	379	950	TLW
A		n		12.0	128	101	4000	4:07	228	415	Micro-fine
A		n		12.0	0	110	3000	6:44			H
A		n		12.0		110	4000	6:00+			H
B		n		12.0		93	2500	4:05	281	350	C
HES-11		n		12.0	80	80	1000	4:16	186	358	TXI
A		n		12.0	90	80	1000		161	308	A
F	y		230	12.0	168	138	8024	4:45	612	921	Micro-fine
B		n		12.0		160	10000	6:00+	562	783	75/25 A/POZ
B		n		12.0		160	10000	6:00+	672	1192	65/35 A/POZ
B		n		12.0		101	4000	4:58			50/50 H/POZ
B		n		12.0		85	4000			50	75/25 A/POZ
HES-11		n		12.0	80	93	2500	4:48	425	693	TXI
A		n		12.0	128	101	4000	4:07	228	415	Micro-fine
B		n		12.0	120	96	3000		116		65/35 A/POZ
		n		12.0	120	96	3000		74		A
B		n		12.0	90	80	1000		58	86	65/35 A/POZ
B		n		12.0		93	2500		0	50	HPLC
A		n		12.0	93	87	1000		269	454	A
A		n		12.0	95	80	1000			234	H
F		n		12.0	237	202	14500	4:03	842	992	Micro-fine
HES-11		n		12.0	142	108	5200	5:18			TLW
		n		12.0	94	83	1300	8:00+	85	110	A
HES-11		n		12.0	150	113	5800	5:00+			TLW
B		n		12.0	125	96	3000	2:30	200	240	85/15 H/POZ
B		n		12.0	130	101	4000	3:57			65/35 A/POZ
HES-3		n		12.0		65	5479	3:36	0	80	FLOSTOP I

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A		n		12.0		65	5479	5:00+	0	FIRM	A
		n		12.0	138	106	4800	7:00+	FIRM	130	A
A	y		6200	12.0		105	14000	5:55	310	330	H
A	y		6200	12.0		79	10000	6:19	105	248	A
		n		12.0	128	101	4000	7:00+	70	180	A
F		n		12.0	128	108	4015	3:00	510	515	Micro-fine
F		n		12.0	128	108	4015	4:18	250	400	Micro-fine
HES-11		n		12.0	104	90	2000	4:52	285	651	TLW
F	y		30	12.0	0	173	7750	4:00	145	750	Micro-fine
F	y		30	12.0	186	186	8881	3:26	590	1460	Micro-fine
HES-11	y		30	12.0	128	101	4000	4:30+	93	289	TLW
B	y		30	12.0	145	111	5684	3:58	260	280	H
B	y		30	12.0	102	89	1950	4:00+	90	230	H
A	y		25	12.0	104	90	2000	5:50	165	500	A
F		n		12.0	230	189	11800	3:51	225	380	Micro-fine
B		n		12.0	125	100	4000	7:00+	80	200	65/35 H/POZ
HES-11		n		12.0	206	158	10500	3:45	821	932	TLW
HES-11		n		12.0	255	207	14180	3:52	703	808	TLW
B		n		12.0	132	101	4000	4:03	115	198	65/35 A/POZ
HES-11		n		12.0	105	90	2150	6:05	240	430	TLW
B		n		12.0	120	99	4000	5:00+	90	120	65/35 A/POZ
		n		12.0	127	101	4100	5:00+	FIRM	200	A
B		n		12.0	224	176	12040	4:32	188	463	65/35 H/POZ
B		n		12.0	205	156	11800	3:36	310	830	65/35 H/POZ
F		n		12.0	238	199	13158	4:00	410	590	Micro-fine
		n		12.0	134	104	4684	5:00+	105	180	A
		n		12.0	134	105	4500	7:00+	130	220	A
		n		12.0	116	96	3000	5:00+		220	A
B		n		12.0	190	146	9825	5:30+	310	490	65/35 H/POZ
F		n		12.0	163	133	6884	4:33	530	1000	Micro-fine
B		n		12.0	128	101	4000			119	65/35 H/POZ
		n		12.0	122	98	3500	7:00+	75	190	A
B	y		102	12.0	126	99	4032	5:00+	220	270	H
B	y		70	12.0	90	80	750	5:00+	110	135	H
B	y		120	12.0	120	96	3000	6:00+	60	110	H
B	y		120	12.0	90	80	750	6:00+	37	60	H
B	y		122	12.0	130	101	4000	5:41	80	120	H
B	y		122	12.0	95	82	1200	5:00+	0	70	H
A	y		140	12.0	120	93	3000	5:00+	170	325	H
F	y		50	12.0	202	162	8750	3:25	1055	1577	Micro-fine
B	y		102	12.0	126	99	4032	5:00	130	150	H
HES-11	y		188	12.0	126	100	3800	4:40	322	1087	TLW
B	y		20	12.0	128	101	4000	12:38	115	154	65/35 H/POZ
B	y		20	12.0	128	101	4000	9:34		90	65/35 H/POZ
F	y		15	12.0		145	5852	4:00+	58	321	Micro-fine
A	y		15	12.0	141	108	7040	5:00+	104	150	H
HES-11	y		25	12.0	150	121	7400	4:04			TLW
HES-11	y		15	12.0	140	113	6000	4:30			TLW
HES-11	y		15	12.0	94	82	1250	6:00+		250	TLW
		n		12.0	134	104	4500	6:00+	46	130	A
B		n		12.0	118	97	3150	4:47			65/35 A/POZ
B		n		12.0	113	94	2650	4:17			65/35 A/POZ
		n		12.0	155	130	8600	5:00+	245	536	A
F		n		12.0	96	89	1295	2:30			Micro-fine
A		n		12.0	117	96	3100	6:00+	110	150	A
B		n		12.0	226	184	15070	2:42			65/35 H/POZ
B		n		12.0	196	149	9685	5:12	510	1090	50/50 H/POZ
B		n		12.0	122	98	3500	7:30+	106	236	65/35 H/POZ
B		n		12.0	140	107	5000	5:00+			65/35 H/POZ
B		n		12.0	160	119	6400	4:30+			65/35 H/POZ
B		n		12.0	185	151	8802	4:00+	159	352	65/35 H/POZ
		n		12.0	115	96	3000	5:00+	FIRM	150	A
F		n		12.0		97	3600		436	445	Micro-fine
		n		12.0	130	103	4500	6:00+	110	120	A
B		n		12.0	130	101	4000	6:00+			65/35 H/POZ
B		n		12.0	130	101	4000	3:40			65/35 A/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
		n		12.0	134	103	4300	5:00+	130	250	A
		n		12.0	134	104	4500	6:00+	40	170	A
B		n		12.0	122	98	3500	3:53			65/35 A/POZ
B		n		12.0	105	91	2300	5:00+	65	115	65/35 A/POZ
B		n		12.0	105	91	2300	5:00+	65	115	65/35 A/POZ
B		n		12.0		97	3500	4:10	97	117	A
B		n		12.0	207	159	10700	3:45			65/35 H/POZ
HES-11		n		12.0	196	149	9958	4:32	869	889	TLW
B		n		12.0	105	91	2200	4:00+	40	100	65/35 A/POZ
		n		12.0	110	93	2600	6:00+	111	210	A
HES-3	y		6679	12.0		65	7800	5:00+	50	135	FLOSTOP I
HES-11		n		12.0	107	90	2000	4:00+	140	250	TLW
A		n		12.0	125	100	3800	5:00+	180	270	A
B		n		12.0	120	98	3500	3:44			65/35 A/POZ
		n		12.0	116	96	3000	5:00+	110	130	A
A	y		550	12.0	103	90	2182	6:00+	125	370	A
F	y		750	12.0	195	168	11261	3:21	780	1290	Micro-fine
F	y		750	12.0	200	164	10025	3:03	780	1290	Micro-fine
A	y		3822	12.0		58	5373	5:30+			A
A	y		72	12.0	135	104	4500	6:00+	120	180	A
B	y		81	12.0	140	105	4904	7:15	150	325	H
B	y		81	12.0	96	80	1000	4:00+	160	234	H
A	y		70	12.0	133	99	4000	5:43	222	262	A
A	y		70	12.0	126	96	4000	3:32			A
F	y		100	12.0	180	153	8130	3:27	670	740	Micro-fine
B	y		108	12.0	90	80	800	4:00+			H
HES-11	y		112	12.0	125	101	4100	6:30+	429	802	TLW
HES-11	y		140	12.0	171	128	8500	4:08	721	979	TLW
HES-11	y		142	12.0	134	104	4500	6:11	270	410	TLW
B	y		170	12.0	140	106	4800	9:00+	53	131	H
F	y		170	12.0	0	160	8260	8:00	0	70	Micro-fine
F	y		170	12.0	160	160	8260	4:20	90	670	Micro-fine
HES-11	y		250	12.0	90	80	817		65	230	TLW
HES-11	y		250	12.0	122	98	3500	7:29	230	470	TLW
HES-11	y		250	12.0	95	82	2198	5:00+	40	180	TLW
HES-11	y		250	12.0	90	80	821	5:00+	120	200	TLW
HES-11	y		250	12.0	94	82	2198	4:30+	100	180	TLW
F	y		250	12.0	220	182	11652	3:29	860	1190	Micro-fine
HES-11	y		245	12.0	131	104	4700	6:00	440	815	TLW
F	y		280	12.0	155	155	7616	4:54	180	990	Micro-fine
F	y		280	12.0	175	142	7900	3:37	780		Micro-fine
B	y		306	12.0	126	100	3800	4:00+	105	300	H
B	y		306	12.0	92	80	950	3:00+	0	110	H
HES-11	y		365	12.0	106	93	2963	5:38	111	471	TLW
HES-11	y		365	12.0	120	98	4003	7:00+	142	402	TLW
B	y		50	12.0	93	80	900	4:00+	231	270	H
B	y		50	12.0	144	112	6448	3:47	110	161	H
B	y		50	12.0	144	112	6448	5:23	50	204	H
B	y		50	12.0	90	80	900	5:00+	0	245	H
F	y		80	12.0	227	187	11782	4:34	750	1200	Micro-fine
B	y		50	12.0	144	112	6448	5:19	103	178	H
A	y		250	12.0	90	80	800	5:00+	SET	120	H
A	y		300	12.0	126	107	5100	5:00+	119	298	H
A	y		25	12.0	125	99	3700	5:10	193	308	A
A	y		25	12.0	91	80	900	5:00+	256	337	A
F	y		25	12.0	181	147	8400	4:10	290	500	Micro-fine
B	y		35	12.0	128	101	4000	5:00+	220	240	H
B	y		35	12.0	90	80	790	5:00+	50	200	H
HES-11	y		50	12.0	228	181	12700	4:00	797	1120	TLW
HES-11	y		50	12.0	130	106	5000	4:46	309	667	TLW
A	y		50	12.0	110	90	2000	5:00+	147	177	H
HES-11	y		50	12.0	130	106	5000	7:22			TLW
A	y		50	12.0		80	1000		0	89	A
HES-11	y		50	12.0	130	106	5000	4:33	346	691	TLW
A	y		50	12.0	125	99	4250	6:00+	259	333	A
B	y		61	12.0	146	111	5500	5:20	200	220	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		68	12.0	120	102	4500	5:00+	100	240	H
A	y		50	12.0	140	107	5000	5:00+	70	160	A
A	y		72	12.0	134	104	4500	4:00+	220	250	A
F	y		82	12.0	148	121	6000	4:54	237	832	Micro-fine
F	y		80	12.0	211	174	11199	4:23	620	880	Micro-fine
F	y		80	12.0	221	183	12088	2:41			Micro-fine
B	y		80	12.0	230	181	13410	4:15	30	120	65/35 H/POZ
B	y		80	12.0	216	167	11614	4:10	96	200	65/35 H/POZ
B	y		80	12.0	216	167	11614	3:41	70	120	65/35 H/POZ
F	y		85	12.0		184	9428	4:06	510	870	Micro-fine
A	y		10	12.0	140	108	5200	3:56			A
A	y		10	12.0	142	109	5250	5:00+	210	320	H
A	y		75	12.0	130	107	5200	2:57	145	280	A
HES-11	y		107	12.0	210	163	11983	3:58	1090	1710	TLW
HES-11	y		120	12.0	82	80	165	3:20	301	500	TLW
E	y		120	12.0	82	80	165	5:00+			H
F	y		123	12.0	130	109	4500	4:20	192	666	Micro-fine
B	y		111	12.0		156	11000	6:24			H
B	y		130	12.0	132	103	4469	7:54	185	240	H
B	y		130	12.0	92	80	1000	5:00+	120	220	H
HES-7	y		137	12.0	163	125	7947	6:00+	219	273	H
HES-7	y		137	12.0	163	125	7947	6:00+	311	632	H
HES-7	y		137	12.0	133	110	5707	5:00+	108	189	H
B	y		130	12.0	91	80	1000	5:00+	108	269	H
B	y		130	12.0	132	105	5150	4:00+	186	1228	H
A	y		140	12.0		80	1230	5:00+	150	309	A
HES-11	y		145	12.0	140	107	5000	5:02	250	450	TLW
B	y		250	12.0	126	100	3800	5:00+	90	180	H
B	y		250	12.0	135	105	4600	6:22	190	305	H
A	y		160	12.0	134	104	4500	4:00+	306	418	A
F	y		138	12.0		158	7067	5:00+	330	1029	Micro-fine
HES-11	y		209	12.0	136	105	4650	6:00+	0	146	TLW
HES-11	y		209	12.0	92	80	975	6:00+	0	50	TLW
HES-11	y		241	12.0	125	101	4150	5:02	140	418	TLW
A	y		254	12.0	93	81	1100	5:00+	70	160	H
F	y		280	12.0	148	148	5574	3:28	260	820	Micro-fine
F	y		280	12.0	148	121	5574	3:45	260	820	Micro-fine
F	y		280	12.0		160	8100	4:45	616	739	Micro-fine
F	y		267	12.0	92	82	1400	4:00+	130	150	Micro-fine
B	y		272	12.0	92	80	1000	5:30+	106	162	H
HES-7	y		272	12.0	131	102	5920	10:00+	448	920	H
B	y		272	12.0	131	102	5920	5:00+			H
B	y		25	12.0	130	104	4700	4:15			H
F	y		600	12.0	150	128	6100	3:00	120	560	Micro-fine
B	y		25	12.0	113	98	3900	5:00+	80	220	H
B	y		25	12.0	134	104	4500	6:22	110	180	H
HES-11	y		25	12.0	234	185	13333	5:33	315	1014	TLW
A	y		20	12.0	92	80	1000	4:00+	200	330	A
A	y		21	12.0	92	80	1000	4:00+	90	130	50/50 H/POZ
A	y		21	12.0	129	101	4060	4:00+	260	300	A
HES-2	y		600	12.0		80	975	6:00+	141	352	A
F	y		71	12.0		188	12152	4:10	973	956	Micro-fine
HES-11		n		12.0	115	100	3015	4:30+			TLW
HES-11		n		12.0	115	100	3015	4:57	254	490	TLW
B		n		12.0	119	96	3000	4:07			65/35 A/POZ
F		n		12.0	130	109	3850	4:30	114	450	Micro-fine
HES-11	y		650	12.0		103	4630	5:30+	220	520	TLW
HES-11	y		980	12.0	0	87	4100	6:00+	160	430	TLW
B		n		12.0	116	96	3000	4:23			65/35 A/POZ
A	y		3822	12.0		106	7450	2:45			A
A	y		3822	12.0		79	7450	5:30+		124	A
A		n		12.0	135	102	4175	8:00+	90	95	A
B		n		12.0	105	91	2250	5:00+	100	130	65/35 A/POZ
		n		12.0	125	99	3700			120	A
F		n		12.0	152	152	6000	5:38	102	572	Micro-fine
A	y		300	12.0		81	1303	6:00+	170	289	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		1250	12.0	102	88	1800	6:45		363	A
HES-11	y		1491	12.0	0	84	4000	4:00+	160	260	TLW
HES-11	y		1491	12.0	0	84	4000	4:00+	80	200	TLW
HES-3	y		1491	12.0		80	2900	6:00+	364	784	A
F	y		250	12.0	185	157	10103	4:18	780	820	Micro-fine
B	y		633	12.0	106	92	2644	3:31	150	180	A
B	y		633	12.0	106	92	2644	6:00+	120	150	H
HES-11	y		850	12.0	0	80	1950	6:00+	100	220	TLW
HES-3	y		981	12.0		80	2600	3:58	483	727	A
HES-3	y		1195	12.0		80	2770	3:50	420	601	FLOSTOP I
A	y		1195	12.0		80	2770	5:00+		50	A
A	y		1250	12.0	100	87	1800	4:45	344	461	A
A	y		1250	12.0	130	102	4250	4:47	365	618	A
F	y		1250	12.0	160	131	7250	5:13	420	1031	Micro-fine
A	y		1250	12.0	100	87	1700	7:04		198	A
A	y		1250	12.0	130	102	4250	2:45			A
F	y		1250	12.0		60	600	2:30+	0	0	Micro-fine
F	y		760	12.0		242	13500	3:22	560		Micro-fine
HES-11	y		760	12.0		83	2612	5:00+		170	TLW
F	y		760	12.0	242	202	13500	3:00	1895		Micro-fine
F	y		760	12.0	214	176	11200	3:34	750		Micro-fine
F	y		760	12.0	170	143	10000	2:45	400	1410	Micro-fine
A	y		855	12.0	120	105	4900	6:00+	50	80	H
HES-7		n		12.0		123	6200	7:00+		0	A
HES-7		n		12.0		122	5500	7:00+	28	153	A
HES-7		n		12.0		122	5200	6:32	0	218	A
HES-7		n		12.0		122	5500	5:23			A
A		n		12.0	100	84	1450	5:30+	225	385	A
HES-11		n		12.0	105	94	1700	4:12	214	360	TLW
A		n		12.0	85	80	300		30	255	A
A		n		12.0	85	80	300		FIRM	70	A
A		n		12.0	85	80	300				A
A		n		12.0	85	80	300		0	160	A
A		n		12.0	85	80	300		0	80	A
A		n		12.0	85	80	300		140	270	A
		n		12.0	134	104	4500	5:00+	FIRM	50	A
B		n		12.0	206	158	10500	3:08			65/35 H/POZ
		n		12.0	128	101	4000	8:00+			A
		n		12.0	128	101	4000	8:00+	105	140	A
		n		12.0	125	100	4000	6:00+		73	A
F		n		12.0	180	153	8660	3:16	460	530	Micro-fine
B		n		12.0	122	100	4000	4:58	131	217	65/35 A/POZ
A	y		255	12.0	115	101	4350	3:24	439	603	A
HES-11	y		100	12.0		93	2636	6:26	130	287	TLW
HES-7	y		106	12.0	220	173	14010	4:23	153	285	H
HES-11	y		106	12.0	116	96	3000	4:00+	322	1085	TLW
B	y		50	12.0	226	176	13193	4:00	400	530	65/35 H/POZ
HES-7	y		100	12.0	218	170	12500	6:00+	180	208	H
F	y		100	12.0	220	184	12820	3:08	1450	1545	Micro-fine
B	y		150	12.0	218	168	13053	4:13	150	320	65/35 H/POZ
HES-7	y		220	12.0	161	122	8288	6:00+	197	340	H
F	y		221	12.0	174	149	12390	4:25	530	1410	Micro-fine
HES-7	y		206	12.0	158	131	7866	4:00+	180	520	H
B	y		96	12.0	207	159	11120	6:30+	421	1238	50/50 H/POZ
HES-11	y		920	12.0	121	103	4610	5:00	168	408	TLW
A	y		693	12.0	0	90	3400	4:00+	100	210	A
HES-11	y		1711	12.0		90	4200	6:24	106	328	TLW
A	y		1086	12.0		81	5000	7:00+	130	250	H
HES-7	y		100	12.0	185	143	9953	6:00+	295	1215	H
HES-7	y		138	12.0	230	181	16160	5:00+	FIRM	40	H
F	y		240	12.0	153	129	7500	3:19	80	740	Micro-fine
A	y		218	12.0	134	104	4500	4:00+	55	100	H
F	y		206	12.0	165	140	8490	2:43	480	730	Micro-fine
F	y		95	12.0	180	147	8768	2:55	1260	1870	Micro-fine
A	y		30	12.0	122	98	3500	2:20	260	420	A
A	y		58	12.0	88	80	750	6:00+	115	180	H

*Slurry Type	Offshore		Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi)		Base Cement Type
	Yes	No							12 hr	24 hr	
A	y		58	12.0	117	96	3120	6:00+	190	230	H
HES-11	y		60	12.0	145	109	5000	4:20	130	385	TLW
F	y		65	12.0	205	165	9152	3:24	1170	1210	Micro-fine
F	y		356	12.0	210	176	12490	4:10	680	880	Micro-fine
F	y		356	12.0	227	189	12600	3:15	760	1710	Micro-fine
F	y		356	12.0	180	146	8200	5:14	370	890	Micro-fine
B	y		190	12.0	92	80	1000	5:30+	0	60	H
B	y		50	12.0	119	96	3000	3:00+			H
F	y		926	12.0	183	153	10462	5:16	0	540	Micro-fine
HES-11	y		926	12.0	121	103	4610	4:30			TLW
HES-3	y		926	12.0		80	2050	5:00+	414	665	A
F	y		633	12.0	168	146	13174	3:44	490	715	Micro-fine
A	y		720	12.0	117	99	3834	3:43	281	436	A
F	y		720	12.0	124	100	5623	2:21	350	441	Micro-fine
HES-11	y		720	12.0	118	99	3834	5:50	233	286	TLW
F	y		720	12.0	132	112	6400	4:40	158	258	Micro-fine
A	y		720	12.0	117	99	3788	4:28	259	582	A
B	y		720	12.0	99	90	2300	6:00+	0	60	A
HES-11	y		720	12.0	117	99	3834	5:30	106	284	TLW
B	y		720	12.0	99	90	2300	4:30	68	110	A
A	y		720	12.0	117	99	3834	6:27	183	292	A
HES-7	y		700	12.0	117	97	4066	6:00+	70	90	H
B	y		700	12.0	95	88	1850	5:00+	FIRM	100	H
A	y		1605	12.0		100	4600	6:00+	180	320	TLW
A	y		1605	12.0		100	4600	5:30+	110	205	H
A	y		1605	12.0		90	4200	6:13	100	260	TLW
A	y		1419	12.0		95	6600	3:56			A
HES-11	y		1711	12.0		90	4200	5:25			TLW
HES-11	y		1646	12.0		80	4200	8:46	66	169	TLW
F	y		1646	12.0		168	16700	5:30	232	623	Micro-fine
HES-11	y		2200	12.0		70	3550	6:00+		120	TLW
F	y		1500	12.0	0	132	10700	3:35	150	290	Micro-fine
F	y		2663	12.0	0	120	13450	2:55	95	120	Micro-fine
HES-11	y		2081	12.0		70	3700	4:00+	0	120	TLW
HES-11	y		2081	12.0		75	3700	4:00+		0	TLW
HES-11	y		2120	12.0		75	3800	6:00+		0	TLW
		n		12.0	130	101	4000	6:30+	0	66	A
		n		12.0	124	100	4000	7:00+	130	260	A
B		n		12.0	135	109	5500	4:00+	105	310	H
B		n		12.0	114	97	3500	3:00+	220	320	H
F		n		12.0	166	136	7550	4:38	52	1072	Micro-fine
B		n		12.0	132	101	4000	6:30+			65/35 H/POZ
	y		200	12.0	115	96	3000	5:00+	110	200	A
F	y		200	12.0	165	137	8572	3:51	700	1270	Micro-fine
A	y		100	12.0	93	82	1200	6:30+		309	A
B		n		12.0	99	85	1500	5:30+	0	54	65/35 A/POZ
C	y		883	12.0		100	4000	3:38	95	188	A
HES-11	y		518	12.0	0	90	2000	4:30+	78	163	TLW
HES-7	y		2046	12.0		72	5934	5:45	40	60	H
HES-7	y		2046	12.0		72	5934	5:00+	20	170	H
A	y		2100	12.0	0	92	5600	6:17	0	100	A
A	y		2100	12.0	0	65	3600	10:00+	0	0	A
HES-7	y		2841	12.0	0	80	7000	5:15+	30	110	A
HES-11	y		517	12.0		99	4150	4:45	160	240	TLW
HES-11	y		517	12.0		72	1700	4:00+	110	170	TLW
HES-11	y		760	12.0	110	93	2550	7:30	64	147	TLW
HES-11	y		760	12.0	103	92	2550	8:45	58	152	TLW
A	y		1306	12.0		80	2490	5:00+	110	250	A
A	y		1306	12.0		88	4190	5:00+	110	250	A
HES-11	y		3227	12.0		70	4875		60	117	TLW
HES-11	y		3227	12.0		70	4875	5:00+	0	50	TLW
A	y		3227	12.0		70	4875	4:00+	0	50	A
HES-11	y		3227	12.0		70	4875	4:00+	0	0	TLW
F	y		3227	12.0	0	128	14735	3:30	95	640	Micro-fine
HES-11	y		3227	12.0		70	4875	4:00+	0	100	TLW
HES-11	y		3325	12.0		70	5200	5:00+	0	0	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		3467	12.0		65	5200	5:30+	FIRM	30	TLW
A	y		525	12.0		80	2300	4:00+		0	A
E	y		525	12.0		80	2300	4:30+	0	0	TLW
HES-2	y		525	12.0		80	2300	4:00+	0	50	A
E	y		525	12.0		80	2300	4:30+	0	0	TLW
HES-11	y		525	12.0		80	2300	4:00+	90	152	TLW
A	y		4100	12.0		75	8500	5:10		373	A
A	y		4100	12.0		72	7250	5:00+		191	A
HES-3	y		4243	12.0		80	6321	3:23			A
HES-11	y		856	12.0	127	99	3950	6:26	26	405	TLW
HES-11	y		856	12.0	103	90	2200	5:00+	140	318	TLW
HES-11	y		856	12.0	103	90	2100	7:30+	79	177	TLW
F	y		900	12.0		175	15200	4:45	818	1590	Micro-fine
A	y		6500	12.0	0	65	5119	10:16	0	40	TLW
HES-11	y		750	12.0	118	101	5400	5:00+	1660	2275	TLW
HES-11		n		12.0	250	201	13050	4:07	600	707	TLW
HES-11		n		12.0	250	201	13050	5:30+	530	588	TLW
HES-11		n		12.0	250	201	13050	3:51	232	239	TLW
HES-11		n		12.0	250	201	13050	5:30+	436	1036	TLW
B		n		12.0	125	98	3500	5:30+			65/35 A/POZ
B		n		12.0	210	161	10700	5:28	114	456	65/35 H/POZ
HES-11		n		12.0	150	122	5528	3:30	130	390	TLW
		n		12.0	116	96	3000	6:00+	FIRM	160	A
B	y		40	12.0	170	127	7500	8:30+	60	70	65/35 H/POZ
B	y		40	12.0	120	98	3500	5:00+	104	258	65/35 A/POZ
B	y		40	12.0	209	158	10100	5:58	310	460	65/35 H/POZ
A	y		50	12.0	133	103	4400	2:26	280	500	A
A	y		51	12.0	116	96	3005	2:50	170	380	A
A	y		51	12.0	92	80	1000	4:00+	75	220	A
B	y		50	12.0	120	96	3000	5:39	100	150	H
B	y		50	12.0	90	80	750	5:00+	60	100	H
A	y		51	12.0	114	95	2800	4:10	220	380	A
A	y		51	12.0	88	80	700	4:00+	121	261	A
B	y		52	12.0	134	104	4400	4:00+	170	225	H
B	y		55	12.0	122	98	3912	4:55	115	160	65/35 A/POZ
A	y		55	12.0	90	80	800	4:39	232	440	A
F	y		100	12.0	170	143	10226	4:40	386	933	Micro-fine
F	y		170	12.0	186	150	8244	3:49	1091	1564	Micro-fine
A	y		360	12.0		55	670	3:00+	54		A
A	y		380	12.0	92	82	1200	4:00+	130	160	H
A	y		380	12.0	118	96	3999	6:00+	220	350	H
HES-11	y		342	12.0		100	4729	7:44	162	413	TLW
HES-11	y		342	12.0		100	4729	6:46	187	404	TLW
HES-11	y		342	12.0		89	2000	6:15	54	105	TLW
HES-11	y		342	12.0		102	4676	6:35	128	225	TLW
HES-11	y		300	12.0	119	96	3000	6:00+	233	322	TLW
F	y		300	12.0	198	162	9900	3:28	990	1340	Micro-fine
HES-11	y		252	12.0	96	80	1000	4:30+	50	285	TLW
HES-11	y		252	12.0	116	96	3000	4:48	190	430	TLW
A	y		275	12.0	130	105	4900	5:30	240	290	H
HES-11	y		250	12.0	121	98	4836	5:00+	498	967	TLW
HES-11	y		250	12.0	110	93	3905	4:30+	150	180	TLW
F	y		283	12.0	270	232	12676	4:12	690	850	Micro-fine
F	y		283	12.0	191	159	7398	3:47	470	600	Micro-fine
F	y		285	12.0		242	11972	3:41	1044	1374	Micro-fine
F	y		285	12.0		205	11600	3:04	1112	1222	Micro-fine
HES-11	y		478	12.0		85	1500	8:00	105	204	TLW
A	y		350	12.0	105	92	2500			69	H
HES-11	y		80	12.0	100	85	1500	7:00+	130	330	TLW
A	y		100	12.0	105	92	2500			53	H
A	y		100	12.0	105	92	2500			72	H
HES-11	y		292	12.0	128	101	4000	4:35	280	640	TLW
HES-11	y		292	12.0	128	101	4000	3:26			TLW
A	y		360	12.0	118	97	5000	4:00+	190	300	H
F	y		250	12.0	105	94	2100	4:00+	55	120	Micro-fine
HES-11	y		288	12.0		119	6641	8:02	0	371	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		329	12.0		91	4250	7:37	53	132	TLW
HES-11	y		390	12.0		89	2000	6:15	31	42	TLW
A	y		22	12.0	134	104	4500	6:00+	270	295	A
B	y		50	12.0	158	116	8222	5:00+	100	130	65/35 H/POZ
A	y		285	12.0	122	98	3450	4:00+	100	170	H
A	y		324	12.0	92	82	1200	6:00+	150	220	H
A	y		324	12.0	120	97	3400	5:00+	110	228	H
HES-11	y		324	12.0	120	97	3225	4:00+	550	940	TLW
HES-11	y		347	12.0		102	4270	7:25	34	197	TLW
B	y		219	12.0	126	100	4000	6:24	50	130	H
B	y		219	12.0	90	80	1000	7:00+		90	H
F	y		220	12.0	126	126	3575	3:32	70	250	Micro-fine
A	y		220	12.0		83	1543	4:30+	28	164	H
HES-11	y		220	12.0	120	96	3217	5:00+	370	740	TLW
HES-11	y		265	12.0	116	96	3000	5:30+	171	346	TLW
HES-11	y		265	12.0	116	96	3000	3:35			TLW
F	y		280	12.0	172	147	8400	2:39	470	1230	Micro-fine
F	y		280	12.0	172	147	8400	5:02	720	1170	Micro-fine
HES-11	y		300	12.0	108	92	3134	6:00+	193	314	TLW
HES-11	y		300	12.0	112	94	4903	5:30+	204	331	TLW
A	y		61	12.0	90	80	900	4:00+	120	240	A
B	y		61	12.0	170	113	5200	8:00+	66	227	65/35 H/POZ
A	y		220	12.0		100	4117	6:00+	87	173	H
A	y		324	12.0	92	82	1200	4:00+	140	170	H
HES-11	y		324	12.0	118	96	3400	4:00+	220	485	TLW
HES-11	y		342	12.0	127	102	4800	7:56	71	244	TLW
A	y		200	12.0	130	102	4200	3:07			A
A	y		235	12.0	114	95	3000	5:00+	100	110	H
HES-11	y		342	12.0	127	97	3220	7:06	347	600	TLW
F	y		342	12.0	131	111	6200	3:33	161	379	Micro-fine
HES-11	y		342	12.0	104	92	6116	4:00+		235	TLW
B		n		12.0	100	85	1500	5:00+	61	111	65/35 H/POZ
B		n		12.0	152	115	6000	5:00+	90	185	65/35 H/POZ
B		n		12.0	122	98	3500	4:30+	0	89	65/35 H/POZ
F	y		208	12.0	100	88	1700	5:00+	80	100	Micro-fine
A	y		218	12.0	103	89	2379	5:00+		109	H
		n		12.0	100	85	1500	5:00+			A
F		n		12.0	220	181	11117	10:31+	636	1546	Micro-fine
		n		12.0	140	107	5000	7:00+	220	370	A
		n		12.0	125	101	4200	4:00+	90	160	A
B		n		12.0	170	127	7700	4:30+	266	510	65/35 H/POZ
B		n		12.0	170	128	7500	5:48	120	170	65/35 H/POZ
B		n		12.0	212	162	10600	6:56	90	120	65/35 H/POZ
		n		12.0	122	98	3500	5:00+			A
HES-11		n		12.0	181	145	7200	2:20	1152	1425	TLW
B		n		12.0	116	96	3000	6:04	83	151	65/35 A/POZ
B		n		12.0	270	224	14625	6:00+			65/35 H/POZ
B		n		12.0	130	101	4000	6:00			65/35 H/POZ
		n		12.0	115	99	4000		80	105	A
		n		12.0	130	101	4000	7:00+	135	225	A
B		n		12.0	120	100	4000		66	264	65/35 H/POZ
B		n		12.0	155	114	5800	6:00+			65/35 H/POZ
B		n		12.0	120	100	4000		87	300	65/35 A/POZ
		n		12.0	115	95	2910	5:00+	110	200	A
B		n		12.0	120	100	4000	4:39			65/35 A/POZ
B		n		12.0	122	98	3500	5:00+			65/35 A/POZ
		n		12.0	155	117	6200	7:00+	SET	120	A
F		n		12.0	188	150	7727	4:01	990	1310	Micro-fine
HES-11		n		12.0	119	98	3500	5:00+	234	656	TLW
		n		12.0	120	96	3200	7:00+			A
F		n		12.0		280	12862	2:41	535	588	Micro-fine
A		n		12.0	110	96	3500	7:03	110	170	A
		n		12.0	122	98	3500		70	180	A
F		n		12.0	221	191	12650	3:05	505	560	Micro-fine
F		n		12.0		210	10393	5:20	1265	1355	Micro-fine
		n		12.0	129	102	4100	6:00+	100	240	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B		n		12.0	107	92	2450	7:00+	170	295	65/35 A/POZ
B		n		12.0	110	93	2600	5:00+	120	160	65/35 A/POZ
		n		12.0	117	97	3300	5:00+	20	70	A
		n		12.0	116	96	3000	5:00+	128	137	A
B		n		12.0	108	92	2400		0	116	65/35 H/POZ
B		n		12.0		85	1000	6:00+			65/35 A/POZ
		n		12.0	130	102	4200	7:00+	110	1200	A
B		n		12.0	130	101	4000	6:00+	0	176	65/35 H/POZ
F		n		12.0	190	153	8451	3:10	1090	1360	Micro-fine
F		n		12.0	160	130	6500	3:00	770	1090	Micro-fine
		n		12.0	110	95	3000	5:00+	105	120	A
		n		12.0	126	100	3800	7:00+	75	195	A
B		n		12.0	128	101	4000	6:00+	80	200	65/35 A/POZ
B		n		12.0	265	213	15100	5:19	430	550	65/35 H/POZ
B		n		12.0	156	118	6350	5:30+		255	65/35 H/POZ
F		n		12.0	140	117	6004	4:45	255	673	Micro-fine
B		n		12.0	164	123	7000	6:00+		493	65/35 H/POZ
B		n		12.0	160	117	6100	6:00	65	125	65/35 H/POZ
F	y		1025	12.0	159	135	10076	3:35	708	825	Micro-fine
F		n		12.0	138	117	4860	4:30+	130	420	Micro-fine
F	y		40	12.0	140	116	5085	1:07			Micro-fine
F	y		40	12.0	140	116	5085	0:37			Micro-fine
F	y		158	12.0	164	164	7173	4:32	230	620	Micro-fine
F	y		200	12.0	165	136	7428	3:02	540	1010	Micro-fine
HES-11	y		120	12.0	122	98	3500	5:00+	0	265	TLW
A	y		120	12.0	91	80	920	4:00+	164	260	A
F	y		138	12.0	119	103	3272	4:00+	95	110	Micro-fine
A	y		145	12.0	116	96	3000	5:00+	400	450	A
HES-11	y		167	12.0	120	98	3500	4:47	375	944	TLW
A	y		253	12.0	115	97	3500	6:01	380	450	A
A	y		253	12.0	119	98	3500	4:00+	110	240	A
A	y		253	12.0	115	97	3500	4:14	363	490	A
A	y		184	12.0	90	80	900	4:00+	160	305	A
F	y		195	12.0	126	108	3804	4:30+	90	200	Micro-fine
HES-11	y		222	12.0	115	95	5724	5:30+	SET	350	TLW
HES-11	y		222	12.0	125	99	8539	5:30+	195	360	TLW
HES-11	y		227	12.0	116	96	6200	4:00+	25	630	TLW
HES-11	y		227	12.0	105	90	6323	5:30	90	360	TLW
F	y		230	12.0	147	122	6514	2:24	404	686	Micro-fine
B	y		303	12.0	126	106	5000	5:00	110	150	H
HES-7	y		295	12.0	119	96	3750	4:00+	100	160	H
B	y		200	12.0	110	91	2305		76	155	65/35 H/POZ
F	y		200	12.0	128	108	3671	6:30+	333	1147	Micro-fine
HES-11	y		215	12.0	134	104	4500	5:48	580	969	TLW
B	y		210	12.0	112	89	1975	6:00+	60	130	50/50 A/POZ
F	y		210	12.0	102	84	1859	4:25	305	346	Micro-fine
B	y		210	12.0	88	80	856	10:00+	50	118	50/50 A/POZ
HES-11	y		210	12.0		84	1859	5:30+	76	130	TLW
HES-11	y		210	12.0	88	80	856	10:09	97	142	TLW
HES-11	y		210	12.0	97	84	2100	9:48	88	131	TLW
HES-11	y		210	12.0	110	97	2600	4:11	313	465	TLW
HES-11	y		210	12.0	102	84	1859	7:00+	103	189	TLW
B	y		210	12.0	94	80	905	6:00+	50	64	50/50 A/POZ
A	y		210	12.0		91	2100	4:08	109	320	Micro-fine
HES-2	y		210	12.0		91	2100		595	1914	A
A	y		210	12.0	110	97	2600	3:35	243	329	A
HES-11	y		210	12.0	110	97	2600	6:00+	69	121	TLW
F	y		50	12.0	174	174	7825	3:54	426	895	Micro-fine
HES-7	y		240	12.0	128	100	4000	4:30+	80	110	H
B	y		38	12.0	113	95	3000	4:30+	50	105	H
A	y		20	12.0	107	92	2500	5:44	232	318	A
B	y		20	12.0	108	92	2500	6:00+	FIRM	50	65/35 H/POZ
A	y		120	12.0	123	103	4500	5:00+	0	170	H
A	y		120	12.0	118	99	4034	3:00+	100	120	H
A	y		120	12.0	128	103	4630		141	229	H
A	y		120	12.0	120	100	4000	4:00+	110	130	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F	y		42	12.0		130	4851	2:41	113	362	Micro-fine
B	y		65	12.0	143	105	4500	5:30+	150	215	H
B	y		65	12.0	94	80	1000	4:00+	160	230	A
HES-11		n		12.0	206	156	10000	3:58	500	873	TLW
A	y		77	12.0	90	80	700	5:00+	130	150	H
F	y		80	12.0	180	146	8000	3:09	690	1030	Micro-fine
A	y		80	12.0	95	82	1250	5:53	105	210	A
HES-11	y		100	12.0	94	80	1000	5:30+	100	510	TLW
HES-11		n		12.0		210	4060	3:10	956	1029	TLW
B		n		12.0	116	96	3000	6:00+	100	113	65/35 A/POZ
F		n		12.0	202	166	10129	3:46	400	780	Micro-fine
F		n		12.0	203	166	10134	3:29	400	780	Micro-fine
A	y		3797	12.0		82	9500	4:56	120	170	A
HES-7	y		1200	12.0		72	5934	7:00+	40	140	H
A	y		1025	12.0	102	89	2053	5:00+	90	180	A
F	y		1025	12.0	128	110	4150	4:30+	100	190	Micro-fine
A	y		1025	12.0	104	90	2287	5:00+	0	0	A
A	y		1025	12.0	125	102	4400	7:00+	160	270	A
F	y		1025	12.0	126	108	3849	3:30	90	200	Micro-fine
A	y		3030	12.0		120	12000	7:58	166	217	H
A	y		3633	12.0		96	9896	6:00+	100	150	H
HES-11	y		2095	12.0		90	4673	7:00+	104	289	TLW
HES-11	y		6627	12.0		125	14820	4:25	233	578	TLW
HES-11	y		6627	12.0		125	14820	3:08			TLW
F	y		6627	12.0		105	12700	2:03	70	90	Micro-fine
HES-11	y		6627	12.0		125	15000	3:25	122	309	TLW
A	y		6739	12.0	120	96	4136	6:00+	140	250	H
HES-11	y		6739	12.0		125	15500	3:40	176	396	TLW
HES-11	y		6588	12.0		120	14550	3:41	205	530	TLW
A	y		1300	12.0	110	94	4000	5:00+	221	304	A
A	y		1300	12.0	122	100	6000	5:00+	211	298	A
HES-11	y		1334	12.0		75	4500	7:00+	56	230	TLW
HES-11	y		1334	12.0		63	2750	5:00+	0	115	TLW
HES-11	y		1400	12.0		80	1780	4:00+	120	220	TLW
HES-7	y		3200	12.0		145	13685	3:53	300	380	H
HES-11	y		6037	12.0	0	90	12000	5:55	FIRM	430	TLW
A	y		2707	12.0		105	6500	5+00+	120	250	A
A	y		2707	12.0		90	5000	4:00+	185	290	A
A	y		2707	12.0		101	6250	6:00+	230	310	A
HES-2	y		2945	12.0			5100			159	A
HES-2	y		2945	12.0	72	72	5100	2:56			A
A	y		2945	12.0	72	72	5100	5:00+		32	A
HES-2	y		3000	12.0			5500		0	54	A
F	y		3000	12.0	0	159	19597	3:49	740	770	Micro-fine
A	y		3800	12.0		82	9500	4:56	120	170	A
HES-3	y		3944	12.0		70	3950	4:00+	92	324	A
HES-3	y		5378	12.0		80	9050	4:03	67	204	A
HES-3	y		5378	12.0		80	9050	6:05			A
HES-7	y		3855	12.0	0	72	5450	4:30+	0		A
HES-7	y		3845	12.0	0	63	7000	6:00+	74	149	A
B	y		14	12.0	300	270	18261	4:24	211	244	H
B	y		48	12.0	106	90	2000	4:00+	160	250	H
HES-7	y		54	12.0	105	90	2000	4:00+	128	308	H
HES-11	y		52	12.0	150	115	6000	5:00+	122	208	TLW
HES-11	y		52	12.0	0	255	17000	7:10	0	0	TLW
HES-11	y		52	12.0	318	276	17000	7:57	0	0	TLW
F	y		49	12.0		62	400	2:00+	0	120	Micro-fine
B	y		60	12.0	100	82	1200	5:00+	115	184	H
B	y		60	12.0	100	87	1700	5:00+	60	195	H
B	y		60	12.0	100	87	1700	4:00+	106	206	H
B	y		60	12.0	130	103	4500	4:00+	144	254	H
B	y		46	12.0	302	261	16867	3:10	360	550	H
HES-7	y		45	12.0	105	89	2000	5:30+	0	114	H
HES-11	y		60	12.0	230	178	11500	7:50		633	TLW
HES-11	y		50	12.0		83	1000	6:00+	0	0	TLW
A	y		240	12.0	126	102	4553	8:30+	141	270	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		200	12.0	155	110	5000	5:29	411	412	TLW
A	y		174	12.0	155	110	5000	4:10	155	205	H
F	y		172	12.0	280	242	13259	3:38	430	960]	Micro-fine
F	y		170	12.0	259	206	10336	3:44	730	880	Micro-fine
B		n		12.0	120	99	4000	7:00+	40	120	65/35 A/POZ
B		n		12.0	128	101	4000	6:00+			65/35 H/POZ
B		n		12.0	135	102	4200	3:08	94	188	65/35 A/POZ
F	y		150	12.0	0	224	10929	3:35	534	860	Micro-fine
A	y		160	12.0	175	121	7500	5:45	120	230	H
B		n		12.0	131	102	4230	3:38			65/35 A/POZ
A		n		12.0	104	88	1800	4:01	50	200	A
HES-7		n		12.0		50	50			51	A
		n		12.0	124	100	4000	7:00+	60	100	A
		n		12.0	122	97	3500	5:00+	80	125	A
		n		12.0	135	104	4450	5:00+	140	195	A
B		n		12.0	128	100	4000	5:00+	100	125	65/35 A/POZ
		n		12.0	110	94	3000		95	120	A
HES-11		n		12.0	93	84	1500		94	248	TLW
B		n		12.0	256	211	12600	3:08	750	760	65/35 H/POZ
F		n		12.0	225	184	11070	3:20	820	1600	Micro-fine
		n		12.0	125	98	3500	5:00+	40	150	A
HES-11		n		12.0		178	13500	6:12		792	TLW
HES-11		n		12.0		178	13500	8:56			TLW
A		n		12.0	113	95	3000	8:00+	240	340	A
B		n		12.0		96	3000	5:30+	89	152	65/35 A/POZ
		n		12.0	122	98	3500	6:30+			A
B		n		12.0	128	101	4000	4:05			65/35 A/POZ
F		n		12.0	104	94	2000	3:00	230	270	Micro-fine
F		n		12.0	250	202	11154	3:29	820	980	Micro-fine
HES-11		n		12.0	165	126	9485	2:50	720	840	TLW
		n		12.0	133	103	4400	6:00+	120	310	A
B		n		12.0	122	98	3500	5:00	120	175	65/35 A/POZ
		n		12.0	150	112	5620	8:00+			A
B		n		12.0	95	80	1000	6:00+	30	140	H
B		n		12.0	118	96	3000	3:38			65/35 A/POZ
B	y		67	12.0	142	111	6316	4:00+	100	120	H
A	y		191	12.0	134	104	5598	5:30+	220	280	H
A	y		200	12.0	134	104	5512	5:30	160	223	H
B	y		200	12.0	171	128	10105	5:00+	240	480	65/35 H/POZ
A	y		191	12.0	134	104	5030	5:00+	240	250	H
F	y		212	12.0		173	9038	4:50	FIRM	670	Micro-fine
HES-11	y		220	12.0	115	96	5000	6:00+	90	380	TLW
F	y		332	12.0		176	13365	3:03	700	1710	Micro-fine
F	y		174	12.0	164	136	8303	3:06	420	780	Micro-fine
B	y		75	12.0	143	109	5250	5:34	60	170	H
A	y		525	12.0		89	2370	6:00+	55	210	A
A	y		525	12.0		89	2370	7:18	130	370	A
HES-11	y		525	12.0	134	106	4940	6:10	270	676	TLW
HES-2	y		525	12.0	110	97	3700	6:11	50	80	A
F	y		525	12.0		140	5580	5:43	210	946	Micro-fine
HES-2	y		525	12.0	100	91	2370	5:00+	112	140	A
HES-11	y		525	12.0	140	110	5595	5:29	276	643	TLW
F	y		90	12.0	265	224	15054	9:00+	1580	1940	Micro-fine
HES-11	y		94	12.0	140	109	5400	5:15	224	649	TLW
B	y		60	12.0	135	105	4800	6:56	70	150	H
B	y		60	12.0	135	105	4800	7:02	100	190	H
B	y		95	12.0	130	102	4100	4:55	110	150	H
A	y		130	12.0	142	108	5200	6:00+	82	116	H
B	y		128	12.0	140	107	5000	5:00+	144	176	65/35 A/POZ
B	y		128	12.0	92	80	1000	4:00+		100	65/35 A/POZ
B	y		122	12.0	134	104	4727	6:04	210	290	H
B	y		122	12.0	134	104	4644	5:36	160	210	H
B	y		122	12.0	116	96	3831	5:58	196	253	H
B	y		124	12.0	132	103	4400	6:15	170	240	H
B	y		124	12.0	134	104	4644	6:20	190	300	H
F	y		137	12.0	253	214	14600	3:06	510	955	Micro-fine

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		150	12.0	135	106	5000	4:47	165	263	H
A	y		182	12.0	96	83	1300	4:00+	160	200	H
HES-11	y		182	12.0	142	108	5200	7:29	55	195	TLW
B	y		150	12.0	128	101	4000	5:00+	429	487	65/35 H/POZ
B	y		150	12.0	128	101	4000	5:06	819	890	65/35 A/POZ
B		n		12.0	180	143	10764	6:11	180	370	65/35 H/POZ
B		n		12.0	120	96	3000	5:40	330	520	85/15 H/POZ
B		n		12.0	180	180	10764	4:16	410	550	65/35 H/POZ
B	y		380	12.0	104	89	2000	5:00+	40	160	H
B	y		380	12.0	150	114	5800	5:05	70	120	H
A	y		51	12.0	122	98	3500	6:00+	159	215	A
F	y		51	12.0	110	97	2500	2:39	294	332	Micro-fine
F	y		51	12.0	175	144	8841	3:04	350	798	Micro-fine
F	y		108	12.0	170	138	7500	3:56	540	1000	Micro-fine
F	y		108	12.0	182	148	8500	3:35	1000	1050	Micro-fine
F	y		108	12.0	210	172	10500	4:28	1150	1320	Micro-fine
HES-11	y		108	12.0	118	97	3200	5:30+	250	550	TLW
F	y		108	12.0	194	159	9500	4:44	990	1650	Micro-fine
A	y		530	12.0	98	87	1800	6:00+	140	340	H
F	y		209	12.0		140	13270	2:53	1092	1216	Micro-fine
A	y		325	12.0	104	90	2425	3:00+	110	228	A
A	y		325	12.0	105	90	2100	4:00+	124	244	A
F	y		325	12.0	104	94	2000	4:30+	171	296	Micro-fine
B	y		328	12.0	135	104	4500	5:15	128	230	65/35 A/POZ
A	y		328	12.0	98	85	1500	4:00+	325	360	A
B	y		328	12.0	142	108	5100	4:28	120	185	65/35 A/POZ
F	y		200	12.0	166	166	8050	5:17	270	1090	Micro-fine
B	y		190	12.0	98	85	1500	4:00+	40	120	H
B	y		200	12.0	97	85	1500	6:00+	30	75	H
HES-11	y		385	12.0	189	151	11390	6:07		567	TLW
B	y		380	12.0	120	99	4393	5:30	140	250	H
HES-11	y		380	12.0	141	113	6000	5:39	285	776	TLW
A	y		380	12.0	140	112	5800	6:24	130	200	H
B	y		380	12.0	100	83	1300	7:00+	120	240	H
HES-11	y		420	12.0	201	167	14300	4:43	237	1560	TLW
B		n		12.0	120	97	3300	5:00+	25	25	65/35 H/POZ
F		n		12.0	92	80	800	6:00+	182	324	A
B	y		37	12.0	126	104	4600	4:57	90	190	H
HES-11	y		37	12.0	115	96	3000	5:00+	121	487	TLW
A	y		35	12.0	126	103	4500	6:30+	211	244	H
A	y		29	12.0	125	101	4100	5:00+	230	405	A
A	y		65	12.0	140	108	5150	6:00+	170	220	A
A	y		65	12.0	140	107	5000	4:00+	230	380	A
A	y		30	12.0		114	6000	7:00+	185	250	H
B	y		48	12.0	116	96	3000	5:37	160	200	H
F	y		50	12.0	144	119	5800	2:34	270	580	Micro-fine
F	y		55	12.0	140	116	5852	3:20	260	610	Micro-fine
F	y		60	12.0	165	138	9065	5:00+			Micro-fine
B	y		60	12.0	129	102	4100	6:01	80	240	H
HES-7	y		60	12.0		145	9265	7:00+			H
HES-7	y		60	12.0	88	80	800	5:00+	40	50	H
HES-7	y		60	12.0	120	98	3700	5:00+	45	60	H
B	y		55	12.0	92	80	1000	4:00+	25	130	H
HES-7	y		55	12.0	120	98	3700				H
F	y		60	12.0	165	138	9065	6:30+	260	930	Micro-fine
HES-7	y		60	12.0	90	80	1000	6:00+		0	H
F	y		60	12.0	165	138	9065	0:59			Micro-fine
HES-7	y		60	12.0	167	145	9265				H
HES-7	y		60	12.0	167	145	9265	7:00+	186	265	H
HES-11	y		96	12.0	94	83	1856	4:30+			TLW
B	y		90	12.0	202	154	11210	5:30+	189	330	65/35 H/POZ
F	y		90	12.0	188	188	9200	6:25	195	1690	Micro-fine
F	y		90	12.0	0	190	10000	3:15	520	870	Micro-fine
B	y		90	12.0	180	144	11950	4:42	268	1051	65/35 H/POZ
B	y		90	12.0	180	144	11950	4:57	0	955	65/35 H/POZ
F	y		90	12.0	192	159	10135	4:23	1054	1077	Micro-fine

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		60	12.0	93	81	1110	6:00+	160	240	H
B	y		60	12.0	93	81	1110	6:00+	120	230	H
B	y		60	12.0	138	106	4820	6:57	140	180	H
B	y		110	12.0	131	102	4230	4:53	170	210	H
B	y		60	12.0	120	98	3320	7:30+	90	150	H
B	y		60	12.0	120	98	3320	5:55	200	280	H
B	y		105	12.0	115	96	3000	4:30+	58	192	H
HES-11	y		75	12.0	129	102	4300	6:58	464	1260	TLW
F	y		105	12.0		210	11576	4:52	340	550	Micro-fine
F	y		110	12.0		160	7120	4:44	370	980	Micro-fine
F	y		113	12.0		148	8300	4:15	390	1000	Micro-fine
F	y		130	12.0	215	177	11300	4:18	890	990	Micro-fine
HES-11	y		184	12.0	135	104	4500	6:00+	93	230	TLW
HES-11	y		184	12.0	88	80	900		116	326	TLW
HES-11	y		184	12.0	135	104	4500	3:00			TLW
HES-11	y		184	12.0	117	96	3000	4:00+	221	867	TLW
A	y		200	12.0	118	97	3670	4:00+	150	190	A
A	y		235	12.0	133	103	5400	3:30+	372	328	A
A	y		235	12.0	98	85	1500	3:00+	126	238	A
A	y		235	12.0	132	103	4570	4:00+	228	318	A
A	y		235	12.0	98	85	1500	3:00+	130	252	A
F	y		235	12.0	85	84	500	4:00+	189	303	Micro-fine
HES-11	y		280	12.0	133	104	4800	5:26	316	889	TLW
HES-11	y		370	12.0	125	90	4500	6:56	104	363	TLW
F	y		350	12.0	90	86	797	4:00+	150	190	Micro-fine
B	y		372	12.0	112	95	4280	6:45	110	170	H
F	y		372	12.0		205	16000	5:13	610	1280	Micro-fine
B	y		372	12.0	95	84	1500	5:00+	FIRM	90	H
B	y		372	12.0	95	84	1500	5:00+	20	110	H
A	y		25	12.0	128	101	4000	5:00+	280	340	A
A	y		25	12.0	125	100	4000	7:00+	260	330	A
B	y		30	12.0	139	108	5150	5:12	135	210	H
F	y		30	12.0	224	183	11130	3:21	760	1080	Micro-fine
B	y		181	12.0	174	134	10893	4:35	80	183	65/35 H/POZ
HES-11	y		181	12.0	96	86	1650	7:33	166	260	TLW
B	y		181	12.0	146	114	7250	5:30+	106	177	65/35 H/POZ
B	y		181	12.0	111	98	2591	7:00+	60	130	H
B	y		181	12.0	146	114	7250				65/35 H/POZ
HES-7	y		110	12.0	137	107	5000	5:30+	80	100	H
B	y		110	12.0	94	83	1300	5:00+	70	200	H
B	y		110	12.0	94	83	1300	5:00+	90	240	H
B	y		110	12.0	93	82	1200	4:00+	150	270	A
B	y		110	12.0	94	83	1300				H
B	y		110	12.0	125	102	4500	6:28	130	260	H
B	y		100	12.0	158	120	6685	2:56	120	190	H
B	y		100	12.0	88	80	800	6:00+	25	130	H
F	y		100	12.0	170	145	11000	3:47	650	1520	Micro-fine
B	y		100	12.0	96	84	1450	5:00+	30	90	H
HES-11	y		100	12.0	91	80	1000	5:30+	81	155	TLW
B	y		100	12.0	93	81	1100	5:00+	50	90	H
F	y		100	12.0	228	190	11882	3:10	910	655	Micro-fine
B	y		100	12.0	96	84	1450	8:00+	FIRM	90	A
B	y		100	12.0	93	81	1100	5:00+	170	260	H
HES-11	y		100	12.0	134	104	4500	4:33	445	975	TLW
B	y		100	12.0	152	115	6000	7:04	60	250	H
B	y		100	12.0	113	95	3000	6:36	60	120	H
HES-11	y		100	12.0		104	4600	6:30+	257	703	TLW
F	y		140	12.0	166	135	7200	3:38	621	981	Micro-fine
F	y		60	12.0	195	160	9672	3:45	650	1670	Micro-fine
F	y		164	12.0	0	182	8500	3:45	100	540	Micro-fine
F	y		164	12.0	182	182	8500	2:17	680	720	Micro-fine
F	y		40	12.0		199	9900	4:38	440	1030	Micro-fine
F	y		40	12.0		199	9900	5:26	430	1020	Micro-fine
F	y		230	12.0	200	200	10086	4:06	450	1300	Micro-fine
HES-11	y		211	12.0	125	103	4500	6:20	116	310	TLW
HES-11	y		180	12.0	125	103	4500	4:50			TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		303	12.0	126	103	4889	5:08	330	720	TLW
HES-11	y		380	12.0	95	84	1400	5:00+	129	367	TLW
HES-11	y		380	12.0	95	84	1400	3:30	145	367	TLW
F	y		280	12.0	0	80	585	5:27	FIRM	90	Micro-fine
A	y		288	12.0	139	105	5550	5:00+	138	242	A
A	y		288	12.0		78	1300	5:00+		313	A
HES-11	y		288	12.0	139	105	5550	4:12	70	330	TLW
A	y		288	12.0		90	4600	6:00+		265	A
A	y		288	12.0	140	107	5000	5:00+	90	190	A
A	y		288	12.0	95	83	1300	6:00+	279	380	A
HES-11	y		288	12.0	139	105	5550	4:12	70	330	TLW
B	y		62	12.0	92	80	1000	6:00+	60	120	H
B	y		62	12.0	134	104	4500	6:00+		140	H
B	y		62	12.0	134	104	4500	5:04	270	340	H
B	y		62	12.0	124	98	4200	6:00+	90	150	H
B	y		62	12.0	92	80	1000	6:00+		140	H
B	y		62	12.0	128	100	4000	5:03	130	220	H
B	y		62	12.0	92	80	1000	6:00+		100	H
B	y		62	12.0	134	104	4500	4:01	250	315	H
B	y		62	12.0	124	100	4000	5:30	190	260	H
HES-7	y		62	12.0	187	161	11745	6:30+	228	310	H
B	y		62	12.0	134	104	4500	7:15	190	240	H
B	y		62	12.0	92	80	1000	6:00+	60	90	H
B	y		62	12.0	124	100	4000	5:00	70	160	H
B	y		62	12.0	124	98	4200	6:00+	120	140	H
B	y		55	12.0	90	80	800	4:00+	30	90	H
B	y		63	12.0	114	94	3000	6:15+	70	135	H
F	y		62	12.0	215	177	11050	3:43	900	1220	Micro-fine
B	y		62	12.0	135	105	4600	5:00	160	215	H
B	y		62	12.0	135	105	4600	4:30+	185	235	H
B	y		62	12.0	92	80	1000	4:00+	100	170	H
HES-11	y		62	12.0	112	94	2650	4:00	293	527	TLW
F	y		62	12.0	224	193	12077	2:36	650	990	Micro-fine
B	y		62	12.0	132	104	4500	6:37	90	200	H
F	y		80	12.0	130	130	5820	6:08	100	310	Micro-fine
		n		12.0	124	100	4000	6:00+	110	180	A
F		n		12.0	225	184	11200	3:10	1050	1260	Micro-fine
B		n		12.0	110	95	3000	5:00+	145	240	65/35 A/POZ
B		n		12.0	115	96	3000	8:00+			65/35 A/POZ
F	y		50	12.0	181	147	8500	4:27	470	920	Micro-fine
F	y		50	12.0	235	196	13061	6:20	790	950	Micro-fine
B		n		12.0	125	97	3100	10:12	120	390	85/15 H/POZ
B		n		12.0	125	97	3100	2:46	200	235	85/15 H/POZ
F		n		12.0	205	174	9582	3:47	830	1150	Micro-fine
B		n		12.0	136	104	4500	3:08			65/35 A/POZ
B		n		12.0	97	84	1400	5:00+			65/35 A/POZ
		n		12.0	129	101	4280	5:00+	60	120	A
F		n		12.0	180	142	6200	5:30+			Micro-fine
F		n		12.0	160	129	6300	3:02	990	1000	Micro-fine
F		n		12.0	115	100	2700			1100	Micro-fine
F		n		12.0	115	100	2700	3:00+	345		Micro-fine
A	y		50	12.0	124	100	4000	6:00+	300	370	A
F		n		12.0	140	115	4300	4:00	240	610	Micro-fine
B		n		12.0	122	98	3500	6:00+			65/35 A/POZ
		n		12.0	122	98	3500	5:00+	124	245	A
B		n		12.0	114	95	3100	5:00+	90	110	65/35 A/POZ
B		n		12.0	124	100	4000	5:07	150	196	65/35 A/POZ
B		n		12.0	179	131	7630	6:00+			65/35 H/POZ
F		n		12.0	215	185	11000	4:10	750	1020	Micro-fine
		n		12.0	105	90	2000	5:00+	95	125	A
		n		12.0	122	97	3300	5:00+	SET	100	A
HES-10		n		12.0		80	1000			60	A
		n		12.0	135	105	4600	7:00+			A
B		n		12.0	126	100	3800	6:00+	1049	1510	65/35 H/POZ
B		n		12.0	105	91	2250	5:00+	40	100	65/35 A/POZ
		n		12.0	150	104	4200	9:22	60	140	85/15 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
		n		12.0	150	104	4200	2:45	239	300	85/15 H/POZ
HES-7	y		127	12.0	95	80	1000	6:00+	FIRM	550	H
A	y		75	12.0	134	103	4340	5:00+	150	180	A
A	y		103	12.0	134	104	4500	4:30+	306	318	A
A	y		100	12.0	92	80	1000	4:00+	47	289	A
A	y		90	12.0	125	98	3500	4:00+	194	253	A
A	y		90	12.0	90	80	800	4:00+	133	258	A
A	y		103	12.0	116	96	3800	3:00+	142	254	A
B	y		103	12.0	140	109	5500	6:32	114	348	65/35 A/POZ
B	y		103	12.0	94	83	1300	6:00+	84	170	65/35 A/POZ
A	y		110	12.0	92	80	1020	3:00+	97	206	A
A	y		110	12.0	89	80	800	4:00+	47	290	A
A	y		110	12.0	122	98	3500	4:00+	160	320	A
A	y		110	12.0	116	96	3000	4:00+	198	363	A
F	y		111	12.0	0	190	9716	3:59	400	1230	Micro-fine
A	y		111	12.0	138	106	5146	6:03	173	350	A
A	y		110	12.0	92	80	1000	4:00+	97	206	A
A	y		110	12.0	127	100	4610	4:00+	255	304	A
A	y		110	12.0	132	103	4330	4:00+	363	394	A
A	y		110	12.0	92	80	1000	4:30+	152	188	A
A	y		110	12.0	134	104	4500	4:00+	236	322	A
F	y		90	12.0	192	165	10722	3:05	870	1170	Micro-fine
A	y		110	12.0	125	103	4500	4:50	267	372	A
HES-7	y		127	12.0	135	107	5000	6:00+	FIRM	155	H
HES-7	y		127	12.0	103	88	1900	6:00+	30	105	H
HES-7	y		127	12.0	143	108	4973	6:00+	100	173	H
A	y		120	12.0	92	80	1000	4:00+	150	175	A
A	y		120	12.0	134	104	4500	4:00+	210	265	A
A	y		111	12.0	92	80	1000	4:00+	130	240	A
A	y		111	12.0	125	100	3800	4:00+	159	200	A
B	y		143	12.0	128	101	4597	5:00+	180	220	H
B	y		143	12.0	128	101	4597	5:31	200	230	H
B	y		143	12.0	93	81	1100	4:00+	135	210	H
A	y		181	12.0	92	80	1000	6:00+	124	221	H
A	y		181	12.0	128	101	4000	6:00+	150	250	H
B	y		186	12.0	166	128	10618	5:00+	260	480	65/35 H/POZ
B	y		186	12.0	148	112	9221	5:30+	220	250	65/35 H/POZ
F	y		202	12.0	130	110	5286	4:02	218	240	Micro-fine
F	y		210	12.0	150	150	5711	2:59	324	805	Micro-fine
A	y		215	12.0	132	103	4300	6:00+	170	225	H
A	y		220	12.0	125	99	3700	8:00+	210	250	H
A	y		220	12.0	128	101	4000	7:30+	121	237	H
A	y		220	12.0	128	101	4000	6:00+	187	200	H
B	y		290	12.0	145	110	5400	5:27	140	160	65/35 A/POZ
B	y		60	12.0	128	101	4000	4:42	99	285	H
B	y		60	12.0	89	80	750	4:00+	50	157	H
B		n		12.0	110	92	2500	5:00+	30	80	65/35 A/POZ
		n		12.0	122	94	2500	6:00+	140	210	A
B	y		122	12.0	174	130	7950	4:06	95	282	H
B	y		122	12.0	96	83	1350		160	380	H
B	y		122	12.0	96	83	1350	4:00+	120	195	H
B	y		120	12.0	185	136	8100	4:15	257	284	H
HES-7	y		108	12.0	93	80	1028	6:00+	FIRM	40	H
HES-7	y		320	12.0	120	105	5000	6:30+	SET	90	H
HES-7	y		722	12.0	150	117	8355	6:00+	70	100	H
B	y		1514	12.0		95	6000	4:00+	240	550	65/35 A/POZ
B	y		1514	12.0		95	6000	4:00+	130	200	65/35 A/POZ
HES-3	y		2649	12.0		75	3784	2:45			A
HES-3	y		2920	12.0		70	5000	5:30+	119	419	A
HES-3	y		3270	12.0		70	5200	3:23			FLOSTOP I
HES-3	y		3270	12.0		70	5200	4:34	140	340	FLOSTOP I
HES-3	y		3270	12.0		70	5200	3:42			FLOSTOP I
A	y		1051	12.0		76	2800	4:00+	128	300	A
A	y		1051	12.0		97	4882	6:00+	140	310	A
		n		12.0	128	103	4500	6:00+	60	130	A
F	y		40	12.0		140	4903	6:38	1041	1755	Micro-fine

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
F	y		40	12.0	275	275	11464	6:09	880	955	Micro-fine
HES-11	y		47	12.0		131	8200	4:25			TLW
B	y		45	12.0	88	80	700	4:00+	100	170	H
A	y		40	12.0	134	104	4500	5:00+	90	200	A
A	y		40	12.0	92	80	1000	4:00+	60	210	A
A	y		40	12.0	94	80	1000	6:30	220	465	A
A	y		35	12.0	134	104	4500	4:22	220	300	A
A	y		35	12.0	92	80	1000	4:00+	130	280	A
HES-7	y		44	12.0	134	104	4500	6:00+	90	160	H
HES-7	y		44	12.0	134	104	4500	8:00+	80	140	H
HES-7	y		20	12.0	139	106	4600	5:00+	150	180	H
HES-7	y		20	12.0	140	106	4700	5:00+	50	110	H
HES-7	y		20	12.0	139	105	4500	5:00+	80	150	H
HES-7	y		20	12.0	148	107	4700	8:00+	110	190	H
HES-7	y		20	12.0	148	107	4700	8:00+	160	220	H
B	y		53	12.0	113	95	3000	6:00+	95	150	H
B	y		53	12.0	93	80	1000	4:00+	130	195	H
B	y		53	12.0	150	111	6010	7:54	50	230	H
B	y		52	12.0	94	80	1050	4:00+	120	240	H
B	y		52	12.0	152	112	5500	7:30	0	160	H
HES-11	y		57	12.0	141	105	4500	4:19	766	1040	TLW
HES-11	y		57	12.0	141	105	4500	6:00+	561	662	TLW
HES-11	y		57	12.0	134	104	4900	5:00+	480	1093	TLW
A	y		62	12.0	89	80	800	6:00+	160	200	A
A	y		62	12.0	119	98	3500	5:00+	290	440	A
A	y		70	12.0	128	101	4000	4:00+	130	465	A
HES-11	y		38	12.0	134	104	4500	6:30+	500	891	TLW
F	y		66	12.0	167	136	7220	3:40	730		Micro-fine
B	y		22	12.0	172	125	7000	7:30+	186	470	65/35 H/POZ
B	y		145	12.0	123	98	5054	6:00+	60	100	H
HES-11	y		160	12.0	150	114	7150	2:20	640	840	TLW
HES-11	y		160	12.0	125	100	4400	4:30	430	625	TLW
HES-11	y		160	12.0	125	100	4400	5:16			TLW
HES-7	y		160	12.0	160	128	9451	5:00+	130	200	H
F	y		153	12.0	158	135	7800	3:41	196	940	Micro-fine
HES-11	y		175	12.0	97	84	1950	5:30+	108	247	TLW
F	y		184	12.0	150	123	6000	3:32	260	820	Micro-fine
F	y		184	12.0	85	84	500	4:00+	220	247	Micro-fine
F	y		291	12.0		240	1074	3:00	1240	1590	Micro-fine
A	y		256	12.0	83	82	586	4:00+	0	98	H
A	y		300	12.0	138	105	4500	5:00+	120	140	H
F	y		300	12.0	0	117	3918	3:48	160	480	Micro-fine
F	y		300	12.0	0	103	2298	4:15+	150	450	Micro-fine
A	y		40	12.0	95	82	1175	5:00+	91	228	H
A	y		40	12.0	144	109	5300	8:00+	243	345	H
A	y		296	12.0	118	96	3000	5:00+	330	420	A
A	y		296	12.0	116	96	3000	5:00+	170	240	A
F	y		325	12.0	120	120	3054	5:00	155	190	Micro-fine
HES-11	y		354	12.0	135	98	3129	5:30	440	975	TLW
HES-11	y		35	12.0		102	4500	6:15	61	125	TLW
HES-11	y		35	12.0		102	4500	6:48	52	234	TLW
B	y		36	12.0	170	128	7595	6:42	170	260	65/35 H/POZ
B	y		40	12.0	129	99	3500	6:30	220	260	H
B	y		40	12.0	89	80	750	5:30+	130	210	H
HES-11	y		85	12.0	92	80	1000	6:00+	50	125	TLW
HES-11	y		240	12.0	207	166	13380	6:17	75	815	TLW
A	y		245	12.0	110	93	2500	4:00+	160	310	A
HES-11	y		225	12.0	188	150	11370	4:52	497	1194	TLW
HES-11	y		225	12.0	210	169	14000	7:33	0	1322	TLW
HES-11	y		225	12.0	210	169	14000	5:22	95	954	TLW
B	y		210	12.0	120	98	3600	4:00+	150	260	H
B	y		240	12.0	120	98	3600	6:20	115	188	H
B	y		210	12.0	181	136	8593	3:53	540	550	H
HES-11	y		210	12.0	120	98	3600	6:00+	110	250	TLW
F	y		40	12.0	233	196	13640	3:21	605	1340	Micro-fine
A	y		54	12.0	90	80	850	5:00+		81	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		54	12.0		92	4500	4:14			A
A	y		54	12.0	145	114	6025	5:00+			H
A	y		35	12.0	115	97	3500	5:23	157	332	A
B	y		68	12.0	93	82	1200	4:00+	105	170	H
B	y		68	12.0	130	103	4500	4:30+	110	310	H
B	y		105	12.0	138	106	4900	5:00+	60	160	H
HES-11	y		100	12.0		109	5150	4:50	368	730	TLW
F	y		126	12.0	87	85	558	5:00+	130	175	Micro-fine
HES-11	y		126	12.0	123	99	5965	4:00+	300	700	TLW
HES-11	y		126	12.0	108	92	4300	4:00+	100	340	TLW
F	y		126	12.0	123	106	5940	4:50	100	230	Micro-fine
HES-7	y		126	12.0	190	145	9792	4:05	158	167	H
HES-11	y		151	12.0	106	91	4533	5:00+	155	260	TLW
HES-11	y		151	12.0	132	103	7660	4:00+	270	530	TLW
HES-11	y		151	12.0	124	100	6029	5:00+	230	520	TLW
HES-7	y		152	12.0	229	183	13866	6:00+	91	135	H
HES-7	y		155	12.0	208	161	12288	4:50	573	800	H
HES-7	y		155	12.0	222	174	14554	5:30+	186	224	H
F		n		12.0		92	1000	5:50			Micro-fine
F		n		12.0		92	1000	5:00+		203	Micro-fine
B	y		28	12.0	136	103	4300	4:20	181	236	H
B	y		28	12.0	136	103	4300	4:36			H
B	y		28	12.0	136	103	4300	6:18	103	108	H
B	y		28	12.0	136	103	4300	3:03		196	H
B	y		28	12.0	136	103	4300	5:29			H
A	y		36	12.0	146	111	5425	5:30+		180	H
B		n		12.0	106	90	2000	4:41		659	65/35 A/POZ
F		n		12.0	116	101	3000	5;12	95	220	Micro-fine
		n		12.0	120	96	3000	7:00+	50	200	A
F		n		12.0	205	165	8896	3:07			Micro-fine
B		n		12.0	123	99	3600	5:00+	0	96	65/35 A/POZ
B		n		12.1		230	14000			1030	75/25 POZ/A
B		n		12.1	215	165	11433	2:26			65/35 H/POZ
B	y		47	12.1		80	1000			96	65/35 A/POZ
HES-3	y		2761	12.1		80	4900	4:02	172	573	A
HES-3	y		2000	12.1		80	3500	4:02	183	580	A
HES-3	y		2841	12.1		80	4925	3:34		154	A
HES-3	y		2920	12.1		70	5000	3:51			A
HES-11	y		47	12.1	153	113	8100	5:15+	70	160	TLW
B	y		200	12.1	172	132	11000	3:47	166	233	H
B		n		12.1	170	127	7500	5:06	330	415	65/35 H/POZ
B		n		12.1	225	176	12100	6:03	890	940	65/35 H/POZ
HES-3	y		3270	12.1		65	5200	6:00+			FLOSTOP I
HES-3	y		3270	12.1		65	5200	7:10	57	345	FLOSTOP I
B	y		280	12.1	93	82	1200	4:30	131	176	H
HES-3	y		6224	12.2		70	7700	3:45	0	331	A
B		n		12.2	245	199	14900	7:34	970	990	65/35 H/POZ
HES-11		n		12.2	207	159	10600	4:30	522	1511	TLW
B		n		12.2	124	97	3200	3:10	250	290	85/15 A/POZ
B		n		12.2	190	145	9400	8:50	0	252	65/35 H/POZ
HES-11	y		20	12.2	159	120	6600	4:20	313	876	TLW
HES-11		n		12.2	173	132	8400	3:39	450	800	TLW
B	y		10	12.2	212	164	11000	6:30+	510	600	50/50 H/POZ
B	y		83	12.2	185	139	8800	3:20	140	310	65/35 H/POZ
B	y		83	12.2	197	150	9807	6:00+	210	370	65/35 H/POZ
B	y		83	12.2	191	145	9400	5:00+	85	235	65/35 H/POZ
B	y		83	12.2	185	139	8800	4:19	135	230	65/35 H/POZ
B	y		83	12.2	210	163	11600	6:00+	250	420	65/35 H/POZ
B	y		83	12.2	200	152	10320	3:31	120	170	65/35 H/POZ
HES-11	y		107	12.2	210	163	12227	4:08	0	1190	TLW
HES-11	y		167	12.2		90	1950	4:30+	189	557	TLW
B	y		20	12.2	116	96	3000	5:49			65/35 A/POZ
HES-3	y		1756	12.2		80	3500	4:03			FLOSTOP I
A		n		12.2	85	80	300		160	306	A
HES-3	y		1646	12.2		90	4200	4:46	475	580	FLOSTOP I
A	y		250	12.2	130	103	4835	4:00+	305	450	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		890	12.2	121	104	4500	5:30+	152	253	H
HES-3	y		1419	12.2		80	3500	7:20	253	450	A
HES-11		n		12.2	193	146	9450	3:54	505	824	TLW
B		n		12.2	224	171	10800	3:14			65/35 H/POZ
F	y		2521	12.2	0	107	7200	3:42	760	850	FLOSTOP I
F	y		2521	12.2	0	107	7200	3:38			FLOSTOP I
HES-3	y		2841	12.2		80	4925	2:46			A
HES-3	y		2588	12.2		70	3590	4:46			A
HES-3	y		4243	12.2		70	6321	4:30	0	324	A
B	y		50	12.2	230	181	13410	3:59			65/35 H/POZ
HES-11	y		350	12.2		110	5925	5:06	50	500	TLW
B	y		210	12.2	186	137	12735	6:30+	130	260	65/35 H/POZ
A		n		12.2		80	50			56	A
B		n		12.2	105	90	2100		51	91	65/35 A/POZ
HES-7	y		1000	12.2	100	90	2200	6:00+		48	H
HES-3	y		2100	12.2		70	3000	3:25	180	419	A
HES-3	y		2707	12.2		70	4105	4:00+	0	154	FLOSTOP I
HES-3	y		2707	12.2		70	4105	3:52	190	280	FLOSTOP I
HES-11	y		63	12.2	114	94	2800	5:00+	445	780	TLW
A	y		63	12.2	114	94	2800	5:00+	230	260	H
A		n		12.2	104	88	1800		170	255	A
B		n		12.2	215	167	11800	3:40	521		65/35 H/POZ
B		n		12.2	119	96	3000	3:02	380	520	85/15 A/POZ
B		n		12.2	220	172	11700	4:32			65/35 H/POZ
B	y		130	12.2	216	167	11624	5:30+	780	940	50/50 H/POZ
HES-8	y		50	12.2	92	80	800	6:00+	85	215	A
F	y		372	12.2	145	121	6800	3:40	275	1100	Micro-fine
HES-11	y		180	12.2	95	82	1250	6:00+	150	170	TLW
HES-11	y		380	12.2	130	103	4500	6:32	200	480	TLW
HES-3	y		50	12.2		80	960	3:30	965	1522	A
HES-11		n		12.2	200	148	9000	3:25			TLW
B		n		12.2		143	10150	4:00			50/50 H/POZ
	y		122	12.2	92	80	1000	4:00+	109	189	H
A	y		1136	12.2		90	5882	3:11	63	423	A
HES-3	y		3236	12.2		60	5200	4:37	0	190	FLOSTOP I
HES-11	y		167	12.2	130	101	4000	4:08	550	1240	TLW
HES-11	y		167	12.2	130	101	4000	4:51	700	850	TLW
HES-11	y		1490	12.3	121	103	4962	5:00	378	937	TLW
HES-11		n		12.3		96	2900	2:28	277	575	TXI
HES-11	y		126	12.3	184	139	10599	3:50	817	1330	TLW
HES-3	y		2672	12.3		70	3950	5:32			FLOSTOP I
HES-3	y		2672	12.3		80	3875	3:55	456	537	FLOSTOP I
HES-3	y		3907	12.3		70	3950	4:27			A
HES-11		n		12.3	96	82	1200	3:41	431	649	TXI
A	y		1419	12.3		95	6600	3:39			A
HES-3	y		1900	12.3		80	3800	3:43	76	242	A
HES-3	y		1419	12.3		80	3500	5:20	0	182	A
B		n		12.3	115	96	3000	8:00+	78	105	65/35 A/POZ
B		n		12.3	115	93	2500		290	367	50/50 TXI/POZ
B	y		46	12.3	200	151	9800	8:30	85	217	65/35 H/POZ
HES-11		n		12.3		96	2900	3:02	360	437	TXI
HES-3	y		5372	12.3		85	2000	4:45	656	1027	A
HES-3	y		1000	12.3	97	89	2000	3:07			A
A	y		60	12.3	142	107	4800	7:17	199	262	H
B		n		12.3	132	103	4400		576	720	Micro-fine
HES-11		n		12.3	132	103	4400	3:22	332	403	TXI
B	y		120	12.3	91	80	1000	4:00+	180	220	A
B	y		120	12.3	165	127	7800	4:48	380	640	H
HES-7	y		200	12.3	220	172	13450	5:55	555	1300	H
HES-3	y		2100	12.3		70	3000	2:38	111	436	A
B	y		85	12.3	93	80	1000	5:00+	120	230	H
HES-11	y		1564	12.3		93	7400	3:50	160	669	TLW
HES-3	y		3343	12.3		65	5200	3:30+			FLOSTOP I
B	y		35	12.3	90	80	900	7:00+	180	230	65/35 A/POZ
HES-7	y		3845	12.3	0	63	7000	6:00+	78	148	A
B		n		12.3	125	97	3200	4:55	170	320	85/15 A/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		35	12.3	120	98	3600	3:22	170	370	65/35 A/POZ
B	y		110	12.3		245	15500	3:43	164	197	HTLD
B	y		52	12.3	318	276	17000	9:10			65/35 H/POZ
B	y		52	12.3	318	276	17000	9:00+			65/35 H/POZ
B		n		12.3	120	97	3263		640	670	85/15 A/POZ
HES-3	y		1334	12.3		70	2750	5:04	270	850	FLOSTOP I
HES-3	y		1753	12.3		70	4500	2:41	FIRM	170	FLOSTOP I
HES-11	y		3236	12.3		110	10208	3:55	280	504	TLW
HES-3	y		1756	12.3		80	3400	6:58	150	250	FLOSTOP I
B		n		12.3	170	118	6000	3:18	280	560	65/35 H/POZ
HES-3	y		1756	12.3		80	3500	3:45	360	560	FLOSTOP I
HES-3	y		1753	12.3		70	4500	2:41	FIRM	170	FLOSTOP I
HES-7	y		1025	12.3		115	12000	5:30+	162	210	H
HES-3	y		3105	12.3		57	5020	5:00+	FIRM	160	FLOSTOP I
HES-3	y		3105	12.3		78	7170	5:00+	FIRM	160	FLOSTOP I
HES-3	y		6588	12.3		65	7425	4:40	FIRM	190	FLOSTOP I
HES-3	y		1074	12.3		71	2408	2:56	FIRM	380	FLOSTOP I
B	y		70	12.3	256	207	13500	9:00+	0	90	65/35 H/POZ
B	y		35	12.3	125	97	3100	4:03	345	390	65/35 A/POZ
HES-3	y		3500	12.3		65	5475	5:40			FLOSTOP I
HES-11	y		35	12.4	140	107	5000	4:47	274	671	TLW
HES-11	y		18	12.4	160	123	7270	3:32	539	1041	TLW
HES-11	y		16	12.4		113	6200	4:19			TLW
HES-11	y		13	12.4	140	113	6000	4:48		1250	TLW
HES-11	y		35	12.4	154	116	6200	3:28	777	1447	TLW
HES-11	y		13	12.4	146	114	6000	3:52	470	1338	TLW
HES-11	y		13	12.4	146	114	6000	3:42	541	1185	TLW
B		n		12.4		80	50			180	H
HES-11	y		20	12.4	148	115	6200	3:40	500	1260	TLW
F	y		100	12.4	200	200	10500	2:45	542	1920	Micro-fine
HES-11	y		16	12.4	138	109	5320	3:30+	0	1027	TLW
HES-11	y		16	12.4	140	109	5420	4:25	397	895	TLW
HES-11	y		16	12.4	92	82	1200	7:00+		157	TLW
HES-11	y		13	12.4	92	82	1200	7:00+		138	TLW
HES-11	y		18	12.4	93	82	1200	7:42		417	TLW
F	y		220	12.4	148	121	5645	1:38			Micro-fine
HES-11	y		13	12.4	140	113	6000	3:52			TLW
B		n		12.4	177	133	8100	3:56	320	620	65/35 H/POZ
B	y		40	12.4	120	98	3500	6:00+	164	262	65/35 A/POZ
HES-11		n		12.4	186	139	8500	4:55			TLW
F	y		950	12.4		60	600	4:00+	0	99	Micro-fine
B	y		90	12.4	238	181	13110	7:00+			65/35 H/POZ
B	y		90	12.4	203	152	10650	6:22			65/35 H/POZ
B	y		90	12.4	203	152	10650	2:07	173	546	65/35 H/POZ
B		n		12.4	236	188	13000	4:13	357	647	65/35 H/POZ
B		n		12.4	100	91	1485	4:04	169	331	65/35 A/POZ
F	y		100	12.4	200	200	10500	1:25			Micro-fine
HES-11	y		365	12.4		106	5000	7:00+	753	951	TLW
B	y		37	12.4	135	105	4600	6:00+	110	251	65/35 H/POZ
B	y		35	12.4	135	106	4900	6:00+	164	373	65/35 H/POZ
HES-11	y		365	12.4		86	1955	4:26	113	421	TLW
B	y		120	12.4	158	120	6800	5:30+	167	322	65/35 H/POZ
B	y		100	12.4		95	4140	4:30+	55	136	65/35 H/POZ
B		n		12.4		80	50			108	A
B		n		12.4	116	96	3000	5:00+	50	131	65/35 H/POZ
B		n		12.4	230	182	12800	3:20	672	1009	65/35 H/POZ
B		n		12.4	245	196	12800	5:50			65/35 H/POZ
B		n		12.4	220	172	11700	4:57	537	904	65/35 H/POZ
B		n		12.4	218	169	11670	2:25	50	852	65/35 H/POZ
B	y		56	12.4	200	151	9647	5:30+	0	344	65/35 H/POZ
HES-11		n		12.4	138	105	4600	4:10			TLW
B	y		60	12.4	172	128	7600	5:00+	286	822	65/35 H/POZ
HES-3	y		2588	12.4		70	3590	3:37	104	681	A
B		n		12.4	150	109	5000	4:28	185	326	65/35 A/POZ
B		n		12.4	130	101	4000	6:00+	139	237	65/35 H/POZ
B	y		40	12.4	138	104	4500	7:13	144	260	65/35 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B		n		12.4	136	104	4500	4:03	96	170	65/35 A/POZ
B		n		12.4	116	96	3200	6:30+		198	65/35 A/POZ
B	y		40	12.4	120	98	3500	3:00			65/35 A/POZ
B	y		53	12.4	193	139	8880	5:30+	0	115	65/35 H/POZ
F		n		12.4	133	111	4412	1:52	576	1056	Micro-fine
B		n		12.4		80	50			89	A
B		n		12.4		90	0	3:36	98	168	A
HES-11	y		145	12.4	140	107	5008	5:44	289	353	TLW
HES-11	y		170	12.4	130	102	4683	5:35	415	707	TLW
B	y		40	12.4	135	135	4513	3:26			65/35 H/POZ
HES-11	y		326	12.4	102	90	2167	6:50			TLW
F	y		200	12.4		170	9910	3:39	1148	1200	Micro-fine
HES-11	y		326	12.4	91	81	1100	9:21		256	TLW
F	y		200	12.4		170	9910	7:00+			Micro-fine
HES-3	y		2588	12.4	62	60	3590	3:15(5:5			A
B	y		30	12.4		94	2800	4:14			H
B	y		30	12.4		94	2800	7:55			H
HES-11	y		95	12.4	148	109	5000	4:59	855	1140	TLW
B	y		80	12.4	134	104	4500	6:00+			65/35 A/POZ
B		n		12.4	134	104	4500	8:00+			65/35 A/POZ
F		n		12.4	250	210	14200	4:30+	811	1689	Micro-fine
HES-11	y		326	12.4	102	90	2167	6:50			TLW
E		n		12.4	175	127	7200	3:30	110	150	H
A	y		93	12.4	104	90	2000	10:00+(*	90	290	A
B	y		93	12.4	104	90	2000	6:30	140	160	H
B	y		80	12.4	230	181	13366	5:08	90	130	65/35 H/POZ
A	y		140	12.4	132	101	4323	5:00+	240	260	H
B		n		12.4	93	80	1000			230	65/35 A/POZ
B	y		83	12.4	204	156	11006	4:00+			65/35 H/POZ
HES-7	y		160	12.4	175	129	8972	6:00+	161	233	H
HES-7	y		160	12.4	175	129	8340	5:30+	210	320	H
HES-7	y		210	12.4		94	3200		0	167	H
HES-7	y		210	12.4		94	3200		0	86	H
B	y		20	12.4	118	97	3200	5:30+	80	180	65/35 A/POZ
B	y		20	12.4	90	80	800	5:00+	75	110	65/35 A/POZ
HES-11	y		80	12.4	225	176	13090	4:31	1318	1580	TLW
HES-7	y		160	12.4	180	134	9105	5:40	200	290	H
B		n		12.4	212	165	11800	4:31	390	1010	65/35 H/POZ
B	y		120	12.4	189	143	9100	5:00+	210	280	65/35 H/POZ
B	y		55	12.4	218	170	12100	5:24	180	395	65/35 H/POZ
B	y		55	12.4	218	169	12100	3:32	800	1400	65/35 H/POZ
B	y		55	12.4	200	154	11000	3:05	225	400	65/35 H/POZ
B	y		55	12.4	213	166	11700	4:21	140	380	65/35 H/POZ
B		n		12.4	115	93	2500	5:00+	200	340	65/35 A/POZ
B	y		80	12.4	254	205	15774	8:04	0	60	65/35 H/POZ
B		n		12.4	217	168	11400	4:02	600	650	65/35 H/POZ
B	y		70	12.4	248	201	14000	3:50	40	140	65/35 H/POZ
B		n		12.4	295	248	15470	5:02	825	1070	65/35 H/POZ
B		n		12.4	250	202	14675	4:20	740	860	65/35 H/POZ
HES-7	y		160	12.4	170	126	8432	6:00+	231	310	H
HES-7	y		158	12.4	144	107	5467	7:00+	165	630	H
B		n		12.4	266	219	14300	8:00+	590	660	65/35 H/POZ
B		n		12.4	162	122	6900	5:06	110	240	65/35 H/POZ
B	y		83	12.4	204	156	11006	3:15	210	340	65/35 H/POZ
B	y		83	12.4	193	146	9800	3:51	120	240	65/35 H/POZ
HES-11	y		219	12.4	116	96	3000	5:24	154	506	TLW
HES-11	y		415	12.4	158	119	12200	3:54	817	1100	TLW
HES-11	y		650	12.4	138	108	5300	4:50	629	1160	TLW
HES-11	y		170	12.4	122	101	4260	5:00+	190	388	TLW
HES-11	y		170	12.4	122	101	4260	5:00+	218	404	TLW
HES-11	y		57	12.4	141	105	4500	5:17	486	684	TLW
HES-11	y		219	12.4	137	104	4350	4:15			TLW
B	y		20	12.4	90	80	800	5:00+	75	110	65/35 A/POZ
HES-11	y		219	12.4	116	96	3000	5:40	283	1010	TLW
B	y		90	12.4	180	144	11950	4:07	359	742	65/35 H/POZ
HES-11	y		15	12.4	122	98	3500	5:03	380	710	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		15	12.4	122	98	3500	6:00+	309	775	TLW
F	y		140	12.4		80	240	2:05	325	500	Micro-fine
B		n		12.4	203	153	9817	3:45			65/35 H/POZ
B		n		12.4	135	104	4400	6:00+			65/35 A/POZ
F		n		12.4	250	210	14200	2:52	850	1139	Micro-fine
HES-11	y		168	12.4	126	99	3500	3:55	0	0	TLW
B		n		12.4		80	1000		182	285	85/15 A/POZ
B		n		12.4	210	160	10400	5:35	600	660	65/35 H/POZ
B	y		49	12.4		98	4385	4:18	245	465	H
B	y		83	12.4	204	156	10725	3:06	105	298	65/35 H/POZ
B		n		12.4	210	160	10400	3:35	640	1160	65/35 H/POZ
B	y		83	12.4	204	156	10970	4:03	103	250	65/35 H/POZ
B		n		12.4	224	162	9650	3:36	490	1040	65/35 H/POZ
B	y		83	12.4	215	159	9807	3:48	90	710	65/35 H/POZ
B		n		12.4	145	108	4900	6:40	220	340	65/35 A/POZ
B	y		83	12.4	206	158	10582	5:12	550	900	65/35 H/POZ
HES-3	y		2081	12.4		70	3700	4:38	200	350	FLOSTOP I
F	y		52	12.4	120	103	3300	5:08	587	875	Micro-fine
B	y		250	12.4	245	200	15050	4:07	106	240	65/35 H/POZ
B	y		250	12.4	245	199	17842	5:36		215	65/35 H/POZ
B		n		12.4	150	115	6000	5:00+			65/35 H/POZ
B	y		83	12.4	210	163	11900	6:20	486	714	65/35 H/POZ
B	y		122	12.4	178	134	8250	6:22	140	440	65/35 H/POZ
B		n		12.4	238	190	13281	6:03			65/35 H/POZ
A	y		255	12.5		73	1340	5:30+		368	A
A	y		130	12.5	95	83	1470	4:49	524	856	A
HES-11	y		265	12.5	90	82	1200	6:05	143	370	TLW
A	y		70	12.5	92	82	1000	3:00+	369	513	A
A	y		84	12.5	92	82	1000	3:30+	211	408	A
A	y		130	12.5	94	82	1300	4:00+	258	469	A
HES-11	y		75	12.5	106	93	2963	6:00+			TLW
HES-3	y		5372	12.5		85	2000	4:56	298	932	A
A	y		130	12.5	107	93	3402	4:00+	225	425	A
HES-11	y		155	12.5	122	98	3500	5:58	396	1291	TLW
HES-11	y		127	12.5	118	97	3748	5:45+	139	205	TLW
HES-11	y		116	12.5	118	97	3748	4:35	0	646	TLW
HES-11	y		127	12.5	118	97	3748	4:45	173	418	TLW
A	y		53	12.5	125	97	3200	2:39			A
A	y		70	12.5	133	99	4000	3:15			A
A	y		23	12.5	126	100	6000	4:30+	289	316	H
HES-11	y		127	12.5	122	98	3798	6:22	216	671	TLW
HES-11	y		116	12.5	122	98	3798	5:18	440	1251	TLW
HES-11	y		127	12.5	125	99	3865	5:56	319	1054	TLW
A	y		255	12.5	115	101	4350	2:22			A
F	y		1736	12.5		80	4200	2:23			TLW/Micro-fine
F	y		1736	12.5		80	4200	2:48			TLW/Micro-fine
F	y		1736	12.5		80	4200	3:00			TLW/Micro-fine
HES-11	y		116	12.5	125	101	4816	4:23	421	711	TLW
A	y		1736	12.5		80	4200	3:28			TLW
A	y		1736	12.5		80	4200	6:00	94	279	TLW
A	y		255	12.5	122	101	4200	3:25	445	678	A
A	y		170	12.5	136	105	4700	6:00+		263	H
HES-11	y		90	12.5	134	102	4200	4:58	201	338	TLW
A	y		76	12.5	130	102	4300	4:00+	320	455	H
HES-11	y		100	12.5	131	104	4600	6:30+	333	442	TLW
B		n		12.5	138	104	4500	6:00+	110	418	65/35 A/POZ
HES-3	y		500	12.5		59	5100	5:00	121	503	A
A	y		90	12.5	146	111	7160	3:14	192	331	H
HES-11	y		90	12.5	144	109	5300	5:15	565	1800	TLW
HES-3	y		3270	12.5		74	6700	5:24	54	140	A
B	y		2161	12.5		93	7400		189	377	65/35 A/POZ
HES-3	y		5370	12.5		60	7600	4:30+	50	108	A
HES-11	y		100	12.5	186	137	8876	3:15	671	1471	TLW
B	y		80	12.5	170	136	9000	5:15		200	65/35 H/POZ
HES-3	y		6500	12.5		65	9150	3:50	185	800	A
HES-11	y		127	12.5	195	147	9945	3:20	1012	1182	TLW

*Slurry Type	Offshore		Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi)		Base Cement Type
	Yes	No							12 hr	24 hr	
HES-11	y		116	12.5	194	145	10332	3:08	834	873	TLW
HES-11	y		98	12.5	189	144	9540	4:45	0	223	TLW
HES-11	y		98	12.5	205	158	13450		229	400	TLW
HES-11	y		127	12.5	208	158	12466	3:14	658	950	TLW
HES-3	y		5370	12.5		92	10750	3:59			A
HES-3	y		6500	12.5		85	11200	2:30	267	610	A
HES-11	y		127	12.5	219	169	12222	4:10	928	1115	TLW
B		n		12.5	230	180	11900	4:30	275	1200	75/25 POZ/H
B		n		12.5	230	180	11900		270	1065	75/25 POZ/H
HES-11	y		90	12.5	221	176	13829	4:42	1139	1436	TLW
B	y		30	12.5	230	182	13500	6:30	1044	1254	50/50 H/POZ
HES-11	y		90	12.5	225	179	13900	3:45			TLW
F	y		300	12.5	105	95	2700	2:30	624	1285	Micro-fine
HES-11	y		1736	12.5		95	6600	2:53			TLW
HES-11	y		1736	12.5		95	6600	3:23	121	595	TLW
F		n		12.5	204	169	11272	3:11	1334	1368	Micro-fine
F	y		106	12.5		228	13082	3:51	1250	2244	Micro-fine
F	y		106	12.5		228	13082	4:10	550	1730	Micro-fine
A	y		10	12.5	92	80	1000	4:00+	250	510	A
HES-11	y		10	12.5	92	80	1000	4:00+	280	520	TLW
A	y		10	12.5	92	80	1000	4:00+	100	380	A
A	y		10	12.5	92	80	1000	4:00+	278	607	A
HES-11	y		10	12.5	92	80	1000	4:00+	247	645	TLW
A		n		12.5	118	96	3000	2:39			A
A	y		2500	12.5		60	7000			436	A
A	y		2500	12.5		85	10000			512	A
HES-11	y		45	12.5	91	80	900	5:00+	193	230	TLW
A	y		184	12.5	90	80	900	5:00+	172	377	A
A	y		184	12.5	90	80	900	3:00+	150	330	A
HES-11	y		184	12.5	92	80	1000	5:00	221	521	TLW
HES-11	y		45	12.5	122	97	3500	3:38	528	771	TLW
HES-11	y		184	12.5	135	104	4500	1:50			TLW
HES-11	y		184	12.5	135	104	4500	4:30+	293	500	TLW
HES-11	y		209	12.5	139	109	7474	5:01	575	979	TLW
A	y		2588	12.5		73	6650	6:50			A
B	y		153	12.5	170	127	9550	4:09	199	528	65/35 H/POZ
HES-7	y		66	12.5	170	127	8688	4:30+	233	317	H
HES-7	y		155	12.5	169	128	8918	5:30+	0	50	H
HES-7	y		50	12.5	202	151	10750	4:30+	91	192	H
B		n		12.5	200	152	10760	4:07	847	934	65/35 H/POZ
HES-11	y		100	12.5		157	11130	3:04	798	949	TLW
B	y		100	12.5	207	159	11120	6:30+	540	865	50/50 H/POZ
HES-7	y		35	12.5	223	172	11000	6:00+	172	324	H
HES-7	y		85	12.5	214	167	12817	5:02	1600	2500	H
HES-7	y		85	12.5	214	167	12617	4:32	302	407	H
HES-11	y		32	12.5		225	15600	6:23			TLW
HES-11	y		32	12.5		254	15600	5:00			TLW
HES-11	y		60	12.5		283	19000	9:36			TLW
HES-11	y		167	12.5		87	1732	4:30	155	342	TLW
HES-7	y		124	12.5		152	9969	10:26	260	400	H
B	y		130	12.5		143	10800	5:45			H
HES-7	y		66	12.5		169	11562	11:00	370		H
B	y		63	12.5		237	15883	10:30+			HTLD
B	y		63	12.5		258	17400	11:38			HTLD
B	y		60	12.5		283	19000	7:16			HTLD
B	y		60	12.5		283	19000	7:10			HTLD
B	y		60	12.5		283	19000	8:38			HTLD
B	y		63	12.5		283	19000	5:30			HTLD
B	y		63	12.5		283	19000	5:34			HTLD
B	y		50	12.5		283	19000	12:38			HTLD
B	y		63	12.5		283	19000	8:32			HTLD
F		n		12.5	168	136	6976	3:05	1168	1297	Micro-fine
HES-11	y		100	12.5	193	161	11052	5:00+	357	946	TLW
A	y		79	12.5	92	80	1000	4:00+	110	270	H
HES-11	y		1450	12.5	121	103	4962	3:34			TLW
HES-11	y		1450	12.5	121	103	4962	4:10			TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		1491	12.5	121	103	4500	3:42	197	516	TLW
B		n		12.5		95	700	5:00+	105	227	65/35 A/POZ
B	y		150	12.5	92	80	1000		70	185	65/35 A/POZ
B	y		150	12.5	92	80	1000		102	224	65/35 H/POZ
A	y		158	12.5	93	80	1000		430	1376	A
A	y		98	12.5	109	92	4980	5:02	395	613	A
A		n		12.5	112	94	2700	5:44	80	333	A
HES-11	y		722	12.5		50	2500	6:00+	30	115	TLW
HES-11	y		722	12.5		78	2020	7:04	127	162	TLW
HES-11	y		722	12.5		78	2020		76	134	TLW
HES-11	y		2000	12.5		60	2600	6:00+	83	162	TLW
HES-11	y		12	12.5	110	93	2500	5:00+	448	920	TLW
A	y		424	12.5	100	89	2000	4:31	261	654	A
B	y		305	12.5	135	106	4700	5:51		379	65/35 H/POZ
B	y		150	12.5	129	102	4500	8:02	127	241	65/35 H/POZ
B		n		12.5	130	101	4000	7:00+			65/35 A/POZ
HES-11	y		2192	12.5		82	4507	4:00+	110	140	TLW
HES-11	y		3227	12.5		97	6430	5:00	102	115	TLW
B	y		3227	12.5		105	9260	4:38	180	270	65/35 A/POZ
B		n		12.5		240	15400	7:00+			H
HES-7	y		23	12.5	95	82	1200	4:00+	85	173	H
HES-7	y		23	12.5	190	143	9511	5:30+	510	1086	H
B	y		144	12.5	206	156	10300	4:02	262	607	65/35 H/POZ
B		n		12.5	97	84	1400	5:00+		138	65/35 A/POZ
A		n		12.5	97	84	1400	4:45		239	A
B		n		12.5	97	84	1400	4:39		244	A
B		n		12.5		144	8450	5:00+	223	1485	65/35 H/POZ
A		n		12.5		80	50			50	A
HES-11		n		12.5		175	11200	3:07	1174	1550	TLW
HES-11		n		12.5	226	175	11200	3:50			TLW
B		n		12.5	190	155	9174	3:55	480	820	H
B	y		50	12.5	167	125	7250	6:12			65/35 H/POZ
HES-11	y		18	12.5	144	109	5773	3:45	721	970	TLW
HES-11	y		18	12.5	151	115	6508	3:32	597	989	TLW
HES-11	y		18	12.5	151	114	6258	3:32	597	989	TLW
HES-11	y		13	12.5	151	113	6200	3:30	826	1060	TLW
F	y		47	12.5	105	94	2100	2:28	770	950	Micro-fine
B		n		12.5		80	1000		85	156	50/50 A/POZ
B		n		12.5	115	93	2500	4:01	361	512	50/50 TXI/POZ
A	y		385	12.5	130	103	4540	5:00+	275	404	H
B		n		12.5	183	138	8600	5:30+	317	627	65/35 H/POZ
B		n		12.5	212	165	11820	4:02	829	1364	65/35 H/POZ
B		n		12.5	250	202	15135	4:23	1097	1201	65/35 H/POZ
B		n		12.5	85	83	600	3:00+	121	182	65/35 A/POZ
B	y		210	12.5	88	80	856	6:00+	0	62	50/50 H/POZ
HES-11	y		385	12.5	95	83	1300	7:39	0	175	TLW
HES-11	y		385	12.5	95	83	1300	7:13	221	487	TLW
A	y		515	12.5		85	1750	5:00+			A
HES-11	y		222	12.5		80	1000	6:00+	150	349	TLW
HES-11	y		220	12.5		80	1000	6:00+	244	453	TLW
HES-11	y		750	12.5		86	1900	6:00+	159	429	TLW
HES-11	y		220	12.5		80	1000	6:00+	143	563	TLW
HES-11	y		210	12.5		84	1859	6:42	50	375	TLW
A	y		750	12.5		80	1750	5:50	162	379	A
HES-11	y		210	12.5		84	1859	6:00+	113	743	TLW
A	y		400	12.5		82	1200	5:00+	147	445	A
A	y		400	12.5		82	1200	5:00+	85	125	H
HES-11	y		550	12.5	105	94	2996	4:00+	191	502	TLW
A	y		340	12.5	103	91	2901	5:20	248	469	A
HES-11	y		385	12.5	110	93	2600	5:30	217	482	TLW
HES-11	y		385	12.5	110	93	2600	4:18	400	835	TLW
A	y		1072	12.5	90	80	2350	6:13	196	725	A
HES-11	y		50	12.5		90	2110	5:51	151	512	TLW
HES-11	y		45	12.5		93	2600	5:34	316	754	TLW
HES-11	y		50	12.5		93	2600	3:54	38	957	TLW
HES-11	y		280	12.5	110	95	6000	5:00+	126	527	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		342	12.5		90	3716	4:45	100	250	TLW
HES-11	y		342	12.5	111	96	3861	4:57		205	TLW
A	y		2672	12.5		80	3875	5:00+		99	A
A	y		280	12.5	116	97	4500	3:15	404	494	A
B		n		12.5	119	96	3000	3:59	115	202	65/35 A/POZ
A	y		1419	12.5		80	3500	5:00+	159	270	A
A	y		515	12.5		82	3000	5:00+	265	439	A
HES-11	y		290	12.5		95	3050	5:30+		945	TLW
HES-11	y		750	12.5		98	3800	4:00	308	974	TLW
HES-11	y		220	12.5		99	3575	6:00+	150	403	TLW
A	y		400	12.5	116	98	3600	4:48	304	620	A
A	y		300	12.5	116	98	3600	5:00+	116	265	H
HES-11	y		32	12.5		104	4500	5:35	288	1025	TLW
HES-11	y		340	12.5		102	4676	6:37	52	305	TLW
A		n		12.5		92	4700	6:30+	1588	2342	A
HES-11	y		300	12.5		105	5000	7:20	0	162	TLW
HES-11	y		2000	12.5		65	4500	3:48	0	60	TLW
HES-11	y		220	12.5		92	4450	6:00+	367	752	TLW
HES-11	y		280	12.5	128	102	4700	3:11		579	TLW
B	y		525	12.5	127	110	5896	6:37			65/35 H/POZ
HES-11	y		350	12.5		110	5925	3:30			TLW
HES-11	y		220	12.5	142	108	5200	3:33	147	882	TLW
HES-11	y		3200	12.5		70	5200	5:00+			TLW
HES-11	y		350	12.5		111	6030	7:43	0	1254	TLW
B	y		525	12.5	127	110	5896	4:00+	140	240	65/35 H/POZ
HES-11	y		33	12.5		119	6800	8:06	0	377	TLW
A	y		1419	12.5		95	6600	8:00+		265	H
A	y		1419	12.5		95	6600	3:41			A
HES-11	y		290	12.5		124	6500	6:30+	266	580	TLW
HES-11	y		290	12.5		124	6500	4:20	243	551	TLW
HES-7	y		1900	12.5		97	6100	6:00+		106	A
HES-7	y		1900	12.5		90	6100	6:00+	123	196	A
B		n		12.5	165	124	7100	3:45+	209	464	65/35 H/POZ
HES-7	y		1419	12.5		115	7700	5:30+	305	354	A
HES-7	y		1419	12.5		128	8900	7:00+			A
HES-11	y		32	12.5	174	132	8250	4:12	221	1129	TLW
HES-7	y		420	12.5		135	8160	6:00+	95	198	H
HES-11	y		120	12.5	181	138	9400	4:00	0	1609	TLW
HES-11	y		120	12.5	182	139	9060	3:26	489	1355	TLW
HES-11	y		170	12.5	210	156	9650	4:00	102	1556	TLW
HES-11	y		35	12.5	185	142	10700	3:37	262	1530	TLW
HES-7	y		420	12.5		145	10112	5:44			H
HES-11	y		40	12.5	215	161	10100	7:49		0	TLW
B	y		40	12.5	215	161	10100	10:30+	497	738	HTLD
HES-11	y		45	12.5		161	10000	9:48			TLW
HES-11	y		45	12.5		161	10000	10:45	0	0	TLW
HES-11	y		2000	12.5		95	11351	4:18	229	409	TLW
B	y		35	12.5	193	152	11140	4:14	198	1087	65/35 H/POZ
HES-11		n		12.5		161	10100	9:04	0	25	TLW
HES-11	y		385	12.5	206	160	11945	6:15		0	TLW
HES-11	y		420	12.5		164	12300	6:50	0	1205	TLW
HES-11	y		420	12.5		164	13371	5:25	0	1344	TLW
B	y		35	12.5	219	174	12900	3:43	699	1605	65/35 H/POZ
B	y		35	12.5	219	174	12900	4:12	142	1643	65/35 H/POZ
HES-11	y		420	12.5		180	14913	5:24	0	1222	TLW
HES-11	y		420	12.5		197	15165	4:00	1153	1402	TLW
B	y		63	12.5	349	317	19500	8:09	216	486	HTLD
B	y		63	12.5		260	19000	7:59	50	165	HTLD
HES-11	y		150	12.5	95	82	1200	5:30+	101	131	TLW
HES-11		n		12.5	320	271	16050	3:30	343	533	TLW
F		n		12.5	152	124	6000	0:24			Micro-fine
F		n		12.5	152	124	6000	2:50	1089	1653	Micro-fine
HES-11	y		120	12.5	182	148	8700	2:45	1290	1676	TLW
B	y		20	12.5	116	101	3050	3:53	134	249	65/35 A/POZ
HES-11	y		50	12.5		204	9560	3:02	717	1000	TLW
HES-11	y		55	12.5		156	9500	5:57	462	1142	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
A	y		844	12.5	108	95	3300	4:16	245	518	A
HES-11	y		360	12.5	136	105	5169	4:26	165	520	TLW
HES-11	y		360	12.5	136	105	5169	8:11	120	424	TLW
B	y		225	12.5	160	120	8100	5:00+	220	448	65/35 H/POZ
B		n		12.5	160	137	9700	3:10			65/35 H/POZ
HES-7	y		117	12.5		180	11970	8:00+	228	268	H
HES-7	y		45	12.5	196	159	14852	3:56	310	385	H
B		n		12.5	250	202	14000	4:11			65/35 H/POZ
HES-3	y		1010	12.5		60	3650		70	191	A
HES-3	y		1010	12.5		60	3650	6:00+	146	229	A
HES-11		n		12.5	228	179	12300	3:13	65	1123	TLW
F	y		800	12.5		60	600	4:00+	73	395	Micro-fine
A	y		450	12.5		60	1452	4:00+	100	160	H
A	y		450	12.5		60	1452	4:00+	68	266	H
A	y		295	12.5	120	100	3950	6:00+	169	340	H
A	y		295	12.5	120	100	3950	6:00+	149	324	H
A	y		372	12.5		95	4950	5:00+	130	190	H
A	y		450	12.5		95	4952	7:00+	178	220	H
A	y		450	12.5		95	4952	7:00+	155	321	H
A	y		295	12.5	130	105	4875	6:00+	163	257	H
B		n		12.5	230	180	11900	4:20	0	105	65/35 H/POZ
HES-11	y		10	12.5	229	181	12425	4:20	1122	1255	TLW
B		n		12.5	282	240	15764		92	265	H
B	y		237	12.5	120	99	3800	4:30+	142	235	65/35 H/POZ
A	y		645	12.5		83	4500	4:00+	153	300	A
HES-11	y		380	12.5	130	103	4500	5:27			TLW
A	y		645	12.5		90	4000	4:29	270	350	A
B		n		12.5	185	139	8750	5:30	0	770	65/35 H/POZ
B		n		12.5	190	140	8300	3:56			65/35 H/POZ
B		n		12.5	212	163	10700	4:33			65/35 H/POZ
B		n		12.5	240	175	10300	5:18	1000	1730	65/35 H/POZ
B		n		12.5	240	174	10100	5:16	158	480	65/35 H/POZ
F	y		2940	12.5		40	3210	4:00+			Micro-fine
F	y		2940	12.5		40	3210	6:00+		165	Micro-fine
A	y		3300	12.5		47	4140		0	92	A
B	y		220	12.5	130	102	4200	3:45	218	349	65/35 A/POZ
HES-3		n		12.5		60	4085			146	A
HES-3	y		3300	12.5		58	5340	5:00+	0	197	A
B		n		12.5	160	117	6300	4:00			65/35 H/POZ
B	y		122	12.5	165	127	7800	5:35	800	940	H
B	y		122	12.5	174	130	7950	4:44	182	527	H
B	y		122	12.5	185	136	8100	4:15	288	1121	H
B		n		12.5	188	142	9000	3:02	135	383	65/35 H/POZ
B		n		12.5	228	161	9000	3:32	880	960	65/35 H/POZ
B		n		12.5	224	174	11500	3:16	113	626	65/35 H/POZ
B		n		12.5	232	184	12756	6:22	702	1440	65/35 H/POZ
HES-3	y		3907	12.5		70	3950	2:59	121	669	A
B	y		325	12.5	144	122	7763	3:02	336	508	65/35 A/POZ
B	y		325	12.5	144	122	7763	3:10	224	562	65/35 A/POZ
A	y		45	12.5	120	103	3000	3:00+			H
A	y		45	12.5	120	103	3000	3:00+			H
HES-10	y		3855	12.5		50	5200	4:00+			TLW
HES-10	y		3855	12.5		50	5200	4:00+			TLW
HES-11	y		1754	12.5	111	94	2825		175	230	TLW
HES-11	y		1754	12.5		71	2825	4:44	170	235	TLW
HES-3	y		2700	12.5		55	2950	3:55	64	216	A
A	y		720	12.5	124	100	3800	6:00+	194	400	H
A	y		720	12.5	124	100	5623	3:31	255	500	A
B	y		50	12.5	122	98	3500	3:15	190	390	65/35 A/POZ
A	y		1754	12.5		70	3016	5:00+	0	120	TLW
HES-11	y		252	12.5	137	105	7000	5:00+	474	1494	TLW
HES-3	y		2700	12.5		70	4200	3:41	0	436	A
HES-3	y		2700	12.5		80	5300	3:00	0	563	A
HES-3	y		2700	12.5		90	5700	2:33	250	378	A
HES-11	y		1754	12.5		94	5560	5:00+	330	500	TLW
HES-11	y		1754	12.5	135	114	6325	3:26		310	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-3	y		4243	12.5		65	6321	4:05	121	787	A
HES-11	y		67	12.5	166	126	7500	4:20	215	1200	TLW
B	y		60	12.5	198	152	10300	5:03	182	921	H
B	y		4243	12.5		105	10900	4:49	0	180	65/35 H/POZ
HES-11	y		981	12.5	115	99	4000	4:16	185	427	TLW
HES-11	y		70	12.5	146	114	6000	4:02	610	717	TLW
HES-11	y		50	12.5	160	122	8300	3:45	1068	1250	TLW
HES-11	y		10	12.5	172	133	9000	2:42			TLW
HES-11	y		10	12.5	172	133	9000	5:08	159	1989	TLW
HES-11	y		138	12.5	182	137	9120	4:26	771	1509	TLW
HES-11	y		10	12.5	190	151	11138	4:05	0	1079	TLW
HES-11		n		12.5	223	173	12100	4:30			TLW
B	y		70	12.5	290	249	17500	6:55	252	309	HTLD
HES-11	y		70	12.5	322	281	17500	6:00+			TLW
B	y		70	12.5	322	281	17500	7:32	139	1362	HTLD
HES-7	y		41	12.5	100	85	1500	5:00+	110	180	H
HES-7	y		167	12.5	111	93	3925	4:00+	150	230	H
HES-7	y		167	12.5	129	102	8549	5:00+	150	220	H
HES-7	y		176	12.5	150	112	6100	5:00+			H
HES-7	y		41	12.5	166	125	7300	5:35	90	230	H
HES-7	y		41	12.5	166	125	7300	7:00+	320	330	H
B	y		150	12.5	188	136	10250	4:15	120	400	65/35 H/POZ
B	y		160	12.5	180	133	10000	5:40	101	372	65/35 H/POZ
B		n		12.5	168	126	7300	4:20	178	259	65/35 H/POZ
F		n		12.5	130	109	4215	1:50		586	Micro-fine
F		n		12.5	138	115	5132	1:30			Micro-fine
HES-3	y		2707	12.5		70	4105	4:00	124	497	FLOSTOP I
HES-3	y		3227	12.5		70	4875	3:47	114	468	FLOSTOP I
B	y		2096	12.5		100	6395	5:23	150	230	65/35 A/POZ
F	y		110	12.5	180	148	8900	3:35	1120	1410	Micro-fine
HES-3		n		12.5		70	3950	4:06	50	280	FLOSTOP I
HES-3		n		12.5		70	4150	3:33	830	880	FLOSTOP I
F	y		29	12.5	270	232	16316	5:48	1430	1480	Micro-fine
HES-3	y		1754	12.5		75	2825	3:24	125	500	FLOSTOP I
F		n		12.5	225	184	11200	3:26	1040	1280	Micro-fine
HES-11	y		3325	12.5		95	7100	5:11			TLW
A		n		12.5	85	80	300			460	A
B		n		12.5	230	181	12770	5:30+	760	1080	75/25 POZ/A
B		n		12.5	200	152	10000	7:00+	580	750	75/25 POZ/A
B	y		40	12.5	188	130	9021	3:33	485	1060	H
B		n		12.5	190	144	9100	5:00+	570	760	75/25 POZ/A
B		n		12.5	194	147	9800	5:00+	580	780	75/25 POZ/A
HES-11		n		12.5	176	132	8000	2:43			TLW
HES-11		n		12.5	196	139	8000	3:53	SET	1160	TLW
B	y		525	12.5	125	102	4384	5:47	190	270	65/35 H/POZ
B	y		525	12.5	126	109	5700	4:00+	140	290	65/35 H/POZ
A	y		450	12.5		95	4952	9:30	265	405	H
HES-11	y		182	12.5	125	107	5150	5:48	200	705	TLW
A	y		633	12.5	120	105	5303	4:00+	150	290	A
B	y		60	12.5	290	249	17500	4:45	200	310	HTLD
B	y		60	12.5	290	249	17500	6:25		220	HTLD
HES-2	y		1086	12.5		70	2400	6:00+	160	450	A
HES-2	y		1086	12.5		70	2400	6:00+	110	350	A
B	y		85	12.5	142	107	4800	4:18	240	340	H
HES-11	y		2081	12.5		85	5100	4:00+	95	130	TLW
HES-11	y		51	12.5	197	149	10503	5:00	0	260	TLW
A	y		1195	12.5		90	4900	5:00+		0	H
B	y		120	12.5	188	145	10043	3:33	210	300	65/35 H/POZ
F	y		550	12.5		155	6800	3:46	1230	1390	Micro-fine
A	y		3153	12.5		70	8800	4:00+	1250	1360	A
B		n		12.5	206	158	10500	6:00+	620	670	75/25 POZ/A
HES-11	y		310	12.5	92	84	1500	5:00+	100	260	TLW
HES-11	y		310	12.5	115	98	3600	6:06	420	940	TLW
A	y		40	12.5	140	107	5602	4:31	185	220	H
B	y		41	12.5	134	104	4500	4:47	105	230	85/15 H/POZ
HES-11	y		222	12.5	118	96	6200	4:00+	70	485	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-3	y		6738	12.5		65	7800	3:39	120	360	FLOSTOP I
A	y		40	12.5	92	80	1000	4:00+	190	330	A
B	y		144	12.5		157	10150	11:20	SET	410	H
A	y		1195	12.5		90	4900	5:00+		72	H
A	y		1195	12.5		90	4900	5:00+	0	58	H
B		n		12.5	211	163	12000	4:03	570	1210	65/35 H/POZ
A	y		224	12.5	128	101	4692	3:51	200	340	H
B		n		12.5	220	172	11700	4:49	790	860	75/25 POZ/A
A	y		40	12.5	140	107	5602	5:42	140	230	H
HES-7	y		143	12.5		160	10750	10:41	0	440	H
A	y		3752	12.5		70	5650	5:00+	130	200	H
A	y		3752	12.5		70	5650	6:00+	150	265	H
A	y		3752	12.5		94	7500	5:00+	185	340	H
A		n		12.5	85	80	300		0	99	A
A		n		12.5	85	80	300		90	410	A
A		n		12.5	85	80	300		0	190	A
A		n		12.5	85	80	300		FIRM	175	A
A	y		663	12.5	115	97	3500	4:00+	110	250	A
B		n		12.5	190	144	9240	4:00	200	840	65/35 H/POZ
B	y		525	12.5	127	109	6600	5:06	150	270	65/35 H/POZ
B	y		525	12.5	127	109	6600	7:03	88	185	65/35 H/POZ
B	y		200	12.5	110	93	2700	4:30+	170	270	50/50 H/POZ
B	y		41	12.5	134	104	4500	4:06	120	200	85/15 H/POZ
HES-11	y		42	12.5	145	110	5300	4:54	850	1175	TLW
A	y		1736	12.5		95	5800	7:22	135	140	H
A	y		1736	12.5		95	5800		70	185	H
B	y		1736	12.5		80	3304	2:00+	160		A
A	y		1136	12.5		80	6150	4:00+	120	180	H
B	y		25	12.5	215	167	11860	0:52			50/50 H/POZ
A	y		663	12.5	115	97	3500	7:00+	100	180	H
A	y		663	12.5	115	97	3500	6:00+	290	390	H
A	y		663	12.5	115	97	3500	6:00+	290	390	H
HES-7	y		587	12.5		88	4500	5:00+	0	140	H
HES-7	y		1753	12.5		70	4500	4:00+		0	H
HES-7	y		420	12.5	190	154	11900	6:30+	440	655	H
A	y		209	12.5	153	117	6508	5:00+	251	469	H
B	y		80	12.5	176	132	8350	5:18	80	195	65/35 H/POZ
A	y		209	12.5	188	141	10678	2:24			H
HES-7	y		209	12.5	188	141	10678	6:30+	230	250	H
A	y		1736	12.5		95	5800	4:30+	137	279	H
HES-3	y		6385	12.5		65	7500	3:44	FIRM	220	FLOSTOP I
E	y		255	12.5	94	87	1240	2:30	65	140	A
HES-7	y		688	12.5	116	97	4066	7:00+	82	250	H
B		n		12.5	95	86	1700	4:14	129	190	85/15 A/POZ
B		n		12.5	115	98	3550	5:00+	80	290	85/15 H/POZ
HES-11	y		100	12.5	129	99	3500	6:15			TLW
HES-11	y		2192	12.5		65	4417	7:00+	0	50	TLW
HES-11	y		2192	12.5		65	4417	6:00+	FIRM	100	TLW
B	y		34	12.5	223	175	12728	3:54	992	1270	50/50 H/POZ
A	y		633	12.5	105	90	3100	5:00+	60	200	H
HES-3	y		2134	12.5		65	3630	6:22	0	190	FLOSTOP I
B	y		525	12.5	137	111	5700	7:39	90	250	65/35 H/POZ
B	y		525	12.5	137	111	6100	5:44	80	280	65/35 H/POZ
A	y		240	12.5	145	108	5077	5:30	160	250	H
HES-11	y		288	12.5		80	1619	5:45+	359	653	TLW
HES-11	y		288	12.5	139	105	5550	5:00	0	0	TLW
HES-11	y		288	12.5	139	105	5550		500	1380	TLW
HES-1		n		12.5		100	6400	7:16			SLAG
HES-1		n		12.5		100	6400	5:40			SLAG
HES-7	y		650	12.5	118	100	4350	6:00+	148	301	H
B	y		277	12.5	172	132	8352	4:22	140	200	65/35 H/POZ
HES-7	y		650	12.5	181	149	12000	5:34	126	190	H
	y		80	12.5	230	181	13410	5:30+			65/35 H/POZ
B		n		12.5	175	127	7200	4:26	250	365	65/35 H/POZ
B	y		277	12.5	207	159	14156	3:35	30	60	65/35 H/POZ
HES-1	y		2940	12.5		81	6400	5:11	255	605	SLAG

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-1	y		2940	12.5		81	7100	5:11	255	605	SLAG
HES-11	y		34	12.5	230	189	11510	3:07	1200	1710	TLW
A	y		1061	12.5		70	2800	10:00+	50	150	H
A	y		2978	12.5		90	8000	5:00+	60	120	H
A	y		2978	12.5		86	7000	5:00+	70	200	H
HES-7	y		478	12.5		94	4650	5:30+	0	80	H
HES-7	y		478	12.5		128	4090	5:30+	194	305	H
A	y		227	12.5	100	80	1000	5:00+	110	380	A
B		n		12.5	228	179	12800	5:26	260	750	65/35 H/POZ
B	y		100	12.5	170	134	11000	4:12	160	207	65/35 H/POZ
A	y		650	12.5	126	101	4485	5:06	140	210	A
HES-7	y		650	12.5	126	101	4486	6:00+	144	298	A
B	y		86	12.5	237	189	13500	3:53	310	340	65/35 H/POZ
B	y		100	12.5	145	113	6021	7:09	80	180	65/35 H/POZ
B		n		12.5	219	166	10700	3:50	510	680	65/35 H/POZ
B	y		650	12.5		63	1874	5:30+	40	100	A
HES-3	y		3400	12.5		65	5200	3:38			FLOSTOP I
A		n		12.5		110	4000	10:00+	250		H
HES-7	y		130	12.5	134	109	5500	8:00+	140	260	H
A	y		372	12.5	140	107	5000	5:57	230	280	H
HES-11	y		722	12.5		65	2620	5:00+	0	FIRM	TLW
A	y		236	12.5	135	105	4700	5:00+	190	290	A
HES-7	y		1200	12.5		70	4500	6:00+	50	150	A
HES-7	y		1200	12.5		70	4500	6:30+	60	110	A
HES-7	y		3244	12.5		73	6800	5:00+	0	75	H
F	y		145	12.5		80	250	3:27	145	210	Micro-fine
HES-7	y		3200	12.5		109	10765	5:30+	30	120	H
HES-7	y		3200	12.5		109	10765	6:00+	30	120	H
HES-11	y		320	12.5	120	96	3000	4:13	310	1180	TLW
HES-7	y		110	12.5	180	135	8300	6:00+	297	396	H
HES-7	y		55	12.5		153	10400	7:00			H
HES-3		n		12.5		53	4358	3:06	90	250	FLOSTOP I
B		n		12.5	120	97	3263	5:00+	160	230	65/35 H/POZ
B		n		12.5	120	97	3263		320	360	65/35 A/POZ
A	y		1072	12.5		92	4200	5:00+	128	200	H
HES-1	y		3800	12.5		82	9500	4:00	543	576	SLAG
A	y		3800	12.5		82	9500	2:15			A
HES-7	y		2320	12.5		80	5000	4:30+	60	100	H
A		n		12.5	110	90	2000	5:30+	130	200	A
A	y		650	12.5	125	101	5831	4:47	160	350	A
B	y		305	12.5	193	147	10300	4:21	540	1000	65/35 H/POZ
HES-7	y		209	12.5	194	147	11858	7:00+	280	390	H
HES-7	y		209	12.5	194	147	11858	6:00+	220	260	H
B	y		83	12.5	209	161	11500	4:13	80	180	65/35 H/POZ
B	y		83	12.5	209	161	11500	4:39	90	190	65/35 H/POZ
B	y		90	12.5	225	176	13986	4:27	225	360	65/35 H/POZ
B	y		80	12.5	235	187	13390	6:54	130	180	65/35 H/POZ
HES-8	y		3210	12.5		70	5450	6:00+	32	92	FLOSTOP III
HES-8	y		3210	12.5		70	5450	6:37	110	455	FLOSTOP III
HES-7	y		360	12.5	182	136	9957	6:00+	370	490	H
HES-1	y		3800	12.5		82	9500	4:50	626	670	SLAG
A	y		1072	12.5	118	100	4200	5:00+	130	180	H
HES-1	y		2945	12.5		81	7110	3:45		0	SLAG
HES-1	y		2940	12.5		82	7110	4:59	0	102	SLAG
B	y		66	12.5	261	209	15100	6:10	220	240	HTLD
HES-11	y		2407	12.5		58	3849	6:00+	123	205	TLW
HES-1	y		2945	12.5		81	7110	4:56	336	580	SLAG
A	y		1070	12.5		80	2200	5:00+	FIRM	230	H
HES-11	y		42	12.5	94	80	1000	5:00+		240	TLW
B	y		36	12.5	180	136	10940	6:25	390	660	65/35 H/POZ
B	y		83	12.5	198	150	10500	6:18	300	1120	65/35 H/POZ
HES-7	y		3940	12.5		109	9725	6:00+	250	280	H
HES-11	y		42	12.5	94	80	1000			180	TLW
HES-11	y		42	12.5	134	101	4650	4:00+		630	TLW
B	y		36	12.5	204	159	14500	8:02	70	200	65/35 H/POZ
B	y		36	12.5	235	180	14500	7:16	125	256	65/35 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		185	12.5	126	98	4527	6:30+	640	1429	TLW
HES-7	y		68	12.5	245	198	15800	9:30+	0	102	H
B	y		372	12.5	120	99	4350	6:00+	80	120	H
B	y		372	12.5	120	99	4350	7:56	100	260	H
A	y		220	12.5	0	75	1600	4:00+	140	420	A
A	y		220	12.5	95	85	1600	6:00+	80	210	H
A	y		220	12.5	150	109	5000	2:30	470	500	A
A	y		220	12.5	150	109	5000	5:00+	170	245	H
A	y		2517	12.5	0	70	5400	5:20	150	410	A
HES-1	y		3800	12.5	0	81	9500	4:18	800	880	SLAG
HES-8	y		3940	12.5	0	109	9725	3:35	610	810	FLOSTOP III
B	y		83	12.5	198	150	10100	3:58	260	610	65/35 H/POZ
B	y		83	12.5	198	150	10250	4:35	370	850	65/35 H/POZ
HES-7	y		209	12.5	202	154	14802	5:30+	350	480	H
HES-7	y		377	12.5	130	100	3906	8:00+	60	160	H
A	y		163	12.5	102	85	1500	5:00+	60	220	H
A	y		1309	12.5	0	65	2300	4:30+	0	160	H
A	y		1309	12.5	0	65	2300	4:30+	0	120	A
A	y		1309	12.5	0	65	2300	5:00+	65	269	A
B	y		280	12.5	218	168	11500	4:55	560	580	65/35 H/POZ
B	y		280	12.5	218	168	11500	6:54	365	630	65/35 H/POZ
A	y		530	12.5	98	86	1707	5:00+	70	390	A
A	y		530	12.5	121	97	5294	6:00+	180	390	A
B	y		90	12.5	160	120	6800	6:17	160	290	65/35 H/POZ
HES-7	y		186	12.5	173	130	11700	5:00+	185	325	H
B	y		83	12.5	198	151	10250	5:36	161	709	65/35 H/POZ
F	y		90	12.5	122	104	3500	3:16	90	180	Micro-fine
A	y		6037	12.5	0	65	9000	5:30+	0	FIRM	A
HES-7	y		55	12.5	204	157	12550	4:25	210	314	H
B		n		12.5	215	168	13400	5:00	330	765	65/35 H/POZ
HES-7	y		110	12.5	0	207	15785	6:00	450	710	H
HES-7	y		110	12.5	0	207	15785	7:18	350	570	H
HES-7	y		377	12.5	150	114	5806	7:00+	70	150	H
HES-11		n		12.5	124	98	3500	4:57	440	1076	TLW
A	y		650	12.5	116	96	5801	6:30+	180	260	A
A	y		650	12.5	125	101	9302	4:50	260	270	A
	y		83	12.5	188	142	9873	5:30+	290	336	H
HES-7	y		5467	12.5	0	75	8400	7:00+	110	256	A
B	y		36	12.5	219	170	11847	4:47	305	1040	65/35 H/POZ
HES-7	y		6037	12.5	0	95	11850		85	164	H
HES-7	y		35	12.5	215	166	11565	3:43	410	478	H
B	y		150	12.5	183	135	8100	5:08	270	430	H
HES-7	y		35	12.5	237	181	11565	5:40	320	430	H
A	y		530	12.5	121	97	5294	4:38	220	420	H
A	y		530	12.5	98	86	1707	5:00+	114	320	H
HES-7	y		209	12.5	196	149	13661	5:13	140	220	H
A	y		650	12.5	0	101	9302	3:20	200	230	A
B	y		55	12.5	307	253	17900	7:47	55	94	HTLD
HES-7	y		650	12.5	164	124	10676	4:30+	230	360	H
F	y		210	12.5	101	88	2300	2:58	220	325	Micro-fine
B	y		110	12.5	162	137	9900	5:28	125	227	H
HES-7	y		110	12.5	162	137	9900	6:00+	270	500	H
HES-7	y		52	12.5	0	145	9600	6:21	213	330	H
B		n		12.5	200	152	9900	3:27	310	600	65/35 H/POZ
A	y		2800	12.5	0	65	3600	5:00+	0	60	A
HES-3	y		2800	12.5	0	60	3960	5:38	1020	1230	FLOSTOP I
HES-7	y		1753	12.5	0	70	5000	6:00+	80	120	A
A	y		650	12.5	113	95	6012	5:40	160	290	H
B		n		12.5	200	152	9900	7:48	260	1000	65/35 H/POZ
HES-7	y		105	12.5	122	97	3500	6:00+	750	830	H
A	y		650	12.5	113	95	6012	4:39	80	340	A
HES-7	y		45	12.5	213	179	13200	4:30+	158	410	H
A	y		176	12.5	127	101	4500	4:30+	300	350	H
B	y		52	12.5	92	80	1000	5:00+	163	200	H
HES-7	y		36	12.5	218	168	11500	4:00+	228	392	H
B	y		36	12.5	219	170	14008	5:33	84	330	65/35 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		60	12.5	95	83	1300	5:00+	175	220	H
B	y		52	12.5	128	100	4000	5:10	180	290	H
B	y		77	12.5	220	172	13719	3:55	550	800	65/35 H/POZ
B	y		52	12.5	128	100	4000	5:00+	230	340	H
B	y		52	12.5	92	80	1000	5:00+	110	240	H
HES-7	y		52	12.5	0	152	11208	4:33	210	290	H
B	y		36	12.5	219	170	14053	5:30	172	455	65/35 H/POZ
B	y		52	12.5	129	100	4000	6:00+	215	260	H
HES-11	y		950	12.5	136	108	5342	4:18	200	660	TLW
A	y		1611	12.5	139	110	5424	5:13	130	140	H
HES-11	y		3400	12.5	0	70	5200	7:32	70	250	TLW
HES-11	y		3400	12.5	0	70	5200	7:35	50	430	TLW
B	y		110	12.5	92	80	1000	4:00+	200	270	H
B	y		110	12.5	116	95	3000	5:41	200	440	H
B	y		63	12.5	132	104	4500	6:34	170	360	H
B	y		150	12.5	192	142	8600	5:15	160	830	65/35 H/POZ
HES-11	y		340	12.5	169	127	7400	3:52	770	990	TLW
HES-11	y		340	12.5	187	141	12260	3:03	452	935	TLW
HES-11	y		340	12.5	187	141	12260	2:08			TLW
HES-11	y		340	12.5	187	141	12260	4:18	710	1644	TLW
A	y		3600	12.5	0	65	5200	5:00+	0	0	A
A	y		3600	12.5	0	75	6700	4:19	105	603	A
B		n		12.5	142	108	5000	4:17	122	209	65/35 A/POZ
A	y		220	12.5	95	81	1200	4:00+	180	380	A
HES-11	y		6200	12.5	0	68	5305		57	157	TLW
HES-11	y		6200	12.5	0	68	5305	3:51	105	380	TLW
HES-1	y		3800	12.5	0	79	9500	3:59	329	365	SLAG
HES-7	y		3778	12.5	0	120	13275	9:45	0	80	H
HES-7	y		186	12.5	164	124	9170	5:00+	210	2450	H
HES-7	y		290	12.5	182	137	12718	5:38	138	212	H
HES-7	y		40	12.5	245	192	14000	5:30+	290	340	H
HES-7	y		40	12.5	260	202	14000		340	380	H
HES-11	y		950	12.5	105	91	2890	2:33	220	590	TLW
HES-11	y		950	12.5	141	111	7198	3:44	270	970	TLW
HES-11	y		3400	12.5	0	70	5200	6:45	140	272	TLW
B	y		110	12.5	127	100	4050	3:30+	170	320	H
B	y		110	12.5	127	100	4050	3:38	190	310	H
HES-7	y		110	12.5	127	100	4050	6:00+	130	290	H
B	y		110	12.5	137	107	5000		200	350	H
HES-7	y		85	12.5	140	108	5000	6:00+	79	340	H
HES-7	y		127	12.5	200	152	10752	8:00+	160	190	H
A	y		50	12.5	133	103	4400	6:00+	150	260	H
A	y		3550	12.5	0	85	9858		90	360	H
A	y		3550	12.5	0	83	8378	2:33	275	710	A
A	y		3550	12.5	0	83	8378	3:41	290	440	A
A	y		3550	12.5	0	80	9200	5:00+	0	94	H
HES-7		n		12.5	0	70	12500	7:00+	0	95	A
A	y		420	12.5	102	89	2045	6:00+	180	370	A
A	y		420	12.5	122	99	3957	6:57	230	340	A
B	y		90	12.5	220	177	15500	6:38	540	780	HTLD
HES-7	y		190	12.5	134	102	5621	6:00+	400	543	H
HES-1	y		3800	12.5	0	64	7340	5:00+	410	891	SLAG
B	y		40	12.5	90	80	900	4:00+	242	480	65/35 A/POZ
HES-7	y		209	12.5	135	105	5069	4:00+	70	90	H
HES-7	y		209	12.5	202	153	14000	6:00+	352	419	H
A	y		5200	12.5	0	75	10353	5:00+	50	100	H
A	y		5200	12.5	0	115	10300	8:00+	30	60	H
B	y		300	12.6		110	4235	6:00+	61	116	65/35 H/POZ
B		n		12.6	200	150	10000	4:14	366		65/35 H/POZ
HES-11	y		415	12.6	124	100	5068	3:00			TLW
HES-11	y		1754	12.6	192	159	12875	3:11	530	1340	2/1 TLW/H
HES-11	y		1754	12.6	178	149	11391	3:00	438	1250	2/1 TLW/H
HES-11	y		1754	12.6	174	146	10870	5:01	402	670	2/1 TLW/H
F	y		71	12.6	135	112	4500	3:30	1790	1917	Micro-fine
F	y		71	12.6	135	112	4500	4:17	605	671	Micro-fine
F	y		71	12.6	135	112	4500	4:44	428	494	Micro-fine

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
F	y		71	12.6	125	106	3200	3:30	625	692	Micro-fine
B	y		20	12.6	98	86	1700	4:49	190	270	H
B	y		300	12.6		111	5820	5:00+	60	255	65/35 H/POZ
B	y		150	12.6	215	160	10000	3:54	586	816	65/35 H/POZ
B	y		300	12.6		92	2200	4:30+	109	265	65/35 H/POZ
B	y		300	12.6	110	91	2200	4:30+	79	212	65/35 H/POZ
B	y		300	12.6		82	1100	4:30+	150	188	65/35 H/POZ
HES-11		n		12.6	282	240	15764	6:28	711	711	2/1 TLW/H
B		n		12.6	120	96	3000	4:06	136	280	65/35 A/POZ
B	y		45	12.6		93	6206	5:00+	155	220	65/35 H/POZ
B	y		90	12.6	184	147	12438	6:35	0	236	65/35 H/POZ
HES-11	y		760	12.6	117	99	4303	4:30	128	276	TLW
HES-11	y		50	12.6	95	82	1200	6:00+	79	102	1/1 TLW/H
B	y		240	12.6		139	5600	6:24			65/35 H/POZ
B	y		200	12.6	119	96	4800	4:00+	310	370	H
B	y		2161	12.6		93	7400		189	248	65/35 A/POZ
B		n		12.6	256	207	14700	4:45	1260	1310	65/35 H/POZ
B		n		12.6	256	207	14700	7:55	458	925	65/35 H/POZ
HES-3	y		2920	12.6		65	5200	5:00			FLOSTOP I
B	y		200	12.6	119	96	4800	4:00+	210	440	H
HES-11	y		101	12.6	210	163	12227	4:00	190	1760	TLW
B	y		41	12.6	192	145	10423	5:49	0	1130	65/35 H/POZ
B	y		182	12.6	190	144	9300	4:29	140	440	65/35 H/POZ
B	y		182	12.6	190	144	9300	3:33			50/50 H/POZ
B	y		150	12.6	195	143	8500	3:08			65/35 H/POZ
B	y		110	12.6	146	114	6000	5:36	290	640	H
B	y		41	12.6	205	154	10050	4:48	280	1155	65/35 H/POZ
B	y		40	12.6	106	91	2710	4:00+	270	480	H
HES-11	y		1754	12.6	188	152	14050	3:44	340	1350	2/1 TLW/H
HES-11	y		1754	12.6	218	169	16740	5:50	640	945	2/1 TLW/H
HES-11	y		1754	12.6		94	5500	5:00+	220	590	2/1 TLW/H
HES-11	y		1754	12.6		94	5560	5:00+	100	240	2/1 TLW/H
B		n		12.6	85	80	300			290	85/15 A/POZ
B	y		52	12.6	128	101	4000	5:00	480	555	A
B	y		52	12.6	92	80	1000	4:00+	190	300	A
HES-3	y		6201	12.6		65	7300	3:34	140	280	FLOSTOP I
HES-11	y		760	12.6	138	114	7220	7:18	198	1147	TLW
B		n		12.6	200	155	11000	3:43	359	1130	65/35 H/POZ
B	y		76	12.6		92	2300	4:35	116	214	A
B	y		200	12.6		98	4000	5:36			H
B	y		200	12.6		98	4000	4:37			H
B	y		52	12.6	134	104	4500	5:20	240	410	A
B	y		76	12.6	130	103	4500	4:35	251	551	H
B	y		76	12.6	130	103	4500	4:27	387	721	H
B	y		200	12.6	140	107	5369	5:00	110	160	H
B	y		40	12.6	138	106	5010	8:30			H
B	y		40	12.6	138	106	5010	4:19			H
B	y		553	12.6		120	5500	9:24			H
HES-11	y		1050	12.6		70	2400			287	TLW
B	y		553	12.6		108	6800	7:59		330	H
B	y		76	12.6	114	99	3300	4:15	310	360	A
B	y		35	12.6	107	92	2380	5:20	195		H
B	y		35	12.6	106	91	2300	5:03			H
B	y		35	12.6	106	91	2300	3:30+	256	437	H
B	y		40	12.6	93	80	1000	6:30+		79	H
B	y		40	12.6	100	84	1450	6:30	155	289	H
B	y		76	12.6	91	80	1000	4:00+	170	330	A
B	y		52	12.6	92	80	1000	4:00+	120	390	A
B	y		76	12.6		80	750	4:38	121	239	A
B	y		52	12.6	128	101	4000	5:38	200	530	A
HES-11		n		12.6	100	91	1500	4:18	212	417	2/1 TLW/H
B	y		20	12.6	98	86	1700	5:00+	190	350	H
B		n		12.6	211	163	10900	6:30	280	831	65/35 H/POZ
A		n		12.6		80	270	4:00+	111	231	A
B		n		12.6		93	2500		0	50	HPLC
B		n		12.6		160	12000	5:42	272	529	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B		n		12.6		160	12000	5:36	88	489	H
A		n		12.6	110	90	2000	6:23	366	470	A
B		n		12.6	200	152	10000	4:03	0	1194	65/35 H/POZ
B	y		80	12.6	140	113	5963	4:25	324	829	H
HES-11	y		332	12.6	120	100	4126	4:55	82	663	TLW
HES-11	y		760	12.6	138	114	7220	6:12	556	1482	TLW
B	y		26	12.6		165	10500	8:58			H
B	y		26	12.6		165	10500	5:21			H
B	y		200	12.6		140	9100	5:05			H
B	y		35	12.6		134	8210	14:45			H
HES-7	y		120	12.6		115	6000	14:53			H
B	y		35	12.6		87	1750	5:40			H
B	y		165	12.6		87	1732	3:47	200	341	A
B	y		35	12.6		118	8445	8:00	0	630	H
HES-11	y		1485	12.6	143	119	7252	5:45	122	441	TLW
B	y		35	12.6	157	119	8100	6:47	60	390	H
B		n		12.6	219	167	10750	5:05	700	980	65/35 H/POZ
B		n		12.6	280	214	11671	3:30	390	630	HTLD
B	y		35	12.6		141	8950	4:47	0	395	H
HES-7	y		210	12.6		136	9820	6:45	290	380	H
B	y		110	12.6	140	107	5000		160	250	H
B	y		110	12.6	140	107	5000	4:53	95	230	H
B	y		38	12.6		126	7222	5:36	260	530	H
B	y		52	12.6		184	12930	4:58			H
B	y		110	12.6	140	107	5000	6:44	120	230	H
B		n		12.6	256	207	14700	7:10	680	1260	65/35 H/POZ
B	y		80	12.6	188	142	9483	4:10		75	65/35 H/POZ
B	y		50	12.6	122	97	3500	6:22	170	200	H
B		n		12.6		80	1100	5:00+			50/50 H/POZ
B		n		12.6		190	10000	8:00+			H
B		n		12.6		112	4000	4:16			H
B	y		52	12.6		187	14555	10:07			H
B	y		52	12.6	137	104	4500	4:25	250	290	H
B	y		52	12.6	0	143	10600	5:32	SET	570	H
HES-11	y		2800	12.6	0	82	12424	9:29			TLW
HES-11	y		2588	12.6	0	82	12424	7:02	160	380	TLW
B	y		2800	12.6	0	82	12424	10:16	90	211	H
B	y		2800	12.6	0	73	6820	10:32	130	200	H
B	y		2800	12.6	0	79	9938	6:19	25	120	H
B		n		12.6	280	214	11671	2:28			HTLD
B	y		52	12.6	0	143	10600	7:50	FIRM	440	H
B	y		2000	12.6	0	75	6400	7:29	100	220	H
B	y		52	12.6	0	152	11208	4:01	280	620	H
B	y		3000	12.6	0	73	6600	8:29	140	230	H
B	y		52	12.6	0	145	9600	4:30	80	350	H
B	y		55	12.6	92	80	900	5:00+	90	300	H
B	y		55	12.6	131	103	4400	6:43	270	420	H
B	y		2800	12.6	0	80	8720	6:50	70	140	H
B	y		2800	12.6	0	73	6894	7:28	90	180	H
B	y		2000	12.6	0	87	9200	4:20	150	410	H
B	y		50	12.6	122	97	3500	4:04	135	220	H
HES-7	y		200	12.6	145	108	9531	6:00+	254	400	H
B	y		110	12.6	182	137	8930	4:27	230	490	H
B	y		181	12.6		123	7683	6:14	170	620	H
B	y		35	12.6		126	7289	4:37	480	670	H
HES-7	y		190	12.6		148	10200	6:03		220	H
HES-7	y		190	12.6		148	10200	8:55	170	600	H
B	y		2588	12.6		77	8100	5:40			H
B	y		2588	12.6		73	6700	5:53	60	150	H
B	y		2588	12.6		73	6700	6:00+	30	40	H
B	y		50	12.6	120	98	3817	7:33	99	280	H
B		n		12.6	265	218	14700	8:22	644	1290	65/35 H/POZ
B		n		12.6	250	202	14000	6:31	450	680	65/35 H/POZ
B	y		41	12.6	106	91	2800	4:41	100	190	H
B	y		35	12.6		142	9000	7:45			H
B	y		52	12.6	117	96	3100	4:34	130	270	H

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		144	12.6		129	8792	3:48			H
B	y		190	12.6	134	105	5300	6:00	128	800	H
B	y		38	12.6	126	98	4114	5:47			H
B	y		38	12.6	91	81	1100	6:23	50	100	H
B		n		12.6	250	202	14000	5:32	300	565	65/35 H/POZ
B		n		12.6	225	175	11600	4:32	280	750	65/35 H/POZ
B	y		35	12.6		118	8673	4:49	280	370	H
B	y		69	12.6		174	12833	7:10	128	720	H
B	y		144	12.6	172	129	7900	3:39	400	450	H
B	y		35	12.6	115	96	3800	3:36	250	420	H
B	y		52	12.6		150	10443	8:40	0	950	H
B	y		190	12.6	148	148	10200	9:03	0	510	H
B	y		2800	12.6	0	75	7090	7:41	105	280	H
HES-7	y		200	12.6	145	108	9531	4:00+			H
B	y		52	12.6	134	104	4500	4:19	150	350	H
B	y		35	12.6	119	97	3300	3:50	180	340	H
B	y		76	12.6		137	8510	5:53	FIRM	380	H
HES-7	y		99	12.6	215	164	13487	3:46	243	377	H
HES-7	y		200	12.6	129	103	4555	6:00+	220	315	H
B		n		12.6	272	228	16621	6:12	450	490	65/35 H/POZ
HES-7	y		200	12.6	129	103	4555	6:00+	120	1710	H
B		n		12.6	260	211	14900	4:18	320	1000	65/35 H/POZ
B	y		200	12.6	129	103	4555	3:52	160	200	H
B		n		12.6	140	116	5000	4:07	130	290	65/35 A/POZ
HES-7	y		52	12.6	162	141	8900	5:58	387	510	H
HES-7	y		52	12.6		141	8900	5:37	242	1350	H
B	y		35	12.6		119	6430	5:29			H
B	y		52	12.6		120	6650	5:34			H
B	y		52	12.6		120	6650	4:43	208	430	H
B	y		181	12.6		107	6038	6:29	140	300	H
B	y		35	12.6		94	2857	4:51	100	250	H
HES-7	y		35	12.6	244	192	13700	6:31	200	340	H
B	y		52	12.6	128	101	4000	6:02	150	154	H
B	y		35	12.6	123	99	3657	3:44	196	350	H
B	y		35	12.6		131	7900	5:49	0	330	H
B		n		12.7	215	166	11030	5:20	291	990	65/35 H/POZ
B	y		139	12.7	165	126	7500	5:10	272	519	65/35 H/POZ
B		n		12.7	235	187	12900	5:13			65/35 H/POZ
HES-11	y		261	12.7	112	94	2600	5:30+	342	567	TLW
HES-11	y		261	12.7		94	2650	5:30+	26	851	TLW
HES-11	y		261	12.7	113	95	2930	5:30+	376	874	TLW
B		n		12.7	110	93	2500			385	65/35 A/POZ
HES-11	y		261	12.7	118	97	3180	5:36	405	1227	TLW
HES-11	y		261	12.7		101	4200	5:35	656	662	TLW
HES-11	y		261	12.7		105	4750	4:35	777	928	TLW
HES-11	y		80	12.7	124	100	4030	5:05		1446	TLW
HES-11	y		105	12.7	189	144	9400	4:25		1205	TLW
B		n		12.7	190	143	9000	4:33	360	1200	65/35 H/POZ
HES-11	y		130	12.7		171	12632	6:20	116	1695	TLW
B		n		12.7	225	175	11600	2:19			65/35 H/POZ
HES-8	y		800	12.7		65	1625	5:44	248	391	A
HES-11	y		225	12.7	120	98	3400	5:07	175	753	TLW
B	y		529	12.7	127	110	5896	4:57			65/35 H/POZ
HES-11	y		354	12.7		93	3500	4:20	326	594	TLW
HES-11	y		354	12.7		93	3500	4:10	567	1028	TLW
HES-11	y		130	12.7		171	12850	6:10	323	1593	TLW
HES-8	y		1500	12.7		65	2800	5:36	83	90	A
HES-11	y		130	12.7	218	171	12632	6:00	581	1529	TLW
HES-11	y		800	12.7		65	1625		115	200	TLW
HES-8	y		800	12.7		70	1625	6:00+	0	0	A
HES-11	y		800	12.7		70	1625	6:30+	40	57	TLW
B		n		12.7	177	133	8100	5:27		667	65/35 H/POZ
B	y		40	12.7	163	122	6900	4:54	243	765	65/35 H/POZ
B		n		12.7	220	167	11050	3:03	233	1163	65/35 H/POZ
HES-8	y		1500	12.7		74	3870	3:52	226	250	A
HES-11	y		200	12.7	165	124	7281	3:52	594	1405	TLW

*Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)	(°F)	(°F)	(ft)	(hr:min)	12 hr	24 hr	
B	y		82	12.7	170	136	9000	4:58		309	65/35 H/POZ
A	y		82	12.7		80	100			544	A
B		n		12.7	126	100	3850	3:31			65/35 A/POZ
B		n		12.7		153	10496	7:12			25/75 H/POZ
B	y		122	12.7	91	80	924	4:00+	0	390	H
B	y		120	12.7	95	83	1300	6:00	220	421	H
HES-11	y		1100	12.7		70	2400	6:30+	119	202	TLW
A	y		250	12.7	115	97	3500	2:40	320	380	A
B	y		137	12.7	124	100	4044	5:50	172	427	H
B	y		137	12.7	119	98	3500	5:28			H
HES-11	y		107	12.7	128	101	4000	6:00+	844	1653	TLW
HES-11	y		1100	12.7		85	4700	4:40	346	694	TLW
HES-11	y		1100	12.7	116	100	4700	4:59	298	594	TLW
B		n		12.7	223	173	11250	3:58			65/35 H/POZ
B	y		122	12.7		115	6007	6:41	190	683	H
B		n		12.7	215	165	10800	3:19			65/35 H/POZ
B		n		12.7	224	175	12000	4:58	0	831	65/35 H/POZ
B		n		12.7	228	178	11800	2:42			65/35 H/POZ
B		n		12.7	188	142	9000	6:10	0	138	65/35 H/POZ
B		n		12.7	170	123	6810	3:14	231	686	65/35 H/POZ
A	y		210	12.7	140	104	4410	5:15	245	380	H
B	y		290	12.7	125	107	4906	2:28	200	379	65/35 A/POZ
HES-11	y		80	12.7	160	123	7600	4:17	293	1462	TLW
B	y		111	12.7		99	3730	7:07			H
B	y		1470	12.7		70	2600	6:46			A
B	y		250	12.7		80	1000	6:47			H
HES-7	y		45	12.7	202	154	11157	4:58			H
HES-11	y		80	12.7	175	134	8800	4:54	0	1447	TLW
B	y		34	12.7	194	148	12600	6:01	64	290	65/35 H/POZ
B		n		12.7	197	152	10650	4:01			65/35 H/POZ
B		n		12.7	230	182	12750	5:58	80	720	65/35 H/POZ
HES-11	y		354	12.7	130	106	5000	3:57			TLW
B		n		12.7	134	104	4500		177	330	65/35 A/POZ
B		n		12.7	150	113	5800	6:15	320	571	65/35 H/POZ
B	y		122	12.7	91	80	920	6:39	150	340	H
A	y		7612	12.7		82	14000	4:00+	80	210	H
HES-3	y		2920	12.7		65	5200	4:30	140	610	FLOSTOP I
A	y		3214	12.7		95	9400	5:00+	194	330	H
HES-11		n		12.7	203	156	11060	3:29	890	1160	TLW
HES-11		n		12.7	203	156	11060	2:45	1342	1414	TLW
A	y		210	12.7	132	103	4500	7:00+	400	450	H
B		n		12.7	214	158	9600	6:22	40	775	65/35 H/POZ
B		n		12.7	196	142	8350	4:20	440	1110	65/35 H/POZ
A	y		3125	12.7		70	7500	7:00+	70	220	H
B		n		12.7	270	224	14700	6:00+			65/35 H/POZ
B		n		12.7	284	234	14600	8:00+	660	800	65/35 H/POZ
HES-11	y		260	12.7	182	134	9620	2:38	1045	1147	TLW
B		n		12.7	220	170	11220	3:51	410	840	65/35 H/POZ
B		n		12.7	260	212	13750	7:50	0	620	65/35 H/POZ
F		n		12.7	230	192	12838	4:07	570	880	Micro-fine
B		n		12.7	212	157	9600	6:22	40	630	65/35 H/POZ
HES-3	y		3500	12.7		65	5475	3:15	FIRM	160	FLOSTOP I
B		n		12.7	293	245	15280	8:00+			65/35 H/POZ
A	y		3125	12.7		80	8400	5:00+	110	150	H
B		n		12.7	280	229	14360	5:26	815	1200	65/35 H/POZ
B		n		12.7	287	238	14800	6:30	679	790	65/35 H/POZ
B		n		12.7	273	221	13850	6:12	430	650	65/35 H/POZ
B		n		12.7	263	209	13089	6:22	590	810	65/35 H/POZ
B		n		12.7	238	190	13150	5:44	710	850	65/35 H/POZ
HES-11	y		40	12.7	207	159	11644	3:45	877	1584	TLW
B		n		12.7	305	260	16100	6:22	660	790	65/35 H/POZ
B		n		12.7	152	115	6000	4:39			65/35 H/POZ
B	y		34	12.7	194	148	12600	4:07	228	553	65/35 H/POZ
B		n		12.7	187	131	7168	2:12			HLC
HES-11	y		800	12.7		60	850	6:37	67	191	TLW
HES-11	y		120	12.7	160	120	6700	3:50	1000	1700	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		688	12.7	138	115	7100	4:10	121	224	65/35 H/POZ
B		n		12.7	220	170	11200	4:41			65/35 H/POZ
A	y		57	12.7	97	85	1500	3:00+	250	400	A
B		n		12.7	105	90	2100	6:00+	53	97	65/35 A/POZ
B		n		12.7		101	4300	2:37			65/35 A/POZ
B		n		12.7	122	99	3527	6:11	230	270	65/35 A/POZ
B		n		12.7	122	99	3527	5:21	265	330	65/35 A/POZ
B		n		12.7	186	140	8800	4:02			65/35 H/POZ
B		n		12.7	204	154	9750	5:40			65/35 H/POZ
B	y		35	12.7	206	158	10500	4:01	159	662	65/35 H/POZ
B		n		12.7	190	144	9200	4:40	0	1725	65/35 H/POZ
B		n		12.7		170	10000	6:19	0	982	65/35 H/POZ
HES-11	y		40	12.7	207	159	10800	3:52	0	1346	TLW
HES-11	y		170	12.7	145	106	4500	5:00+	875	950	TLW
HES-11	y		170	12.7	127	100	4900	5:21	394	825	TLW
B		n		12.7	200	152	10000	3:45	685		65/35 H/POZ
B		n		12.7	198	149	9450	5:00+			65/35 H/POZ
B		n		12.7	191	145	9300	6:00	0	100	65/35 H/POZ
B		n		12.7	221	172	11750	4:43			65/35 H/POZ
B		n		12.7	205	154	9600	2:45			65/35 H/POZ
B		n		12.7	130	101	4000	3:49	170	231	65/35 A/POZ
B	y		23	12.7		125	8865	7:00+		977	25/75 H/POZ
B		n		12.7	178	130	7500	4:12	370	790	65/35 H/POZ
B	y		10	12.7		119	5200	5:18	250	442	65/35 H/POZ
HES-11	y		260	12.7	182	134	9620	3:32	1617	1953	TLW
B		n		12.7	208	160	10700	6:31	0	1381	65/35 H/POZ
B	y		18	12.8	92	80	1000	5:17	170	345	65/35 A/POZ
B	y		22	12.8	113	95	3000	3:00+	247	688	65/35 A/POZ
HES-7	y		134	12.8	190	145	11139	4:09	312	521	H
B	y		134	12.8	190	145	11139	4:37	105	280	65/35 H/POZ
HES-11	y		295	12.8	121	98	3471	5:33	525	1040	TLW
HES-11	y		295	12.8	133	104	4450	4:54	840	1920	TLW
B		n		12.8	191	143	8900	3:03	600	1712	50/50 H/POZ
B		n		12.8	299	236	12900	3:45			65/35 H/POZ
HES-8	y		3944	12.8		70	3950	2:44	787	1682	A
B	y		16	12.8	90	80	800	3:00+	210		65/35 A/POZ
HES-11	y		760	12.8	138	113	6200	5:30	249	2055	TLW
B	y		18	12.8	92	80	1000	6:45	197	268	65/35 A/POZ
HES-11	y		760	12.8	138	114	7172	6:00	247	1345	TLW
B		n		12.8		80	2500	5:00+	139	290	65/35 A/POZ
B		n		12.8	110	93	2500	4:40	255	329	65/35 A/POZ
B		n		12.8	101	91	2500	5:14	128	282	65/35 A/POZ
B		n		12.8	111	93	2500	4:20			65/35 A/POZ
B	y		430	12.8	122	98	3500	6:00+			65/35 A/POZ
B		n		12.8		90	3000	6:00+	320	1818	65/35 A/POZ
B	y		18	12.8	116	96	3000	3:04	402	530	65/35 A/POZ
B		n		12.8	115	97	3500	3:30			65/35 A/POZ
B		n		12.8	115	97	3500	4:07			65/35 A/POZ
B		n		12.8	113	95	3000	3:18	237	412	65/35 A/POZ
B	y		40	12.8	206	158	10550	5:00+	259	1115	65/35 H/POZ
B	y		18	12.8	89	80	850	4:00+	230	290	65/35 A/POZ
B		n		12.8	205	157	10350	3:25			65/35 H/POZ
HES-11	y		120	12.8	190	153	12375	4:40	1079	1651	TLW
HES-3	y		6500	12.8		55	7950	4:42	0	150	A
HES-11	y		80	12.8	160	131	6200	2:40			TLW
B		n		12.8	100	87	1700	6:18			65/35 A/POZ
B		n		12.8	109	91	2250	5:05	201	389	65/35 A/POZ
B		n		12.8	215	164	10400	5:00			65/35 H/POZ
B	y		52	12.8	213	166	13035	2:15			H
B	y		52	12.8	213	166	13035	3:24	185	268	H
B	y		1470	12.8		80	5600	5:55			H
B	y		1470	12.8		80	5600	5:28			H
F		n		12.8	262	216	13000	3:30	1784	2023	Micro-fine
HES-11	y		760	12.8	138	114	7310	5:15	263	1229	TLW
HES-11		n		12.8	122	98	3500	3:31	753	1464	TLW
B		n		12.8	120	98	3500	3:57		250	65/35 A/POZ

*Slurry Type	Offshore Yes	No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	24 hr	Base Cement Type
B		n		12.8	206	159	10845	4:03	80	1657	65/35 H/POZ
B		n		12.8	134	104	4500	5:12	148	325	65/35 H/POZ
B	y		100	12.8	164	122	8200	4:10	257	669	65/35 H/POZ
B	y		100	12.8	172	130	9900	4:39	300	710	65/35 H/POZ
B		n		12.8	220	172	11800	4:30	0	1078	65/35 H/POZ
B		n		12.8	236	188	12995	7:20			65/35 H/POZ
B		n		12.8	223	173	11500	7:45			65/35 H/POZ
HES-11		n		12.8	145	119	5200	3:24	878	1279	TLW
B	y		200	12.8	129	103	5000	5:05			65/35 H/POZ
HES-11	y		470	12.8		105	4600	4:32	550	800	TLW
HES-11	y		1050	12.8		65	4500	7:00+	0	0	TLW
B		n		12.8	95	80	1000			226	65/35 H/POZ
A		n		12.8	0	75	6000	5:57	45	142	A
B	y		18	12.8	118	97	3200	4:30+	277	580	65/35 A/POZ
HES-7		n		12.8	218	170	11875	4:23	2020	3280	H
B	y		22	12.8	90	80	900	5:00+	190	250	65/35 A/POZ
B	y		18	12.8	92	80	1000	4:00+	180	250	65/35 A/POZ
B	y		22	12.8	116	96	3000	2:30	245	380	65/35 A/POZ
HES-11		n		12.8	155	126	6350	3:06	1170	1260	TLW
B	y		22	12.8	118	97	3200	3:30+	240	415	65/35 A/POZ
HES-7	y		189	12.8	132	103	4300	7:00+	126	260	H
B	y		62	12.8	214	187	13200	10:00+		0	H
B	y		432	12.8	165	124	9550	3:56	110	270	65/35 H/POZ
HES-11	y		68	12.8	245	198	15800	6:34	1022	1663	TLW
B		n		12.8	218	170	11875	5:30	450	580	65/35 H/POZ
B	y		1047	12.8	180	135	9100	4:05	440	530	H
HES-11	y		760	12.8		104	6750	4:00			TLW
A		n		12.8	0	75	6000	6:00+	0	68	A
A		n		12.8	0	65	8000	6:42	0	190	A
HES-7	y		470	12.8	145	114	6000	5:27	395	1211	TLW
HES-7	y		68	12.8	245	198	15800	7:25	325	434	H
HES-11	y		760	12.8	128	111	6090	2:48			TLW
B	y		365	12.8	139	107	8800	5:34	177	287	65/35 H/POZ
B	y		365	12.8	142	107	8800	6:00+	133	157	65/35 H/POZ
B		n		12.8	140	109	5400	5:38	207	362	65/35 H/POZ
B		n		12.8	169	128	7700	5:30+	144	167	65/35 H/POZ
B		n		12.8	180	136	8366	3:38	410	723	H
B		n		12.8	180	138	10300	5:23	90	336	65/35 H/POZ
HES-11		n		12.8	105	95	3100	4:28	381	880	TLW
HES-11		n		12.8	213	166	12100	7:15	0	1647	TLW
HES-11		n		12.8	213	166	12100		1432	1894	TLW
HES-11		n		12.8	145	119	5000	2:40	885	1695	TLW
HES-11	y		760	12.8	128	111	6090	4:45	170	390	TLW
B	y		113	12.8	185	139	9615	3:30	220	390	65/35 H/POZ
HES-7	y		1120	12.8	0	123	11393	4:00+	130	270	H
B	y		134	12.8	185	142	9779	3:46	140	340	65/35 H/POZ
B	y		134	12.8	185	142	9779	4:25	110	196	65/35 H/POZ
B	y		134	12.8	190	146	11410	3:32	110	190	65/35 H/POZ
B	y		182	12.8	190	156	9700	3:17	510	660	H
B	y		60	12.8	290	249	17500	7:10	605		HTLD
B	y		60	12.8	290	249	17500	7:20	240	400	HTLD
HES-7	y		152	12.8	165	115	8700	4:00+			H
HES-7	y		225	12.8	161	121	7233	5:11	270	460	H
HES-11	y		107	12.8	210	163	12227	4:31	1150	1640	TLW
HES-11	y		48	12.8	139	106	5200	4:30+	750	1570	TLW
B	y		50	12.9	310	255	16000	8:00+			HTLD
B	y		200	12.9		140	9100	6:28			H
B	y		1100	12.9	135	104	4500	4:36	208	464	65/35 H/POZ
B	y		350	12.9	255	206	14600	5:28	487	731	HTLD
B		n		12.9	210	163	11750	6:26	0	248	H
B		n		12.9	315	265	15815	4:24			HTLD
B		n		12.9	275	226	14500	5:43	765	1950	HTLD
B		n		12.9	290	237	14500	5:00+			HTLD
B	y		35	12.9		175	13010	3:44	52	296	H
B		n		12.9	270	223	14500	5:20	680	1220	HTLD
B		n		12.9	275	226	14400	4:33	530	600	HTLD

*Slurry Type	Offshore		Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi)		Base Cement Type
	Yes	No							12 hr	24 hr	
B		n		12.9	275	226	14400	1:55			HTLD
B		n		12.9	260	210	13520	4:22	620	880	HTLD
B		n		12.9	275	226	14430	4:46	650	760	HTLD
B		n		12.9	145	106	4500	5:00+	115	270	60/40 A/POZ
HES-1	y		3214	12.9		95	9037	6:36	390	455	SLAG
B	y		50	12.9	240	196	16000	7:00+	490	790	HTLD
B		n		12.9	223	183	11300	3:37	348	553	H
B		n		13.0		96	3500		86	168	65/35 A/POZ
B		n		13.0		96	3500		71	81	25/75 A/POZ
B		n		13.0	225	176	12000	4:40	780	1225	25/75 H/POZ
HES-11		n		13.0	111	98	2500	2:29	523	848	TLW
B		n		13.0	230	167	10000	4:23	400	940	65/35 H/POZ
B		n		13.0	230	166	9855	4:20			65/35 H/POZ
HES-11		n		13.0	172	125	6942	5:45	1865	2362	TLW
A		n		13.0	115	100	3000		260	442	A
B	y		40	13.0	175	133	8560	5:22	0	418	H
HES-11	y		40	13.0	210	176	12300	3:15	1724	1796	TLW
HES-11		n		13.0	100	91	1500	2:56	397	850	TLW
HES-11		n		13.0	206	158	10500	4:18	611	694	TLW
B		n		13.0	235	187	12850	5:40	1156	1670	65/35 H/POZ
HES-11		n		13.0	95	80	1000	4:00+	131	301	TLW
B		n		13.0	204	156	10321	5:53	310	975	65/35 H/POZ
B		n		13.0	224	175	12019	4:19	980	1080	65/35 H/POZ
HES-11		n		13.0	222	173	11800	3:54			2/1 TLW/H
HES-11		n		13.0	100	91	1700	4:00+	595	858	TLW
HES-11		n		13.0		170	12423	6:18	1408	1954	2/1 TLW/H
HES-11		n		13.0	135	112	4600	2:37	1240	2034	TLW
B	y		102	13.0	187	133	10095	3:14	430	720	H
B	y		77	13.0	160	115	5800	3:33	188	838	65/35 H/POZ
HES-11	y		15	13.0	165	134	7100	4:03	0	1249	TLW
HES-11	y		15	13.0	128	102	4200	3:00+	203	634	TLW
HES-11		n		13.0	230	182	12900	6:00+			2/1 TLW/H
HES-11		n		13.0	215	168	12720	5:50	840	1125	2/1 TLW/H
HES-11		n		13.0	222	175	12913	5:40	1020	3483	2/1 TLW/H
HES-11		n		13.0	178	140	9400	6:30	707	1691	2/1 TLW/H
HES-11		n		13.0	230	185	13945	4:07	1342	2526	2/1 TLW/H
B		n		13.0	215	168	12720	5:25	385	816	65/35 H/POZ
B		n		13.0	185	142	9500	5:42	0	641	65/35 H/POZ
B		n		13.0	250	186	11300	3:39	690	870	65/35 H/POZ
B		n		13.0	134	103	4350	4:45	440	510	A
B		n		13.0	142	108	5000	2:24			65/35 A/POZ
HES-3		n		13.0		50	6600	8:20			A
B		n		13.0	215	166	11150	5:26	1686	1730	50/50 H/POZ
B		n		13.0	329	292	18300	8:00			HTLD
B		n		13.0	345	314	19500	7:02	---	113	HTLD
B		n		13.0	345	314	19500	6:52	315	1563	HTLD
B		n		13.0		207	13000	15:00+	350	390	HTLD
B		n		13.0		207	13000	14:00+	0	220	HTLD
HES-11		n		13.0	215	167	11780	4:51	747	1068	2/1 TLW/H
HES-7	y		3800	13.0		120	9660	6:30+	0	375	H
B	y		84	13.0	300	244	16316	5:44			65/35 H/POZ
B	y		84	13.0	300	244	16316	3:52	600	776	65/35 H/POZ
HES-11	y		240	13.0	141	116	4700	2:58	1096	1737	TLW
B	y		43	13.0	219	170	13067	4:05	1710	1980	50/50 H/POZ
HES-7	y		27	13.0	216	169	12800	6:02	543	676	H
HES-11	y		55	13.0	98	85	1500			711	TLW
HES-11	y		55	13.0	98	85	1500	2:02	393	825	TLW
HES-11	y		60	13.0	183	138	8600	4:03	420	1550	TLW
B	y		85	13.0	207	159	10660	6:30+	370	870	65/35 H/POZ
B	y		85	13.0	207	159	10660	3:19	120	310	65/35 H/POZ
B	y		80	13.0	200	152	10204	5:56	0	571	65/35 H/POZ
	y		10	13.0	215	167	11200		467	553	H
B	y		10	13.0	215	167	11200	7:08	0	1173	65/35 H/POZ
B	y		110	13.0	206	158	10500	3:04	767	1011	50/50 H/POZ
HES-11	y		120	13.0	190	157	13048	5:26	0	1814	TLW
HES-11	y		120	13.0	211	167	13048	5:20	0	855	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11	y		120	13.0	165	137	10600	5:13	26	2211	TLW
HES-11	y		120	13.0		240	17500	9:47			TLW
HES-11	y		120	13.0		240	17500	8:15	80	100	TLW
HES-7	y		130	13.0	204	156	13038	5:04	450		H
HES-7	y		130	13.0		147	9549	6:00			H
HES-7	y		137	13.0		132	9814	5:43	920		H
HES-7	y		137	13.0		132	8000	6:27	260	420	H
HES-11	y		147	13.0	92	80	1000	6:00+	219	632	TLW
B	y		170	13.0	160	127	9917	5:09	89	628	65/35 H/POZ
B	y		170	13.0	160	130	8641	4:29	66	358	65/35 H/POZ
HES-7	y		180	13.0	193	146	9925	3:44	316	340	H
B	y		180	13.0	193	146	9925	3:04	305	535	50/50 H/POZ
HES-11	y		180	13.0	143	115	7200	3:26	1313	2440	TLW
HES-11	y		180	13.0	143	115	7200	3:29	1050	1730	TLW
B	y		210	13.0	148	112	5650	4:44	178	263	65/35 H/POZ
F	y		200	13.0	160	160	8100	0:18			Micro-fine
HES-11	y		250	13.0	133	104	6872	7:20	673	1549	TLW
HES-11	y		250	13.0	134	104	5664	4:27	725	1199	TLW
HES-11	y		250	13.0	136	105	6085	4:18	342	654	TLW
HES-11	y		250	13.0	134	105	6485	4:45	474	1191	TLW
HES-11	y		250	13.0	140	109	7700	5:45	539	1250	TLW
HES-11	y		250	13.0	148	112	7475	3:38	309	1324	TLW
HES-11	y		250	13.0	134	105	6485	4:30	746	1235	TLW
HES-11	y		1491	13.0	143	119	7252	4:57	361	1465	TLW
MICROFINE	y		1800	13.0		74	3870	3:21			A
HES-11	y		220	13.0	120	105	5300	7:14	430	1170	TLW
HES-11	y		200	13.0	0	80	50		150	270	TLW
B	y		645	13.0		111	6500	6:30+	60	135	50/50 H/POZ
HES-11	y		700	13.0	142	107	4800	4:30	466	1200	TLW
B	y		630	13.0	141	109	5144	4:20	222	290	H
A	y		557	13.0	141	109	5144	6:19	140	180	H
B	y		557	13.0	141	109	5148	4:40	200	410	H
HES-3	y		1195	13.0		80	2770	2:49			FLOSTOP I
HES-7	y		1756	13.0		120	12183	4:54	430	616	H
HES-11	y		760	13.0		104	6750	6:20		300	TLW
B	y		2046	13.0		80	8537			187	65/35 A/POZ
A	y		340	13.0	130	106	5000	6:00+	310	1250	H
B	y		220	13.0	178	134	14596	4:00	404	551	65/35 H/POZ
HES-7	y		600	13.0	156	118	7400	6:00+	315	407	H
HES-7	y		600	13.0	156	118	7400	6:30+	862	1246	H
HES-7	y		2000	13.0	0	82	12429	10:00+	0	188	H
B	y		220	13.0	159	120	10907	3:14			65/35 H/POZ
A	y		300	13.0	114	97	3525	5:00+	170	350	H
HES-3	y		1611	13.0		80	3700	2:50			A
HES-3	y		1611	13.0		80	3700	3:55	588		A
HES-3	y		1611	13.0		80	3700	1:36			A
HES-3	y		1611	13.0		80	3700	2:22	1244	1671	A
HES-3	y		1611	13.0		80	3700	2:35			A
B	y		688	13.0	138	117	6950	2:45	208	851	65/35 H/POZ
HES-7	y		1419	13.0		95	6600	6:47	268	537	A
HES-7	y		1419	13.0		140	9744	6:40	309	554	A
HES-7	y		1419	13.0		128	8900	6:15	224	530	A
HES-11	y		2200	13.0		82	4500	5:10	130	180	TLW
HES-7	y		3393	13.0	0	75	8000	5:00+	0	74	A
HES-7	y		5100	13.0	0	90	13000	5:57	174	240	H
B		n		13.0	285	236	14830	7:00+	0	95	HFC-12.5
HES-11		n		13.0	190	152	7820	2:19	2084	2338	TLW
B		n		13.0	200	150	9400	5:42	425	667	65/35 H/POZ
B	y		3000	13.0	0	80	8720	3:49	0	172	H
A	y		1785	13.0		45	2975	4:00+	0	108	A
HES-7	y		1968	13.0		101	9600	5:13	230	351	H
HES-3	y		517	13.0		70	1109	2:28	520	920	FLOSTOP I
HES-3	y		517	13.0		86	1695	1:31	1590	2790	FLOSTOP I
HES-3	y		517	13.0		80	1109	2:35	700	1410	FLOSTOP I
HES-7	y		2840	13.0	0	80	8720	12:00+	102	386	H
HES-11	y		2161	13.0		93	7400	3:38	499	1371	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-1	y		833	13.0		80	2400	4:45	1052	1226	SLAG
HES-7	y		1965	13.0		71	5100	8:00+	FIRM	120	H
B	y		2025	13.0	0	75	6400	5:33	100	310	H
HES-7	y		2025	13.0	0	75	6400	5:30+	60	120	H
HES-7	y		2025	13.0		79	5700	10:00+	32	120	H
HES-7	y		3329	13.0		80	8000	4:00+	230	260	H
HES-7	y		3329	13.0		80	9020	6:00+	60	230	H
A	y		3329	13.0		80	9000	4:00+	70	200	A
B	y		3325	13.0		104	9100	3:28	210	340	65/35 A/POZ
HES-11	y		4243	13.0		150	16000	2:30			2/1 TLW/H
HES-11	y		4243	13.0		150	16000	4:12	518	1418	2/1 TLW/H
HES-7	y		5467	13.0	0	86	10000	5:30+	170	250	H
HES-7	y		5467	13.0	0	75	8400	7:00+	150	290	A
FOAMED	y		5467	13.0	0	75	8400	6:30+			A
B		n		13.0	250	201	13050	3:34	286	712	25/75 H/POZ
B		n		13.0	250	201	13050	5:45	395	510	25/75 H/POZ
HES-7	y		45	13.0	198	148	9600	5:07	260	360	H
B	y		50	13.0	220	164	10100	6:36	272	1318	65/35 H/POZ
HES-7	y		50	13.0	166	121	7291	5:00+	351	503	H
B	y		51	13.0	159	133	8500	2:37	370	490	H
B	y		55	13.0		150	11913	4:00+	310	460	50/50 H/POZ
B	y		40	13.0	146	111	5500	5:44	110	120	85/15 H/POZ
B	y		40	13.0	189	143	9100	4:00+		260	65/35 H/POZ
B	y		280	13.0	0	132	8929	2:08			65/35 H/POZ
HES-7	y		34	13.0	176	132	8000	4:00+	140	290	H
HES-7	y		60	13.0	176	132	8539	4:00+	289	760	H
HES-7	y		293	13.0	131	100	4200	5:00+	185	290	H
HES-11		n		13.0		155	12131	4:04	1227	1696	2/1 TLW/H
B		n		13.0	230	181	12500	6:34	0	51	65/35 H/POZ
B		n		13.0	131	102	4100	4:47	110	220	A
HES-11		n		13.0	130	109	4100	3:15	660	1010	TLW
HES-11		n		13.0	230	178	11500	6:00	624	967	2/1 TLW/H
B		n		13.0	197	147	9000	4:35	0	560	65/35 H/POZ
B		n		13.0	230	180	12000	4:49			65/35 H/POZ
B		n		13.0	205	160	10000	4:52	0	886	25/75 A/POZ
B		n		13.0	205	160	10000	5:09	0	979	25/75 A/POZ
B		n		13.0	205	160	10000	4:38	49	1146	25/75 H/POZ
POZMIX		n		13.0	205	160	10000	5:09	645	719	Pozmix 140
B		n		13.0	205	160	10000	4:06	40	1360	25/75 H/POZ
HES-11		n		13.0	178	145	8910	5:39	1153	1516	2/1 TLW/H
B		n		13.0	95	83	1275	7:00+	0	138	65/35 H/POZ
HES-11		n		13.0	228	177	11400	6:38	387	1655	2/1 TLW/H
B		n		13.0	210	162	10900	4:27			50/50 H/POZ
B		n		13.0	261	213	14600	5:13	780	920	65/35 H/POZ
B		n		13.0	220	176	13550	5:15	1340	1700	50/50 H/POZ
HES-11		n		13.0		215	15100	5:50	784	1214	2/1 TLW/H
HES-11		n		13.0		150	9650	5:15	1037	1764	2/1 TLW/H
HES-11		n		13.0		145	10235	5:34			2/1 TLW/H
HES-11		n		13.0		155	10800	5:30+	380	1273	3/2 TLW/H
HES-11		n		13.0	200	153	10500	5:30+	736	1946	2/1 TLW/H
B		n		13.0		136	8350	2:58	454	674	H
B	y		36	13.0		145	10374	7:00	112	970	H
A	y		210	13.0	102	88	2112	7:23	300	570	A
B	y		210	13.0	101	87	1750	5:30+	40	240	50/50 H/POZ
B	y		210	13.0	101	87	1750	5:00+	50	160	50/50 H/POZ
B	y		300	13.0	169	127	7400	4:30+	390	780	50/50 H/POZ
HES-7	y		250	13.0	0	141	9733	5:47	425	575	H
HES-7	y		40	13.0		141	8950	5:20	366	485	H
HES-7	y		40	13.0		112	5545	8:20	395	520	H
B	y		40	13.0	115	96	3240	5:21	220	280	H
B	y		20	13.0	166	141	10200	3:32	104	641	65/35 H/POZ
HES-11	y		40	13.0	180	136	8500	4:20	545	1090	TLW
HES-11	y		82	13.0		115	3500	2:52	300	564	TLW
B	y		58	13.0	194	147	9500	7:55	105	768	65/35 H/POZ
HES-7	y		250	13.0	0	141	9733	5:23			H
A	y		154	13.0	155	112	5400	3:54	253	370	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B		n		13.0	241	201	13428	4:15	297	536	H
B		n		13.0	238	199	13210	3:40	625	855	H
B		n		13.0	215	166	11000	2:58			65/35 H/POZ
B		n		13.0	140	115	4490	3:42	460	630	H
HES-1	y		2940	13.0		94	11770	4:06	290	338	SLAG
HES-1	y		2940	13.0		94	11770	4:30	672	726	SLAG
HES-7	y		6000	13.0	0	84	14000	7:00+	84	213	H
HES-7	y		2500	13.0	0	113	10200	3:21	244	346	H
HES-7	y		3500	13.0	0	120	11650	3:30+	162	270	H
HES-7	y		3500	13.0	0	135	14650	4:00+	210	592	H
HES-7	y		3500	13.0	0	135	14650	2:30	0	94	H
HES-7	y		3600	13.0	0	125	12500	4:38	280	290	H
HES-7	y		3600	13.0	0	125	12500	5:56			H
HES-7	y		3600	13.0	0	140	14600	6:30+			H
HES-7	y		5000	13.0	0	85	9500	5:00+	204	312	H
HES-7	y		5000	13.0	0	105	11557	4:32	161	329	H
HES-7	y		2407	13.0	0	94	8500	6:00+	90	290	H
HES-7	y		2320	13.0		82	6500	6:15+	118	259	H
HES-11	y		1334	13.0		75	4500	5:00+	225	410	TLW
HES-7	y		2559	13.0	77	70	5200	7:00+	0	131	H
HES-7	y		2559	13.0	77	70	5200	9:23		125	A
HES-7	y		3210	13.0		73	6300	15:57	0	160	H
HES-7	y		3257	13.0		77	7500	10:00+	45	140	H
HES-1	y		3000	13.0		100	11875	4:55	0	410	SLAG
HES-3	y		3944	13.0		70	5650	1:47	800	1720	A
HES-7	y		3875	13.0	0	73	6435	6:00+	30	60	A
HES-7	y		3875	13.0	0	75	9100	5:00+	90	235	H
HES-7	y		3845	13.0	0	87	10383	5:30+	267	380	H
HES-7	y		4000	13.0	0	75	9000	6:30+	85	220	A
HES-7	y		4000	13.0	0	82	9000	6:30+	156	271	A
HES-7	y		3982	13.0	0	75	8200	5:00+	120	210	H
HES-7	y		3982	13.0	0	70	7020	6:00+	FIRM	870	H
HES-7	y		84	13.0	0	135	8000	5:47	382	509	H
HES-11	y		50	13.0	230	178	11500	9:00		1197	TLW
HES-11	y		60	13.0	106	90	2000	5:00+	250	500	TLW
HES-11	y		52	13.0	0	255	17000	7:00	943	1347	TLW
B	y		55	13.0		203	13400	10:00+			HTLD
B	y		85	13.0		135	8000	5:13	0	860	H
HES-7	y		85	13.0	145	109	5000	8:00+	510	967	H
A	y		158	13.0	93	80	1000		728	1412	A
B	y		150	13.0	233	167	9500	4:47	62	236	65/35 H/POZ
B		n		13.0	172	127	7300	5:00	226	827	65/35 H/POZ
HES-11		n		13.0	150	113	5800	5:00+	932	2318	2/1 TLW/H
HES-11		n		13.0	150	113	5800	5:00+	389	793	2/1 TLW/H
B		n		13.0		80	50			88	50/50 A/POZ
B		n		13.0		80	50			105	50/50 A/POZ
B		n		13.0	221	159	9400	8:00+	290	730	65/35 H/POZ
B		n		13.0	206	146	8700	4:25	470	710	65/35 H/POZ
HES-7		n		13.0		135	8300	7:07	400	525	H
B		n		13.0	300	253	15800	5:17	0	1465	HTLD
B		n		13.0	116	96	3000	6:00+		340	65/35 A/POZ
HES-11		n		13.0	225	180	11600	4:06	1077	2535	2/1 TLW/H
B		n		13.0	118	96	3000	3:58	267	515	A
B		n		13.0	124	98	3500	4:35	262	461	A
HES-11		n		13.0	186	140	8810	3:00	1226	1682	TLW
B		n		13.0	200	150	9500	3:36			65/35 H/POZ
B	y		350	13.0	135	103	5250	3:00+	209	761	65/35 A/POZ
B	y		240	13.0	174	130	9600	5:30+	0	0	50/50 H/POZ
B	y		240	13.0	177	133	9585	6:30+		0	50/50 H/POZ
HES-11	y		21	13.0	198	149	10298	2:30	1012	1460	2/1 TLW/H
HES-11	y		21	13.0	198	149	10298	3:10	802	1609	2/1 TLW/H
HES-11	y		16	13.0	205	157	10400	3:05	1240	1420	2/1 TLW/H
HES-11	y		18	13.0	210	163	11820	3:40	779	1890	2/1 TLW/H
HES-11	y		18	13.0	201	154	11028	3:17	1090	2060	2/1 TLW/H
B	y		63	13.0	252	205	15100	4:58	260	1110	65/35 H/POZ
B	y		95	13.0	194	147	9514	4:47	242	1250	65/35 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		95	13.0	185	139	8550	4:45	0	1230	65/35 H/POZ
B	y		102	13.0	242	194	13400	4:40	768	935	HLC
B	y		102	13.0	242	194	13400	8:11	870	1120	65/35 H/POZ
HES-7	y		124	13.0		146	9450	4:00	230	340	H
HES-7	y		50	13.0		153	10400		310	360	H
HES-7	y		51	13.0	165	123	8360	5:00+	1060	1330	H
HES-7	y		51	13.0	145	111	5500	5:00+	443	1000	H
HES-7	y		51	13.0	145	110	5500	5:00+	483	1620	H
HES-7	y		51	13.0	190	143	9511	5:00+	1339	3577	H
HES-7	y		51	13.0	155	126	6246	3:00+	310	520	H
HES-7	y		70	13.0	164	123	7000	5:00+	275	710	H
HES-7	y		70	13.0	196	149	10200	3:48	431	508	H
HES-7	y		70	13.0	196	149	10200	3:33	494	520	H
HES-7	y		70	13.0	195	148	10160	3:50	349	1100	H
HES-7	y		70	13.0	145	111	6100	5:00+	609	833	H
A	y		186	13.0	113	96	3809	5:00+	230	403	H
DIACEL-M	y		325	13.0	191	158	10060	4:00	415	640	H
B	y		200	13.0	113	95	4700	4:00+	250	460	H
HES-11	y		200	13.0		107	4950	7:15			TLW
HES-7	y		20	13.0	208	162	12764		330	380	H
HES-7	y		20	13.0	208	162	12764	4:58	260	320	H
B	y		21	13.0	212	164	11000	3:46	60	460	50/50 H/POZ
B	y		21	13.0	220	172	12250	3:25	240	1290	50/50 H/POZ
B	y		34	13.0	208	163	12400	3:46	1380	1800	50/50 H/POZ
B	y		48	13.0	220	163	10042	4:08	817	1944	65/35 H/POZ
HES-7	y		65	13.0		159	10700	10:00+			H
HES-7	y		65	13.0		169	11562	7:37	475	552	H
HES-7	y		60	13.0		174	11980	5:16			H
HES-11	y		184	13.0	110	93	2750	5:25	453	905	2/1 TLW/H
HES-11	y		235	13.0	118	97	3180	5:30+		1235	TLW
HES-11	y		235	13.0	118	97	3180	6:08		904	TLW
B	y		235	13.0	190	152	11025	4:38	65	645	65/35 H/POZ
HES-11	y		280	13.0	140	107	5000	5:44	545	1312	TLW
B	y		26	13.0	236	188	14358	4:55	512	2110	50/50 H/POZ
B	y		26	13.0	128	101	4000	5:00+	335	700	50/50 A/POZ
B	y		26	13.0	220	172	11700	2:32	600	706	50/50 H/POZ
B	y		26	13.0	220	172	11700	3:02	920	1420	50/50 H/POZ
B	y		26	13.0	220	172	11700	4:20	1080	1550	50/50 H/POZ
HES-7	y		160	13.0	0	218	16309	6:10	420	600	H
B	y		181	13.0	122	100	4000	3:17	320	415	H
B	y		181	13.0	96	86	1650	6:10	220	355	H
HES-11	y		70	13.0		85	525	2:16	320	470	TLW
B	y		70	13.0	268	215	17000	6:54	372	411	HTLD
HES-7	y		70	13.0		209	15110	8:29	295	435	H
B	y		60	13.0		106	4850	7:04			H
B	y		280	13.0	194	147	9500	3:42	188	420	65/35 H/POZ
A	y		150	13.0	134	104	4500	5:18	232	562	H
HES-11	y		280	13.0	139	105	5550	4:30	915	1710	TLW
HES-11	y		280	13.0		80	1619	6:00+	430	705	TLW
HES-11	y		280	13.0	139	105	5550	4:30	915	1710	TLW
HES-7	y		447	13.0		136	3500	4:55	267	470	H
HES-11	y		64	13.0	242	195	14978	5:45			TLW
HES-11	y		64	13.0	242	195	14978	6:10			TLW
HES-11	y		64	13.0	128	101	4000			550	TLW
HES-7	y		64	13.0		161	11745	5:48	470	540	H
B	y		64	13.0		174	12309	8:12	677	1040	H
HES-11	y		64	13.0	242	195	14978	5:55	990	1050	TLW
HES-11	y		64	13.0	212	167	12680	8:06	0	1385	TLW
B	y		64	13.0	0	143	12180	3:43	160	450	H
HES-11	y		64	13.0	242	195	14978		1153	2170	TLW
B	y		64	13.0	0	176	13145	4:02	233	780	H
B	y		63	13.0	157	120	7716	3:54	647	820	H
B	y		60	13.0		80	1000	5:36			H
B		n		13.0	205	156	10200	4:09	58	652	65/35 H/POZ
B		n		13.0	217	180	11760	3:03	0	380	H
B		n		13.0	219	168	10890	4:52	1359	1990	50/50 H/POZ

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
HES-11		n		13.0		150	10000	5:49	1296	1464	2/1 TLW/H
B		n		13.0	230	167	10000	6:30+	740	1320	65/35 H/POZ
HES-7	y		25	13.0	152	115	6080	5:00+	236	522	H
HES-7	y		25	13.0	150	114	6050	5:00+	467	1774	H
B		n		13.0	122	98	3500	2:00			A
HES-11	y		60	13.0	193	145	8790	5:30+			2/1 TLW/H
B	y		60	13.0	171	128	7689	3:10			65/35 H/POZ
B	y		60	13.0		132	8000	4:26	400	1191	65/35 H/POZ
HES-11	y		60	13.0		132	8000	3:53	583	1636	2/1 TLW/H
B	y		60	13.0	215	157	9650	4:34	170	580	65/35 H/POZ
B		n		13.0	165	125	7300	3:12			65/35 H/POZ
B		n		13.0	207	159	10550	2:58	130	570	65/35 H/POZ
B		n		13.0	188	142	9000	3:28	139	1064	65/35 H/POZ
B		n		13.0	219	171	11600	3:47			65/35 H/POZ
HES-7	y		127	13.0	0	155	10300	4:23	243	322	H
B	y		90	13.0	184	147	12438	5:58	0	297	65/35 H/POZ
HES-7	y		127	13.0	0	155	11594	4:30	0	700	H
HES-7	y		127	13.0	0	175	13355	5:33	160	430	H
B	y		190	13.0	166	128	10618	5:08	185	900	65/35 H/POZ
B	y		350	13.0	140	119	8625	5:48	455	556	65/35 H/POZ
B	y		42	13.0		150	9700	5:41	131	847	65/35 H/POZ
B	y		360	13.0	160	119	9350	6:01	290	1000	65/35 H/POZ
HES-11	y		360	13.0	169	131	8300	3:39			2/1 TLW/H
HES-11		n		13.0	190	143	8950	5:28	835	3471	2/1 TLW/H
HES-11		n		13.0	190	145	9050	5:59	1070	1811	2/1 TLW/H
HES-11		n		13.0	190	143	8975	4:00	1531	1778	2/1 TLW/H
B	y		120	13.0		132	7800	5:05			H
B	y		300	13.0		135	8100	7:51			H
B	y		300	13.0	174	134	10800	5:30+	400	2800	50/50 H/POZ
HES-7	y		2526	13.0	0	85	9200	5:25+	100	240	H
HES-1	y		3214	13.0		95	9400	4:42	440	560	SLAG
HES-3	y		3200	13.0		70	5200	2:32			FLOSTOP I
HES-11	y		3236	13.0		110	9908	2:40	540	870	TLW
B	y		40	13.0	206	151	9120	4:00+	1190	2800	50/50 H/POZ
B	y		40	13.0	206	151	9120	2:34	1090	1245	50/50 H/POZ
B	y		40	13.0	206	151	9120	3:51	1025	1225	50/50 H/POZ
HES-7	y		28	13.0		177	11500	11:03			H
B	y		60	13.0	224	162	11108	3:30	745	820	50/50 H/POZ
B	y		60	13.0	190	145	11108	4:13	600	900	50/50 H/POZ
B	y		59	13.0	205	155	10000	4:20	190	261	H
B	y		79	13.0	91	80	1000	4:00+	90	270	50/50 H/POZ
B	y		50	13.0	200	153	10350	8:30+			65/35 H/POZ
HES-7	y		153	13.0	170	125	8890	3:00+	392	670	H
HES-11	y		176	13.0	202	154	11035	3:40	1140	2520	TLW
A	y		174	13.0	117	99	6600	4:00+	300	380	H
A	y		174	13.0	96	87	3000	3:00+	188	375	H
HES-11	y		185	13.0	155	115	12345		920	1180	TLW
HES-11	y		185	13.0	155	115	12345	4:40	1070	1515	TLW
HES-11	y		167	13.0	245	198	14600	5:20	570	729	1/1 TLW/H
B	y		260	13.0	162	122	7950	3:17			H
HES-11		n		13.0	249	201	13350	5:16	1197	1800	2/1 TLW/H
HES-11		n		13.0	200	153	10150	6:30+			2/1 TLW/H
HES-11		n		13.0	208	160	10730	5:18	774	1602	2/1 TLW/H
HES-11		n		13.0	200	153	10150		234	1196	2/1 TLW/H
HES-11	y		225	13.0	192	154	11700	4:36	681	1312	TLW
HES-11	y		225	13.0	207	166	13380	6:08	820	1645	TLW
B	y		245	13.0	212	176	12000	2:55	790	840	H
HES-11	y		225	13.0	210	169	14000	5:20	990	1782	TLW
HES-7	y		225	13.0	160	136	9975	5:08		400	H
HES-11	y		225	13.0	149	123	6716	5:26	1204	1448	TLW
HES-11	y		258	13.0		172	11400	4:27	0	2368	TLW
HES-11	y		258	13.0	233	184	12615	4:42	1161	1455	TLW
HES-11	y		258	13.0		144	11520	4:31	400	2182	TLW
HES-11	y		258	13.0		143	10976	5:39	0	1361	TLW
HES-11	y		258	13.0		185	14550	4:38	547	1316	TLW
HES-11	y		258	13.0	244	196	13473	5:52	1395	1506	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
B	y		210	13.0		182	12750	8:00+			H
B	y		210	13.0		182	12750	7:03			H
B	y		210	13.0		182	12750	1:07			H
B	y		210	13.0		181	12602	6:11			H
B	y		410	13.0	280	236	16000	6:40	366	481	HTLD
B	y		50	13.0		158	12422	6:16	0	909	H
HES-7	y		250	13.0		181	12700	9:51	380	550	H
B		n		13.0	225	186	11900	4:56	330	818	H
B		n		13.0	170	127	7496	5:43	280	667	50/50 H/POZ
A	y		150	13.0		80	1050	4:00+	124	328	H
HES-11	y		150	13.0		80	1050	4:00+	215	314	TLW
B		n		13.0	230	178	12000	4:42	970	1240	65/35 H/POZ
B		n		13.0	165	125	7100	5:23	430	950	65/35 H/POZ
HES-11		n		13.0		350	1400	2:04	135	220	TLW
B		n		13.0	223	174	12000	4:05	747	1545	50/50 H/POZ
HES-11		n		13.0		380	1130	2:08	160	200	TLW

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed HES-8	y		113	7.0	15.2	180	148	8900	180		SET	85	A
Foamed HES-8	y		3800	10.0	15.1		65	5300	54		40	200	A
Foamed HES-8	y		3800	10.0	15.1		75	5450	95		630	730	A
Foamed HES-8	y		3800	10.0	15.5		68	6030	75		50	290	A
Foamed HES-8	y		3800	10.0	15.5		68	6030	61		32	110	A
Foamed HES-8	y		3800	10.0	15.5		65	5450	73		140	370	A
Foamed HES-8	y		3800	10.0	15.5		65	5450	54		FIRM	160	A
Foamed HES-8	y		1646	10.5	15.0		80	3330	60		0	76	A
Foamed HES-8	y		3778	10.5	15.2		70	6100	70		150	440	A
Foamed HES-8	y		6600	10.5	15.1		65	7200	55		70	230	A
Foamed HES-8	y		3800	10.5	15.1		70	7000	70		380	520	A
Foamed HES-8	y		3800	10.5	15.1		65	5300	54		50	220	A
Foamed HES-8	y		3800	10.5	15.1		90	7000	100		450	670	A
Foamed HES-8	y			10.5	15.2		75	6000	65		200	312	A
Foamed HES-8	y			10.5	15.2		75	6000	65		FIRM	FIRM	A
Foamed HES-8	y		3800	10.5	15.1		73	7200	76		FIRM	390	A
Foamed HES-8	y		3800	10.5	16.2		90	7000	100		50	270	A
Foamed HES-8	y		3800	10.5	15.1		90	7000	100		480	660	A
Foamed HES-8	y		1420	10.5	15.4		65	2500	57		30	110	A
Foamed HES-1	y		1420	10.5	15.4		65	3000	60		40	125	A
Foamed HES-8	y		3800	10.5	15.5		73	7200	69		136	350	A
Foamed HES-8	y		3800	10.5	15.5		73	7000	73		70	160	A
Foamed HES-8	y		3800	10.5	15.5		90	7000	100		430	450	A
Foamed HES-8	y		3800	10.5	15.5	0	73	7200	69		110	270	A
Foamed HES-8	y		3800	10.5	15.0	0	64	7337	54		0	90	A
Foamed HES-8	y			10.5	15.4		75	6000	65		110	170	A
Foamed HES-8	y		3800	10.5	15.0	0	64	7281	72		140	360	A
Foamed HES-8	y		3800	10.5	15.5	0	73	7325	64		105	360	A
Foamed HES-8	y		2049	10.8	15.6		65	3900	65		30	280	A
Foamed HES-8	y		2100	10.8	15.6		65	3900	65		40	250	A
Foamed HES-8	y		3480	10.8	17.3	0	121	12638	150		90	135	H
Foamed HES-8	y		3153	11.0	15.2		70	5000	50		0	140	A
Foamed HES-8	y		1968	11.0	15.1		65	3150	50		0	120	A
Foamed HES-8	y			11.0	14.5		70	6880	70		190	310	SLAG
Foamed HES-8	y			11.0	15.2		55	5000	55		180	180	A
Foamed HES-8	y		3150	11.0	15.2	0	65	4330	50		180	650	A
Foamed HES-8	y		3150	11.0	15.1	0	65	4330	50		280	340	A
Foamed HES-8	y		3778	11.0	15.2		70	6100	70		130	430	A
Foamed HES-8	y		3778	11.0	15.2		70	6100	70		180	500	A
Foamed HES-8	y		2841	11.0	15.1		65	3850	47		80	240	A
Foamed HES-8	y		3800	11.0	15.1		65	5300	54		60	230	A
Foamed HES-8	y		3900	11.0	15.2		70	5820	50		0	200	A
Foamed HES-8	y		3153	11.0	15.6		70	6500	68		0	350	A
Foamed HES-8	y		3153	11.0	15.6		70	8800	68		0	350	A
Foamed HES-8	y		2841	11.0	15.1		65	3850	47		15	22	A
Foamed HES-8	y		3944	11.0	15.6		78	6880	57		0	110	A
Foamed HES-8	y		7600	11.0	15.5	0	58	8800	56		90	270	A
Foamed HES-8	y		3500	11.0	15.5	0	58	7300	48		20	80	A
Foamed HES-8	y		1420	11.0	15.4	0	54	2800	55		50	120	A
Foamed HES-8	y		285	11.0	16.3	97	85	1500	85		70	318	H
Foamed HES-8	y		285	11.0	16.4		85	50	85		180	330	H
Foamed HES-8	y		285	11.0	16.4		85	1500	85		180	330	H
Foamed HES-8	y		3944	11.0	15.6		78	6880	70		190	340	A
Foamed HES-8	y		3944	11.0	15.6		78	6880	70		220	430	A
Foamed HES-8	y		3944	11.0	15.4		65	5350	56		FIRM	115	A
Foamed HES-8	y		3944	11.0	15.6		80	6880	57		90	200	A
Foamed HES-8	y		3907	11.0	15.6		80	6880	57		60	260	A
Foamed HES-8	y		1510	11.0	15.4		65	3700	50		360	420	A
Foamed HES-8	y		3393	11.0	15.5	0	60	4500	55		0	250	A
Foamed HES-8	y		3855	11.0	15.4	0	65	4500	50		60	180	A
Foamed HES-8	y		52	11.0	15.0	318	276	17000	150		SET	330	50/50 H/POZ
Foamed HES-8	y		1965	11.1	15.1		70	3750	50		FIRM	50	A
Foamed HES-8	y		2588	11.2	14.1		70	4800	50		0	140	A
Foamed HES-8	y		3500	11.2	15.5	0	67	8000	57		38	70	A
Foamed HES-8	y		3210	11.2	15.6		64	4900	60		143	220	A
Foamed HES-8	y		1700	11.5	15.1		65	3200	65		60	250	A
Foamed HES-8	y		3940	11.5	15.1		60	4975	60		280	370	A
Foamed HES-8	y		3800	11.5	15.1		65	4910	49		40	370	A
Foamed HES-8	y		1500	11.5	15.5		65	4200	50		0	65	A
Foamed HES-8	y			11.5	16.3		65	4200	54		FIRM	260	H

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed HES-8	y			11.5	15.5		65	4200	54		0	120	A
Foamed HES-8	y		4000	11.5	15.0	0	55	5000	50		40	120	A
Foamed HES-8	y		4000	11.5	15.0	0	65	7100	70		223	480	A
Foamed HES-8	y		4000	11.5	15.0	0	65	7100	70		310	480	A
Foamed HES-8	y		3982	11.5	15.4	0	65	4980	52		0	90	A
Foamed HES-8	y		6700	11.5	15.5	0	58	9419	72		160	375	A
Foamed HES-8	y		3800	11.5	15.5		60	4920	49		FIRM	140	A
Foamed HES-8	y		3855	11.5	15.4	0	65	4550	52		40	150	A
Foamed HES-8	y		3855	11.5	15.4	0	73	6435	65		FIRM	170	A
Foamed HES-8	y		3845	11.5	15.5	0	63	7000	70		200	360	A
Foamed HES-8	y		4000	11.5	15.4		65	5000	52		40	140	A
Foamed HES-8	y		3900	11.5	15.0	0	65	7700	73		190	270	A
Foamed HES-8	y		3900	11.5	15.0	0	55	5842	50		110	520	A
Foamed HES-8	y		1753	11.5	15.5	0	62	3162	49		260	500	A
Foamed HES-8	y		2841	11.5	15.5	0	70	3850	48		70	210	A
Foamed HES-8	y		2841	11.5	15.5	0	70	4400	52		70	220	A
Foamed HES-8	y		2841	11.5	15.5	0	70	4400	52		70	220	A
Foamed HES-8	y		2841	11.5	15.5	0	75	5600	60		100	310	A
Foamed HES-8	y		3982	11.5	15.4	0	65	4980	52		0	80	A
Foamed HES-8	y		3982	11.5	16.3	0	70	7020	67		87	290	H
Foamed HES-8	y		3480	11.5	16.2	0	70	7200	72		190	240	H
Foamed HES-8	y		1646	11.6	15.0		80	3330	80		100	450	A
Foamed HES-8	y		2588	11.6	14.6		70	4800	50		0	240	A
Foamed HES-8	y		1736	11.6	15.0		80	3330	80		0	330	A
Foamed HES-8	y		2594	11.6	15.5	70	65	3400	65		250	360	A
Foamed HES-8	y		5400	11.8	15.0	0	60	5600	50		FIRM	170	A
Foamed HES-8	y		5400	11.8	15.0	0	65	7100	50		FIRM	160	A
Foamed HES-8	y		2100	11.8	15.1		65	2700	54		100	210	A
Foamed HES-8	y		2446	11.8	16.3		65	3800	74		299	410	H
Foamed HES-8	y		3944	12.0	15.1		65	5048	50		50	370	A
Foamed HES-8	y		3944	12.0	15.1		65	5048	50		30	340	A
Foamed HES-8	y		3557	12.0	15.1		65	5823	50		0	50	A
Foamed HES-8	y		1074	12.0	15.1		71	2408	71		800	880	A
Foamed HES-8	y		2588	12.0	15.0		70	4800	50		0	320	A
Foamed HES-8	y		1451	12.0	15.1		100	4600	90	3:49	250	590	A
Foamed HES-8	y		1451	12.0	15.1		100	4600	90		240	990	A
Foamed HES-8	y		3150	12.0	15.2	0	65	4330	50		250	410	A
Foamed HES-8	y		3150	12.0	15.1	0	65	4330	50		310	470	A
Foamed HES-8	y		4000	12.0	15.1	0	65	4700	50		FIRM	200	A
Foamed HES-8	y		4000	12.0	15.1	0	90	6000	100		730	1170	A
Foamed Class A	y		2521	12.0	15.2		70	3600	53		150	340	A
Foamed HES-8	y		2521	12.0	15.2		70	4820	65		235	530	A
Foamed Class A	y		2841	12.0	15.1		65	3850	52		75	270	A
Foamed Class A	y		3500	12.0	15.1		70	4800	54		0	230	A
Foamed HES-8	y		3633	12.0	15.1		65	6019	65		50	460	A
Foamed HES-8	y		3907	12.0	15.1		65	5048	50		85	460	A
Foamed Class A	y		3907	12.0	15.1		65	5048	50		102	290	A
Foamed Class A	y		3030	12.0	15.1		65	5662	72		410	610	A
Foamed Class A	y		3272	12.0	15.1		57	4573	50		FIRM	300	A
Foamed HES-8	y		3900	12.0	15.2		70	5000	40		0	120	A
Foamed HES-8	y		3900	12.0	15.1		65	5048	50		60	250	A
Foamed HES-8	y		3900	12.0	15.2		70	5000	40		0	120	A
Foamed Class A	y		3900	12.0	15.1		70	5000	40		0	140	A
Foamed HES-8	y		4100	12.0	15.1	0	65	7773	50		0	650	A
Foamed HES-8	y		4000	12.0	15.1		65	5800	60		290	520	A
Foamed HES-8	y			12.0	15.1		65	4000	RM		280	740	A
Foamed HES-8	y		7300	12.0	15.5	0	66	10100	72		180	420	A
Foamed HES-8	y		4500	12.0	15.1		70	8392	50		0	0	A
Foamed HES-8	y			12.0	15.2	0	65	8000	55		80	100	A
Foamed Class A	y		2841	12.0	15.1		65	4400	52		40	60	A
Foamed Class A	y		6700	12.0	15.5	0	58	9419	72		130	315	A
Foamed HES-8	y		3944	12.0	15.2		70	5048	50		0	170	A
Foamed HES-8	y			12.0	15.1		65	4000	RM		250	800	A
Foamed Class A	y			12.0	15.1	0	65	4000	75		380	710	A
Foamed HES-8	y			12.0	15.1	0	65	4000	55		FIRM	500	A
Foamed Class A	y		7600	12.0	15.5	0	66	10100	72		230	440	A
Foamed HES-8	y		3125	12.0	16.4		70	5400	58		121	320	H
Foamed HES-8	y		3125	12.0	16.4		70	5400	58		50	380	H
Foamed Class A	y		3557	12.0	15.5		65	5023	50		FIRM	50	A
Foamed HES-8	y		3557	12.0	15.5		65	5823	50		FIRM	80	A

*Slurry Type	Offshore		Water Depth	Slurry Density	Base Slurry Density	BHST	BHCT	Casing Depth	Temp for Comp Str	Thickening Time	Compressive Strength (psi)		Base Cement Type
	Yes	No	(ft)	(lb/gal)		(°F)	(°F)	(ft)	(°F)	(hr:min)	12 hr	24 hr	
Foamed Class A	y			12.0	16.0	0	90	8000	70		160	570	H
Foamed Class A	y		719	12.0	15.5		63	1874	63		130	314	A
Foamed HES-8	y		719	12.0	15.5		63	1874	63		73	260	A
Foamed HES-8	y		3000	12.0	15.5	0	62	4400	50		90	220	A
Foamed Class A	y		2521	12.0	15.5	0	70	4850	60		150	690	A
Foamed HES-8	y		2521	12.0	15.6		70	5800	76		290	370	A
Foamed HES-8	y		2521	12.0	15.5	0	65	3750	50		40	290	A
Foamed Class A	y		4000	12.0	15.0	0	76	9100	90		503	860	A
Foamed Class A	y			12.0	15.6		65	6800	65		70	330	A
Foamed Class A	y		285	12.0	16.3	135	105	4600	105		500	760	H
Foamed Class A	y		285	12.0	16.3		85	1500	90		360	420	H
Foamed Class A	y		285	12.0	16.3		85	1500	135		480	611	H
Foamed Class A	y		1300	12.0	15.5	0	62	5000	72		310	520	A
Foamed Class A	y		1300	12.0	15.5	0	62	5000	72		370	680	A
Foamed Class A	y		3100	12.0	15.0	0	58	9400	62		30	120	A
Foamed Class A	y		4200	12.0	16.4	0	65	7773	55		FIRM	330	A
Foamed Class A	y		4200	12.0	15.0	0	65	7773	55		0	90	A
Foamed Class A	y		4200	12.0	16.7	0	65	7773	55		0	180	H
Foamed Class A	y		3855	12.0	15.4	0	72	5450	55		150	570	A
Foamed Class A	y		3845	12.0	15.5	0	75	7000	55		180	500	A
Foamed Class A	y		4000	12.0	15.4		65	5800	52		70	220	A
Foamed Class A	y		3480	12.0	15.4	0	65	5564	68		560	1090	A
Foamed Class A	y			12.0	16.9	0	65	4000	45		SET	120	H
Foamed Class A	y			12.0	16.9	0	65	4000	45		SET	110	H
Foamed Class A	y		3393	12.0	15.5	0	70	7500	67		220	360	A
Foamed Class A	y		3900	12.0	15.5	0	65	4700	50		0	FIRM	A
Foamed Class A	y		3900	12.0	15.5	0	90	6000	100		640	950	A
Foamed Class A	y		3325	12.0	15.0	0	65	5037	50		60	240	A
Foamed Class A	y		5467	12.0	15.4	0	68	7000	70		270	410	A
Foamed Class A	y		1400	12.0	15.5	0	62	5000	72		350	740	A
Foamed Class A	y		4000	12.0	16.4	0	65	7773	55		FIRM	260	A
Foamed Class A	y		4000	12.0	16.7	0	65	7773	55		50	340	H
Foamed Class A	y		3982	12.0	15.4	0	65	5650	54		95	300	A
Foamed Class A	y		3200	12.0	15.5	0	75	2265	50		235	570	A
Foamed Class A	y		3200	12.0	15.5	0	65	2265	50		230	585	A
Foamed Class A	y		6800	12.0	17.5	0	80	9300	70			110	H
Foamed Class A	y		3907	12.1	15.4		66	5800	55		FIRM	240	A
Foamed Class A	y		3907	12.1	15.4		66	5800	55		FIRM	130	A
Foamed Class A	y		3800	12.2	15.1		65	5220	70		580	970	A
Foamed Class A	y		3800	12.2	15.1		65	5220	52		FIRM	140	A
Foamed Class A	y		2841	12.2	15.1		47	3800	63		360	720	A
Foamed Class A	y		3800	12.2	15.1		65	5220	53		90	450	A
Foamed Class A	y		2588	12.4	15.1		70	3400	50		0	130	A
Foamed Class A	y		2588	12.4	15.1		70	3400	50		0	140	A
Foamed Class A	y		4600	12.5	15.0	0	60	8085	50		50	124	A
Foamed Class A	y			12.5	15.1		65	5559	57		160	640	A
Foamed Class A	y		6679	12.5	14.8		65	9000	50		0	70	A
Foamed Class A	y		1965	12.5	15.1		70	3400	60		30	260	A
Foamed Class A	y		2025	12.5	15.1		70	3400	50		40	370	A
Foamed Class A	y		3210	12.5	15.1		70	5450	60		120	910	A
Foamed Class A	y		4100	12.5	15.1	0	90	9273	100		700	895	A
Foamed Class A	y			12.5	15.0		65	4850	54		120	350	A
Foamed Class H	y		7612	12.5	15.2		70	10800	67		210	450	A
Foamed Class H	y		7612	12.5	15.2		70	9300	40		0	130	A
Foamed Class H	y			12.5	15.2		55	5000	55		250	350	A
Foamed Class H	y			12.5	15.1		65	5559	57		160	670	A
Foamed Class H	y		6679	12.5	14.8		65	9000	50		0	110	A
Foamed Class H	y		6679	12.5	15.0		65	9000	50		0	115	A
Foamed Class A	y		3100	12.5	15.0	0	60	5200	50		50	220	A
Foamed Class A	y		3100	12.5	15.2	0	65	5100	50		210	315	A
Foamed Class A	y		3100	12.5	15.1	0	65	5100	50		390	500	A
Foamed Class A	y		3778	12.5	15.0		70	5700	45		0	55	A
Foamed Class A	y		3778	12.5	15.2		70	4600	45	3:22	0	50	A
Foamed Class H	y		2663	12.5	15.1	0	65	3978	55		FIRM	190	A
Foamed Class H	y		3150	12.5	15.2	0	65	4330	50		280	450	A
Foamed Class A	y		3150	12.5	15.1	0	65	4330	50		330	500	A
Foamed Class A	y		1968	12.5	15.1		65	5000	52		30	410	A
Foamed Class A	y		5250	12.5	15.0	0	65	7000	50		105	270	A
Foamed Class A	y		5800	12.5	15.1	0	65	7046	50		FIRM	150	A
Foamed Class A	y		2559	12.5	15.0		65	3377	60		150	350	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed Class A	y		5200	12.5	15.1	0	65	8053	50			110	A
Foamed Class H	y		5200	12.5	15.1	0	65	7393	55		340	520	A
Foamed Class A	y		2559	12.5	15.0		65	3377	60		180	190	A
Foamed Class A	y		3210	12.5	15.1		65	5450	70		310	700	A
Foamed Class A	y		3272	12.5	15.1		85	6537	50		0	FIRM	A
Foamed Class A	y		3900	12.5	15.1		70	5700	40		0	115	A
Foamed Class A	y			12.5	15.2		75	6000	65		FIRM	FIRM	A
Foamed Class A	y		1400	12.5	15.1	0	65	6113	65		270	540	A
Foamed Class A	y		6679	12.5	15.0		65	9000	50		SET	160	A
Foamed Class A	y		2000	12.5	15.5		70	3400	50		0	80	A
Foamed Class H	y		5600	12.5	15.1	0	60	8290	55		110	580	A
Foamed Class A	y			12.5	15.1	0	65	8900	40				A
Foamed Class A	y		3257	12.5	15.1	0	70	5450	50		0	0	A
Foamed Class A	y		3800	12.5	15.5		82	9500	90		370	750	A
Foamed Class A	y		4100	12.5	15.0	0	105	10000	120		100	230	A
Foamed Class A	y		4100	12.5	15.0	0	90	8632	105		230	590	A
Foamed Class A	y			12.5	15.4		75	6000	65		170	425	A
Foamed Class A	y			12.5	15.0	0	65	10500	50		0	40	A
Foamed Class A	y		3557	12.5	15.0	0	60	8085	50		45	230	A
Foamed Class A	y		1485	12.5	15.6	0	70	3000	55		235	650	A
Foamed Class H	y		3000	12.5	15.5	0	65	5200	60		130	270	A
Foamed Class A	y		4000	12.5	15.0	0	65	4650	54		70	240	A
Foamed Class A	y		4000	12.5	15.0	0	65	4650	54		45	100	A
Foamed Class A	y		4600	12.5	16.0	0	68	5305	55		140	270	H
Foamed Class A	y			12.5	15.5		65	5000	57		0	90	A
Foamed Class A	y			12.5	16.3		65	5000	57		FIRM	FIRM	H
Foamed Class A	y		3100	12.5	15.5	0	74	2762	68		230	540	A
Foamed Class A	y		4000	12.5	16.0	0	65	6100	50		0	160	A
Foamed Class A	y		5000	12.5	16.4	0	65	7878	55		180	570	A
Foamed Class A	y		3600	12.5	15.0	0	65	9025	50		0	150	A
Foamed Class A	y		3750	12.5	15.0	0	65	5500	55		120	350	A
Foamed Class A	y		3750	12.5	15.0	0	65	6625	50		0	130	A
Foamed Class A	y		3750	12.5	15.5	0	60	6625	55		190	260	A
Foamed Class A	y		6700	12.5	15.5	0	67	11300	99		380	520	A
Foamed Class A	y		3800	12.5	16.3		82	9500	90		160	385	H
Foamed Class A	y		4200	12.5	16.0	0	90	9273	80		0	90	A
Foamed Class A	y		3900	12.5	15.0	0	62	5600	48		SET	60	A
Foamed Class A	y		3900	12.5	15.0	0	73	9400	88		290	500	A
Foamed Class H	y			12.5	15.4		75	6000	65		180	240	A
Foamed Class H	y			12.5	15.6		70	5200	70		220	380	A
Foamed Class A	y		3393	12.5	15.5	0	65	5500	67		222	430	A
Foamed Class A	y		3393	12.5	15.5	0	60	4500	55		190	500	A
Foamed Class A	y		3393	12.5	15.5	0	75	8000	67		490	840	A
Foamed Class A	y		3393	12.5	15.5	0	75	8000	67		530	810	A
Foamed Class A	y		5000	12.5	15.5	0	68	7000	70		290	560	A
Foamed Class A	y		5000	12.5	15.5	0	70	5700	50		203	710	A
Foamed Class A	y		1965	12.5	15.1		70	3750	5		FIRM	130	A
Foamed Class A	y		2700	12.5	16.4	0	60	4340	60		90	320	H
Foamed Class A	y		3500	12.5	15.2		70	6500	70		70	280	A
Foamed Class A	y		6201	12.5	15.5	0	70	8200	79		490	1075	A
Foamed Class A	y		4000	12.5	16.0	0	90	9273	80		210	570	A
Foamed Class H	y		4000	12.5	16.0	0	90	9273	80		20	1310	H
Foamed Class H	y		3855	12.5	15.4	0	65	4500	50		80	200	A
Foamed Class H	y		52	12.5	16.4	150	115	6000	110		40	820	H
Foamed Class H	y		3329	12.5	15.0		65	4850	54		60	300	A
Foamed Class A	y		3329	12.5	15.0		65	4850	54		25	225	A
Foamed Class A	y		3200	12.5	15.1	70	70	5100	60		65	395	A
Foamed Class H	y		3900	12.5	15.2		65	5000	50		FIRM	124	H
Foamed Class A	y		2588	12.6	14.8		70	4800	50		0	420	A
Foamed Class A	y		1965	12.6	15.6	0	65	3700	65		220	510	A
Foamed Class A	y		4700	12.6	16.0	0	65	7238	65		0	450	H
Foamed Class A	y		4700	12.6	16.0	0	65	7238	50		FIRM	560	H
Foamed Class A	y		3500	12.7	15.1		70	5900	63		180	455	A
Foamed Class A	y		4600	12.8	15.0	0	65	8800	50		40	290	A
Foamed HES-8	y		4200	12.8	15.0		70	2540	60		110	290	A
Foamed HES-8	y		3500	12.8	15.1		70	4850	57		FIRM	200	A
Foamed Class A	y		3500	12.8	15.1		70	4850	57		FIRM	150	A
Foamed Class A	y		3940	12.8	15.1		65	6175	65		350	740	A
Foamed Class H	y		3940	12.8	15.1		65	6175	70		360	694	A
Foamed Class H	y		2663	12.8	15.1	0	90	5820	100		650	890	A

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	Base Slurry Density	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Temp for Comp Str (°F)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type
Foamed Class A	y		3329	12.8	15.1		70	4850	57		0	120	A
Foamed Class A	y		3329	12.8	15.1		70	4850	57		FIRM	130	A
Foamed Class A	y		7612	13.0	15.2		70	8380	40		0	150	A
Foamed Class A	y			13.0	15.1	0	65	8000	55		90	440	A
Foamed Class A	y			13.0	15.1	0	65	8000	55		FIRM	260	A
Foamed Class A	y		2559	13.0	15.0		65	4200	65		200	360	A
Foamed Class A	y		2559	13.0	15.0		65	4200	65		260	410	A
Foamed Class A	y			13.0	15.2	0	65	8000	55		FIRM	270	A
Foamed Class A	y		1210	13.0	15.4	0	75	3800	75		260	490	A
Foamed Class A	y		3000	13.0	15.5	0	75	8200	85		363	1020	A
Foamed Class A	y		2900	13.0	15.5	0	60	3930	50		60	220	A
Foamed Class A	y		2900	13.0	15.0	0	60	3930	50		60	220	A
Foamed Class A	y		2000	13.0	15.5	0	70	4400	60		210	1210	A
Foamed Class A	y		4200	13.0	15.5	0	65	7000	60		232	370	A
Foamed Class A	y		1025	13.0	16.4	170	138	9850	160		300	660	H
Foamed Class H	y		1025	13.0	16.3	170	138	9850	160		290	645	H
Foamed Class H	y		3100	13.0	15.0	0	74	11200	80		120	670	A
Foamed Class A	y		1200	13.0	15.5	0	68	3800	85		490	750	A
Foamed Class A	y		1200	13.0	15.6	0	68	3800	85		450	980	A
Foamed Class A	y		3393	13.0	15.5	0	60	4500	55		210	550	A
Foamed Class H	y		4700	13.0	16.0	0	65	7238	65		0	460	H
Foamed Class A	y		5000	13.0	15.5	0	75	9200	100		120	350	H
Foamed Class H	y		5000	13.0	15.5	0	75	9200	100		380	1130	A
Foamed Class H	y		2000	13.0	15.5	0	70	4400	60		180	500	A
Foamed Class H	y		2000	13.0	15.5	0	70	4000	65		160	580	A
Foamed Class A	y		2700	13.0	16.4	0	60	5440	60		50	290	H
Foamed Class A	y		5467	13.0	15.4	0	75	8400	84		410	710	A
Foamed Class A	y		4000	13.0	16.0	0	65	6691	50		90	430	A
Foamed Class A	y		2025	13.0	15.5	0	70	4400	60		190	510	A
Foamed Class A	y		1500	13.0	17.3	0	113	10200	130		640	670	H
Foamed HES-8	y		3800	10.0 .	15.5		65	5800	58		50	240	A
Foamed Class H	y		3800	10.0 .	15.5		65	5450	55		50	130	A
Foamed Class H	y		2056	12.0 .	15.1		65	4000	50		22	240	A
Foamed Class H	y		2056	12.0 .	15.1		80	6050	50		0	20	A

Product Number:	HES-1
Service Company:	Halliburton
Company Designation:	NewCem
General Description:	Shell "Slag"

Product Number:	HES-2
Service Company:	Halliburton
Company Designation:	Spherelite
General Description:	Pozzalonic Microspheres

Product Number:	HES-3
Service Company:	Halliburton
Company Designation:	Spherelite w/ Microfine Cement
General Description:	Pozzalonic Microspheres w/ Microfine Cement

Product Number:	HES-4
Service Company:	Halliburton
Company Designation:	Spherelite w/ Econolite
General Description:	Pozzalonic Microspheres w/ Sodium Silicate

Product Number:	HES-5
Service Company:	Halliburton
Company Designation:	Diacel-M
General Description:	Diacel-M

Product Number:	HES-6
Service Company:	Halliburton
Company Designation:	EPSEAL
General Description:	EPSEAL

Product Number:	HES-7
Service Company:	Halliburton
Company Designation:	WG-17, WG-17LXP, FWCA
General Description:	Freewater Control

Product Number:	HES-8
Service Company:	Halliburton
Company Designation:	Micro-Matrix
General Description:	Microfine Cement

Product Number:	HES-9
Service Company:	Halliburton
Company Designation:	Microbond
General Description:	Expansive Additives

Product Number:	HES-10
Service Company:	Halliburton
Company Designation:	CalSeal
General Description:	Calcium Sulfate

Product Number:	HES-11
Service Company:	Halliburton
Company Designation:	TLW / TXI
General Description:	TLW / TXI

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type	Mix Water
BJ-1 + 2% CaCl2		x		9.5	90	80	1500	3:50	500		H	Fresh
BJ-1		x		9.5	180	144	10000	4:35		480	H	Fresh
BJ-1		x		9.5	180	144	10000	4:06		510	H	Fresh
BJ-1		x		11.5	180	144	10000	4:10	1638	2482	H	Fresh
BJ-1		x		8.5	180	144	10000		223	753	H	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500	4:25		2940	G	Fresh
BJ-2 + 40% Silica		x		12.2	325	225	8000	4:15		2780	G	Fresh
BJ-2		x		11.6	140	116	5000		300	460	G	Fresh
BJ-2 + 5% Lime		x		11.6	140	116	5000		300	360	G	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500			2771	G	Fresh
BJ-2 + 40% Silica + 5% Lime		x		10.8	400	200	3500			1287	G	Fresh
BJ-2		x		10.2	400	200	3500			276	G	Fresh
BJ-2 + 35% Silica		x		10.4	300	250	5000	4:51	1253	2343	G	Fresh
BJ-2 + 35% Silica + 5% Lime		x		14.0	600	110	4500			1963	Type 1	Fresh
BJ-2 + 35% Silica + 5% Lime		x		12.0	600	110	4500			700	Type 1	Fresh
BJ-3 + 35% Silica		x		14.0	600	110	4500			1213	Type 1	Fresh
BJ-1		x		9.3	95	80	1500	8:00+	75	154	H	Fresh
BJ-1 + 2% CaCl2		x		9.3	95	80	1500	8:00+	140	213	H	Fresh
BJ-1		x		10.3	95	80	1500	8:00+	220	403	H	Fresh
BJ-1 + 2% CaCl2		x		10.3	95	80	1500	6:20	300	496	H	Fresh
BJ-1		x		11.3	95	80	1500	8:00+	384	778	H	Fresh
BJ-1 + 2% CaCl2		x		11.3	95	80	1500	3:02	504	1027	H	Fresh
BJ-1		x		12.3	95	80	1500	8:00	556	1053	H	Fresh
BJ-1 + 2% CaCl2		x		12.3	95	80	1500	2:09	820	1238	H	Fresh
BJ-1 + 6% CaCl2		x		9.6	89	80	1000	8:40		450	G	Fresh
BJ-1 + 1.5% CaCl2		x		9.5	90	85	1000	5:27	263	513	G	Fresh
BJ-1 + 1.5% CaCl2		x		9.5	90	85	1000		513	563	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	90	80	1500	3:30	500		A	Fresh
BJ-1 + 2% CaCl2		X		9.5	40		1000			50	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	55		1000			160	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	95		1000		300	670	A	Fresh
BJ-1 + 2% CaCl2		x		9.5	300		1000			1000	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	40		1000			183	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	55		1000			570	A	Fresh
BJ-1 + 2% CaCl2		x		11.5	95		1000		630	1280	A	Fresh
BJ-3		x		8.5	180	144	10000	4:43	223	753	H	Fresh
BJ-1 + 3% CaCl2 + 35% Silica		x		9.0	144	100	3000	2:57	510	813	G	Fresh
BJ-1, 5% CaCl2, 10% "B"		x		9.0	144	100	3000	5:00	165	225	G	Fresh
BJ-2 + 40% Silica		x		10.8	400	200	3500	4:25		2940	G	Fresh
BJ-2 + 40% Silica		x		12.2	325	225	8000	4:15		2780	G	Fresh
BJ-2 + 40% Silica		x		10.8	400		6000			1914	G	Fresh
BJ-2 + 40% Silica + 5% Lime		x		10.8	400		6000			1114	G	Fresh
BJ-2		x		10.2	400		6000			394	G	Fresh
BJ-2 + 35% Silica + 5% Lime		x		10.4	300	250	5000	4:51	1253	2343	G	Fresh
3% "A"		x		11.8	95	85	1000	4:43		450	A	Fresh
1.5% "A"		x		12.8	80	80	1000	6:00		745	C	Fresh
10% "B"		x		12.5	120	103	7250	2:47		304	C	Fresh
10% "B", 0.2% "A",		x		12.5	120	103	7050	2:58		280	C	Fresh
15% "B"		x		11.7	124	105	5500	5:07	77	129	C	Fresh
16% "B", + dispersant		x		12.1	127	110	8200	2:37		518	C	Fresh
16% "B", + 12 LB Gilsonite		x		11.9	110	100	4570	3:41		265	C	Fresh
16% "B" + 3% Salt + Dis		x		12.1	127	110	8200	1:48		523	C	Fresh
16% "B" + 3% Salt + Dis		x		12.1	105	90	4900	2:54		433	C	Fresh
16% "B" + 3% Salt + Gil		x		12.5	130	110	6800	1:23		375	C	Fresh
3% "A" + 2% CaCl2		x		11.6	80	80	1000	7:20		196	C	Fresh
2% "A"		x		12.4	90	80	1950	6:25		450	C	Fresh
3% "A"		x		11.4	120	105	6000	5:18		255	C	Fresh
3% "A"		x		11.4	110	95	5200	6:50		248	C	Fresh
3% "A"		x		11.9	120	100	5600	5:49		358	C	Fresh
3% "A" + .25% CaCl2		x		11.9	109	102	5800	5:20		394	C	Fresh
3%"A" + 2.0% CaCl2		x		11.6	90	80	1110	6:24		208	C	Fresh
3% "A" + 2% CaCl2		x		11.9	90	80	1135	5:33		338	C	Fresh

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type	Mix Water
3%A" + 2% CaCl2 + Salt		x		11.5	86	80	750	5:55		116	C	Fresh
3% "A" + Gilsonite		x		11.4	160	133	10100	2:43		168	C	Fresh
3%"A" + 5 Lb/sk Salt		x		11.4	120	103	5250	7:06		325	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.4	96	90	2800	8:38		300	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.9	96	90	2800	8:06		325	C	Fresh
3% "A" + 5 Lb/sk Salt		x		11.4	116	103	5250	6:52		373	C	Fresh
BJ-6 + "B" + "A"		x		11.8	126	116	7050	3:29	233	296	C	Fresh
BJ-7+12% Salt+ 2% CC		x		12.6	120	105	7500	2:58		343	C	Fresh
6% "B"		x		12.7	98	88	3500	5:21		400	C	Fresh
6% "B" + 3% Salt		x		12.7	120	100	7023	4:23		655	C	Fresh
6%"B"+3% Salt + Gilsonite		x		12.7	108	96	3950	2:43		1008	C	Fresh
8% "B" + 3% Salt		x		12.9	115	97	5795	3:40		750	C	Fresh
16% "B"		x		11.8	144	127	8500	3:54	93	177	H	Fresh
16% "B" + 2% Salt		x		11.7	145	135	10000	2:54		233	H	Fresh
2% "A"		x		12.6	144	121	9200	2:33		823	H	Fresh
2% "A"		x		12.4	135	115	8700	3:13		450	H	Fresh
20% "B"		x		10.5	160	133	10100	3:45	42	56	H	Fresh
BJ-8		x		12.2	80	80	500	5:53		358	A	Fresh
BJ-8		x		12.6	80	80	900	4:37		356	C	Fresh
BJ-9		x		11.0	160	133	10100	2:36	351	483	C	Fresh
BJ-9 + 8% Attapulgite		x		10.5	160	133	10100	3:48	222	306	C	Fresh
BJ-8		x		11.5	120	105	6000	4:00		55	C	Fresh
BJ-8		x		12.4	120	105	6000	3:54		335	C	Fresh
BJ-8		x		13.0	144	119	8000	3:15		711	C	Fresh
BJ-8		x		12.5	80	80	1150	3:45		475	C	Fresh
BJ-8 + 10% Salt		x		12.8	104	91	3000	5:07		400	C	Fresh
BJ-8 + 2% CaCl2		x		12.7	85	80	1000	5:17	188			Fresh
BJ-8 + 2% CaCl2 + 5lb Gil		x		12.5	110	87	2000	5:30		288	C	Fresh
BJ-8 + 2% CaCl2 + 5lb Kol		x		12.6	90	81	1500	5:16		458	C	Fresh
BJ-8 + 3% Salt		x		12.5	100	90	4800	5:14		275	C	Fresh
BJ-8 + 5 lb Gilsonite		x		12.7	90	83	500	6:42		288	C	Fresh
BJ-8 + 5 lb Gilsonite		x		12.3	156	123	9000	4:05		495	C	Fresh
BJ-8 + 5 lb Gilson + 3% Salt		x		12.5	128	108	6000	3:46		432	C	Fresh
BJ-8 + 5 lb Gilson + 2% KCl		x		12.6	85	80	900	5:23		280	C	Fresh
BJ-8 + 5 lb salt		x		12.6	128	108	6000	1:48		270	C	Fresh
BJ-8 + 5 lb salt		x		12.6	114	99	4000	2:46		375	C	Fresh
BJ-8 + 5% Salt		x		12.4	99	88	1900	4:45	307	623	C	Fresh
BJ-8 + 9% Salt		x		12.5	104	97	3750	3:35		375	C	Fresh
BJ-8		x		12.6	120	100	6100	4:13		375	H	Fresh
BJ-8		x		12.6	123	111	6100	3:30		410	H	Fresh
BJ-8		x		12.5	132	123	8050	2:59		520	H	Fresh
BJ-8		x		12.4	140	118	9000	3:45		595	H	Fresh
BJ-8 + 8 lb Gilson + 3% Salt		x		12.4	127	108	6000	4:07	244	406	H	Fresh
BJ-8 + 8 lb Gilson		x		12.4	152	128	9000	4:48	125	360	H	Fresh
BJ-8		x		12.4	183	145	10300	4:35		850	H	Fresh
BJ-8		x		12.7	148	124	9000	3:32		600	H	Fresh
BJ-8		x		12.4	176	145	12000	3:48		730	H	Fresh
BJ-8		x		12.7	149	131	9000	4:36		500	H	Fresh
BJ-8 + 10% Salt		x		12.4	115	108	5800	3:25		587	H	Fresh
BJ-8 + 10% Salt + 2 lb Gil		x		12.8	96	86	2000	5:05		516	H	Fresh
BJ-9 + 2% CaCl2		x		12.4	110	90	5000	7:07		310	C	Fresh
BJ-9 + 8 lb Gilsonite		x		13.0	165	137	11300	4:06		1892	C	Fresh
BJ-9		x		13.0	157	127	11830	4:14		2150	C	Fresh
BJ-9		x		13.0	144	119	8000	3:12		1490	C	Fresh
BJ-9 + 1 lb salt		x		13.0	155	129	9800	4:09		1583	C	Fresh
BJ-9 + 8 lb salt		x		13.0	130	110	5500	3:44		1334	C	Fresh
BJ-9 + 5 lb Gilsonite		x		13.0	175	141	12900	3:35		2163	C	Fresh
BJ-9 + 1 lb KCl + 5 lb Gilson		x		13.0	148	124	8200	3:38		1700	C	Fresh
BJ-9 + 2% KCl + 8 lb Gilson		x		13.0	170	136	11900	2:30		2680	C	Fresh
BJ-9 + 2% Salt + 0.2% "A"		x		13.0	152	127	8000	2:46		1875	C	Fresh
BJ-9 +1 lb Salt + 5 lb Gilson		x		13.0	165	137	10700	3:41		2650	H	Fresh
BJ-9 + 5 lb Salt		x		11.5	119	96	3200	7:55		375	C	Fresh

*Slurry Type	Offshore Yes	Offshore No	Water Depth (ft)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (ft)	Thickening Time (hr:min)	Compressive Strength (psi) 12 hr	Compressive Strength (psi) 24 hr	Base Cement Type	Mix Water
BJ-10		x		12.3	168	139	11572	3:58		1512	TXI LW	Fresh
A	x			11.8	107	90	3000		70	150	H	FRESH
A	x			12.0	182	119	9450		400	850	H	FRESH
A	x			12.4	98	80	2300		130	400	H	FRESH
B	x			12.0	142	101	5100		160	485	H	FRESH
A	x			12.4	120	91	3860		125	300	H	FRESH
A	x			11.4	120	105	3900		50	150	H	SEA
A	x			12.0	94	81	2150		90	170	H	SEA
A	x			12.4	130	95	4750		150	285	H	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
B	x			11.4	93	81	2000		90	170	H	SEA
A	x			12.5	310	252	16450		410	845	H	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
A	x			11.8	107	90	3000		70	150	H	FRESH
BJ-8 + 3% SALT	x			12.0	110	93	3345		145	290	A	FRESH
BJ-8	x			12.5	93	80	2000		95	240	A	FRESH
TXI LW + "A"	x			12.8	95	80	2160		95	240	H	FRESH
A	x			11.5	113	94	3100		50	210	H	FRESH
A	x			12.4	107	87	2890		140	380	H	FRESH
A	x			12.5	120	105	3900		160	340	H	FRESH
A	x			11.5	100	85	2420		55	104	H	FRESH
A	x			12.0	124	92	3900		120	300	H	FRESH
TXI LW + "B"	x			12.0	101	88	2500		125	295	TXI LW	SEA
BJ-8	x			12.4	116	92	3220		150	285	H	FRESH
BJ-8	x			12.4	185	130	9550		255	967	H	FRESH
BJ-8	x			12.5	110	92	3000		104	425	TYPE 1	FRESH
A	x			11.4	128	101	4500		100	220	H	SEA
A	x			11.4	102	88	2700		50	160	H	SEA
A	x			11.4	122	100	3860		50	135	H	SEA
A	x			11.4	125	100	3950		50	135	H	SEA
B	x			12.6	254	205	15800		SET	400	H	FRESH
A	x			11.4	94	80	2000		50	150	H	SEA
A	x			11.7	224	173	14100		50	200	H	SEA
A	x			11.4	94	80	2000		50	150	H	SEA
A	x			12.5	70	75	800		50	140	H	SEA
A	x			11.4	119	96	3440		50	150	H	SEA
B	x			12.0	94	80	2000		60	175	H	FRESH
A	x			11.4	93	80	2000		60	150	H	SEA
A	x			12.0	94	80	2000		65	170	H	SEA
A	x			12.0	116	93	3300		65	170	H	SEA
BJ-8	x			12.4	92	80	1966		170	356	A	SEA
BJ-8	x			12.4	145	104	5655		65	350	A	SEA
BJ-10	x			12.5	174	128	12100		1050	1460	TXI LW	FRESH
BJ-8	x			11.4	93	80	2000		60	150	H	SEA
A	x			11.4	109	91	3050		50	160	H	SEA
A	x			11.4	93	81	2000		50	150	H	SEA
A	x			11.4	132	104	4920		50	150	H	SEA
A	x			11.4	132	104	4920		50	150	H	SEA
BJ-10 + 4% Gel	x			11.5	90	80	1800		60	530	TXI LW	FRESH
BJ-8	x			12.0	114	93	3110		100	280	H	SEA
BJ-8	x			12.0	114	93	3110		50	170	H	FRESH
BJ-8	x			11.2	124	98	4600		155	250	TYPE 1	FRESH
A	x			11.4	94	80	2000		50	150	H	SEA

Product Number:	BJ-1
Service Company:	BJ Services Company
Company Designation:	LW-7 2000
General Description:	Glass Bubbles, Low Strength

Product Number:	BJ-2
Service Company:	BJ Services Company
Company Designation:	LW-6
General Description:	Ceramic Bubbles

Product Number:	BJ-3
Service Company:	BJ Services Company
Company Designation:	Perlite
General Description:	Expanded Volcanic aggregate

Product Number:	BJ-4
Service Company:	BJ Services Company
Company Designation:	LW-7 10000
General Description:	Glass Bubbles, High Strength

Product Number:	BJ-5
Service Company:	BJ Services Company
Company Designation:	None
General Description:	Blend LW-6 and High Early strength additive

Product Number:	BJ-6
Service Company:	BJ Services Company
Company Designation:	None
General Description:	Blend Anhydrous Sodium Metasilicate and High Strength Additive

Product Number:	BJ-7
Service Company:	BJ Services Company
Company Designation:	Attaclay
General Description:	Attapulgite Clay

Product Number:	BJ-8
Service Company:	BJ Services Company
Company Designation:	None
General Description:	Poz, Cement, Bentonite Blend

Product Number:	BJ-9
Service Company:	BJ Services Company
Company Designation:	None
General Description:	Poz, Cement, Microsilica Blend

Product Number:	BJ-10
Service Company:	BJ Services Company
Company Designation:	TXI Lightweight

General Description: TXI Commercial Lightweight Cement

Product Number: BJ-11

Service Company: BJ Services Company

Company Designation: Prehydrated Gel

General Description: Prehydrated Bentonite Gel

Product Number:

Service Company:

Company Designation:

General Description:

Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)	
	Yes	No	(feet)	(lb/gal)	(°F)	(°F)	(feet)	(Hrs:Min)	12 hrs	24 hrs
A		x		11.8	0	0		3:52		150
A		x		12	50	50		5:50		625
A		x		12.5	0	60		2:43		250
A		x		12	65	65		6:40		525
A		x		11	40	70		5:25		588
A	x			10.5	91	76				55
A	x			10.5	94	80		14:10		58
A	x			11	91	80		7:30		110
SLB-1		x		11.0	92	80		2:45	400	1300
SLB-1		x		11.0	92	80		4:55	700	1350
A	x			11.4	90	80		6:19		210
A	x			11.4	91	80		8:20		125
A	x			11.4	88	80		4:20		220
A		x		11.5	80	80		3:26		462
A		x		11.7	115	80		5:33		135
A		x		11.7	114	80		5:33		135
A		x		11.9	80	80		3:44		606
SLB-1		x		12.0		80		3:05		
SLB-1		x		12.3	92	80		6:10		500
B		x		12.4	80	80		6:31		219
A	x			12.5	66	80		4:45		370
A	x			12.5	80	80		4:00		300
B		x		12.6	80	80		9:27		236
B		x		12.7	80	80		0:00		319
B		x		12.8	80	80		5:11		263
A		x		12.9	98	80		2:07		78
A	x			11.4	91	82		6:00		110
A	x			11.4	92	82		5:00		200
A		x		11.5	92	82		6:30		339
A		x		11.7	102	84		5:33		135
SLB-1		x		10.3	90	85		1:42		980
A	x			10.5	94	85				210
A	x			10.5	94	85		11:00		110
A		x		11.9	0	85		5:07		137
B		x		12.5	100	85		5:31		227
A		x		12.8	95	85		3:26		341
B		x		12.8	85	85		4:03		247
A		x		12.8	100	88		3:30		345
SLB-1		x		10.0	100	90		4:10		675
A	x			11.4	115	90		12:00		160
A	x			11.4	115	90		5:00		200
A		x		12.5	100	90		5:32		225
A	x			11.5	104	91		6:45		175
A	x			11.5	119	91		5:50		610
A		x		11.7	113	91		2:32		180
A		x		11.7	115	92		2:32		180
A		x		11.7	114	92		2:32		180
A		x		11.7	114	92		2:32		180
A		x		11.8	125	92		3:50		353

Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)	
	Yes	No	(feet)	(lb/gal)	(°F)	(°F)	(feet)	(Hrs:Min)	12 hrs	24 hrs
A	x			12	120	92		6:23		860
B		x		12.8	115	94		4:23		219
B		x		12.8	125	95		4:15		490
A	x			11.4	125	96		7:25		90
A	x			11.4	118	97		6:10		200
A	x			11.4	115	97		4:40		150
B		x		12.5	134	98		3:02		330
SLB-1		x		10.6	100	100		9:12	500	1900
A		x		11.8	110	100		4:00		259
A		x		11.8	122	100		5:00		250
A		x		11.8	121	100		5:50		225
B		x		12.4	115	100		4:41		248
A	x			12.5	124	100		3:25		714
A		x		12.8	110	100		4:48		756
A		x		12.8	110	100		4:48		756
A		x		12.8	110	100		4:48		756
SLB-1		x		12.2		102		3:30		2850
B		x		12.5	125	102		3:12		470
A		x		12.9	151	102		4:20		545
B		x		12.9	151	102		4:20		545
A	x			11.4	119	103		4:45		200
A	x			12.7	126	105		6:49		1220
A	x			11.8	125	109		5:41		300
B		x		12.4	125	110		4:02		363
B		x		12.7	156	110		2:52		689
B		x		12.8	168	110		4:30		450
B		x		12.5	174	114		4:54		290
SLB-1		x		12.4		117		2:50		3113
B		x		12.7	160	117		2:35		795
B		x		12.7	160	117		5:31		255
SLB-1		x		10.5		120		5:15		2450
SLB-1		x		10.9		120		5:12		1304
SLB-1		x		11.2		120		3:20		2000
SLB-1		x		12.0	141	121		2:30		970
B		x		12	170	125		3:30		200
SLB-1		x		12		129		3:50		2700
SLB-1		x		12	170	129		3:50		2700
SLB-1		x		12.5		130		2:37		2522
B		x		12.8	202	132		3:19		750
SLB-1		x		12	185	140		5:00		3700
SLB-1		x		12.1		140		5:00		3700
B		x		12.8	212	143		4:24		975
SLB-1		x		12.0	175	145		3:40	1500	2500
SLB-1		x		12.0	190	146		3:05	2000	3700
SLB-1		x		12.0	190	146		3:11	1300	2500
SLB-1		x		12.0	190	146		3:05		1730
B		x		12.7	218	147		3:37		860
B		x		12.5	220	148		4:53		830
SLB-1		x		11.0	206	150		2:56	2600	

Slurry Type	Offshore		Water Depth	Slurry Density	BHST	BHCT	Casing Depth	Thickening Time	Compressive Strength (psi)	
	Yes	No	(feet)	(lb/gal)	(°F)	(°F)	(feet)	(Hrs:Min)	12 hrs	24 hrs
SLB-1		x		11.0	180	150		3:42		2250
B		x		12.8	222	150		4:02		805
SLB-1		x		8.4	180	155		4:00		777
SLB-1		x		8.4	180	155		6:03		1100
B		x		12.5	204	155		3:27		740
SLB-1		x		12.5		155		2:43		3473
B		x		12.7	210	158		3:17		257
SLB-1		x		12.0	231	163		5:30	2200	
SLB-1		x		11.1	195	165		6:07		2150
SLB-1		x		11.9		165		4:20		2658
SLB-1		x		12	220	165		4:20		2660
SLB-1		x		10.0	217	170		2:02		2000
B		x		12.5	244	174		5:13		775
SLB-1		x		11.2		175				3722
B		x		12.7	242	175		4:05		765
B		x		12.8	220	176		4:06		1000
B		x		12.8	247	178		4:17		435
B		x		11.8	250	180		3:22		485
B		x		12.8	250	180		3:41		890
B		x		12.8	250	180		4:41		790
SLB-1		x		11.5	220	185		3:44	2050	
B		x		12.5	260	188		4:31		875
B		x		12.6	259	189		4:28		680
B		x		12.6	259	189		4:28		680
SLB-1		x		10.2	250	190		4:04	1000	1365
SLB-1		x		11.5	260	190		8:15	1000	2200
SLB-1		x		11.5	260	190		5:15	2200	2930
B		x		12.7	261	190		4:32		730
SLB-1		x		11.5	260	191		3:55	1700	
B		x		12.8	240	193		3:54		924
B		x		12.4	268	206		4:30		475
B		x		12.7	268	206		5:25		595
B		x		12.8	278	210		5:00		520
B		x		11.7	280	212		4:54		250
B		x		12.8	282	213		4:32		445
B		x		12.8	282	213		3:49		582
B		x		11.7	283	216		4:15		390
B		x		12.4	283	216		5:04		225
B		x		12	287	220		4:43		495
B		x		12.8	270	220		5:02		600
B		x		12.5	290	224		4:49		480
B		x		12	290	225		4:16		345
B		x		12.7	288	225		4:10		685
B		x		12.8	280	227		5:10		525
B		x		12.6	290	231		5:42		260
B		x		12.4	296	233		4:54		410
B		x		12.4	302	238		3:00		475
SLB-1		x		11.1	290	240		4:10		5530
SLB-1		x		11.0	325	250		11:00	500	1200

Slurry Type	Offshore		Water Depth (feet)	Slurry Density (lb/gal)	BHST (°F)	BHCT (°F)	Casing Depth (feet)	Thickening Time (Hrs:Min)	Compressive Strength (psi)	
	Yes	No							12 hrs	24 hrs
SLB-1		x		11.0	314	251		7:00		3800
B		x		12.4	335	280		3:41		229

Product Number:	1
Service Company:	Schlumberger
Company Designation:	SLB-1
General Description:	LiteCRETE

TXI Lightweight Cement

TXI Information		CSI Information				Free Fluid			Rheology										
Cmt Type	Production Date	Date Received	CSI Log#	Bucket Opened	Test Date	Water Conc. (%bwoc)	mL	% by volume	Water Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
LW	09/18/00	11/06/00	C-108 B-1	11/07/00	11/15/00	105	2	0.8	75	80	57	50	42	38	33	22	12	13	120
LW	09/18/00	11/06/00	C-108 B-2	12/05/00	01/04/01	105	2	0.8	75	80	58	52	45	38	32	21	13	13	125
LW	09/18/00	11/06/00	C-108 B-11	06/24/01	06/26/01	105	2	0.8	75	80	60	55	47	39	21	20	15	15	127
LW	09/18/00	11/06/00	C-108 B-12	07/03/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-7	09/05/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water Conc. (%bwoc)	45°F Strengths			60°F Strengths			80°F Strengths		120°F Strengths		Thickening Time			
Cmt Type	CSI Log#	Test Date		Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 70 Bc	Time to 100 Bc
LW	C-108 B-1	11/15/00	75.0	24	2.0	166	24	1.0	254	24	523	24	1579	5	6	2:02	2:20
LW	C-108 B-2	01/04/01	75.0	24	2.0	161	24	1.0	221	24	441	24	1225	5	5	2:00	2:17
LW	C-108 B-11	06/26/01	75.0	24	2.0	158	---	---	---	24	501	---	---	5	9	1:57	2:18
LW	C-108 B-12	08/14/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-7	09/10/01	75.0	---	---	---	---	---	---	---	---	---	---	5	6	1:57	2:17

TXI Class H Cement

TXI Information		CSI Information				Water	Free Fluid		Rheology									
Cmt Type	Prod. Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	mL	% by volume	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	1.9	0.8	80	89	72	53	45	37	16	10	---	---
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	38.0	3	1.2	80	85	70	53	45	38	14	8	9	19
Class H	09/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	3	1.2	80	95	80	60	51	42	20	12	15	26
Class H	09/27/00	11/06/00	C-108 A-3	02/22/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-4	06/26/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-6	07/20/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-7	08/27/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths		140°F Strengths		Thickening Time		
Cement Type	CSI Log#	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 100 Bc
Class H	C-108 A-1	11/07/00	38.0	8	524	8	2088	---	---	---
Class H	C-108 A-1	11/29/00	38.0	8	480	8	2249	5	12	2:03
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1617	---	---	---
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1550	---	---	---
Class H	C-108 A-2	01/11/01	38.0	8	1201	8	1964	5	7	1:54
Class H	C-108 A-2	01/12/01	38.0	8	1039	8	1756	---	---	---
Class H	C-108 A-2	02/12/01	38.0	8	424	8	1717	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1567	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1580	---	---	---
Class H	C-108 A-4	06/29/01	38.0	---	---	---	---	5	17	2:00
Class H	C-108 A-6	08/13/01	38.0	---	---	---	---	5	15	1:50
Class H	C-108 A-7	09/06/01	38.0	---	---	---	---	5	19	2:00

TXI Class A Cement

TXI Information		CSI Information				Water Conc. (%bwoc)	Rheology									
Cement Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date		Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class A	09/27/00	11/06/00	C-113 A-1	11/09/00	11/17/00	46.0	80	75	62	48	40	33	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-2	11/20/00	11/20/00	46.0	80	80	65	49	40	34	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-3	12/04/00	12/05/00	46.0	80	78	64	50	40	32	16	10	10	19
Class A	09/27/00	11/06/00	C-113 A-4	01/09/01	01/09/01	46.0	80	80	65	52	40	33	17	11	10	20
Class A	09/27/00	11/06/00	C-113 A-5	11/09/00	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-1	03/20/01	03/20/01	46.0	80	77	63	51	39	32	17	10	10	20
Class A	03/10/01	03/19/01	C-189 A-5	06/01/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-8	07/11/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-17	08/30/01	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water Conc. (%bwoc)	100°F Strengths				45°F Strengths			60°F Strengths			80°F Strengths		Thickening Time			
Cement Type	CSI Log #	Test Date		Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	CS (psi)	Test Date	Sch #	Int. Bc	Time to 100 Bc
Class A	C-113 A-1	11/17/00	46.0	---	---	---	---	---	---	---	---	---	---	24	1646	11/15/00	4	9	2:17
Class A	C-113 A-2	11/27/00	46.0	8	754	24	2607	24	2	737	24	1	1194	24	1689	01/05/01	4	8	2:21
Class A	C-113 A-2	02/12/01	46.0	---	---	---	---	---	---	---	---	---	---	24	2022	---	---	---	---
Class A	C-113 A-3	12/05/00	46.0	---	---	24	2585	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-4	01/17/01	46.0	8	729	24	2527	24	2	1042	---	---	---	---	---	01/17/01	4	4	2:09
Class A	C-113 A-5	02/15/01	46.0	8	931	24	2568	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2334	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2590	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2250	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-189 A-1	03/20/01	46.0	8	916	24	2364	---	---	---	24	1	1238	24	1737	03/20/01	4	12	1:42
Class A	C-189 A-5	06/29/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/29/01	4	10	1:37
Class A	C-189 A-8	08/15/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	08/15/01	4	6	1:50
Class A	C-189 A-17	09/12/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	09/12/01	4	6	2:00

Appendix E—Laboratory Procedures for Foamed Cement

The working draft of ISO 10426-4[1] outlines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries. The procedures discussed in this appendix and used for this project were borrowed from ISO 10426-4.

E.1 Preparing Unfoamed Base Slurry

E.1.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density	=	14.5 lb/gal
Surfactant weight	=	10 lb/gal

Base Slurry Calculations:	Weight	Volume
Cement	94 lb	3.59 gal
Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
Water	55.39 lb	6.65 gal
Total	151.39 lb	10.44 gal

Calculation of True Weight % Contributions:		
Cement	62.1 %	(94/151.39)
Surfactant	1.3 %	(2/151.39)
Water	36.6 %	(55.39/151.39)

Slurry without Surfactants:	Weight	Volume
Cement	94 lb	3.59 gal
Water	55.39 lb	6.65 gal
Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

E.2 Equipment

E.2.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure E.1) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

E.2.2 Multi-Blade Assembly

The multi-blade assembly is what is used during this project. The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO 10426-2[2], clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure E.1.

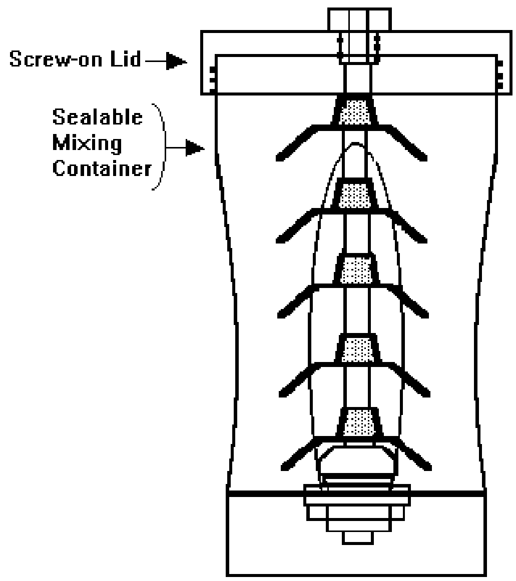

Fig. E.1—Example of a typical blending container

E.3 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

E.4 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section E.1.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section E.2.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Base slurries containing all additives except foaming surfactant(s) should be prepared according to ISO 10426-2[2],clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3.3 rev/s (200 rpm) at 66.7 rev/s (4,000 rpm) and ± 8.3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO 10426-2[2], clause 6.

E.5 Determining Slurry Volumes and Weights

E.5.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times FD \qquad (2)$$

Where:	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	FD	=	Foamed density of the slurry (g/mL)

Example:	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Unfoamed slurry weight	=	1170 mL × 1.2 g/mL = 1404 g

E.5.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 4.

$$GS = GUFS \times (\%Surfactant/100) \qquad (3)$$

Where: GS = Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)
GUFS= Total grams unfoamed slurry prepared in B.1

$$GUSM = GUFS - GS \qquad (4)$$

Where: GUSM = Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example: Unfoamed slurry weight = 1404.1 g
Percent by weight of surfactant = 1.3 %

Surfactant weight	=	1404.1 × 0.013	=	18.5 g
Slurry weight	=	1404.1 - 18.5	=	1385.6 g

E.6 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section E.5.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section E.5.2.

E.6.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section E.2.2, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port or container lid, and verify that the slurry completely fills the slurry-mixing container. If the slurry does not fill the mixing container at the end of the 15-second

mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

E.7 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

E.7.1 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weigh the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry. The density of the foamed slurry in the container is determined by dividing the slurry mass by the container volume and converting to the appropriate density units.

E.7.2 Determining Slurry Stability

E.7.2.1 Unset Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder cannot be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

E.7.2.2 Set Slurry Stability

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 50.8-mm (2-in.) diameter, 101.6-mm (4-in.) tall cylinders or any appropriate covered container. Use of grease or other mold-release agents should be avoided as these materials may affect the stability of the foamed cement.

Cut or break the samples into sections, mark them from the top to the bottom, and

measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined by dividing the weight, W (in grams) by volume, V (in mL). The slurry density can also be determined (SG × 8.33 = lb/gal).

Signs of foam instability include the following:

- More than a trace of free fluid.
- Bubble breakout noted by bubbles appearing on the surface of the sample.
- Excessive gap at the top of the specimen. Minor meniscus effects are normal.
- Visual signs of density segregation as indicated by streaking or light to dark color change from top to bottom.
- Large variations in density from sample top to bottom.

E.7.3 Determining Compressive Strength

The foamed cement slurry is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated. This expansion can result in an undesired density decrease. The mold can be a standard 50.8-mm (2-in.) cube mold with a cover clamped to the top.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is sufficient seal to prevent the slurry from expanding out of the curing mold.

E.8 Determining Other Tests on Base Unfoamed Slurry

A slurry that is foamed at atmospheric pressure should not be tested under pressure. Applying pressure to a foamed slurry prepared at atmospheric pressure will compress the foam, changing the density and gas ratio. This can also allow contamination when tested in a HPHT consistometer for thickening time.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO 10426-2[2], clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

E.8.1 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO 10426-2[2], clause 9.

E.8.2 Determining Fluid Loss

Fluid-loss tests performed with a foamed cement prepared at atmospheric pressure will not yield reliable results. The fluid loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry.

The static fluid-loss test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 10.

E.8.3 Determining Rheological Properties

With the concentration of gas in a foamed slurry changing continuously during pumping of the job, it is impractical to perform rheological testing at all the foam quality concentrations that are needed to model the frictional pressures during pumping of a foamed slurry. Use of a rotational viscometer will result in separation of the gas from the slurry, causing erroneous results. Correlations can be used to convert the rheological properties of the base unfoamed slurry to that of a foamed cement with varying foam qualities to simulate the job.

The rheological test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 12.

References

[1] ISO 10426-4: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 4: Recommended Practice for Atmospheric Foam Cement Slurry Preparation," working draft 2001.
[2] ISO 10426-2: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements," 1998.

Appendix 5

Quarterly Report 5

Ultra-Lightweight Cement

Fifth Quarterly Technical Progress Report

October 1 to December 31, 2001

Fred Sabins

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DOE Award Number
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Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report includes results from laboratory testing of ULHS systems along with other lightweight cement systems: foamed and sodium silicate slurries. Comparison studies of the three cement systems examined several properties: tensile strength, Young's modulus, water permeability, and shear bond. Testing was also done to determine the effect that temperature cycling has on the shear bond properties of the cement systems. In addition, analysis was carried out to examine alkali silica reactivity of slurries containing ULHS.

Data is also presented from a study investigating the effects of mixing and pump circulation on breakage of ULHS. Information is also presented about the field application of ULHS in cementing a 7-in. intermediate casing in south Texas.

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Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe, called a casing, intended to produce a conduit from the reservoir to the surface. The cement sets in place to support the casing in the hole, to isolate various formations from one another, and to control fluid movement within the well.

Typical cement fluid density ranges from 12 to 17 lb/gal. Certain conditions can be encountered during the well construction process that necessitate application of cements with much lower density. Lower density is required to limit hydrostatic pressure exerted on formations through which the wellbore passes in order to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases time to drill and complete the well and increases construction cost due to expensive remedial treatments. Most common sections of a well in which lost circulation occurs are the upper sections: surface casings and intermediate casings. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are relatively low.

The minimum practical density achievable with conventional cements and additives is roughly 11 lb/gal. At this density, the stability of the slurry and strength and permeability of the set cement are only marginally acceptable. The primary density-reducing material in these conventional cements is water. Additional water dilutes the cement, causing low strength and high permeability. Lower temperature further delays strength development. Achieving lower density or greater strength necessitates the use of ultra-lightweight materials mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent as candidate material for producing ultra-lightweight cements. These small, hollow, glass beads effectively encapsulate air in the slurry, thereby lowering the slurry density significantly compared to the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS. The development will be achieved through a carefully designed program of modeling, design, laboratory testing, and field testing.

Executive Summary

The fifth quarter of this investigation focused on laboratory testing that compared slurries containing ULHS to two other lightweight cement systems: foamed and sodium silicate slurries. Comparison studies of the three cement systems examined several properties: tensile strength, Young's modulus, water permeability, and shear bond. Tensile strength testing was performed using ASTM C190 test method. ASTM C496 was also used to perform splitting tensile strength tests. Young's modulus data was performed using ASTM C469.

Testing was also done to determine the effect that temperature cycling has on the properties of the cement systems. Compressive strength and shear bond strength were measured on the samples that were subjected to temperature cycling. In addition, analysis was carried out to examine ULHS for alkali silica reactivity using ASTM C1260.

Data is also presented from a study investigating the effects of mixing and pump circulation on breakage of ULHS. This investigative study looked at the result mixing energy has on ULHS breakage, which then affects the slurry density. Information is also presented about the field application of ULHS in cementing a 7-in. intermediate casing in south Texas.

Because of the large volume of cement required for this project, a quality-control process has been implemented. Information and data gathered for the program are presented.

Preliminary data indicates that the slurries made with ULHS performed as well as or better than the sodium silicate and foamed slurries tested thus far. Further testing in future quarters will help establish performance qualities of cement slurries made with ULHS.

Cement Quality-Control Program

An extensive quality-control program was initiated because of the large quantity of cement used over the course of this project. Each bucket of cement is labeled with a materials log number and date upon receipt. When a bucket is first opened for use, the date of opening is recorded in the materials log. This log number is referenced on the laboratory sheets for each test performed. Where applicable, tests according to API Specification 10A[1] are conducted. Additionally, several other tests tailored specifically for the test conditions and materials (rheology and low-temperature compressive-strength development) are included in this QC Program. Both API Specification tests and tests recommended by advisory board members were performed for the cement quality-control program.

The Class A and Class H cement performance requirements are presented in the original API Specification 10A (January 1995) before Addendum 1 which changed the free fluid procedure. The free fluid procedure used in these tests is the earlier version using graduated cylinders. Because the Lightweight Oilwell cement is not API cement, it is tested according to QC procedures developed by the manufacturer.

The physical requirements used for testing each of the cements are listed in **Table 1**. To accelerate the rate of compressive-strength development at low temperatures, calcium chloride ($CaCl_2$) is being used with the cements according to **Table 2**. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 1—Cement Slurry Compositions for Quality-Control Testing Program

Cement	Mix Water (% BWOC)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Class A	46	15.6	772	355	API Series of Tests
TXI Lightweight	75	13.2	541	406	Thickening Time & Compressive Strength
TXI Lightweight	105	12.1	426	447	Free Fluid
Class H	38	16.4	860	327	API Series of Tests

Table 2—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (% BWOC)
80	0.0
60	1.0
45	2.0

These quality-control tests have been run to provide a baseline for each type of cement. This QC data will provide a comparison when other data for this project is examined. After several cycles of the complete QC program had been performed on the cements, the data showed no significant variations and remained within the vendors' specifications. It was then decided to proceed with a less-stringent program of scheduled thickening-time tests. Each time that a new bucket is opened, a thickening-time test is run. In addition, once a month, a thickening-time test is performed on all opened buckets (for all three cement types). The thickening-time test was chosen as a gauge to detect abnormal cement performance. Appendix A shows the data gathered to date for the quality-control program.

Application Scenarios

One way to gauge the performance of cements made with ULHS is to compare them to other ultra-lightweight cements. Members of the project advisory board decided to compare ULHS cements with foamed cement and with a conventional sodium silicate slurry.

Three different application scenarios were chosen to test the performance of the lightweight cements. Application 1 simulates deepwater cementing. Application 2 simulates a typical land-based surface-pipe cementing job. Application 3 simulates a typical land-based cementing job for intermediate casing.

Table 3 shows the pressure and temperatures associated with the three different applications. The conditions for Application 1 (deepwater cementing) came from typical applications as experienced by the principal investigator. The values for the surface pipe and intermediate casing applications (2 and 3) came from average values obtained from *Worldwide Cementing Practices*[2] as detailed in the first quarterly progress report. For the three different applications, the slurries were designed to try to achieve certain performance standards (although they could not always be achieved). These standards are also listed in **Table 3**.

Table 3—Simulation Conditions for Comparison of Lightweight Slurries

Application	BHCT (°F)	BHST (°F)	Pressure (psi)	Desired Thickening Time (hr)	Maximum Free Fluid (%)	Maximum Fluid Loss
1	65	45	5,300	4 to 6	1.0	NA
2	78	96	1,000	4 to 6	1.0	NA
3	128	174	5,000	4 to 6	0.5	250cc/30min

Of the different classes of ULHS being studied in this project, the 6K beads were chosen because of their ability to withstand the hydrostatic pressures associated with the applications.

Most of the tests were performed as specified in API RP 10B[3]. Some preparation and testing methods were modified to adapt for the ULHS and foamed slurries. The mixing procedures were modified for the ULHS slurries to minimize bead breakage that can occur because of high shear from API blending procedures. The following blending procedure was used for the ULHS slurries.

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry (without ULHS) according to Section 5.3.5 of API RP 10B.[3]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

4. Pour this slurry back into the Waring blender and mix at 4,000 rev/min for 35 seconds to mix and evenly distribute the contents.

Testing methods for foamed slurries were also modified. For example, thickening time is performed on unfoamed slurries only. Because the air in the foam does not affect the hydration rate, the slurry is prepared as usual per API RP 10B[3] and then the foaming surfactants are mixed into the slurry by hand without foaming the slurry. This and the other non-standard procedures for testing foamed cement are presented in Appendix B.

Table 4 presents the slurry compositions for the 11.5-lb/gal slurries. **Table 5** presents the slurry compositions for the 10.0-lb/gal slurries. Additives (slurry extenders, accelerators, foaming agents, etc.) were added to the slurries in order to adapt each slurry to the application conditions as specified in **Table 3**. The additives are widely available, generic additives, and are not specific to any particular service company. These additives include Witcolate® 7093 (a foaming agent), Aromox® C/12 (a foam stabilizer), Natrosol® 250 GXR (a fluid-loss control additive), Melcret® (a dispersant), Marabond® 21 (a retarder), and Diacel® FL (a fluid-loss control additive).

The water content used in the ULHS slurries is guided by the ULHS water requirement of an additional pound of water for every pound of ULHS. It should also be noted that the advisory board group decided to use a 13.5-lb/gal base density for the TXI Lightweight cement slurries foamed to 10.0 lb/gal. Testing of the 10.0-lb/gal slurries does not include sodium-silicate slurries because the density of 10.0 lb/gal is outside of the typical working range for sodium-silicate slurries.

Table 4—Slurry Compositions for 11.5 lb/gal Slurries

Application 1				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.7	8.00	2.0% BWOC $CaCl_2$; 14.9% BWOC (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	1.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% BWOC Sodium Silicate
TXI Lightweight	ULHS	11.5	6.65	2.0% BWOC $CaCl_2$; 11.5%BWOC (6K) ULHS
	Foamed	13.1† (11.4‡)	7.00	2.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.6	12.11	3.0% BWOC Sodium Silicate
Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.5	7.09	16.2% BWOC (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% BWOC Sodium Silicate
TXI Lightweight	ULHS	11.5	6.50	2.0% BWOC $CaCl_2$; 11.9% BWOC (6K) ULHS
	Foamed	13.0† (11.5‡)	7.00	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	12.11	3.0% BWOC Sodium Silicate

†Unfoamed slurry density
‡Foamed slurry density

Table 4—Slurry Compositions for 11.5 lb/gal Slurries (Continued)

Application 3				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class H	ULHS	11.5	8.20	1.1% BWOC Natrosol® 250 GXR; 0.3% BWOC Melcret®; 13.4% BWOC (6K) ULHS
	Foamed	15.6† (11.5‡)	4.97	0.6% BWOC Natrosol® 250 GXR; 0.11 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.42	0.65% BWOC Natrosol® 250 GXR; 0.5% BWOC Melcret®; 2.0% BWOC Sodium Silicate
TXI Lightweight	ULHS	11.5	6.53	0.16% BWOC Marabond® 21; 0.75% BWOC Natrosol® 250 GXR; 0.25% BWOC Melcret®; 10.8% BWOC (6K) ULHS
	Foamed	13.0† (11.5‡)	6.76	0.2% BWOC Marabond® 21; 0.8% BWOC Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
	Sodium Silicate	11.5	11.60	0.75% BWOC Marabond® 21; 1.0% BWOC Natrosol® 250 GXR; 0.5% BWOC Melcret®; 2.0% BWOC Sodium Silicate

†Unfoamed slurry density

‡Foamed slurry density

Table 5—Slurry Compositions for 10.0 lb/gal Slurries

Cement Type	Slurry System	Measured Density (lb/gal)	Water Content (gal/sk)	Additive Concentrations
Application 1				
Class A	ULHS	10.0	8.53	2.0% BWOC $CaCl_2$; 29.6% BWOC (6K) ULHS
	Foamed	15.6† (10.0‡)	5.24	2.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	7.17	2.0% BWOC $CaCl_2$; 26.0% BWOC (6K) ULHS
	Foamed	13.5† (10.0‡)	6.09	2.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	10.0	8.50	29.1% BWOC (6K) ULHS
	Foamed	15.6† (10.0‡)	5.19	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	7.23	2.0% BWOC $CaCl_2$; 26.0% BWOC (6K) ULHS
	Foamed	13.5† (10.0‡)	6.10	2.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
Application 3				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class H	ULHS	10.0	8.48	0.2% BWOC Marabond® 21; 0.50 gal/sk Diacel® FL; 30.0% BWOC (6K) ULHS
	Foamed	15.6† (10.0‡)	5.01	0.6% BWOC Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	8.08	0.15% BWOC Marabond® 21; 1.0% BWOC Natrosol® 250 GXR; 1.0% BWOC Melcret®; 23.6% BWOC (6K) ULHS
	Foamed	13.5† (10.0‡)	5.82	0.3% BWOC Marabond® 21; 0.8% BWOC Natrosol® 250 GXR; 0.05 gal/sk Witcolate® 7093; 0.01 gal/sk Aromox® C/12

†Unfoamed slurry density

‡Foamed slurry density

Because of the low temperatures associated with Applications 1 and 2, calcium chloride ($CaCl_2$) was used with some foamed and ULHS slurries to accelerate hydration. $CaCl_2$ was not used with the sodium silicate slurries because of viscosity issues specific to this slurry. The only viable accelerators for sodium silicate slurries are company-specific and not widely available in a generic form.

Tensile Strength

Mechanical properties of the different cement systems were tested. **Table 6** shows the 14-day tensile strength of the slurries used in Application 2. The samples were cured at atmospheric pressure in a water bath maintained at 96°F (the BHST of Application 2). Tensile strength was tested using two methods: ASTM C190 and ASTM C496. Testing per ASTM C190 consists of pulling on a “dog-bone” shaped cement sample until the sample breaks. ASTM C190 is commonly used when testing oilwell cements. The samples for the ASTM C190 testing measured 3 in. long, 1 in. thick, and 1 in. wide at the waistline of the sample.

Testing was also performed similar to that in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the specimen dimensions were 1.5 in. diameter by 1 in. long. **Figure 1** shows a general schematic of how each specimen is oriented on its side when tested. The force applied to the specimens was manually controlled and applied at a rate of approximately 10 psi/min.

Most of the data in **Table 6** was gathered during the fourth quarter, but is presented again to compare with the recently gathered data. The table shows that the ASTM C190 tests had a greater deviation than the ASTM C496 tests. The sodium silicate slurries had lower tensile strengths than the other cement systems. Last quarter, the project advisory board decided to have the ASTM C190 test of the 10.0 lb/gal, Class A, ULHS sample retested. During the retests, the samples were incorrectly tested at 38 days instead of 14 days. It should be noted that the strength development has been seen to level out around 14 days, so there is expected to be little difference between strengths at 14 and 38 days.

Figure 1—Sample Orientation for ASTM C496-90 Testing

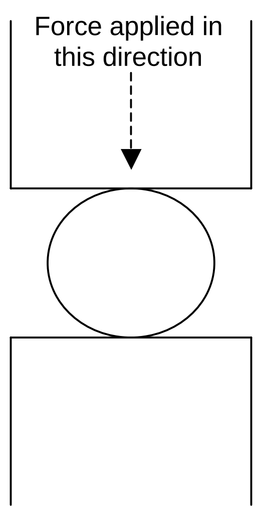


Table 6—Tensile-Strength Data of Cements

Density: 11.5 lb/gal, Application 2									
Cement Type	**Slurry System**	**Tensile Strength (psi) per ASTM C190**				**Splitting Tensile Strength (psi) per ASTM C496**			
		Sample 1	**Sample 2**	**Sample 3**	**Average**	**Sample 4**	**Sample 5**	**Sample 6**	**Average**
Class A	ULHS	324	371	241	312	236	214	286	245
	Sodium Silicate	57	48	66	57	136	131	129	132
	Foamed	224	247	174	215	363	378	383	375
TXI Lightweight	ULHS	365	245	268	293	217	241	164	207
	Sodium Silicate	118	141	154	138	Soft set - retests will be reported next quarter			
	Foamed	177	278	230	228	238	280	221	246
Density: 10.0 lb/gal, Application 2									
Cement Type	**Slurry System**	**Tensile Strength (psi) per ASTM C190**				**Splitting Tensile Strength (psi) per ASTM C496**			
		Sample 1	**Sample 2**	**Sample 3**	**Average**	**Sample 4**	**Sample 5**	**Sample 6**	**Average**
Class A	ULHS (initial test)	220	244	465	310	241	241	304	262
	ULHS (retest)*	217	262	142	207	—	—	—	—
	Foamed	180	121	163	155	282	317	286	295
TXI Lightweight	ULHS	154	228	214	199	149	144	142	145
	Foamed	162	227	197	195	177	217	164	186

* The retest samples were tested at 38 days.

Young's Modulus

In the previous project quarter, data on the mechanical properties of different cement systems were presented. Young's modulus and effective compressive-strength data were presented for the cements used in Application 2. The effective compressive strength is the equivalent unconfined compressive strength, which takes out the effect of confining pressure. "ASTM C469, Standard Test Method for Static Modulus of Elasticity (Young's Modulus) and Poisson's Ratio of Concrete in Compression," was followed for the Young's modulus testing. The diameter of each test specimen was 1.5 in., and the length was 3.0 in.

The following procedure is used for the Young's modulus testing.

1) Each sample is inspected for cracks and defects.
2) The sample is cut to a length of 3.0 in.
3) The sample's end surfaces are then ground to get a flat, polished surface with perpendicular ends.
4) The sample's physical dimensions (length, diameter, weight) are measured.
5) The sample is placed in a Viton jacket.
6) The sample is mounted in the Young's modulus testing apparatus.
7) The sample is brought to 100-psi confining pressure and axial pressure. The sample is allowed to stand for 15-30 min until stress and strain are at equilibrium. (In case of an unconfined test, only axial load is applied.)
8) The axial and confining stress are then increased at a rate of 25-50 psi/min to bring the sample to the desired confining stress condition. The sample is allowed to stand until stress and strain come to equilibrium.
9) The sample is subjected to a constant strain rate of 0.0019 in./min (0.05mm/min).
10) During the test, the pore-lines on the end-cups of the piston are open to atmosphere to avoid any pore-pressure buildup.
11) After the sample is failed, the system is brought back to the atmospheric stress condition; the sample is removed from the cell and stored.

Young's modulus and effective compressive strength data that were collected during the fourth and fifth quarters are presented in **Tables 7** and **8**. The initial data presented in the previous quarter were obtained from cored cement samples. The previous quarter's works contained data from tests that were performed on cement samples that were cured in water, but were stored in air approximately 24 hours before testing. These samples that were inappropriately stored were the 11.5-lb/gal samples tested at zero confining pressure. The incorrectly stored samples are presented in **Table 7** and are marked with †. During the fifth quarter, the 11.5-lb/gal samples at zero confining pressure were run again with new samples that were correctly stored in water up to the moment of testing. The data from these retests (marked with ‡) are presented in **Table 7**. It should be noted that these retests were tested on cement samples that were molded instead of cored. This table also presents the other data of the cement samples that were properly prepared and tested from the previous quarter. All samples were cured for 14 days at atmospheric pressure in a 96°F water bath. The 10.0-lb/gal data presented in **Table 8** are from samples that were cored and properly stored in water up to the time of testing.

Table 7—Mechanical Properties of 11.5-lb/gal Cements

Application 2, Density: 11.5 lb/gal											
Cement Type	Slurry System	Young's Modulus ($x10^5$ psi) at Confining Pressure (psi)					Effective Compressive Strength (psi) at Confining Pressure (psi)				
		0	0	500	1,000	1,500	0	0	500	1,000	1,500
Class A	ULHS	3.46[†]	4.24[‡]	3.40	3.37	2.83	5,000[†]	3,880[‡]	4,508	4,773	5,006
	Sodium Silicate	0.24[†]	0.59[‡]	0.10	0.22	0.52	320[†]	315[‡]	651	777	1,450
	Foamed	1.42[†]	2.50[‡]	0.83	1.21	1.21	1,300[†]	1,590[‡]	1,669	2,041	1,956
TXI Lightweight	ULHS	3.29[†]	3.71[‡]	1.79	2.21	3.87	4,652[†]	3,300[‡]	6,198	6,372	6,349
	Sodium Silicate	0.73[†]	1.99[‡]	0.31	0.45	1.10	752[†]	965[‡]	1,066	1,078	1,134
	Foamed	1.94[†]	2.70[‡]	2.41	1.75	1.70	1,550[†]	2,420[‡]	2,907	2,910	3,168

[†] Samples were stored in air approximately 24 hours prior to testing.

[‡] Samples were tested on molded cement samples during the fifth quarter.

Table 8—Mechanical Properties of 10.0-lb/gal Cements

Application 2, Density: 10.0 lb/gal									
Cement Type	Slurry System	Young's Modulus ($x10^5$ psi) at Confining Pressure (psi)				Effective Compressive Strength (psi) at Confining Pressure (psi)			
		0	500	1,000	1,500	0	500	1,000	1,500
Class A	ULHS	1.94	2.46	2.69	3.00	1,950	3,141	3,291	3,575
	Foamed	1.84	1.07	1.69	2.59	1,193	1,248	1,253	1,250
TXI Lightweight	ULHS	2.47	2.42	3.01	2.84	3,150	4,850	5,470	5,502

Water and Air Permeability

Water and air permeability of the different cement systems was determined. The cement samples for these tests were 1.0 in. diameter and 1.0 in. long. The samples were cured at atmospheric pressure in a water bath at the BHST of the corresponding application (**Table 3**). Because the Application 1 and 3 samples were cured at temperatures significantly different from room temperature (45°F and 174°F respectively), they were placed in an 80°F water bath for 45 minutes before testing.

Testing for the water permeability consisted of placing the cement sample into a rubber sleeve that was then placed into a permeameter. The sleeve was then sealed, using mechanical force. Inlet pressure to the core was then brought to 100 psi and held for five minutes. Fluid volume was collected and measured during that time. Four samples were tested for each cement design. The water permeability was then calculated using the following equation from API RP 10B.[3]

$$K = 14{,}700 \frac{Q \times \mu \times L}{A \times \Delta P} \qquad \text{Equation 1}$$

where K = *permeability, md*
Q = *flow rate, mL/sec*
μ = *liquid viscosity, cp*
L = *sample length, cm*
A = *cross sectional area,* cm^2
P_i = *inlet pressure, psi*
P_o = *outlet pressure, psi*
$\Delta P = P_i - P_o$.

The results of the water permeability testing can be seen in **Tables 9** and **10**.

Table 9—Water Permeability of 11.5-lb/gal Cements

Cement Type	Slurry System	Water Permeability (md)				
Application 1						
Cement Type	**Slurry System**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class A	ULHS	0.00	0.00	0.00	0.00	0.00
	Sodium Silicate	8.72	7.26	8.72	7.26	7.99
	Foamed	2.18	2.18	1.45	1.45	1.82
TXI Lightweight	ULHS	0.00	0.00	0.00	0.00	0.00
	Sodium Silicate	2.91	2.18	2.91	2.91	2.73
	Foamed	0.00	0.00	0.00	0.00	0.00
Application 2						
Cement Type	**Slurry System**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class A	ULHS	0.00	0.00	0.00	0.00	0.00
	Sodium Silicate	0.58	1.74	1.45	0.80	1.14
	Foamed	0.65	0.36	0.29	0.51	0.45
TXI Lightweight	ULHS	0.00	0.00	0.00	0.00	0.00
	Sodium Silicate	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
Application 3						
Cement Type	**Slurry System**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class H	ULHS	0.03	0.05	2.30	0.12	0.63
	Sodium Silicate	1.23	1.45	2.18	2.18	1.76
	Foamed	0.00	0.00	1.45	0.73	0.55
TXI Lightweight	ULHS	2.91	0.31	0.15	0.45	0.96
	Sodium Silicate	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
Class A	Foamed	11.62	9.44	10.89	10.16	10.53

Table 10—Water Permeability of 10.0-lb/gal Cements

Application 1						
Cement Type	**Slurry System**	**Water Permeability (md)**				
		Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class A	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	22.51	26.15	16.70	17.74	20.78
TXI Lightweight	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
Application 2						
Cement Type	**Slurry System**	**Water Permeability (md)**				
		Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class A	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
TXI Lightweight	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
Application 3						
Cement Type	**Slurry System**	**Water Permeability (md)**				
		Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Average**
Class H	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
TXI Lightweight	ULHS	0.00	0.00	0.00	0.00	0.00
	Foamed	0.00	0.00	0.00	0.00	0.00
Class A	Foamed	36.57	35.59	37.04	36.57	36.44

Tests were also performed to evaluate air permeability of cements. After first curing the cement in water, each sample was then dried in a vacuum desicattor at room temperature for 14 hours. The cement sample was placed into a rubber sleeve that was then placed into a permeameter. The sleeve was then sealed, using mechanical force. The procedures put forth in API RP 10B[3] were followed to purge the lines of liquid. The gas flow was then diverted to the cement sample and the pressure was increased until the flow meter indicated a stable flow rate. The gauge pressure and flow rate were recorded. The inlet pressure was again increased and the gauge pressure and stable flowrate recorded. The above procedure was repeated until approximately ten data points were collected over an increasing range of pressures.

Two samples were tested for each cement design. The air permeability was then calculated using the following equation from API RP 10B.[3]

$$K = \frac{2{,}000 \times \mu \times Q_b \times P_b \times L}{A(P_i^2 - P_o^2)} \text{ .... Equation 2}$$

where *K = permeability to gas (md)*
μ = viscosity of gas (cps)
Q_b = flow rate to gas (mL/sec)
P_b = adjusted barometric pressure (atm)
L = cement sample length (cm)
A = cross sectional area (cm^2)

P_i = inlet pressure (atm)
P_o = outlet pressure (atm).

Using the ten data points for each sample, a plot of 2,000×μ×Q_b×P_b×L versus $A(P_i^2-P_o^2)$ is made. The linear portion of the curve represents the linear flow regime where Darcy's law (**Equation 2**) is applicable. Where the data points deviate from linear, the gas is in turbulent flow and **Equation 2** is no longer valid. The permeability of the sample is directly proportional to the slope of the curve in the linear region. **Tables 11** and **12** present air permeability data for cements cured in a water bath at the temperature appropriate for each application.

The water and air permeability data sets do not follow a trend and will require additional investigation. Studies will be made into the limitations of the current methods being used. New cement samples will be made for measuring water permeability. Cementing Solutions will perform testing on these samples and also send duplicate samples to BJ Services for testing and comparison.

Table 11—Air Permeability of 11.5-lb/gal Cements

Application 1					
Cement Type	**Slurry System**	**38-Hour Air Permeability (md)**		**24-Day Air Permeability (md)**	
		Sample 1	**Sample 2**	**Sample 1**	**Sample 2**
Class A	ULHS	4.38	3.06	17.00	15.94
	Sodium Silicate	6.64	7.91	18.66	17.68
	Foamed	7.60	6.47	4.39	3.36
TXI Lightweight	ULHS	10.33	4.15	4.22	3.28
	Sodium Silicate	4.16	2.31	19.26	18.99
	Foamed	1.01	1.05	8.63	11.37
Application 2					
Cement Type	**Slurry System**	**38-Hour Air Permeability (md)**		**24-Day Air Permeability (md)**	
		Sample 1	**Sample 2**	**Sample 1**	**Sample 2**
Class A	ULHS	1.21	1.09	0.98	0.91
	Sodium Silicate	1.80	0.63	4.29	4.67
	Foamed	10.06	8.49	0.96	0.98
TXI Lightweight	ULHS	1.04	1.23	1.71	1.49
	Sodium Silicate	5.90	6.80	1.40	1.83
	Foamed	1.75	2.99	1.59	1.55
Application 3					
Cement Type	**Slurry System**	**38-Hour Air Permeability (md)**		**24-Day Air Permeability (md)**	
		Sample 1	**Sample 2**	**Sample 1**	**Sample 2**
Class H	ULHS	3.09	2.15	0.50	0.51
	Sodium Silicate	4.08	4.11	29.72	24.24
	Foamed	500+	500+	Not Tested	Not Tested
TXI Lightweight	ULHS	1.20	0.91	0.73	0.87
	Sodium Silicate	10.79	8.97	1.63	2.07
	Foamed	1.10	1.15	0.75	0.64
Class A	Foamed	500+	500+	Not Tested	Not Tested

Table 12—Air Permeability of 10.0-lb/gal Cements

Cement Type	Slurry System	38-Hour Air Permeability (md)	
Application 1			
		Sample 1	Sample 2
Class A	ULHS	30.45	32.47
	Foamed	6.65	6.57
TXI Lightweight	ULHS	4.04	4.17
	Foamed	5.27	6.43
Application 2			
Cement Type	**Slurry System**	**38-Hour Air Permeability (md)**	
		Sample 1	**Sample 2**
Class A	ULHS	5.08	5.60
	Foamed	2.94	2.87
TXI Lightweight	ULHS	1.02	1.12
	Foamed	1.91	1.22
Application 3			
Cement Type	**Slurry System**	**38-Hour Air Permeability (md)**	
		Sample 1	**Sample 2**
Class H	ULHS	8.94	6.55
	Foamed	500+	500+
TXI Lightweight	ULHS	0.31	0.32
	Foamed	1.12	1.17
Class A	Foamed	500+	500+

Shear Bond

Testing was also performed to evaluate shear bond strength of the three cement systems. These studies investigate the effect that restraining force has on shear bond. Samples were cured in a pipe-in-pipe configuration (**Figure 2**) and in a pipe-in-soft configuration (**Figure 3**). The pipe-in-pipe configuration consists of a sandblasted internal pipe with an outer diameter (OD) of 1 $^{1}/_{16}$ in. and a sandblasted external pipe with an internal diameter (ID) of 3 in. and lengths of 6 in. A contoured base and top are used to center the internal pipe within the external pipe. The base extends into the annulus 1 in. and cement fills the annulus to a length of 4 in. The top 1 in. of annulus contains water.

For the pipe-in-soft shear bonds, plastisol is used to allow the cement to cure in a less-rigid, lower-restraint environment. Plastisol is a mixture of a resin and a plasticizer that creates a soft, flexible substance. This particular plastisol blend (PolyOne's Denflex PX-10510-A) creates a substance with a hardness of 40 duro.

The pipe-in-soft configuration contains a sandblasted external pipe with an ID of 4 in. A molded plastisol sleeve (with an ID of 3.0 in. and uniform thickness of 0.5 in.) fits inside this external pipe. With the aid of a contoured base and top, a sandblasted internal pipe with an OD of 1 $^{1}/_{16}$ in. is then centered within the plastisol sleeve. The pipes and sleeve are 6 in. long. The base extends into the annulus 1 in. and cement fills the annulus to a length of 4 in. between the plastisol sleeve and the inner 1 $^{1}/_{16}$ -in. pipe. The top inch of annulus is filled with water.

Figure 2—Cross Section of Pipe-in-Pipe Configuration for Shear Bond Tests

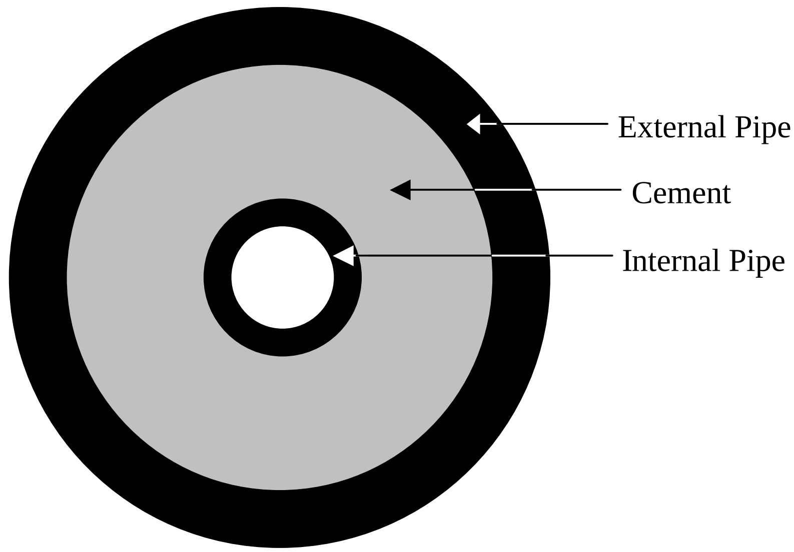
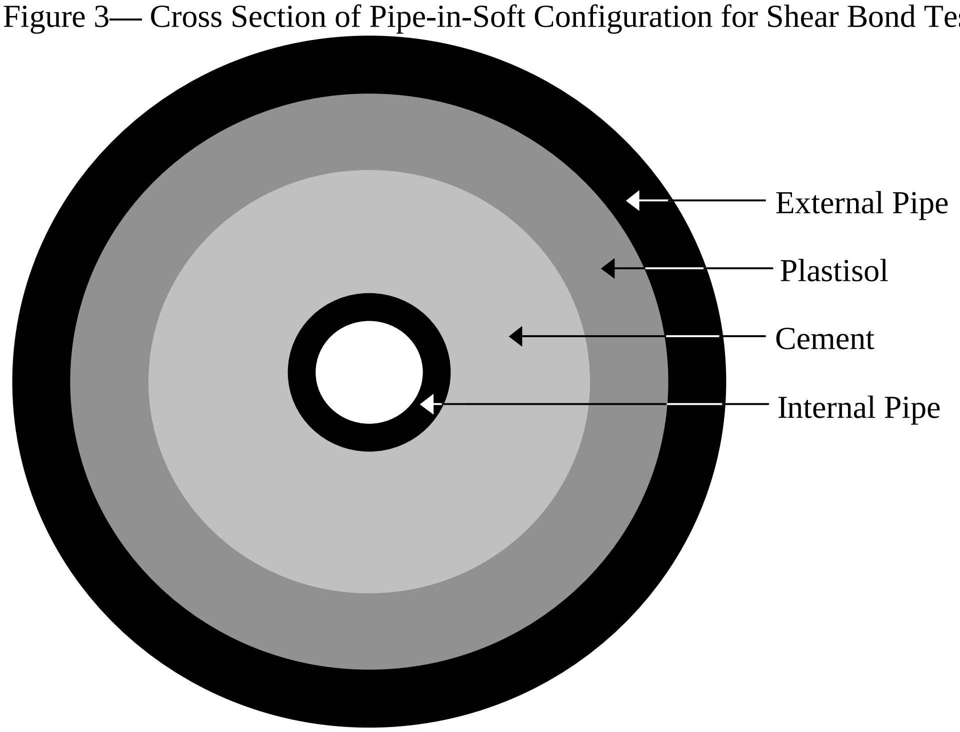


Figure 3— Cross Section of Pipe-in-Soft Configuration for Shear Bond Tests



The cement systems used for these shear bond tests are the formulations used for Application 2. They are cured for seven days at atmospheric pressure in a water bath maintained at 96°F (BHST for Application 2).

The shear bond measures the stress necessary to break the bond between the cement and the internal pipe. This was measured with the aid of a test jig that provides a platform for the base of the cement to rest against as force is applied to the internal pipe to press it through. (**Figure 4**) The shear bond force is the force required to move the internal pipe. The pipe is pressed only to the point that the bond is broken; the pipe is not pushed out of the cement. The shear bond strength is the force required to break the bond (move the pipe) divided by the surface area between the internal pipe and the cement.

Figure 4—Configuration for Testing Shear Bond Strength

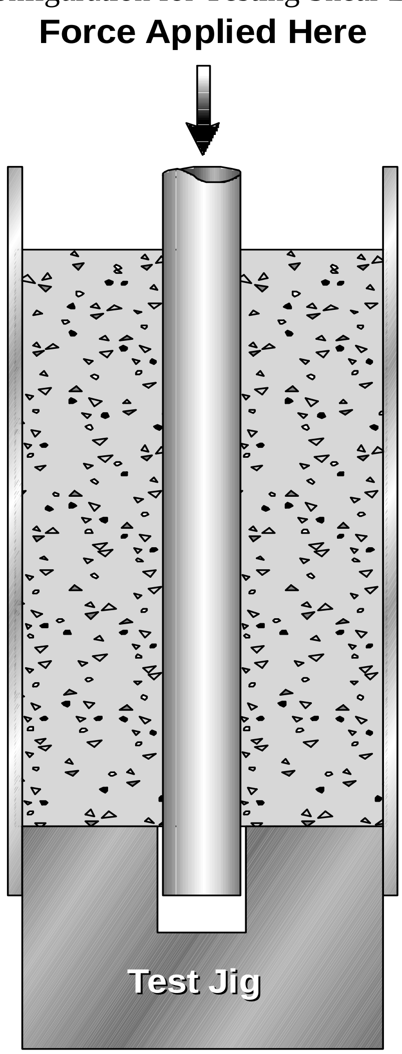


Table 13 presents the seven-day shear bond strengths of the three cement systems in the pipe-in-pipe and pipe-in-soft configurations.

Table 13—Shear Bond Strengths of Lightweight Cement Systems

Application 2, 11.5 lb/gal Density, Class A Cement					
Configuration	Slurry Type	Shear Bond Strength (psi)			
		Sample 1	Sample 2	Sample 3	Average
Pipe-in-pipe	ULHS	460	361	371	397
	Sodium Silicate	163	164	114	147
	Foamed	372	375	587	445
Pipe-in-soft	ULHS	211	262	169	214
	Sodium Silicate	92	54	68	71
	Foamed	235	146	190	190

Testing was also done to determine the effect that temperature cycling has on shear bond. The temperature cycling procedure was designed to simulate temperature conditions that might be seen during production of a well similar to the Application 2 scenario, where temperatures during production could reach 300°F. The samples are first cured for seven days in a 96°F water bath at atmospheric pressure. They are then subjected to five days of temperature cycling. During each of these five days of temperature cycling, the cured samples are cycled as follows.

- Samples are removed from 96°F water bath and placed in an oven. Oven is heated to 180°F in 4 minutes. Samples remain in 180°F oven for 1 hour.
- Oven is heated to 300°F in 5 minutes. Samples remain in 300°F oven for four hours.
- Oven is cooled to 180°F in 15 minutes. Samples remain in 180°F oven for one hour.
- Oven is cooled to 96°F in 15 minutes. Samples are placed back in 96°F water bath.

Because of the high temperatures associated with the temperature cycling, these shear bond samples are cured with a special configuration that has a flange on the outside of the external pipe and at both ends. Each flange has holes that allow a flat, watertight lid to be bolted to it (**Figure 5**). The watertight lids keep water on the cement and prevent the water from boiling off. The lids are placed on the samples at the end of the seven days of curing at 96°F.

The results for the temperature-cycled pipe-in-pipe shear bonds are presented in **Table 14**. It should be noted that the cements did not contain silica to combat strength retrogression.

The pipe-in-soft shear bonds will be tested in the next quarter. Testing will also be done in the next quarter to determine the temperatures achieved in the cement samples during the temperature cycling.

Figure 5—Assembly for Shear Bonds That Are Temperature Cycled

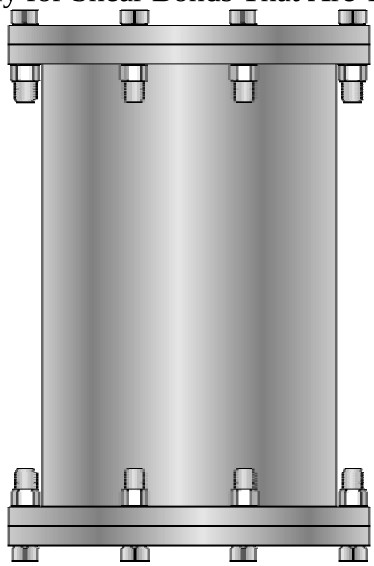


Table 14—Shear Bond Strength of Temperature-Cycled Cements

Application 2, 11.5 lb/gal Density, Class A Cement					
Configuration	**Slurry Type**	**Shear Bond Strength (psi)**			
		Sample 1	**Sample 2**	**Sample 3**	**Average**
Pipe-in-pipe	ULHS	200	69	197	155
	Sodium Silicate	110	120	94	108
	Foamed	300	307	313	307

Mixing Studies

In the fourth quarter, a large-scale study was performed to determine the effect that mixing and pumping has on ULHS. Two different ULHS systems were studied—3K and 6K. The slurry density for both of the systems was 10.0 lb/gal. The formulation for the two slurries is as follows.

3K ULHS System
Class H Cement + 20.49% BWOC 3K ULHS + 9.0 gal of fresh water/sk of cement.
Yield: 2.52 ft^3/sk.

6K ULHS System
Class H Cement + 26.50% BWOC 6K ULHS + 11.0 gal of fresh water/sk of cement.
Yield: 2.80 ft^3/sk.

A slurry volume based on two sacks of cement was tested for each slurry. The slurry was placed in a 50-gal container and agitated by a Lightnin MS-1VM mixer that included two 3-in. diameter marine impellers (Lightnin model number A100). The mixer is also equipped with a controller that allows for variation in impeller rotation speed. The slurry was recirculated through a semi-open impeller, self-priming centrifugal pump (Gorman-Rupp Model 83E1-GX140) and through 24 ft of 3-in. flexible, heavy-duty rubber hose. The 3K ULHS system was pumped at a rate of 68 gallons per minute. The 6K ULHS system was pumped at a rate of 98 gallons per minute. Both systems were circulated for one hour.

The results of these tests are presented in **Tables 15** and **16**. Slurry density and temperature were measured throughout the tests. In **Tables 15** and **16**, the measured slurry density is used to deduce the effective specific gravity of the ULHS. Note that the 3K ULHS is manufactured with a specific gravity of 0.370 (with a minimum specific gravity of 0.340 and a maximum of 0.400 for individual spheres). The 6K ULHS is manufactured with a specific gravity of 0.460 (with a minimum specific gravity of 0.430 and a maximum of 0.490 for individual spheres).

Table 15—Data for Circulation Test of 3K ULHS System

Time (minute)	Turnover (# of volumes)	Density (lb/gal)	Effective ULHS Specific Gravity	Temperature (°F)
0	0	10.00	0.370	92.9
8	14	10.00	0.370	97.0
18	32	10.10	0.381	102.6
24	43	10.20	0.393	105.8
34	61	10.25	0.399	109.0
40	72	10.30	0.406	112.2
48	87	10.30	0.406	114.8
54	97	10.35	0.412	116.7
60	108	10.40	0.418	118.6

Table 16—Data for Circulation Test of 6K ULHS System

Time (minute)	Turnover (# of volumes)	Density (lb/gal)	Effective ULHS Specific Gravity	Temperature (°F)
0	0	10.05	0.460	100.3
8	19	10.05	0.460	107.0
16	37	10.10	0.468	110.4
24	56	10.10	0.468	112.6
32	75	10.10	0.468	115.5
40	94	10.10	0.468	118.0
48	112	10.10	0.468	120.1
54	126	10.10	0.468	120.6
60	140	10.10	0.468	121.1

Figure 6 shows the change of slurry density with respect to time. **Figure 7** shows the effect that the circulation and mixing time have on the effective specific gravity of ULHS.

Figure 6—Effect of Mixing Time on Slurry Density

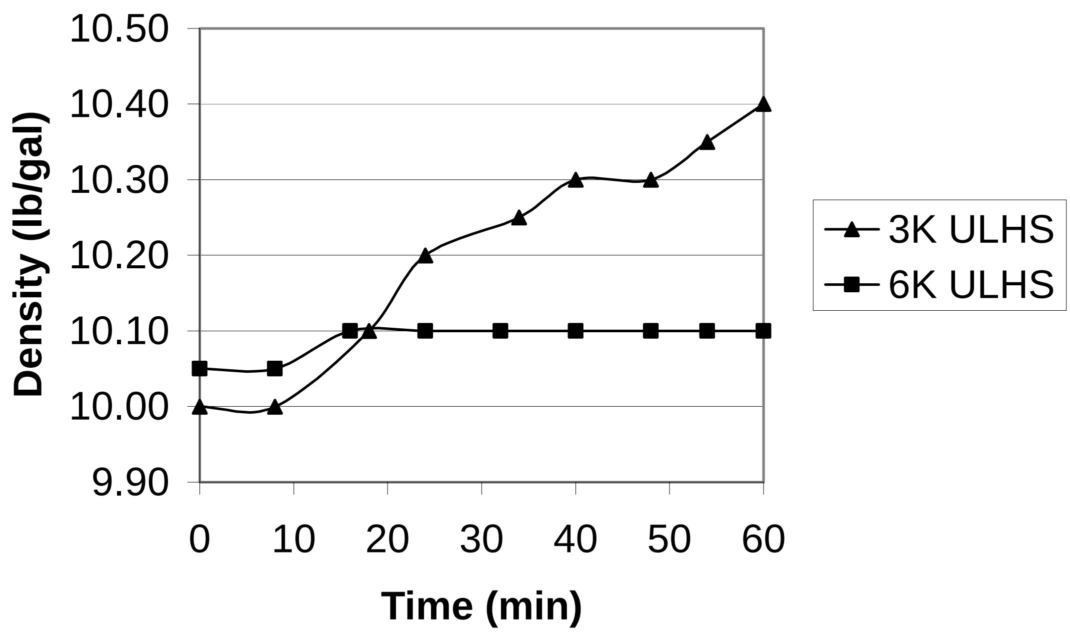
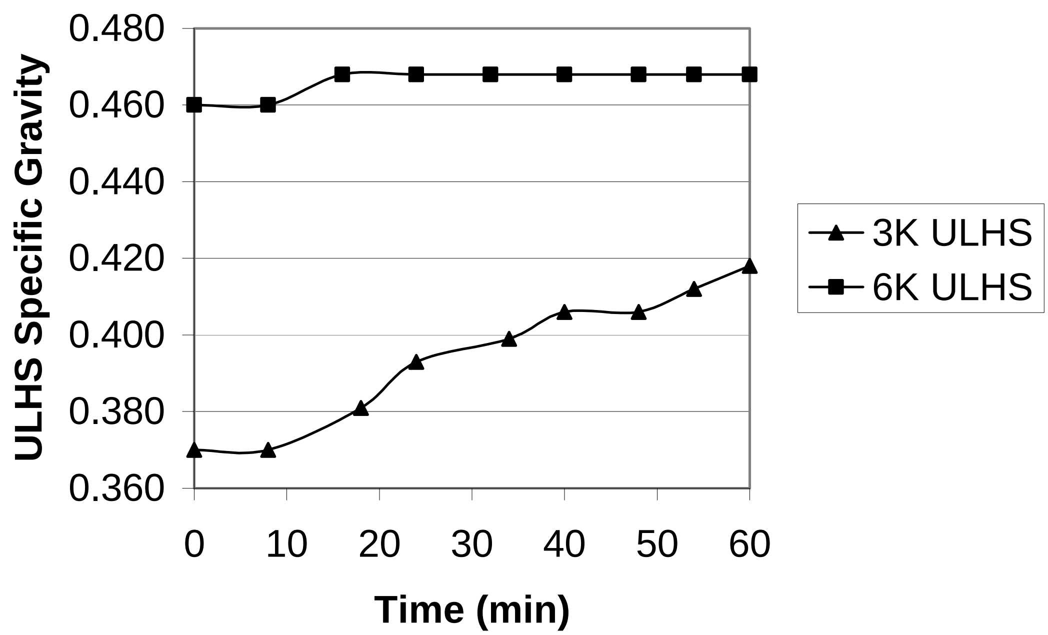


Figure 7—Effect of Mixing Time on ULHS Specific Gravity



The energy (power) supplied to the system is provided by the pump and the mixing from the agitators. The power supplied to a liquid by a pump[4] can be expressed as:

$$P_P = HQ/2.298 \quad \text{Equation 3}$$

where *P_P = power output of the pump, J/s*
H = total dynamic head, psi
Q = capacity, gal/min
2.298 is a conversion factor.

The equation for the power supplied by an impeller[4] can be expressed as:

$$P_A = N_p \rho N^3 D^5 / g_c \quad \text{Equation 4}$$

where *P_A = power supplied to the fluid by the impeller, J/s;*
N_p = power number, dimensionless
ρ = fluid density, kg/m^3
N = rotational speed, rev/s
D = impeller diameter, m
g_c = dimensional constant (1 when using SI units).

The same pumping and mixing equipment and the same impeller rotation speed (23 rev/s) were used for both slurries. The power number (supplied by the manufacturer) for the A100 impeller is 0.87. The impeller diameter is 3 in. (0.076 m), and the slurry density of each cement slurry was 10 lb/gal (1199 kg/m^3). Using **Equation 4** from above, we find that the power supplied to the cement slurry by each impeller was 32.6 J/s. Because there were two impellers, the total power supplied by the mixing equipment was 65.2 J/s.

For the power supplied to the fluid system by the pump, we will use **Equation 3**. While pumping the 3K ULHS system, the pump pressure measured 16 psi. Unfortunately, the pump pressure was not measured when the 6K system was being tested. For the 3K ULHS system that was pumped at a rate of 68 gal/min, the power supplied to the cement slurry by the pump is 473.5 J/s.

The power imparted by the mixing and pumping systems to the cement systems would be distributed over the total mass of each slurry. The mass of the 3K slurry was 170.8 kg and the mass of the 6K slurry was 191.1 kg. It should be noted that during the test, the temperature of the 3K system increased by 25.7°F and the temperature of the 6K system increased by 20.8°F. The difference in the temperature increase for each system can be an indication of the difference in the energy imparted to each system.

The centrifugal pump testing revealed that the 6K ULHS held up better than the 3K ULHS under the mixing and pumping conditions in the study. In the next quarter, the energy imparted to the cement system by the mixing and pumping equipment in this study will be compared to the mixing energy associated with field mixing equipment and API laboratory mixing procedures.

Alkali Silica Reactivity

Stork Southwestern Laboratories tested slurries containing ULHS as well as other materials for alkali silica reactivity (ASR) using a modified version of "ASTM C1260-

94, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)."[5] This test method permits detection within 16 days of the potential for deleterious ASR of aggregate in mortar bars. For comparison purposes, testing was done on 6K ULHS, fumed silica, and pozzolan microspheres (a lightweight additive currently used in the industry). TXI Class A cement was used to make the slurries.

Because the test method is designed for testing aggregates that are used in construction concrete, a modified version was used to account for the difference in admixture concentrations that are typically used in oilfield cement blends. ASTM C1260 requires 1 part of cement to 2.25 parts of graded aggregate by mass and a water to cement ratio equal to 0.47 by mass. To more closely match the slurry consistency and admixture concentrations used in oilwell cements, the concentrations of the admixtures and water were adjusted. The slurry composition adjustments can be seen in **Table 17**. The water concentration of each of the cement systems was chosen to reflect the actual water requirements of typical slurry designs; the ULHS system required more water than the other two systems. Also, because the admixtures used in these tests are very small, the admixtures were not graded by size as specified in ASTM C1260-94.

Table 17—Admixture and Water Concentrations for ASR Study

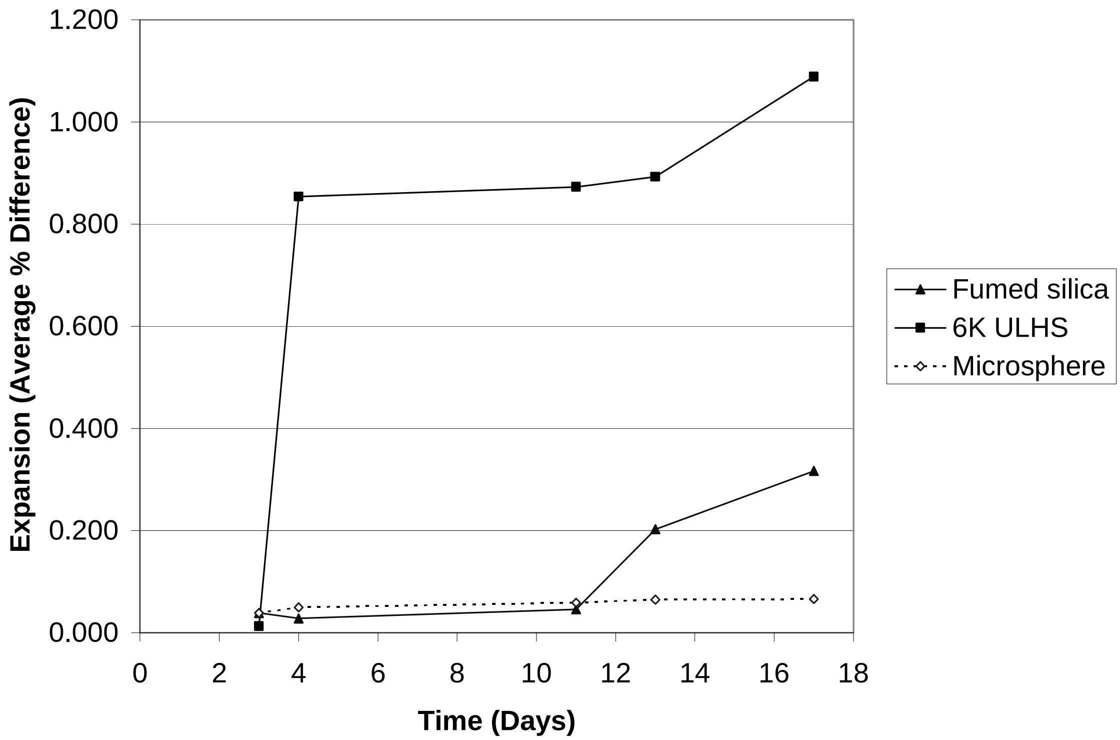
Slurry Type/ Admixture	Admixture Concentration (% BWOC)	Water Concentration (% BWOC)
Fumed silica	20.0	50.0
6K ULHS	20.0	62.1
Microsphere	20.0	50.0

The procedures of ASTM C1260-94 specify that the cement specimens be cured 24 hours in the mortar bar mold in a 73°F moist room. The specimens are then removed from the mold, identified, and initial comparator readings are recorded. The specimens are then submerged and stored in tap water in a sealed container and placed in an oven at 176°F for 24 hours. The specimens are then removed from their containers, dried, and comparator readings are taken and recorded. The specimens are then placed in a container and submerged in a 1N NaOH solution. The container is then sealed and placed back in the oven at 176°F. Additional readings are taken periodically for another 14 days. The results of the testing done on the pozzolan microsphere, fumed silica, and ULHS slurries can be seen in **Table 18** and **Figure 8**. Three samples were tested for each of the three slurries. The average percent difference presented in **Table 18** is an average of the percent expansion of triplicate samples.

Table 18—Results of ASTM C1260 Testing

Slurry	Expansion—Average % Difference				
	3 days	4 days	11 days	13 days	17 days
Fumed silica	0.039	0.028	0.046	0.203	0.317
6K ULHS	0.013	0.854	0.873	0.893	1.089
Microsphere	0.039	0.05	0.059	0.065	0.066

Figure 8—Length Change Data from ASTM C1260 Testing



ASTM C1260-94 uses the following guidelines for interpretation of test results.

- Expansions of less than 0.10% at 16 days after casting are indicative of innocuous behavior in most cases.
- Expansions of more than 0.20% at 16 days after casting are indicative of potentially deleterious expansion.
- Expansions between 0.10 and 0.20% at 16 days after casting include both aggregates that are known to be innocuous and deleterious in field performance. For these aggregates, it is particularly important to develop supplemental information to confirm that the expansion is actually cause by alkali-silica reaction.

Based on the interpretation guidelines, the fumed silica (with a 17-day expansion of 0.317%) demonstrates potentially deleterious expansion. The 6K ULHS (with a 17-day expansion of 1.089%) also demonstrates potentially deleterious expansion. The microsphere (with a 17-day expansion of 0.066%) exhibits expansion that is indicative of innocuous behavior in most cases.

Additional ASR testing is continuing. The permeability data that is being collected is one method of detecting potential ASR problems. We are also considering having testing done using "ASTM C289, Test Method for Potential Reactivity of Aggregates (Chemical Method)." This testing would have to be modified to adapt for the large surface area associated with ULHS.

Field Application

A cement job using ULHS was performed on November 2, 2001. BJ Services performed the job on a well owned by Conoco. The well was the A-3 well on the Jennings Ranch in Zapata County in south Texas. The ULHS cement slurry was pumped as the first lead slurry for cementing a 7-in. intermediate casing. The second lead slurry was a 12.7-lb/gal slurry typical of the lead slurries pumped in that area. The final slurry was a 15.6-lb/gal tail slurry. Total depth was 9,024 ft, and the hole size was 8.75 in. Estimated BHCT was 153°F, and estimated BHST was 218°F. Using an estimated excess annular volume of 30%, the planned fill would be 1,000 ft for the first lead slurry, 1,000 ft for the second lead slurry, and 500 ft for the tail slurry.

The ULHS cement blend (designed for a density of 10.4 lb/gal) was blended at BJ's Laredo district camp on October 31, 2001. 86 sacks of Joppa Class H cement were used in the ULHS cement blend. The blend contained 26.06% BWOC 6K ULHS and 0.25% BWOC R-3 (retarder). This dry cement blend would be mixed with 63.6% BWOC fresh water that contained 0.005 gal/sk FP-6L (defoamer).

The ULHS blend was divided into three separate blends. Each blend consisted of one-third of the total cement, one-third of the total amount of ULHS, and one-third of the total amount of retarder. For each separate blend, half of the cement allotment was added to the blend tank, and then the retarder and ULHS were added to the blend tank through a side hopper. The ULHS were dumped from their individual 125-lb boxes into the hopper at a controlled rate without any significant production of dust, and then the remainder of the cement was added to the blend tank. The cement blend was then blended (using mechanical blending and air circulation) in the blend tank for three minutes. The cement blend was transferred to the auxiliary tank, then transferred back to the blend tank, and then transferred to the cement truck. The same blending process was used for all three separate blends. Bulk plant samples were taken and delivered to BJ's South Texas Region laboratory for analysis.

Rheologies from the pilot tests, bulk plant samples, and on-location samples are presented in **Table 19**. The thickening time on the pilot test ran 4 hours and 0 minutes; the bulk plant sample ran 4 hours and 35 minutes.

Table 19—Rheologies of ULHS Blend for Field Application

RPM	Pilot Test		Bulk Plant Sample		On Location
	80°F Reading	153°F Reading	80°F Reading	153°F Reading	80°F Reading
300	197	143	162	110	173
200	137	103	89	71	123
100	78	65	50	44	74
6	13	13	13	11	18
3	9	9	10	8	13

To ensure a more homogenous ULHS slurry, the ULHS slurry was mixed in a 50-bbl batch mixer on location. Because of operational errors during mixing, less of the ULHS slurry was pumped than anticipated. A sample was taken for density determination. After confirmation, rheology testing was performed. The final ULHS slurry density was 10.45 lb/gal and was pumped downhole without further complication. The second lead slurry and tail slurry were mixed on the fly and pumped downhole.

An ultrasonic log run in tandem with an acoustic log was recommended to evaluate the ULHS cement. The ultrasonic log can detect the ULHS cement, whereas the acoustic log is not expected to be able to sense the ULHS cement. The acoustic log may have trouble properly detecting the ULHS cement because of the air that is entrapped in the ULHS. Because a ULHS cement has low density and acoustic impedance, there would be difficulty distinguishing the ULHS cement from fluids. On November 13, 2001, because of operational issues, only an acoustic bond log was run. The second lead cement and the tail cement showed up on the log, but the acoustic bond log did not detect the ULHS cement.

Plans for Sixth Project Quarter

The following investigations and tests are planned for the next project quarter.

- Further investigations will look at methods for determining Young's modulus of cements that have ambiguous stress-strain curves.
- For comparison, Young's modulus testing will also be done on neat, 15.6-lb/gal Class A cement and on TXI Lightweight cement at 13.5 lb/gal.
- Stress-strain cycling tests will be performed on different Young's modulus samples to evaluate the hysteresis characteristics of cement systems.
- The water and air permeability data sets do not follow a trend and will require additional investigation. Studies will be made into the limitations of the current methods being used.

- New cement samples will be made for measuring water permeability. Cementing Solutions will perform testing and also send duplicate samples to BJ Services for testing and comparison.

- Shear bond testing in the sixth quarter will include testing on Class A cements that have been temperature-cycled in a pipe-in-soft configuration. Pipe-in-pipe and pipe-in-soft shear bonds with and without temperature cycling will also be performed on the different cement systems made with TXI Lightweight cement.

- A literature review will be conducted to determine the mixing energy associated with field mixing equipment and API laboratory mixing procedures to compare with the energy associated with the mixing studies of this project.

- Future testing will look into using a modified version of ASTM C289 (chemical method) and expansion testing to determine if ULHS is susceptible to ASR.

Conclusions

From the work done during the fifth project quarter, the following conclusions can be made.

- ASTM C190 ("dog-bone" tensile strength) tests produced a notable amount of deviation between results. In comparison, ASTM C496 (splitting tensile strength) tests had less variability. For both tests, the tensile strengths of the sodium silicate cements were lower than the foamed and ULHS cements.

- From the Young's modulus testing, there was no noticeable difference between the effective compressive strengths at the different confining pressures. As a general trend, the effective compressive strengths of the ULHS systems were higher than those of the foamed system, which were higher than those of the sodium silicate systems. The effective compressive strengths of the slurries made with TXI Lightweight cement were higher than those made with TXI Class A cement.

- The preliminary centrifugal pump testing revealed that the 6K ULHS held up better than the 3K ULHS under the mixing and pumping conditions in the study.

- From the field job that was performed, it was seen that ULHS can be successfully blended and an ultrasonic log is required to properly evaluate cements made with ULHS.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
OD—outer diameter
psi—pound per square inch
rev—revolution
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Specification 10A: "Specifications for Cements and Materials for Well Cementing," 22nd Edition, American Petroleum Institute, Washington, D.C., January 1995.

2. *Worldwide Cementing Practices,* First Edition, American Petroleum Institute, January 1991.

3. API Recommended Practice 10B: "Recommended Practice for Testing Well Cements," 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

4 *Perry's Chemical Engineers' Handbook,* Sixth Edition, McGraw-Hill Book Co. Inc., New York City, 1984.

5 "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)," ASTM C1260-94, West Conshohocken, PA, May 1994.

TXI Lightweight Cement

TXI Information		CSI Information				Free Fluid			Rheology										
Cmt Type	Production Date	Date Received	CSI Log#	Bucket Opened	Test Date	Water Conc. (%bwoc)	mL	% by volume	Water Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
LW	09/18/00	11/06/00	C-108 B-1	11/07/00	11/15/00	105	2	0.8	75	80	57	50	42	38	33	22	12	13	120
LW	09/18/00	11/06/00	C-108 B-2	12/05/00	01/04/01	105	2	0.8	75	80	58	52	45	38	32	21	13	13	125
LW	09/18/00	11/06/00	C-108 B-11	06/24/01	06/26/01	105	2	0.8	75	80	60	55	47	39	21	20	15	15	127
LW	09/18/00	11/06/00	C-108 B-12	07/03/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-7	09/05/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-14	09/24/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water Conc. (%bwoc)	45°F Strengths			60°F Strengths			80°F Strengths		120°F Strengths		Thickening Time			
Cmt Type	CSI Log#	Test Date		Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 70 Bc	Time to 100 Bc
LW	C-108 B-1	11/15/00	75.0	24	2.0	166	24	1.0	254	24	523	24	1579	5	6	2:02	2:20
LW	C-108 B-2	01/04/01	75.0	24	2.0	161	24	1.0	221	24	441	24	1225	5	5	2:00	2:17
LW	C-108 B-11	06/26/01	75.0	24	2.0	158	---	---	---	24	501	---	---	5	9	1:57	2:18
LW	C-108 B-12	08/14/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-7	09/10/01	75.0	---	---	---	---	---	---	---	---	---	---	5	6	1:57	2:17
LW	C-108 B-14	10/16/01	75.0	---	---	---	---	---	---	---	---	---	---	5	4	2:07	2:26
LW	C-108 B-14	11/13/01	75.0	---	---	---	---	---	---	---	---	---	---	5	5	2:05	2:25
LW	C-108 B-14	12/20/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22

TXI Class H Cement

TXI Information		CSI Information				Water Conc. (%bwoc)	Free Fluid		Rheology									
Cmt Type	Prod. Date	Date Received	CSI Log #	Bucket Opened	Test Date		mL	% by volume	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	1.9	0.8	80	89	72	53	45	37	16	10	---	---
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	38.0	3	1.2	80	85	70	53	45	38	14	8	9	19
Class H	09/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	3	1.2	80	95	80	60	51	42	20	12	15	26
Class H	09/27/00	11/06/00	C-108 A-3	02/22/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-4	06/26/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-6	07/20/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-7	08/27/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water Conc. (%bwoc)	100°F Strengths		140°F Strengths		Thickening Time		
Cement Type	CSI Log#	Test Date		Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 100 Bc
Class H	C-108 A-1	11/07/00	38.0	8	524	8	2088	---	---	---
Class H	C-108 A-1	11/29/00	38.0	8	480	8	2249	5	12	2:03
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1617	---	---	---
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1550	---	---	---
Class H	C-108 A-2	01/11/01	38.0	8	1201	8	1964	5	7	1:54
Class H	C-108 A-2	01/12/01	38.0	8	1039	8	1756	---	---	---
Class H	C-108 A-2	02/12/01	38.0	8	424	8	1717	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1567	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1580	---	---	---
Class H	C-108 A-4	06/29/01	38.0	---	---	---	---	5	17	2:00
Class H	C-108 A-6	08/13/01	38.0	---	---	---	---	5	15	1:50
Class H	C-108 A-7	09/06/01	38.0	---	---	---	---	5	19	2:00
Class H	C-108 A-3	10/09/01	38.0	---	---	---	---	5	12	1:53
Class H	C-108 A-3	11/13/01	38.0	---	---	---	---	5	13	1:50
Class H	C-108 A-3	12/21/01	38.0	---	---	---	---	5	14	1:45

TXI Class A Cement

TXI Information		CSI Information				Water	Rheology									
Cement Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class A	09/27/00	11/06/00	C-113 A-1	11/09/00	11/17/00	46.0	80	75	62	48	40	33	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-2	11/20/00	11/20/00	46.0	80	80	65	49	40	34	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-3	12/04/00	12/05/00	46.0	80	78	64	50	40	32	16	10	10	19
Class A	09/27/00	11/06/00	C-113 A-4	01/09/01	01/09/01	46.0	80	80	65	52	40	33	17	11	10	20
Class A	09/27/00	11/06/00	C-113 A-5	11/09/00	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-1	03/20/01	03/20/01	46.0	80	77	63	51	39	32	17	10	10	20
Class A	03/10/01	03/19/01	C-189 A-5	06/01/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-8	07/11/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-6	10/16/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-17	08/30/01	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths				45°F Strengths			60°F Strengths			80°F Strengths		Thickening Time			
Cement Type	CSI Log #	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	CS (psi)	Test Date	Sch #	Int. Bc	Time to 100 Bc
Class A	C-113 A-1	11/17/00	46.0	---	---	---	---	---	---	---	---	---	---	24	1646	11/15/00	4	9	2:17
Class A	C-113 A-2	11/27/00	46.0	8	754	24	2607	24	2	737	24	1	1194	24	1689	01/05/01	4	8	2:21
Class A	C-113 A-2	02/12/01	46.0	---	---	---	---	---	---	---	---	---	---	24	2022	---	---	---	---
Class A	C-113 A-3	12/05/00	46.0	---	---	24	2585	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-4	01/17/01	46.0	8	729	24	2527	24	2	1042	---	---	---	---	---	01/17/01	4	4	2:09
Class A	C-113 A-5	02/15/01	46.0	8	931	24	2568	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2334	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2590	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2250	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-189 A-1	03/20/01	46.0	8	916	24	2364	---	---	---	24	1	1238	24	1737	03/20/01	4	12	1:42
Class A	C-189 A-5	06/29/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/29/01	4	10	1:37
Class A	C-189 A-8	08/15/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	08/15/01	4	6	1:50
Class A	C-189 A-17	09/12/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	09/12/01	4	6	2:00
Class A	C-189 A-6	10/16/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	10/16/01	4	7	1:41
Class A	C-189 A-6	11/13/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	11/13/01	4	7	1:53
Class A	C-189 A-6	12/21/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	12/21/01	4	6	1:46

Appendix B—Laboratory Procedures for Foamed Cement

The working draft of ISO 10426-4[1] outlines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries. The procedures discussed in this appendix and used for this project were borrowed from ISO 10426-4.

B.1 Preparing Unfoamed Base Slurry

B.1.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density	=	14.5 lb/gal
Surfactant weight	=	10 lb/gal

Base Slurry Calculations:	Weight	Volume
Cement	94 lb	3.59 gal
Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
Water	55.39 lb	6.65 gal
Total	151.39 lb	10.44 gal

Calculation of True Weight % Contributions:		
Cement	62.1 %	(94/151.39)
Surfactant	1.3 %	(2/151.39)
Water	36.6 %	(55.39/151.39)

Slurry without Surfactants:	Weight	Volume
Cement	94 lb	3.59 gal
Water	55.39 lb	6.65 gal
Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

B.2 Equipment

B.2.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure B.1) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

B.2.2 Multi-Blade Assembly

The multi-blade assembly is what is used during this project. The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO 10426-2[2], clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure B.1.

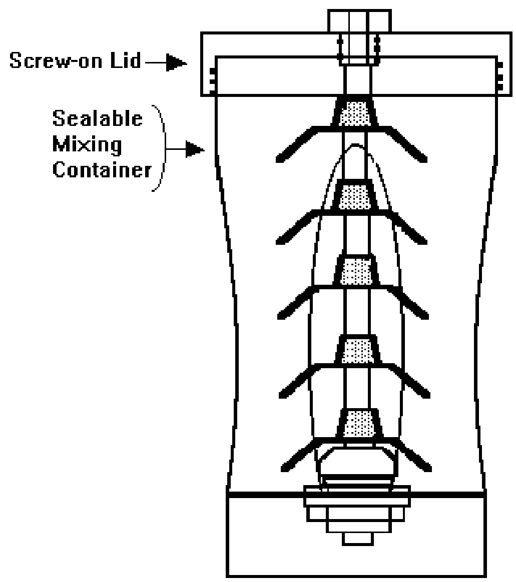


Fig. B.1—Example of a typical blending container

B.3 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

B.4 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section B.1.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section B.2.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Base slurries containing all additives except foaming surfactant(s) should be prepared according to ISO 10426-2[2],clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3.3 rev/s (200 rpm) at 66.7 rev/s (4,000 rpm) and ± 8.3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO 10426-2[2], clause 6.

B.5 Determining Slurry Volumes and Weights

B.5.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times FD \qquad (2)$$

Where:	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	FD	=	Foamed density of the slurry (g/mL)

Example:	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Unfoamed slurry weight	=	1170 mL × 1.2 g/mL = 1404 g

B.5.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 4.

$$GS = GUFS \times (\%Surfactant/100) \qquad (3)$$

Where:

	GS	=	Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)
	GUFS	=	Total grams unfoamed slurry prepared in Section B.1

$$GUSM = GUFS - GS \qquad (4)$$

Where: GUSM = Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example:

Unfoamed slurry weight	=	1404.1 g	
Percent by weight of surfactant	=	1.3 %	

Surfactant weight	=	1404.1 × 0.013	=	18.5 g
Slurry weight	=	1404.1 - 18.5	=	1385.6 g

B.6 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section B.5.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section B.5.2.

B.6.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section B.2.2, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port or container lid, and verify that the slurry completely fills the slurry-mixing container. If the slurry does not fill the mixing container at the end of the 15-second

mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

B.7 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

B.7.1 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weigh the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry. The density of the foamed slurry in the container is determined by dividing the slurry mass by the container volume and converting to the appropriate density units.

B.7.2 Determining Slurry Stability

B.7.2.1 Unset Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder cannot be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

B.7.2.2 Set Slurry Stability

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 50.8-mm (2-in.) diameter, 101.6-mm (4-in.) tall cylinders or any appropriate covered container. Use of grease or other mold-release agents should be avoided as these materials may affect the stability of the foamed cement.

Cut or break the samples into sections, mark them from the top to the bottom, and

measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined by dividing the weight, W (in grams) by volume, V (in mL). The slurry density can also be determined (SG × 8.33 = lb/gal).

Signs of foam instability include the following:
- More than a trace of free fluid.
- Bubble breakout noted by bubbles appearing on the surface of the sample.
- Excessive gap at the top of the specimen. Minor meniscus effects are normal.
- Visual signs of density segregation as indicated by streaking or light to dark color change from top to bottom.
- Large variations in density from sample top to bottom.

B.7.3 Determining Compressive Strength
The foamed cement slurry is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated. This expansion can result in an undesired density decrease. The mold can be a standard 50.8-mm (2-in.) cube mold with a cover clamped to the top.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is sufficient seal to prevent the slurry from expanding out of the curing mold.

B.8 Determining Other Tests on Base Unfoamed Slurry
A slurry that is foamed at atmospheric pressure should not be tested under pressure. Applying pressure to a foamed slurry prepared at atmospheric pressure will compress the foam, changing the density and gas ratio. This can also allow contamination when tested in a HPHT consistometer for thickening time.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO 10426-2[2], clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

B.8.1 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO 10426-2[2], clause 9.

B.8.2 Determining Fluid Loss

Fluid-loss tests performed with a foamed cement prepared at atmospheric pressure will not yield reliable results. The fluid loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry.

The static fluid-loss test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 10.

B.8.3 Determining Rheological Properties

With the concentration of gas in a foamed slurry changing continuously during pumping of the job, it is impractical to perform rheological testing at all the foam quality concentrations that are needed to model the frictional pressures during pumping of a foamed slurry. Use of a rotational viscometer will result in separation of the gas from the slurry, causing erroneous results. Correlations can be used to convert the rheological properties of the base unfoamed slurry to that of a foamed cement with varying foam qualities to simulate the job.

The rheological test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 12.

References

[1] ISO 10426-4: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 4: Recommended Practice for Atmospheric Foam Cement Slurry Preparation," working draft 2001.

[2] ISO 10426-2: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements," 1998.

Appendix 6

Quarterly Report 6

Ultra-Lightweight Cement

Sixth Quarterly Technical Progress Report

January 1 to March 31, 2002

Fred Sabins

Issued April 29, 2002

DOE Award Number
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Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report includes results from laboratory testing of ULHS systems along with other lightweight cement systems, including foamed and sodium silicate slurries. During this project quarter, comparison studies of the three cement systems examined several properties: tensile strength, Young's modulus, and shear bond. Testing to determine the effect of temperature cycling on the shear bond properties of the cement systems was also conducted. In addition, the stress-strain behavior of the cement types was studied. This report discusses a software program that is being developed to help design ULHS cements and foamed cements.

As detailed in the first quarterly report, these conditions are average values obtained from *Worldwide Cementing Practices*[2]. Application 2 cement slurries were designed to achieve a thickening time of 4 to 6 hr with 1.0% maximum free fluid.

Of the different ULHS classes studied in this project, 6K ULHS were chosen because they are able to withstand the hydrostatic pressures associated with the different simulation applications. The 6K indicates that this class of ULHS has a crush strength of 6,000 psi.

Most tests were performed according to the API RP 10B[3] method. To adapt to ULHS and foamed slurries, some preparation and testing methods were modified. To minimize bead breakage caused by high shear from API blending procedures, mixing procedures were modified for the ULHS slurries. The following blending procedure was used for the ULHS slurries:

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry (without ULHS) according to Section 5.3.5 of API RP 10B.[3]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

4. Pour this slurry back into the Waring blender and mix at 4,000 rev/min for 35 seconds to mix and evenly distribute the contents.

Testing methods for foamed slurries were also modified. For example, thickening time is performed on unfoamed slurries only. Because the air in the foam does not affect the hydration rate, the slurry were prepared per API RP 10B[3], then the foaming surfactants were mixed into the slurry by hand without foaming the slurry. This and the other non-standard procedures for testing foamed cement are presented in **Appendix B**.

Table 3 presents slurry compositions for the 10.0- and 11.5-lb/gal slurries tested during this project quarter. To adapt each slurry to the application conditions and to meet the thickening time and free fluid requirements, additives, such as slurry extenders, accelerators, and foaming agents, were added to the slurries. The additives are widely available, generic additives, and are not specific to any particular service company. These additives include Witcolate® 7093 (a foaming agent), Aromox® C/12 (a foam stabilizer), Natrosol® 250 GXR (a fluid-loss control additive), Melcret® (a dispersant), Marabond® 21 (a retarder), and Diacel® FL (a fluid-loss control additive).

The water content of the ULHS slurries is guided by the ULHS water requirement (one pound of water for each pound of ULHS). Note that the advisory board decided to use a 13.5-lb/gal base density for the TXI Lightweight cement slurries foamed to 10.0 lb/gal. Testing of the 10.0-lb/gal slurries does not include sodium-silicate slurries because the density of 10.0 lb/gal is outside of the typical working range for sodium-silicate slurries.

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Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The cement sets in place (1) to support the casing in the hole, (2) to isolate various formations from one another, and (3) to control fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of expensive remedial treatments. The upper sections of the well are where lost circulation most commonly occurs. These include surface and intermediate casings. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum practical density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Water is the primary density-reducing material in these conventional cements. Additional water dilutes the cement, causing low strength and high permeability. Lower temperature, such as those in the upper well sections, delays strength development. To obtain lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

Executive Summary

Laboratory testing during the sixth quarter was a continuation and extension of the testing that has been previously conducted. Testing compared slurries containing ULHS to foamed and sodium silicate cement systems. Comparison studies examined tensile strength, Young's modulus, and shear bond strength. Tensile strength testing during this quarter was performed using the ASTM C496 test method. Young's modulus data was performed using the ASTM C469 test method.

Testing to determine the effect of temperature cycling on cement system properties was also conducted. The compressive strength and shear bond strength of the samples that were subjected to temperature cycling were also measured.

As a part of the project, a software program is being created to assist with the design of cement slurries made with ULHS. The program will also assist with the design of foamed cements.

Because of the large volume of cement required for this project, a quality-control process has been implemented. Information and data gathered for the program are presented.

Preliminary data indicates that the slurries made with ULHS performed very well. Further testing in future quarters will help establish performance qualities of cement slurries made with ULHS.

Cement Quality-Control Program

Because of the large quantities of cement used in the course of this project, an extensive quality –control (QC) program was initiated. Upon receipt, each bucket of cement is labeled with a materials log number and date. When a bucket is first opened for use, the date of opening is recorded in the materials log. This log number is referenced on the laboratory sheets for each test performed. Where applicable, tests are conducted according to API Specification 10A[1]. Additionally, several tests tailored for the test conditions and materials (rheology and low-temperature compressive-strength development) are included in this QC program. API Specification tests and tests recommended by advisory board members were performed for the QC program.

The Class A and Class H cement performance requirements are presented in the original API Specification 10A (January 1995) before Addendum 1, which changed the free fluid procedure. The free fluid procedure used in these tests is the earlier version that uses graduated cylinders. Because the Lightweight Oilwell cement is not API cement, it is tested according to QC procedures developed by the manufacturer.

The physical requirements used to test each cement are listed in **Table 1**. **Table 2** shows calcium chloride ($CaCl_2$) concentrations used at different temperature to accelerate the rate of compressive strength development at low temperatures. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 1—Cement Slurry Compositions for Quality-Control Testing Program

Cement	Mix Water (% BWOC)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Class A	46	15.6	772	355	API Series of Tests
TXI Lightweight	75	13.2	541	406	Thickening Time & Compressive Strength
TXI Lightweight	105	12.1	426	447	Free Fluid
Class H	38	16.4	860	327	API Series of Tests

Table 2—Percent $CaCl_2$ for Low-Temperature Compressive Strengths

Temperature (°F)	$CaCl_2$ (% BWOC)
80	0.0
60	1.0
45	2.0

These quality-control tests have been conducted to provide a baseline for each type of cement. This QC data will provide a basis of comparison for other data for this project. After several cycles of the complete QC program had been performed, the data showed no significant variations and remained within the vendors' specifications. Testing then proceeded with a less-stringent program of scheduled thickening-time tests. Each time a new bucket is opened, a thickening-time test is conducted. Additionally, a thickening-time test is performed once a month on all opened buckets. The thickening-time test was chosen as a gauge to detect abnormal cement performance. **Appendix A** shows the QC program data gathered to date.

Application Scenarios

One way to gauge the performance of cements made with ULHS is to compare them to other ultra-lightweight cements. Members of the project advisory board decided to compare ULHS cements to foamed cement and a conventional sodium silicate slurry.

Sixth-quarter testing focused on a cementing scenario referred to as Application 2. Application 2 conditions simulated a typical land-based surface-pipe cementing job with the following conditions:

- bottomhole circulating temperature (BHCT) of 78°F
- bottomhole static temperature (BHST) of 96°F
- bottomhole pressure (BHP) of 1,000 psi

There has been some concern about foaming Class A cement with a density of 15.6 lb/gal down to 11.5 and 10.0 lb/gal, resulting in foam qualities of 26 and 36% respectively. Many experts in the industry recommend a foam quality between 25 and 35%, so foaming Class A down to 11.5 lb/gal is within the recommended range and 10.0 lb/gal is not far out of that range. Although not ideal, many jobs have been successfully designed and executed using foam qualities of 36% and higher. The foamed slurries presented in this report were tested for comparison with the other lightweight slurries. As with any cement slurry that is to be pumped down a well, foamed cements should be designed, tested, and qualified for the specific application.

Table 3—Slurry Compositions for Application 2 Slurries

Density: 10.0-lb/gal, Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	10.0	8.50	29.1% BWOC (6K) ULHS
	Foamed	15.6† (10.0‡)	5.19	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
TXI Lightweight	ULHS	10.0	7.23	2.0% BWOC $CaCl_2$; 26.0% BWOC (6K) ULHS
	Foamed	13.5† (10.0‡)	6.10	2.0% BWOC $CaCl_2$; 0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
Density: 11.5-lb/gal, Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Class A	ULHS	11.5	7.09	16.2% BWOC (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% BWOC Sodium Silicate
TXI Lightweight	ULHS	11.5	6.50	2.0% BWOC $CaCl_2$; 11.9% BWOC (6K) ULHS
	Foamed	13.0† (11.5‡)	7.00	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	12.11	3.0% BWOC Sodium Silicate

†Unfoamed slurry density

‡Foamed slurry density

Because of Application 2's low temperatures, calcium chloride ($CaCl_2$) was used with some foamed and ULHS slurries to accelerate hydration. $CaCl_2$ was not used with the sodium silicate slurries because of viscosity issues specific to this slurry. The only viable accelerators for sodium silicate slurries are company-specific and not widely available in a generic form.

Tensile Strength

Mechanical property testing of Application 2 cement systems continued during the sixth quarter. The samples were cured at atmospheric pressure in a water bath maintained at 96°F (Application 2's BHST). Testing similar to that in ASTM C496-90, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," was performed. For this testing, specimen dimensions were 1.5 in. diameter by 1 in. long. **Figure 1** shows how each specimen is oriented on its side when tested. The force applied to the specimens was manually controlled and applied at a rate of approximately 10 psi/min.

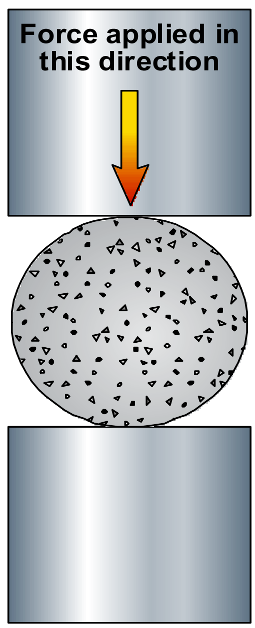

Figure 1—Sample orientation for ASTM C496-90 testing

Table 4 shows the 14-day tensile strength of the slurries used in Application 2. Most data in **Table 4** were gathered during the fifth quarter, but were presented again for comparison to recently gathered data.

Table 4—Tensile Strengths of Application 2 Cements

Cement Type	Slurry System	Tensile Strength (psi) per ASTM C496			
Density: 10.0 lb/gal, Application 2					
Cement Type	**Slurry System**	**Sample 1**	**Sample 2**	**Sample 3**	**Average**
Class A	ULHS	241	241	304	**262**
	Foamed	282	317	286	**295**
TXI Lightweight	ULHS	149	144	142	**145**
	Foamed	177	217	164	**186**
Density: 11.5 lb/gal, Application 2					
Cement Type	**Slurry System**	**Tensile Strength (psi) per ASTM C496**			
		Sample 1	**Sample 2**	**Sample 3**	**Average**
Class A	ULHS	236	214	286	**245**
	Sodium Silicate	136	131	129	**132**
	Foamed	363	378	383	**375**
TXI Lightweight	ULHS	217	241	164	**207**
	Sodium Silicate	199	212	210	**207**
	Foamed	238	280	221	**246**

To determine the effect that temperature cycling has on tensile strength, testing was conducted. The temperature cycling procedure was designed to simulate temperature conditions that might be seen during production of a well similar to the Application 2 scenario, where temperatures during production could reach 300°F.

The samples were first cured for 14 days in a 96°F water bath at atmospheric pressure, then placed in a watertight container filled with water. (**Figure 2)** Then, the samples were subjected to five days of temperature cycling. During each of these five days, the samples were cycled as follows.

- Samples were removed from 96°F water bath and placed in an oven. Oven was heated to 180°F in four minutes. Samples remained in 180°F oven for one hour.
- Oven was heated to 300°F in five minutes. Samples remained in 300°F oven for four hours.
- Oven was cooled to 180°F in 15 minutes. Samples remained in 180°F oven for one hour.
- Oven was cooled to 96°F in 15 minutes. Samples were placed back in 96°F water bath.

The samples were placed in the watertight containers to keep water on the cement samples and prevent the water from boiling off.

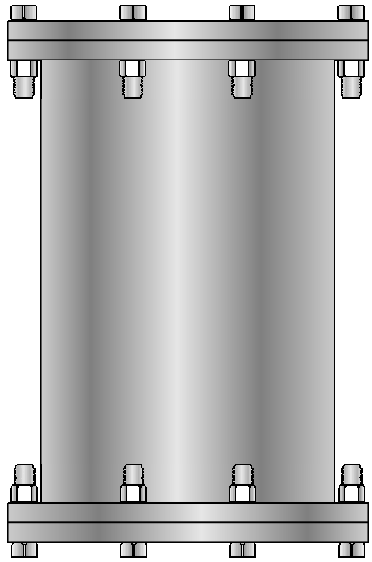

Figure 2—Watertight container for temperature cycling

Table 5 presents the tensile strengths of the three cement systems that were exposed to five temperature cycles. Note that the cements did not contain silica to combat strength retrogression. For comparison, **Table 5** also shows tensile strength data that was in the fifth quarterly report. This additional tensile strength data is from samples that were not temperature cycled, but they were cured for 14 days at atmospheric pressure in a water bath maintained at 96°F.

Table 5—Tensile Strength Data of Lightweight Cements

Density: 11.5 lb/gal, Application 2						
		Tensile Strength (psi) per ASTM C496				
Cement Type	Slurry System	Temperature Cycled				Not Temperature Cycled
		Sample 1	Sample 2	Sample 3	Average	Average
Class A	ULHS	136	136	129	**134**	**245**
	Sodium Silicate	52	57	57	**55**	**132**
	Foamed	125	125	118	**123**	**375**

Depending on the decisions of the advisory board, future temperature-cycled tensile strength tests may also be run on the TXI Lightweight cement slurries and on cement slurries with silica to diminish the potential effects that strength retrogression might have on the tensile strength.

Compressive Strength

Compressive strength testing was also done on cement samples that had been temperature cycled. The samples had a 1.5-in. diameter and an average length of 2.75 in. to better accommodate the container (**Figure 2**) used for temperature cycling.

The samples were cured for 14 days at atmospheric pressure in a 96°F water bath. The samples were then placed in the watertight container filled with water. Then, the samples were subjected to five days of temperature cycling. During each of these five days of temperature cycling, the cured samples were cycled as follows.

- Samples were removed from 96°F water bath and placed in an oven. Oven was heated to 180°F in 4 minutes. Samples remained in 180°F oven for 1 hour.
- Oven was heated to 300°F in 5 minutes. Samples remained in 300°F oven for 4 hours.
- Oven was cooled to 180°F in 15 minutes. Samples remained in 180°F oven for 1 hour.
- Oven was cooled to 96°F in 15 minutes. Samples were placed back in 96°F water bath.

The samples were then placed vertically in a press and crushed to determine compressive strength. The results of these tests can be seen in **Table 6**. For broad comparison, compressive strengths are also presented of 2-in. cube samples that were cured for 7 days at atmospheric pressure in a 96°F water bath and were not temperature cycled.

Table 6—Compressive Strengths of Lightweight Cements

Density: 11.5 lb/gal, Application 2						
Cement Type	Slurry System	Compressive Strength (psi)				
		Temperature Cycled				Not Temperature Cycled
		14 days, cylinder				7 days, 2-in cube
		Sample 1	Sample 2	Sample 3	Average	Average
Class A	ULHS	3038	2994	3891	**3308**	**2140**
	Sodium Silicate	306	393	—	**350**	**350**
	Foamed	2540	2435	1902	**2292**	**1180**

Depending on the decisions of the advisory board, future temperature-cycled compressive-strength tests may also be run on the TXI Lightweight cement slurries and on cement slurries with silica.

Young's Modulus

In the fifth project quarter, data for the mechanical properties of different cement systems were presented. Young's modulus and effective compressive-strength data were presented for the Application 2 cements. The difference between the failure strength and the confining pressure is the effective compressive strength. In a continuation of the study of the mechanical properties, testing during this quarter was conducted on neat 15.6-lb/gal Class A cement and on TXI Lightweight cement at 13.5 lb/gal. The Young's modulus data of the neat Class A and TXI Lightweight cements can be used as another way to compare the performance of the ULHS, sodium silicate, and foamed cements.

The Young's modulus samples of the neat Class A and neat TXI Lightweight cements were cured for 14 days at atmospheric pressure in a 96°F water bath. The samples were molded in a cylinder and cut to length and not cored.

"ASTM C469, Standard Test Method for Static Modulus of Elasticity (Young's Modulus) and Poisson's Ratio of Concrete in Compression," was followed for the Young's modulus testing. The diameter of each test specimen was 1.5 in, and the length was 3.0 in.

The following procedure was used for the Young's modulus testing.
1) Each sample was inspected for cracks and defects.
2) The sample was cut to a length of 3.0 in.
3) The sample's end surfaces were ground to obtain a flat, polished surface with perpendicular ends.
4) The sample's physical dimensions (length, diameter, weight) were measured.
5) The sample was placed in a Viton jacket.
6) The sample was mounted in the Young's modulus testing apparatus.
7) The sample was brought to 100-psi confining pressure and axial pressure. The sample was allowed to stand for 15-30 min until stress and strain were at equilibrium. (In unconfined testing, only axial load was applied.)
8) Axial and confining stresses were increased at a rate of 25-50 psi/min to bring the sample to the desired confining stress condition. The sample was allowed to stand until stress and strain were at equilibrium.
9) The sample was subjected to a constant strain rate of 0.0019 in./min (0.05mm/min).
10) During the test, the pore lines on the end cups of the piston were opened to atmosphere to avoid any pore-pressure buildup.
11) After the sample failed, the system was returned to the atmospheric stress condition and the sample was removed from the cell.

Table 7 presents the Young's modulus data of the neat Class A and neat TXI Lightweight cements. **Table 8** presents Young's modulus data that were gathered prior to the sixth quarter. **Table 8** shows Young's modulus data of the 11.5-lb/gal lightweight cement systems for Application 2. These samples were also cured for 14 days at atmospheric pressure in a 96°F water bath.

Table 7—Young's Modulus Data of Neat Class A and TXI Lightweight Cements

Cement Type	Young's Modulus (10^5 psi) at Confining Pressure (psi)		Effective Compressive Strength (psi) at Confining Pressure (psi)	
	0	1,000	0	1,000
Class A	11.6	11.2	5,820	7,700
TXI Lightweight	9.30	9.01	4,740	5,000

Table 8—Young's Modulus Data of 11.5-lb/gal Lightweight Cements

Cement Type	Slurry System	Young's Modulus (10^5 psi) at Confining Pressure (psi)		Effective Compressive Strength (psi) at Confining Pressure (psi)	
		0	1,000	0	1,000
Class A	ULHS	4.24	3.37	3,880	4,773
	Sodium Silicate	0.59	0.22	315	777
	Foamed	2.50	1.21	1,590	2,041
TXI Lightweight	ULHS	3.71	2.21	3,300	6,372
	Sodium Silicate	1.99	0.45	965	1,078
	Foamed	2.70	1.75	2,420	2,910

Shear Bond

Testing continued with the evaluation of the shear bond strength of the three cement systems. These studies investigated the effect of restraining force on shear bond strength. Samples were cured in a pipe-in-pipe configuration (**Figure 3**) and in a pipe-in-soft configuration (**Figure 4**). The pipe-in-pipe configuration consisted of a sandblasted internal pipe with an outer diameter (OD) of 1 $^1/_{16}$ in. and a sandblasted external pipe with an internal diameter (ID) of 3 in. Both pipes were 6 in. long. To center the internal pipe within the external pipe, a contoured base and top were used. The base extended 1 in. into the annulus and cement filled 4 in. of the annulus. The top 1 in. of annulus contained water.

To allow the cement to cure in a less-rigid, lower-restraint environment, plastisol was used for the pipe-in-soft shear bond strength tests. Plastisol, a mixture of a resin and a plasticizer, creates a soft, flexible substance. The plastisol blend used for these tests (PolyOne's Denflex PX-10510-A) creates a substance with a 40-duro hardness.

The pipe-in-soft configuration contained a sandblasted external pipe with an ID of 4 in. A molded plastisol sleeve (with an ID of 3.0 in. and uniform thickness of 0.5 in.) fit inside this external pipe. Using a contoured base and top, a sandblasted internal pipe with an OD of 1 $^1/_{16}$ in. was centered within the plastisol sleeve. The pipes and sleeve were 6 in. long. The base extended 1 in. into the annulus and cement filled the annulus to a length of 4 in. between the plastisol sleeve and the inner 1 $^1/_{16}$ -in. pipe. The top inch of annulus was filled with water.

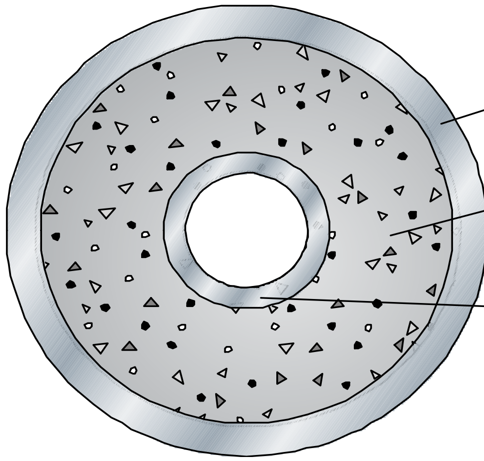

Figure 3—Cross section of pipe-in-pipe configuration for shear bond tests

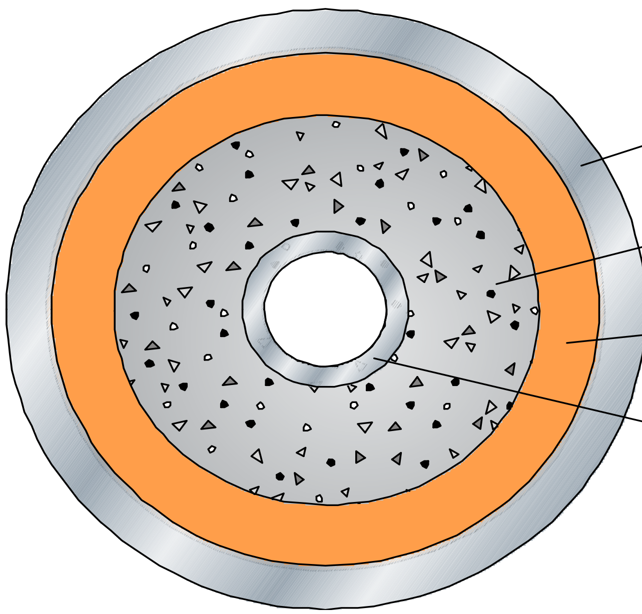

Figure 4— Cross section of pipe-in-soft configuration for shear bond tests

Application 2 cement systems were used for the shear bond strength tests. Testing to determine the effect of temperature cycling on shear bond strength was conducted. The temperature cycling procedure was designed to simulate temperature conditions encountered during production of a well similar to the Application 2 scenario, in which production temperatures could reach 300°F.

The samples were first cured for seven days in a 96°F water bath at atmospheric pressure. They were then subjected to five days of temperature cycling. During each day of temperature cycling, the cured samples were cycled as follows.

- Samples were removed from 96°F water bath and placed in an oven. Oven was heated to 180°F in 4 minutes. Samples remained in 180°F oven for 1 hour.
- Oven was heated to 300°F in 5 minutes. Samples remained in 300°F oven for 4 hours.

• Oven was cooled to 180°F in 15 minutes. Samples remained in 180°F oven for 1 hour.
• Oven was cooled to 96°F in 15 minutes. Samples were placed back in 96°F water bath.

Because of the high temperatures associated with the temperature cycling, these shear bond samples were cured using a special configuration with a flange on the outside of the external pipe and at both ends. Each flange had holes that allow a flat, watertight lid to be bolted to it (**Figure 2**). The watertight lids kept water on the cement and prevented the water from boiling off. The lids were placed on the samples at the end of the seven days of curing at 96°F.

Shear bond measures the stress needed to break the bond between the cement and the internal pipe. Shear bond was measured with the aid of a test jig that creates a platform for the base of the cement to rest against as force is applied to the internal pipe. (**Figure 5**) Shear bond force is the force required to move the internal pipe. The pipe was pressed until the bond was broken; the pipe was not pushed out of the cement. The shear bond strength is the force required to break the bond (move the pipe) divided by the surface area between the internal pipe and the cement.

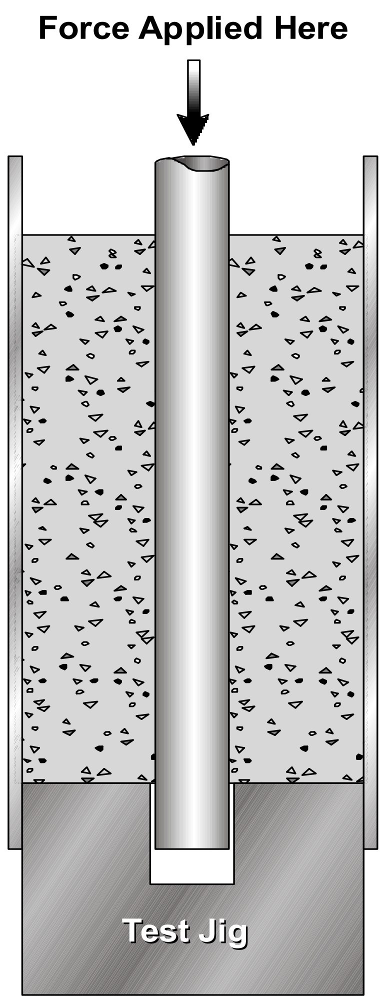

Figure 5—Configuration for testing shear bond strength

Table 9 presents the seven-day shear bond strengths for the three cement systems in the pipe-in-pipe and pipe-in-soft configurations. The results of the temperature-cycled pipe-in-pipe shear bonds are also presented in **Table 9**. Note that the cements did not contain silica to combat strength retrogression.

The shear bond strengths of the TXI Lightweight cements in the pipe-in-soft configuration were low. To get a better understanding of what could be causing the low shear bond strength, expansion testing is being conducted and will be reported in the next quarterly report. Shear bond tests may be done on temperature-cycled TXI Lightweight cements after analyzing the outcome of the expansion testing.

Table 9—Shear Bond Strengths of Lightweight Cement Systems

Density: 11.5 lb/gal, Application 2, Baseline									
Cement Type	Slurry System	Pipe-in-Pipe Shear Bond Strength (psi)				Pipe-in-Soft Shear Bond Strength (psi)			
		Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average
Class A	ULHS	466	365	375	**402**	214	266	171	**217**
	Sodium Silicate	173	166	115	**151**	93	55	68	**72**
	Foamed	377	380	595	**451**	238	148	192	**193**
TXI Lightweight	ULHS	120	118	119	**119**	20	20	15	**18**
	Sodium Silicate	37	44	44	**42**	17	12	15	**15**
	Foamed	127	120	136	**128**	10	13	9	**11**
Density: 11.5 lb/gal, Application 2, Temperature Cycled									
Cement Type	Slurry System	Pipe-in-Pipe Shear Bond Strength (psi)				Pipe-in-Soft Shear Bond Strength (psi)			
		Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average
Class A	ULHS	203	70	200	**158**	37	32	0	**23**
	Sodium Silicate	112	121	95	**109**	15	16	0	**10**
	Foamed	304	311	317	**311**	108	149	71	**109**

Software Program

A software program is being created to assist in designing foamed cements and cement slurries made with ULHS. The program does not simulate cement jobs and fluid dynamics. Instead, the program focuses on the static final placement of the fluids. To date, the work that has been done related only to ULHS cement slurries. Screen captures of the current program and their description follow.

The first window that the user of the program encounters is *Cement Slurry* window with the *Well and Other Data* tab active (see **Figure 6**). To help the user understand the program and the required data, a fixed graphic of a wellbore also appears on the *Well and Other Data* tab. “Fixed” means that the graphic does not change when the user inputs data. The program accepts a wellbore geometry with input for one previously-cemented casing and an open hole with one geometry (diameter and excess annular volume). To make the program easier to use, fluid input is available for one mud, one spacer, one lead cement, and one tail cement. If more than one fluid will be used for each case, the data for the multiple fluids must be consolidated and entered as one fluid. For example, a pre-flush and a spacer should be consolidated by using the sum of the lengths (or volumes) and a weighted average of their densities. When inputting volumes for the tail cement, the software program considers only the tail cement in the annulus and not the cement in the shoe joint.

To use the program, the user would first select a slurry type from the *Cement Slurry Type* box. In the current version of the program, the options read as **Cement Slurry** and **Foam Cement Slurry** (*not yet activated*). To better distinguish the ULHS cement slurry option, in the next version, the options will read as **ULHS Cement Slurry** and **Foam Cement Slurry.** To date, the work that has been done is for ULHS cement slurries; the windows for the foamed cements have not been created yet and will not be presented in this report.

In addition to the *Cement Slurry Type* box, the *Well and Other Data* tab has a box with the eleven required fields and a set of toggle buttons that allow the user to select the way in which the fluid information will be entered. The options are **By Length** and **By Volume**. **Figure 6** shows the required fields when **By Length** is selected—*Length of Spacer*, *Length of Lead Cement*, and *Length of Tail Cement*. The unit for those fields is *ft*. When **By Volume** is selected, the fields are *Volume of Spacer*, *Volume of Lead Cement*, and *Volume of Tail Cement*, and the unit for those fields is *bbl*. Other required fields address wellbore geometry and mud and spacer densities.

In the next software version, the *Well and Other Data* window will be changed to read *Current Casing OD*, rather than *Drill Pipe OD*. Additionally, the *Excess Volume* field will be renamed *Excess Annular Volume*. A revision that will be made throughout the program will be to change the term “foam” to “foamed.”

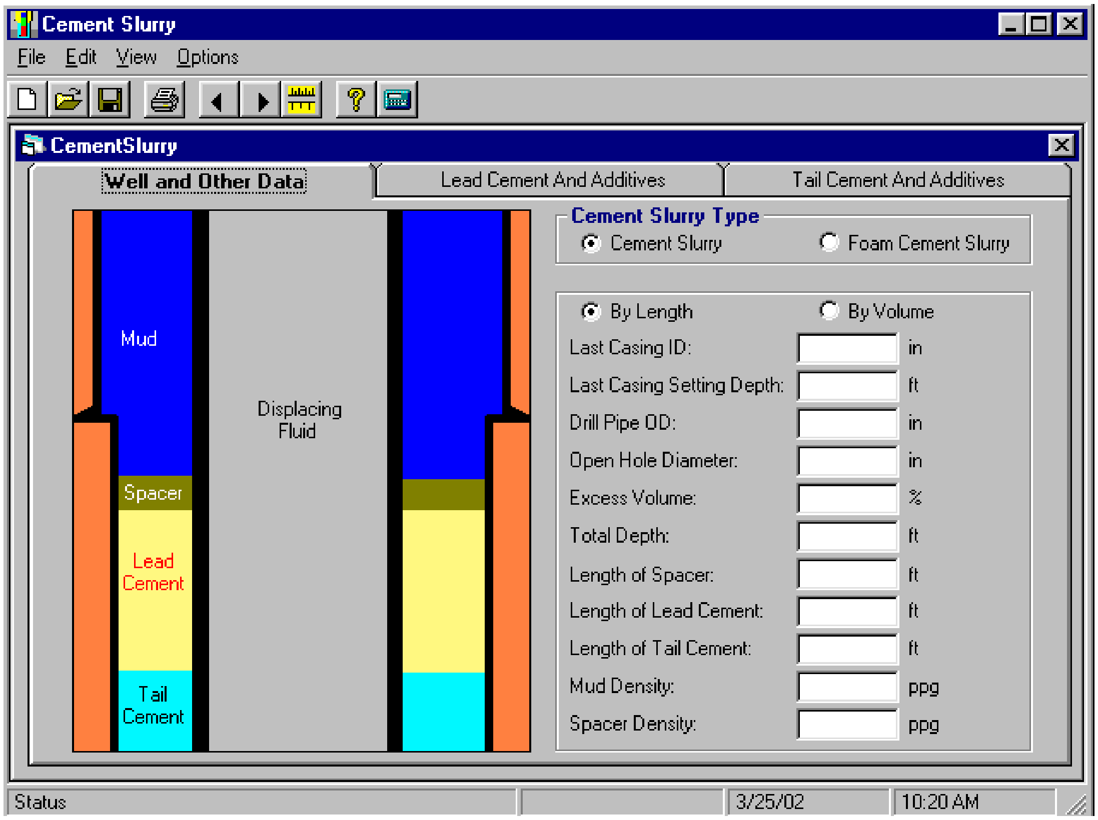

Figure 6—*Well and Other Data* tab

The next tab is the *Lead Cement and Additives* tab (see **Figure 7**). Slurry information for the lead cement is entered on this tab. The *Lead Cement* and the *Tail Cement* tabs are organized the same way. In the next version of the software, the term "beads" on the *Tail Cement* and the *Lead Cement* tabs will be changed to "ULHS."

The yellow fields circled in **Figure 7** are information-only fields that change when data that is entered into fields on this tab and on the *Well and Other Data* tab. Another revision for the software will be for the *Pressure at Middle of Lead Cement* field. This field was incorrectly designed to present the hydrostatic pressure to be used for calculating the extent of ULHS crushing and the resulting crushed ULHS specific gravity. The next version of the software will calculate the range of hydrostatic pressures that the cement will experience as it first enters the annulus and as the last part of the cement enters the annulus. These conditions will bracket the possibilities of highest hydrostatic pressures. (At this time, friction pressure is not factored into the pressure calculations.) An average of the two hydrostatic pressures will be used in determining the amount of crushing done to the ULHS. The resulting crushed specific gravity will be displayed in the *Beads [ULHS] Specific Gravity* field. The field title, *Pressure at Middle of Lead Cement*, will be either renamed to reflect these corrections or the field and its title will not be displayed. The same revisions will be made on the *Tail Cement and Additives* tab.

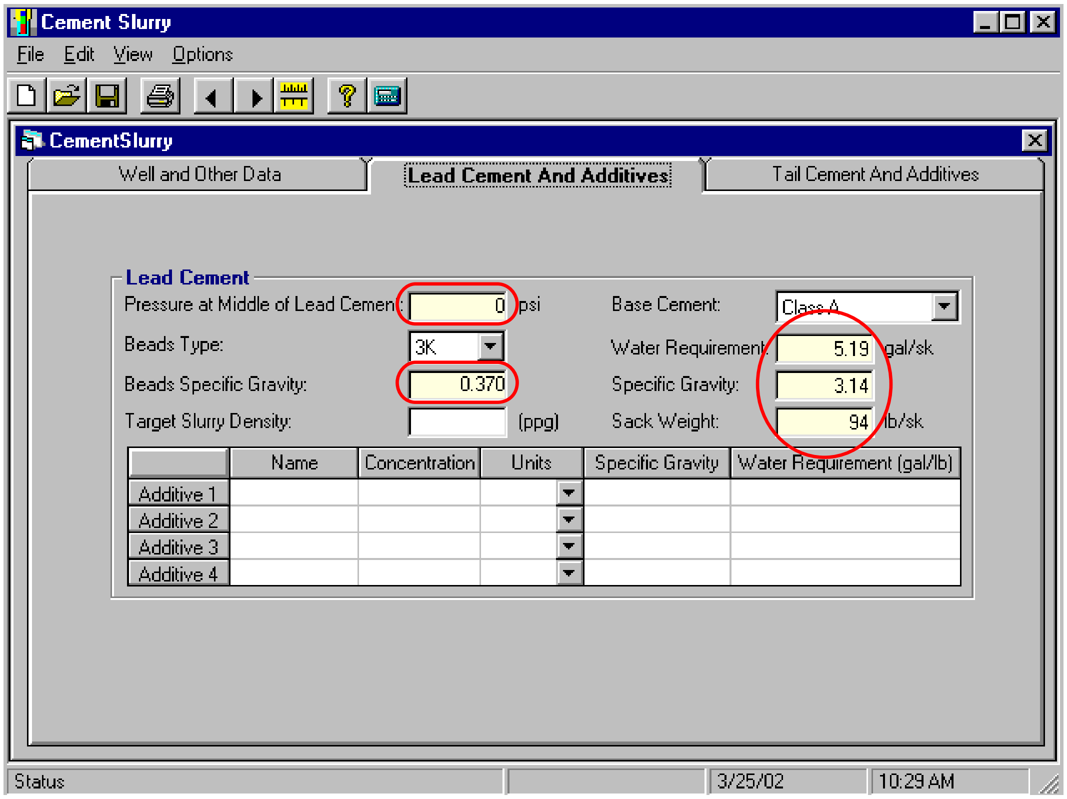

Figure 7—*Lead Cement and Additives* tab

Figure 8 shows the dropdown menu for the *Beads* [*ULHS*] *Type* field. The type of ULHS that is chosen will determine the specific gravity at surface and at the hydrostatic pressure experienced by the ULHS during the cement job. The resulting (crushed) downhole specific gravity is displayed in the *ULHS Specific Gravity* field. The "crushed" specific gravity database used for this program comes from laboratory tests previously performed in this project.

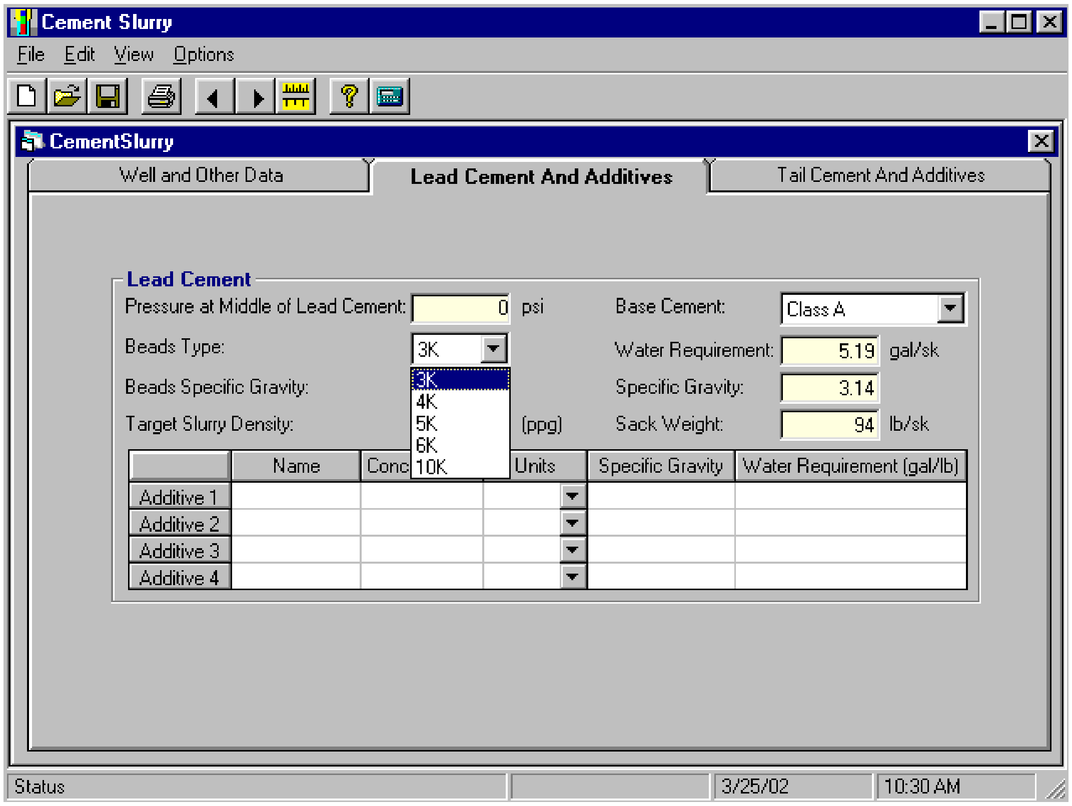

Figure 8—Drop-down menu for *ULHS Type* field

On the right side of the *Lead Cement* tab, information about the cement is entered and displayed. A dropdown menu in the *Base Cement* field allows the user to select the type of cement. (**Figure 9**) Once the cement is selected, the related yellow information-only fields (*Water Requirement*, *Specific Gravity*, and *Sack Weight*) are automatically populated from a database for the specific cement chosen. One of the dropdown menu options in the *Base Cement* field is **Other Cement**. When **Other Cement** is selected, the user can enter data for the *Water Requirement*, *Specific Gravity*, and *Sack Weight.*

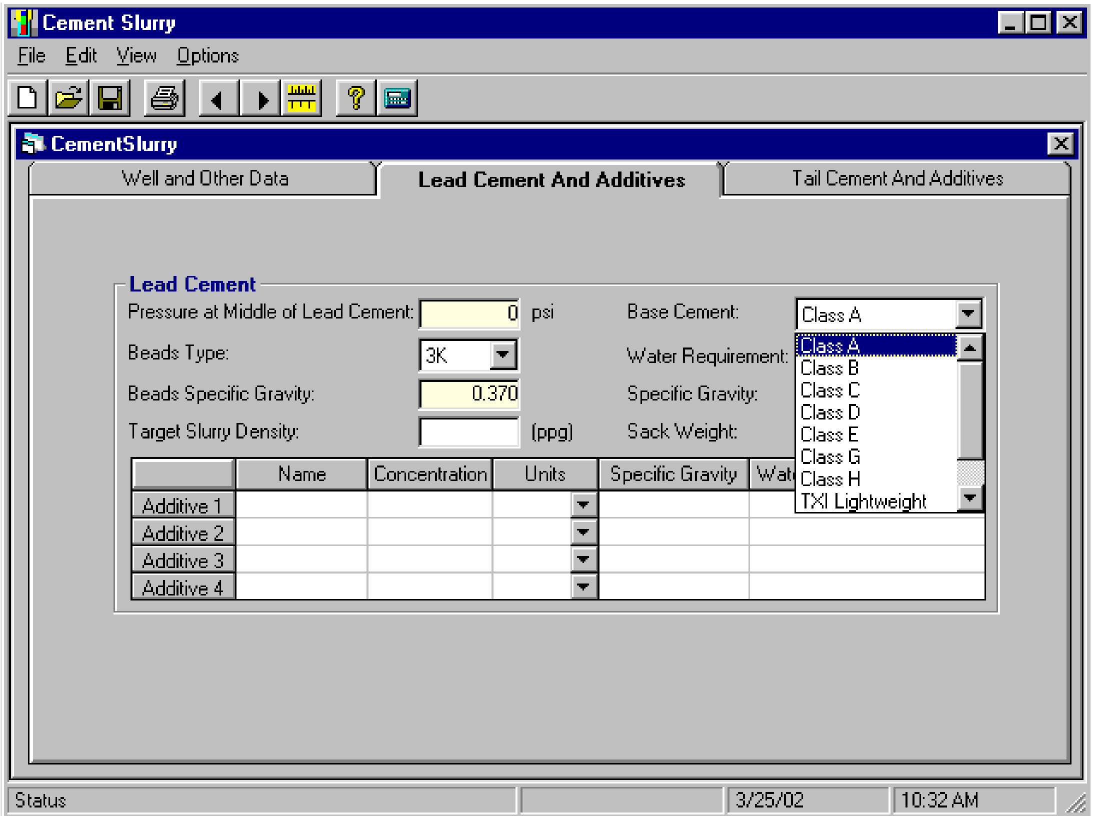

Figure 9—Drop-down menu for *Base Cement* field

The lower portion of the *Lead Cement* tab is used to enter information about other additives in the lead cement slurry. As shown in **Figure 10,** the *Units* field has a dropdown menu with three options—**lb/sk**, **gal/sk**, and **%BWOC**. For the next software version, **%BWOW** will be added as another option in the *Units* field.

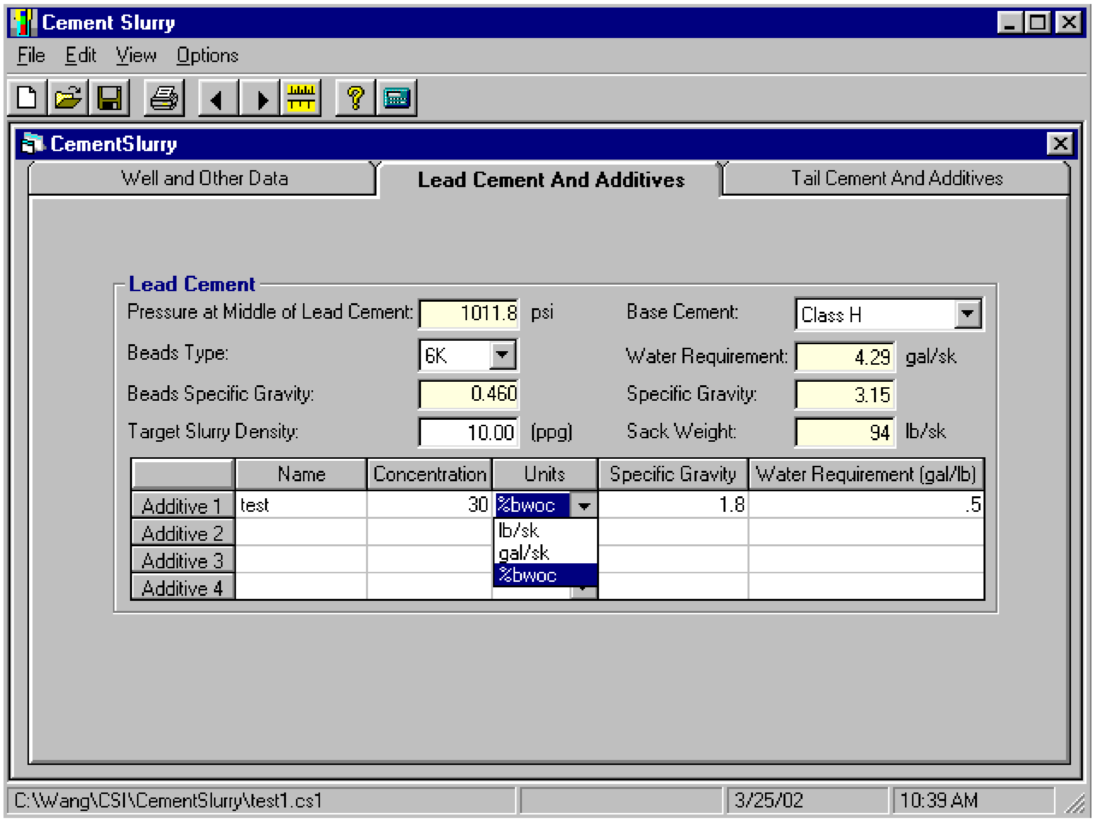

Figure 10—Drop-down menu for *Units* field

Once all the data is correctly entered into the input tabs (*Well and Other Data*, *Lead Cement and Additives*, and *Tail Cement and Additives*), the user can click the output button (located on the toolbar) to view the *Output* window (**Figure 11**). The program is designed to calculate the ULHS concentration, slurry water requirement, and the cement slurry yields. The water requirement is calculated using the water requirements of the cement, additives, and the ULHS. Using an algorithm, the program varies the ULHS concentration (thereby varying the water requirement) to attain the desired slurry density. The input button on the toolbar can be used to toggle back to the input tabs, from which the input data can be reviewed or changed.

The last item in the *Output* window is a third *ULHS Concentration* field that has units in ft. This field is intended to be *Length of Mud* and will be changed to read as such in the next version.

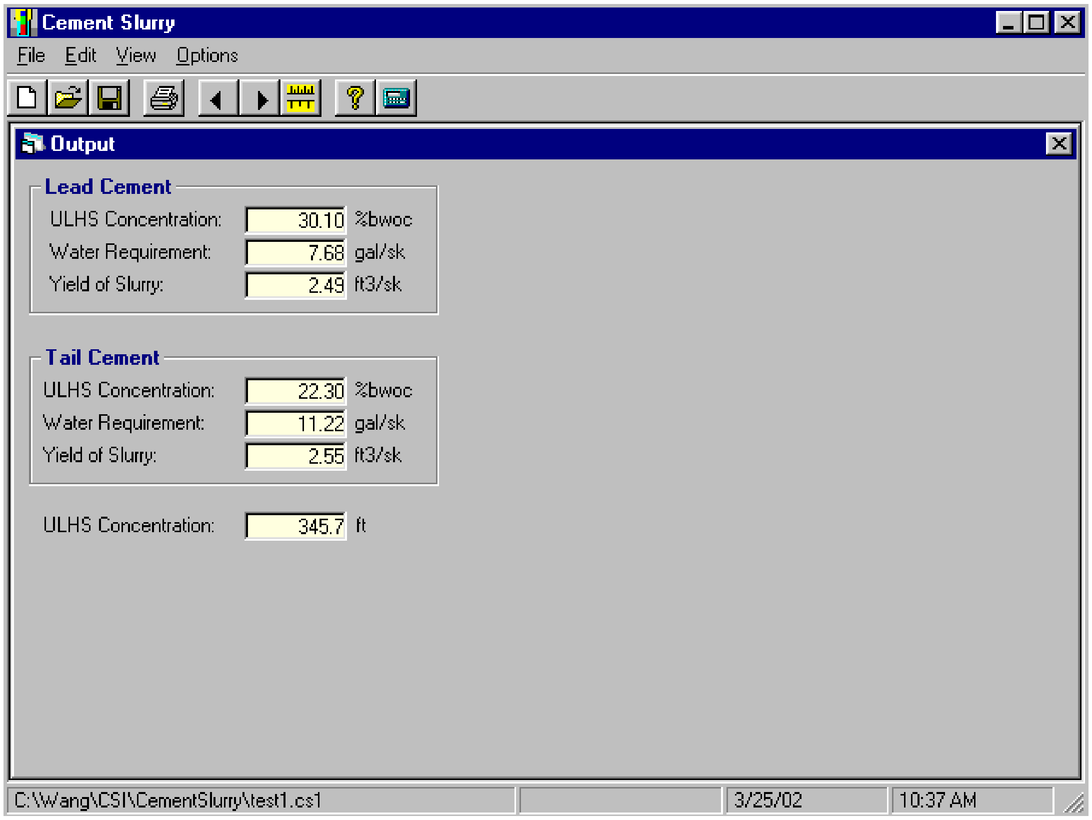

Figure 11—*Output* window

Plans for Seventh Project Quarter

The following investigations and tests are planned for the next project quarter.

- Further experiments on the alkali-reactivity of ULHS will be conducted.
- To determine the competence of ULHS and other lightweight cement systems during drillout, testing will be conducted. The tests will measure bulk permeability of the cement before and after drillout.
- To get a better understanding of what could be causing the low shear bond strength of the TXI Lightweight cement systems, expansion testing will be conducted.
- Another field job using ULHS is planned for the seventh quarter. The job planned for the end of the first week of April was cancelled because of a dry hole.
- Work will continue on the software program that will assist with ULHS and foamed cement slurry design.

- Tests will be performed on ULHS, sodium silicate, and foamed cements to evaluate the effect of pressure testing on shear bond strength.

Conclusions

Results from temperature-cycling tests have been presented. Tests will be done to determine if deterioration of strength due to temperature cycling can be prevented by the use of silica.

Tests will be done to complete the suite of tests on temperature cycling.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
BWOW—by weight of water
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
OD—outer diameter
psi—pound per square inch
rev—revolution
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Specification 10A: "Specifications for Cements and Materials for Well Cementing," 22nd Edition, American Petroleum Institute, Washington, D.C., January 1995.

2. *Worldwide Cementing Practices,* First Edition, American Petroleum Institute, January 1991.

3. API Recommended Practice 10B: "Recommended Practice for Testing Well Cements," 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

Appendix A—Quality Control Testing

TXI Lightweight Cement

TXI Information		CSI Information				Free Fluid			Rheology										
Cmt Type	Production Date	Date Received	CSI Log#	Bucket Opened	Test Date	Water Conc. (%bwoc)	mL	% by volume	Water Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
LW	09/18/00	11/06/00	C-108 B-1	11/07/00	11/15/00	105	2	0.8	75	80	57	50	42	38	33	22	12	13	120
LW	09/18/00	11/06/00	C-108 B-2	12/05/00	01/04/01	105	2	0.8	75	80	58	52	45	38	32	21	13	13	125
LW	09/18/00	11/06/00	C-108 B-11	06/24/01	06/26/01	105	2	0.8	75	80	60	55	47	39	21	20	15	15	127
LW	09/18/00	11/06/00	C-108 B-12	07/03/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-7	09/05/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-14	09/24/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-13	12/04/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-15	01/22/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-18	02/25/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water Conc. (%bwoc)	45°F Strengths			60°F Strengths			80°F Strengths		120°F Strengths		Thickening Time			
Cmt Type	CSI Log#	Test Date		Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 70 Bc	Time to 100 Bc
LW	C-108 B-1	11/15/00	75.0	24	2.0	166	24	1.0	254	24	523	24	1579	5	6	2:02	2:20
LW	C-108 B-2	01/04/01	75.0	24	2.0	161	24	1.0	221	24	441	24	1225	5	5	2:00	2:17
LW	C-108 B-11	06/26/01	75.0	24	2.0	158	---	---	---	24	501	---	---	5	9	1:57	2:18
LW	C-108 B-12	08/14/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-7	09/10/01	75.0	---	---	---	---	---	---	---	---	---	---	5	6	1:57	2:17
LW	C-108 B-14	10/16/01	75.0	---	---	---	---	---	---	---	---	---	---	5	4	2:07	2:26
LW	C-108 B-14	11/13/01	75.0	---	---	---	---	---	---	---	---	---	---	5	5	2:05	2:25
LW	C-108 B-14	12/20/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-13	01/11/02	75.0	---	---	---	---	---	---	---	---	---	---	5	8	1:58	2:12
LW	C-108 B-15	02/08/02	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:05	2:15
LW	C-108 B-18	03/04/02	75.0	---	---	---	---	---	---	---	---	---	---	5	13	2:11	2:27

TXI Class H Cement

TXI Information		CSI Information				Water	Free Fluid		Rheology									
Cmt Type	Prod. Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	mL	% by volume	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	1.9	0.8	80	89	72	53	45	37	16	10	---	---
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	38.0	3.0	1.2	80	85	70	53	45	38	14	8	9	19
Class H	09/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	3.0	1.2	80	95	80	60	51	42	20	12	15	26
Class H	09/27/00	11/06/00	C-108 A-3	02/22/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-4	06/26/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-6	07/20/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-7	08/27/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-8	01/14/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths		140°F Strengths		Thickening Time		
Cement Type	CSI Log#	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 100 Bc
Class H	C-108 A-1	11/07/00	38.0	8	524	8	2088	---	---	---
Class H	C-108 A-1	11/29/00	38.0	8	480	8	2249	5	12	2:03
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1617	---	---	---
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1550	---	---	---
Class H	C-108 A-2	01/11/01	38.0	8	1201	8	1964	5	7	1:54
Class H	C-108 A-2	01/12/01	38.0	8	1039	8	1756	---	---	---
Class H	C-108 A-2	02/12/01	38.0	8	424	8	1717	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1567	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1580	---	---	---
Class H	C-108 A-4	06/29/01	38.0	---	---	---	---	5	17	2:00
Class H	C-108 A-6	08/13/01	38.0	---	---	---	---	5	15	1:50
Class H	C-108 A-7	09/06/01	38.0	---	---	---	---	5	19	2:00
Class H	C-108 A-3	10/09/01	38.0	---	---	---	---	5	12	1:53
Class H	C-108 A-3	11/13/01	38.0	---	---	---	---	5	13	1:50
Class H	C-108 A-3	12/21/01	38.0	---	---	---	---	5	14	1:45
Class H	C-108 A-3	01/11/02	38.0	---	---	---	---	5	13	2:00
Class H	C-108 A-8	02/08/02	38.0	---	---	---	---	5	28	1:55
Class H	C-108 A-8	03/05/02	38.0	---	---	---	---	5	14	1:55

TXI Class A Cement

TXI Information		CSI Information				Water	Rheology									
Cement Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class A	09/27/00	11/06/00	C-113 A-1	11/09/00	11/17/00	46.0	80	75	62	48	40	33	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-2	11/20/00	11/20/00	46.0	80	80	65	49	40	34	17	10	10	19
Class A	09/27/00	11/06/00	C-113 A-3	12/04/00	12/05/00	46.0	80	78	64	50	40	32	16	10	10	19
Class A	09/27/00	11/06/00	C-113 A-4	01/09/01	01/09/01	46.0	80	80	65	52	40	33	17	11	10	20
Class A	09/27/00	11/06/00	C-113 A-5	11/09/00	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-1	03/20/01	03/20/01	46.0	80	77	63	51	39	32	17	10	10	20
Class A	03/10/01	03/19/01	C-189 A-5	06/01/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-8	07/11/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-6	10/16/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-17	08/30/01	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-11	01/17/02	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-12	02/17/02	---	---	---	---	---	---	---	---	---	---	---	---
Class A	03/10/01	03/19/01	C-189 A-13	02/28/02	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths				45°F Strengths			60°F Strengths			80°F Strengths		Thickening Time			
Cement Type	CSI Log #	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	CS (psi)	Test Date	Sch #	Int. Bc	Time to 100 Bc
Class A	C-113 A-1	11/17/00	46.0	---	---	---	---	---	---	---	---	---	---	24	1646	11/15/00	4	9	2:17
Class A	C-113 A-2	11/27/00	46.0	8	754	24	2607	24	2	737	24	1	1194	24	1689	01/05/01	4	8	2:21
Class A	C-113 A-2	02/12/01	46.0	---	---	---	---	---	---	---	---	---	---	24	2022	---	---	---	---
Class A	C-113 A-3	12/05/00	46.0	---	---	24	2585	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-4	01/17/01	46.0	8	729	24	2527	24	2	1042	---	---	---	---	---	01/17/01	4	4	2:09
Class A	C-113 A-5	02/15/01	46.0	8	931	24	2568	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2334	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2590	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-113 A-5	02/22/01	46.0	---	---	24	2250	---	---	---	---	---	---	---	---	---	---	---	---
Class A	C-189 A-1	03/20/01	46.0	8	916	24	2364	---	---	---	24	1	1238	24	1737	03/20/01	4	12	1:42
Class A	C-189 A-5	06/29/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/29/01	4	10	1:37
Class A	C-189 A-8	08/15/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	08/15/01	4	6	1:50
Class A	C-189 A-17	09/12/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	09/12/01	4	6	2:00
Class A	C-189 A-6	10/16/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	10/16/01	4	7	1:41
Class A	C-189 A-6	11/13/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	11/13/01	4	7	1:53
Class A	C-189 A-6	12/21/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	12/21/01	4	6	1:46
Class A	C-189 A-11	01/14/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	01/14/02	4	8	1:42
Class A	C-189 A-12	02/11/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	02/11/02	4	15	1:40
Class A	C-189 A-13	03/04/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	03/04/02	4	14	2:10

Appendix B—Laboratory Procedures for Foamed Cement

The working draft of ISO 10426-4[1] outlines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries. The procedures discussed in this appendix and used for this project were borrowed from ISO 10426-4.

B.1 Preparing Unfoamed Base Slurry

B.1.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density = 14.5 lb/gal

Surfactant weight = 10 lb/gal

Base Slurry Calculations:	Weight	Volume
Cement	94 lb	3.59 gal
Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
Water	55.39 lb	6.65 gal
Total	151.39 lb	10.44 gal

Calculation of True Weight % Contributions:		
Cement	62.1 %	(94/151.39)
Surfactant	1.3 %	(2/151.39)
Water	36.6 %	(55.39/151.39)

Slurry without Surfactants:	Weight	Volume
Cement	94 lb	3.59 gal
Water	55.39 lb	6.65 gal
Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

B.2 Equipment

B.2.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure B.1) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

B.2.2 Multi-Blade Assembly

The multi-blade assembly is what is used during this project. The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO 10426-2[2], clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure B.1.

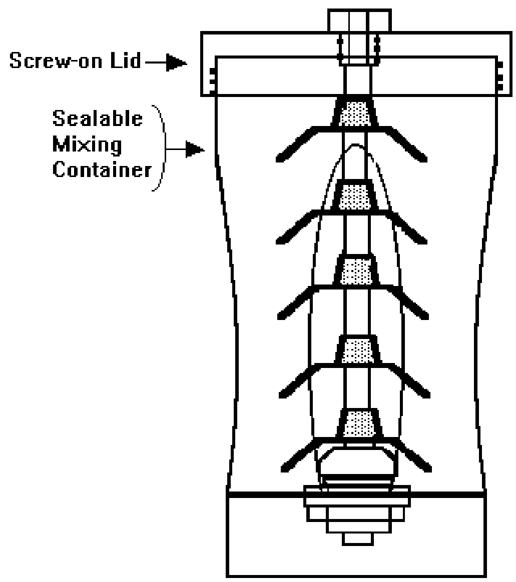

Fig. B.1—Example of a typical blending container

B.3 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

B.4 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section B.1.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section B.2.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Base slurries containing all additives except foaming surfactant(s) should be prepared according to ISO 10426-2[2],clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3.3 rev/s (200 rpm) at 66.7 rev/s (4,000 rpm) and ± 8.3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO 10426-2[2], clause 6.

B.5 Determining Slurry Volumes and Weights

B.5.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:

	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times FD \qquad (2)$$

Where:

	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	FD	=	Foamed density of the slurry (g/mL)

Example:

	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Unfoamed slurry weight	=	1170 mL × 1.2 g/mL = 1404 g

B.5.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 4.

$$GS = GUFS \times (\%Surfactant/100) \qquad (3)$$

Where: GS = Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)

GUFS= Total grams unfoamed slurry prepared in Section B.1

$$GUSM = GUFS - GS \qquad (4)$$

Where: GUSM= Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example: Unfoamed slurry weight = 1404.1 g

Percent by weight of surfactant = 1.3 %

Surfactant weight = 1404.1 × 0.013= 18.5 g

Slurry weight = 1404.1 - 18.5 = 1385.6 g

B.6 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section B.5.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section B.5.2.

B.6.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section B.2.2, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port or container lid, and verify that the slurry completely fills the slurry-mixing container. If the slurry does not fill the mixing container at the end of the 15-second

mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

B.7 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

B.7.1 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weigh the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry. The density of the foamed slurry in the container is determined by dividing the slurry mass by the container volume and converting to the appropriate density units.

NOTE: Downhole densities may be different than designed values depending on pressure and temperature conditions. Special software is used to predict downhole densities.

B.7.2 Determining Slurry Stability

B.7.2.1 Unset Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder cannot be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

B.7.2.2 Set Slurry Stability

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 50.8-mm (2-in.) diameter, 101.6-mm (4-in.) tall cylinders or any appropriate covered container. Use of grease or other mold-release agents should be avoided as these materials may affect the stability of the foamed cement.

Cut or break the samples into sections, mark them from the top to the bottom, and measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined by dividing the weight, W (in grams) by volume, V (in mL). The slurry density can also be determined (SG × 8.33 = lb/gal).

Signs of foam instability include the following:
- More than a trace of free fluid.
- Bubble breakout noted by bubbles appearing on the surface of the sample.
- Excessive gap at the top of the specimen. Minor meniscus effects are normal.
- Visual signs of density segregation as indicated by streaking or light to dark color change from top to bottom.
- Large variations in density from sample top to bottom.

B.7.3 Determining Compressive Strength

The foamed cement slurry is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated. This expansion can result in an undesired density decrease. The mold can be a standard 50.8-mm (2-in.) cube mold with a cover clamped to the top.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is sufficient seal to prevent the slurry from expanding out of the curing mold.

B.8 Determining Other Tests on Base Unfoamed Slurry

A slurry that is foamed at atmospheric pressure should not be tested under pressure. Applying pressure to a foamed slurry prepared at atmospheric pressure will compress the foam, changing the density and gas ratio. This can also allow contamination when tested in a HPHT consistometer for thickening time.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO 10426-2[2], clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

B.8.1 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO 10426-2[2], clause 9.

B.8.2 Determining Fluid Loss

Fluid-loss tests performed with a foamed cement prepared at atmospheric pressure will not yield reliable results. The fluid loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry.

The static fluid-loss test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 10.

B.8.3 Determining Rheological Properties

With the concentration of gas in a foamed slurry changing continuously during pumping of the job, it is impractical to perform rheological testing at all the foam quality concentrations that are needed to model the frictional pressures during pumping of a foamed slurry. Use of a rotational viscometer will result in separation of the gas from the slurry, causing erroneous results. Correlations can be used to convert the rheological properties of the base unfoamed slurry to that of a foamed cement with varying foam qualities to simulate the job.

The rheological test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 12.

References

[1] ISO 10426-4: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 4: Recommended Practice for Atmospheric Foam Cement Slurry Preparation," working draft 2001.
[2] ISO 10426-2: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements," 1998.

Appendix 7

Quarterly Report 7

Ultra-Lightweight Cement

Seventh Quarterly Technical Progress Report

April 1 to June 30, 2002

Fred Sabins

Issued July 30, 2002

DOE Award Number
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Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report includes results from laboratory testing of ULHS systems along with other lightweight cement systems, including foamed and sodium silicate slurries. During this project quarter, a comparison study of the three cement systems examined the effect that cement drillout has on the three cement systems. Testing to determine the effect of pressure cycling on the shear bond properties of the cement systems was also conducted. This report discusses testing that was performed to analyze the alkali-silica reactivity of ULHS in cement slurries.

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Corrigendum

One of the cement types used in the project's tests has been inaccurately referred to as Class A in the past quarterly progress reports. The cement is actually Type I cement. Although Class A and Type I cements are very similar, they are still different cements.

In the past progress reports, the "Class A" designation should be replaced with "Type I" when in the context of the cement that is being tested.

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The cement sets in place (1) to support the casing in the hole, (2) to isolate various formations from one another, and (3) to control fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of expensive remedial treatments. The upper sections of the well are where lost circulation most commonly occurs. These include surface and intermediate casings. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum practical density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Water is the primary density-reducing material in these conventional cements. Additional water dilutes the cement, causing low strength and high permeability. Lower temperature, such as those in the upper well sections, delays strength development. To obtain lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water to the slurry.

This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

Executive Summary

Laboratory testing during the seventh quarter was a continuation and extension of the testing that has been previously conducted. Testing compared slurries containing ULHS to foamed and sodium silicate cement systems. Comparison studies examined shear bond strength after pressure-cycling conditions. Studies also simulated drillout operations to evaluate the resilience of the three cement systems after drillout procedures.

Because of the large volume of cement required for this project, a quality-control process has been implemented. Information and data gathered for the program are presented.

Cement Quality-Control Program

Because of the large quantities of cement used in the course of this project, a quality – control (QC) program was initiated. Upon receipt, each bucket of cement is labeled with a materials log number and date. When a bucket is first opened for use, the date of opening is recorded in the materials log. This log number is referenced on the laboratory sheets for each test performed. Where applicable, tests are conducted according to API Specification 10A[1]. Additionally, several tests tailored for the test conditions and materials (rheology and low-temperature compressive-strength development) are included in this QC program.

For the QC program the Class A test specifications were used for the Type I cement. The Type I and Class H cement performance requirements are presented in the original API Specification 10A (January 1995) before Addendum 1, which changed the free fluid procedure. The free fluid procedure comes from the January 1995 edition that uses graduated cylinders. Because the Lightweight Oilwell cement is not API cement, it is tested according to QC procedures developed by the manufacturer.

The physical requirements used to test each cement are listed in **Table 1**. Calcium chloride ($CaCl_2$) is being used to accelerate the rate of compressive-strength development at low temperatures. **Table 2** shows the temperatures and concentrations at which calcium chloride is used. Calcium chloride was selected because it is one of the most effective and commonly used cement accelerators.

Table 1—Cement slurry compositions for quality-control testing program

Cement	Mix Water (% BWOC)	Density (lb/gal)	Cement (g)	Water (mL)	Test
Type I	46	15.6	772	355	API Series of Tests
TXI Lightweight	75	13.2	541	406	Thickening Time & Compressive Strength
TXI Lightweight	105	12.1	426	447	Free Fluid
Class H	38	16.4	860	327	API Series of Tests

Table 2—Percent $CaCl_2$ for low-temperature compressive strengths

Temperature (°F)	$CaCl_2$ (% BWOC)
80	0.0
60	1.0
45	2.0

These quality-control tests have been conducted to provide a baseline for each type of cement. This QC data will provide a basis of comparison for other data for this project. After several cycles of the complete QC program had been performed, the data showed no significant variations and remained within the vendors' specifications. Testing then proceeded with a less-stringent program of scheduled thickening-time tests. Each time a new bucket is opened, a thickening-time test is conducted. Additionally, a thickening-time test is performed once a month on all opened buckets. The thickening-time test was chosen as a gauge to detect abnormal cement performance. **Appendix A** shows the QC program data.

Application Scenarios

One way to gauge the performance of cements made with ULHS is to compare them to other ultra-lightweight cement systems. Members of the project advisory board decided to compare ULHS cements to foamed cement and a conventional sodium silicate slurry.

Seventh-quarter testing focused on a cementing scenario referred to as Application 2. Application 2 conditions simulated a typical land-based surface-pipe cementing job with the following conditions:

- bottomhole circulating temperature (BHCT) of 78°F
- bottomhole static temperature (BHST) of 96°F
- bottomhole pressure (BHP) of 1,000 psi

As detailed in the first quarterly report, these conditions are average values obtained from *Worldwide Cementing Practices*[2]. Application 2 cement slurries were designed to achieve a thickening time of 4 to 6 hr with 1.0% maximum free fluid.

Of the different ULHS classes studied in this project, 6K beads were chosen because they are able to withstand the hydrostatic pressures associated with the different simulation applications.

Most tests were performed according to the API RP 10B[3] method. To adapt to ULHS and foamed slurries, some preparation and testing methods were modified. To minimize bead breakage caused by high shear from API blending procedures, mixing procedures were modified for the ULHS slurries. The following blending procedure was used for the ULHS slurries:

1. Weigh out the appropriate amounts of the cement sample and additives, water, and ULHS into separate containers.

2. Mix the cement slurry (without ULHS) according to Section 5.3.5 of API RP 10B.[3]

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.

4. Pour this slurry back into the Waring blender and mix at 4,000 rev/min for 35 seconds to mix and evenly distribute the contents.

Testing methods for foamed slurries were also modified. For example, thickening time is performed on unfoamed slurries only. Because the air in the foam does not affect the hydration rate, the slurry was prepared per API RP 10B[3], then the foaming surfactants were mixed into the slurry by hand without foaming the slurry. This and the other non-standard procedures for testing foamed cement are presented in **Appendix B**.

Table 3 presents slurry compositions for the 11.5-lb/gal slurries tested during this project quarter. To adapt each slurry to the application conditions and to meet the thickening time and free fluid requirements, additives, such as slurry extenders, accelerators, and foaming agents, were added to the slurries. The additives are widely available, generic additives, and are not specific to any particular service company. These additives include sodium silicate, calcium chloride, Witcolate® 7093 (a foaming agent), and Aromox® C/12 (a foam stabilizer).

Table 3—Slurry compositions for Application 2 slurries

Density: 11.5-lb/gal, Application 2				
Cement Type	**Slurry System**	**Measured Density (lb/gal)**	**Water Content (gal/sk)**	**Additive Concentrations**
Type I	ULHS	11.5	7.09	16.2% BWOC (6K) ULHS
	Foamed	15.6† (11.5‡)	5.20	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	16.87	3.0% BWOC Sodium Silicate
TXI Lightweight	ULHS	11.5	6.50	2.0% BWOC $CaCl_2$; 11.9% BWOC (6K) ULHS
	Foamed	13.0† (11.5‡)	7.00	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	11.5	12.11	3.0% BWOC Sodium Silicate

†Unfoamed slurry density

‡Foamed slurry density

Because of Application 2's low temperatures, calcium chloride ($CaCl_2$) was used with some foamed and ULHS slurries to accelerate hydration. $CaCl_2$ was not used with the sodium silicate slurries because of viscosity issues specific to this slurry. The only viable accelerators for sodium silicate slurries are company-specific and not widely available in a generic form.

Shear Bond

Testing continued with the evaluation of the shear bond strength of the three cement systems. These studies investigated the effect of restraining force on shear bond strength. Special shear bond strength testing was done to determine the effect of pressure cycling on shear bond strength.
Samples were cured in a pipe-in-pipe configuration (**Figure 1**). The pipe-in-pipe configuration consisted of a sandblasted internal pipe with an outer diameter (OD) of 1 $^1/_{16}$ in. and a sandblasted external pipe with an internal diameter (ID) of 3 in. For the pressure cycling tests, the internal pipe of the shear bond samples is a 40/41 coiled tubing pipe. Other dimensions & properties of the coiled tubing include: wall thickness of 0.087 in., internal yield pressure of 11,480 psi, and hydro test pressure of 9,200 psi.

Both the internal and external pipes were 6 in. long. To center the internal pipe within the external pipe, a contoured base and top were used. The base extended 1 in. into the annulus and cement filled 4 in. of the annulus. The top 1 in. of annulus contained water.

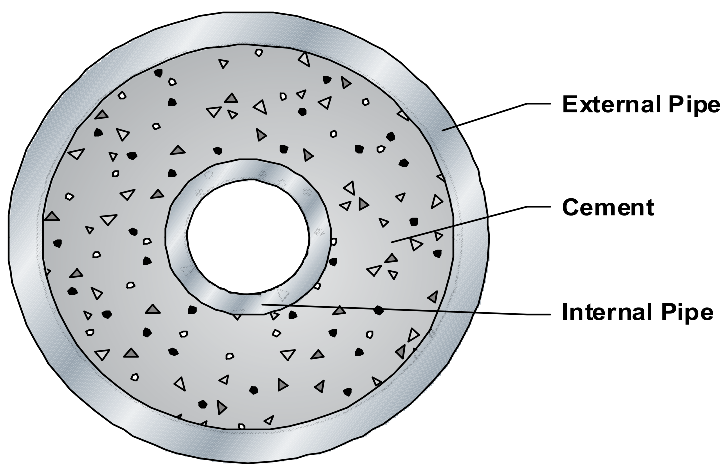

Figure 1—Cross section of pipe-in-pipe configuration for shear bond tests

Application 2 cement systems were used for the shear bond strength tests. Special shear bond strength testing was done to determine the effect of pressure cycling on shear bond strength. The pressure cycling procedure was designed to simulate conditions encountered during production of a well similar to the Application 2 scenario. The samples were first cured for seven days in a 96°F water bath at atmospheric pressure. They were then subjected to five periods of pressure cycling in which the interior pipe is pressured to 5,000 psi for 10 minutes and then allowed to rest at 0 psi for 10 minutes.

Shear bond measures the stress needed to break the bond between the cement and the internal pipe. Shear bond was measured with the aid of a test jig that creates a platform for the base of the cement to rest against as force is applied to the internal pipe. (**Figure 2**) Shear bond force is the force required to move the internal pipe. The pipe was pressed until the bond was broken. The shear bond strength is the force required to break the bond (move the pipe) divided by the surface area between the internal pipe and the cement.

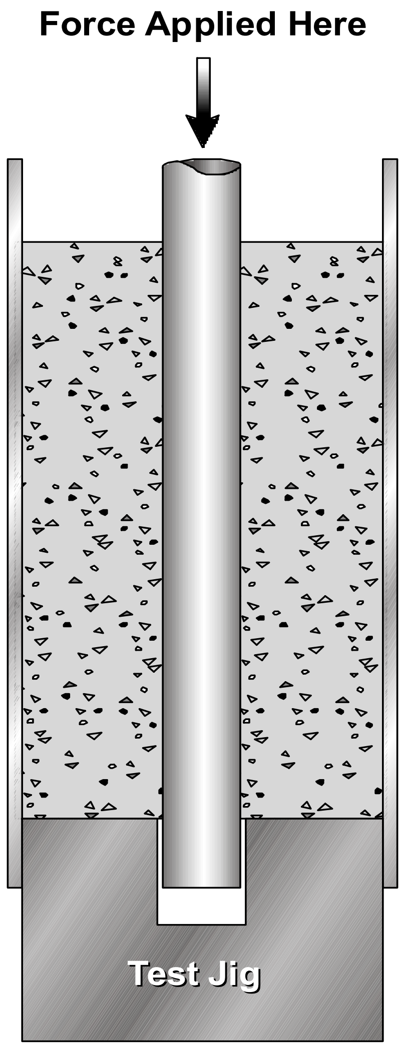

Figure 2—Configuration for testing shear bond strength

Table 4 presents the seven-day shear bond strengths for the three cement systems in the pipe-in-pipe configuration. The results of the pressure-cycled pipe-in-pipe shear bonds are also presented in **Table 4**. Current testing is also investigating pressure-cycled shear bonds in a pipe-in-soft configuration. The pipe-in-soft configuration allows the cement to cure in a less-rigid, lower-restraint environment. Results from the pipe-in-soft tests will be presented in the next progress report.

Table 4—Shear bond strength data of lightweight cement systems that have and have not been exposed to pressure cycling

Density: 11.5 lb/gal, Application 2, Baseline (Uncycled)						
Cement Type	Slurry System	Pipe-in-Pipe Shear Bond Strength (psi)				
		Sample 1	Sample 2	Sample 3	Average	
Type I	ULHS	466	365	375	**402**	
	Sodium Silicate	173	166	115	**151**	
	Foamed	377	380	595	**451**	
TXI Lightweight	ULHS	120	118	119	**119**	
	Sodium Silicate	37	44	44	**42**	
	Foamed	127	120	136	**128**	

Density: 11.5 lb/gal, Application 2, Pressure Cycled					
Cement Type	Slurry System	Pipe-in-Pipe Shear Bond Strength (psi)			
		Sample 1	Sample 2	Sample 3	Average
Type I	ULHS	332	273	257	**287**
	Sodium Silicate	130	103	140	**124**
	Foamed	308	275	333	**305**
TXI Lightweight	ULHS	127	104	107	**113**
	Sodium Silicate	164	140	122	**142**
	Foamed	296	251	304	**284**

Drillout Testing

Testing was performed to evaluate the competence of ULHS and other lightweight cement systems during drillout of a cemented shoe joint. To simulate the drillout conditions, 3-ft models were used. Each model consisted of an inner pipe (4.500-in. OD, 4.026-in. ID) concentrically centered within an outer pipe (8.625-in. OD, 7.98-in. ID). To join the pipes together at the base and to make a watertight base, a plate was welded to the bottom of each pipe. The plate had a concentrically centered, raised circular surface with a diameter slightly less than the ID of the inner pipe. The raised circular surface in the middle was designed to center the inner pipe within the outer pipe. **Figure 3** illustrates how the inner pipe and outer pipe are joined together at the weld plate.

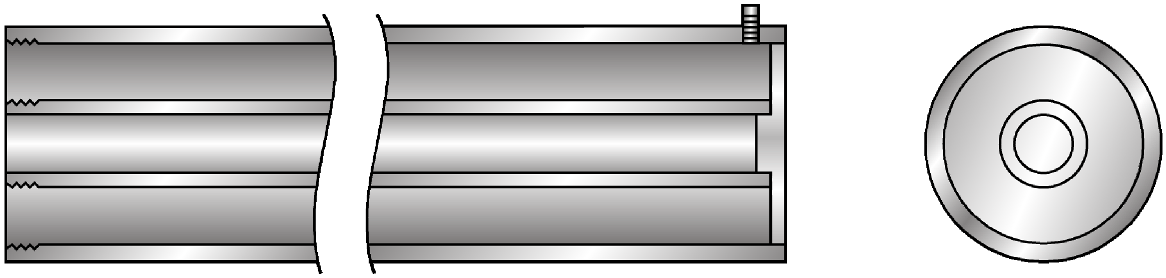

Figure 3—Diagram of model for drillout testing

To test the competence of the cement in the annulus, testing was done to measure the fluid flow in the annulus before and after drillout. This annular fluid flow accounts for the flow through the cement (permeability) as well as any flow around the cement such as cracks or a microannulus. Using the fluid flow data, calculations were also performed to determine an equivalent bulk permeability; the bulk permeability assumes that the fluid flows through the cement and no fluid flows through cracks or a microannulus.

On the outside of the outer pipe, a 0.25-in. hole (with fitting) served as the pressure inlet port during fluid flow testing. The port was located 1 in. from the bottom of the pipe, just above the weld plate. During fluid flow testing, a cap was used to seal off the inner pipe. During annular fluid flow testing an annular disc was used to isolate the annulus. The annular disc had an outlet port for collecting fluid that permeated through the cement.

Figure 4 depicts the drillout model equipped with the cap for the inner pipe and the annular disc. It is in this configuration that the annular fluid flow of the cement is measured. **Figure 4** shows the drillout model for the case where the cement in the inner pipe has already been drilled; however, the same equipment is also used prior to drillout for fluid flow measurements of the annulus.

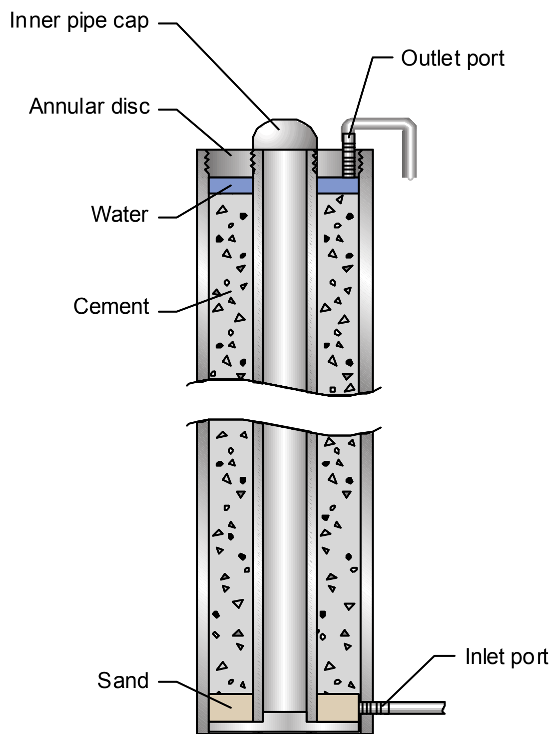

Figure 4—Diagram of model equipped for fluid flow testing (after cement in inner pipe has been drilled out)

To prepare the drillout models, the pressure inlet port was capped and then sand was placed to a depth of 3 in. in the bottom of the annular space between the inner and outer pipes. The cement that was to be tested was mixed in the laboratory and poured into the inner pipe and the annulus to within 3 in. of the top of the pipes.

The three different cement slurries that were tested are shown in **Table 5**. They were all designed for a final density of 11.5 lb/gal. For the foamed slurry, the unfoamed slurry density was 15.0 lb/gal and then the slurry was foamed (and verified) to 11.5 lb/gal using methods specified in **Appendix B**.

Table 5—Composition for lightweight cement systems used in drillout testing

Cement Type	Slurry System	Water Content (gal/sk)	Additive Concentrations
Type I	ULHS	7.09	16.2% BWOC (6K) ULHS
	Foamed	6.02	0.03 gal/sk Witcolate® 7093; 0.02 gal/sk Aromox® C/12
	Sodium Silicate	16.87	3.0% BWOC Sodium Silicate

Water was then added on top of the cement up to the top rim of the pipes. The cement was cured for 7 days at atmospheric pressure and room temperature (approximately 75°F). On the eighth day, an initial annular fluid flow test was run on each sample.

The annular fluid flow testing consisted of:

1. Replace the water on top of the cement with new water.
2. Screw the cap on the inner pipe.
3. Screw the annular disc between the inner and outer pipes. As the disc is screwed on, make sure water comes out the outlet port and that there are not any air bubbles. If necessary, use a syringe to add water.
4. Attach the outlet hose and collection beaker.
5. Remove the cap on the inlet port.
6. Attach the inlet water system to the inlet port.
7. Adjust the water pressure to the differential test pressure. The water pressure was supplied by a regulated nitrogen system.
8. Allow the system to stay at the test pressure for the required amount of time. This time changes for each circumstance.
9. After the flow rate has stabilized, measure the flow rate of the fluid flowing out the outlet port.

The initial fluid flow testing performed on the eighth day was performed at a differential test pressure of 100 psi. The sodium silicate cement had immediate water flow and after the flow had stabilized a flow rate of 134 cc/min was measured. The foamed cement and ULHS cements had zero flow after 24 hours. The results from the initial and other fluid flow tests are presented in **Table 6**. **Table 7** presents the equivalent bulk permeability of the tests. The bulk permeability is based on the fluid flowing through the cement (i.e., no microannulus or cracks).

Table 6—Annular fluid flow of drillout tests

	Annular Flow Rate (cc/min)			
	8th Day	10th Day	11th Day	
Differential Test Pressure (psi):	**100**	**100**	**100**	**500**
Sodium Silicate	134	137	—	—
ULHS	0	0	0	80
Foamed	0	0	0	100

Table 7—Equivalent bulk permeability of drillout tests

	Equivalent Bulk Permeability (md)			
	8th Day	10th Day	11th Day	
Differential Test Pressure (psi):	**100**	**100**	**100**	**500**
Sodium Silicate	88	90	—	—
ULHS	0	0	0	10
Foamed	0	0	0	12

On the ninth day, the cement inside the inner pipe of each model was drilled out. Each model was clamped down in a horizontal direction. A 3-7/8-in. mill tooth roller cone bit was used to drill out the cement. The weight on bit was 2500 pounds and the speed was 70 rpm. Water (the drilling fluid) was circulating at a rate of 70 gal/min. The rate of penetration for the sodium silicate cement averaged roughly 1,000 ft/hr; the ULHS cement averaged 100 ft/hr; the foamed cement averaged 150 ft/hr.

On the tenth day another annular flow test was performed on each sample using 100 psi of differential test pressure. The sodium silicate cement had immediate water flow and after the flow had stabilized a flow rate of 137 cc/min was measured. The foamed cement and ULHS cements had zero flow after 24 hours. Because the sodium silicate cement system had annular fluid flow prior to the drillout, no further fluid flow testing was performed on the sodium silicate cement.

On the eleventh day, the inner pipe was subjected to eight periods of pressure cycling in which the inner pipe is pressured to 2,000 psi and held for 10 minutes and then allowed to rest at 0 psi for 10 minutes. Annular fluid flow testing was then performed on the ULHS and foamed cements with 100-psi differential test pressure; both cements had zero flow. The test pressure was then increased to 500 psi. Water flowed at that point for both cement systems. After the fluid flow stabilized, the fluid flow for the ULHS cement was 80 cc/min and the fluid flow for the foamed cement was 100 cc/min. The test pressure was then increased to 1,000 psi. After the fluid flow stabilized, the fluid flow for the ULHS cement was 300 cc/min and the fluid flow for the foamed cement was 140 cc/min.

Expansion Testing

Work done previously in the project led to interest in expansion of neat cements and cement slurries with ULHS. Neat cement slurries are slurries that are mixed according to the manufacturer's recommended amount of water and they contain no other additives. **Table 8** presents the composition of the slurries that were tested.

Table 8—Composition of cement slurries used for expansion testing

Slurry Type	Water Content (gal/sk)	Density (lb/gal)	Additional Contents
Neat TXI Lightweight	6.07	13.5	—
Neat Type I	5.19	15.6	—
TXI Lightweight with ULHS	6.50	11.5	2.0% BWOC $CaCl_2$; 11.9% BWOC (6K) ULHS

Three different test methods were used: linear bar expansion, annular ring expansion, and cylindrical sleeve expansion. The linear bar and annular ring methods measure linear expansion; the cylindrical sleeve expansion measures bulk expansion. For each method used, the samples are cured and stored in 100°F water. In all cases, there was free access by the cement matrix to water, albeit in the ring and cylinder tests to a limited exterior surface. Expansion measurements are taken at 1, 3, and 7 days.

- Linear Bar Expansion

The linear bar expansion testing method is from ASTM C490[4]. The bars were molded to have initial dimensions of 1×1×11¼ in. with a 10-in. gage length (comparator bar). The length of the bars is measured at 1, 3, and 7 days of curing. The linear expansion is calculated as follows.

$$L = \frac{(L_x - L_i)}{G} \times 100$$

where:

L = change in length at x age, %,

L_x = comparator reading of specimen at x age minus comparator reading of reference bar at x age; in.,

L_i = initial comparator readingof specimen minus comparator reading of reference bar at that same time; in.,

G = nominal gage length (10 in.).

- Annular Ring Expansion

The annular ring expansion testing method is from API Technical Report 10TR2 [5]. The test model consists of an inner ring and outer ring. The solid ring OD is 2 in. and the outer expansion ring ID is 3.5 in. Two steel balls are attached to each side of the split on the expandable ring. These steel balls are used for taking measurements. **Figure 5** shows the configuration of the annular ring expansion test mold.

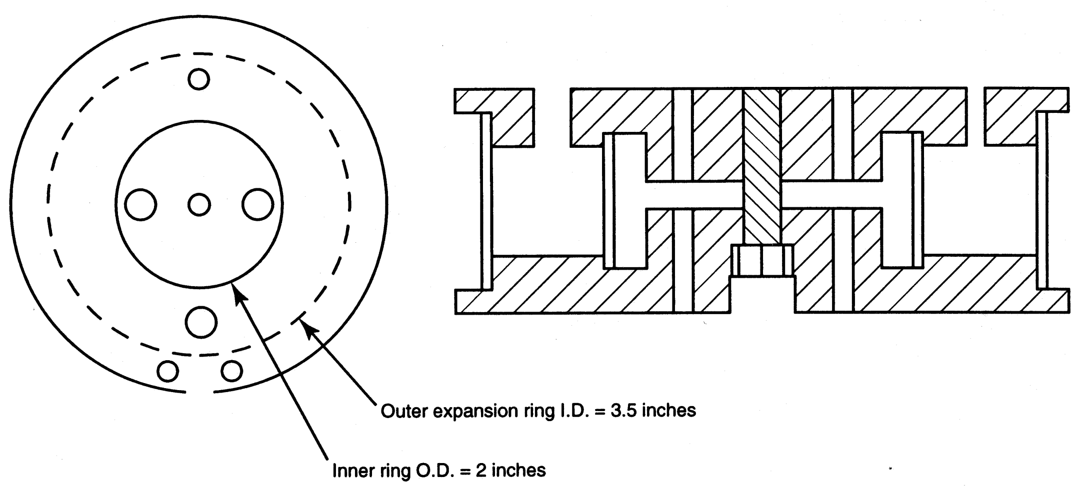

Figure 5—Diagram of test mold for annular ring expansion testing (reprinted from API Technical Report 10TR2[5])

When the cement is initially poured into the annular ring mold, an initial measurement of the spacing of the balls is taken with a micrometer for calibration of the annular ring. The distance between the outside of the steel balls is the measurement that's monitored. Measurements are also taken at 1, 3, and 7 days of curing. The percent linear expansion can be calculated as follows:

$$\%L_{ex} = (M_t\text{-}M_i)\times\pi\times ID_e$$

where:
$\%L_{ex}$= percent linear expansion, %,
M_t = micrometer measurement after curing at time t, in.,
M_i = initial micrometer measurement (before curing), in.,
ID_e = inner diameter of expansion ring, in.

- Cylindrical Sleeve Expansion

The cylindrical sleeve expansion used for these expansion tests is a modified version of the cylindrical sleeve method in API Technical Report 10TR2. The customized sleeve expansion model is a brass sleeve that is 1.63 in. long and has two splits down the side. As seen in **Figure 6**, eight steel balls (four sets of two balls) are welded along the split.

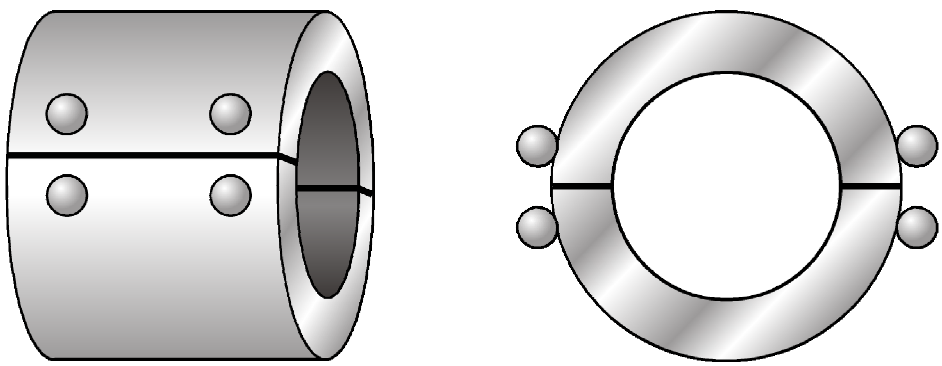

Figure 6—Diagram of test mold for cylindrical sleeve expansion testing

To measure expansion with the cylindrical sleeve expansion molds, a caliper is used to take an initial measurement of the distance between the two balls for each of the four sets. At 1, 3, and 7 days of curing, measurements are also taken. The measurements between the two steel balls in each set are used to track the expansion of the diameter of the sleeve, which can then be used to determine the bulk expansion. The calculations involved with the cylindrical sleeve expansion testing are as follows.

$$Cx = Ci + (Mx1 - Mi1) + (Mx2 + Mi2)$$

where:
Cx = circumference at x age, in.
Ci = initial circumference
Mx1 = caliper measurement at x age—left side average of two, in.
Mi1 = initial caliper measurement—left side average of two, in.
Mx2 = caliper measurement at x age—right side average of two, in.
Mi2 = initial caliper measurement—right side average of two, in.

$$V_x = L\left(\frac{Cx}{\pi}\right)^2 \times \frac{\pi}{4}$$

where:
V_x = volume at x age, in.^{3},
L = length of sample, (1.625 in.),

$$\%B_{ex} = 100 \times \frac{V_x - V_i}{V_i}$$

where:
$\%B_{ex}$= percent bulk expansion, %,
V_i = initial volume, (2.87 in.^{3}).

Table 9 presents a summary of the expansion testing that was done. All cement samples were cured and stored in a water bath maintained at 100°F.

Table 9—Summary of expansion testing

Linear Bar Expansion			
	Percent Linear Expansion		
Slurry Type	1 Day	3 Days	7 Days
Neat TXI Lightweight	0.000	0.007	0.007
Neat Type I	0.000	0.016	0.016
Annular Ring Expansion			
	Percent Linear Expansion		
Slurry Type	1 Day	3 Days	7 Days
Neat TXI Lightweight	0.000	0.240	0.240
Neat Type I	0.000	0.048	0.049
TXI Lightweight with ULHS	0.164	0.188	0.201
Cylindrical Sleeve Expansion			
	Percent Bulk Expansion		
Slurry Type	1 Day	3 Days	7 Days
Neat TXI Lightweight	0.109	0.115	0.115
TXI Lightweight with ULHS	0.148	0.235	0.331

Alkali Silica Reactivity

To get a better understanding of the possible alkali-silica reactivity (ASR) between ULHS and Portland cement, Halliburton Energy Services was commissioned to analyze theoretical alkali levels in cement slurries that contain ULHS. The objective of the study was to determine the potential for ASR based on theoretical determination of cement alkali content.

It has been reported[6] that states the alkali levels of cracked concrete typically range from 5.0 to 9.0 kg/m^3 and these values were the basis for the calculations undertaken. In reality, there are many other operative mechanisms that may have contributed to the cracking of the previous concretes, rendering the correlation with alkali level tenuous.

For example, it has been clearly demonstrated that certain aggregates of carbonate composition also participate in reactions with alkalis, undergoing the so-called alkali carbonate reaction (ACR) and producing detrimental expansion and cracking. Other known forces that are generally found to be present in cracked concrete are freezing and thawing, stresses associated with concrete dryness, formation of ettringite, and even traffic loading.

The method used to perform the analysis is based on theoretical slurry compositions and can readily be applied to actual slurry formulations. This theoretical approach is, however, limited to ordinary Portland cements, and as such, cannot be used for blended cements or pozzolanic blended cements.

Although soluble alkali and total alkali content were used for the computation of alkali concentration in slurries ranging in density between 6 to 12 lb/gal, the voluminous ASR technical literature overwhelmingly considers the initial soluble alkali content as the critical threshold level for establishing potential interaction with reactive materials.

The following two tables summarize the data gathered from the analysis. Near the top of each of these tables is listed the total alkali content and the soluble alkali content for each cement. The cement manufacturer provided the total alkali content of the cement. Halliburton Energy Services performed analysis to determine soluble alkali content using ASTM C114.[7]

Calculations to determine the potential alkali contents in slurries of different densities were based on theoretical slurry formulations using 4K and 10K ULHS, cement, and water. The following two tables show varying amount of ULHS and varying densities. The alkali content for each slurry was then calculated using the following equation:

$$A = B \times \frac{C}{W} \times 10$$

where:
A = alkali content of slurry, kg/m^3,
B = % Na_2O_e (soluble or total) for the cement used,
C = weight of cement in the slurry, g,
W = volume of water in the slurry, mL.

As indicated by the expression above, the cement-to-water ratio determines the critical alkali concentration. Since the alkali concentration in a slurry is related to the original alkali content of the cement and to the amount of water included in the formulation, a higher cement-to-water ratio (higher density slurries) corresponds to a higher alkali concentration in the slurry.

Table 10—Alkali concentration of Class H cement slurries with ULHS

Cement: soluble alkali (Na_2O_e) - 0.066% Cement: total alkali (Na_2O_e) - 0.325%							
				ULHS Type			
Slurry Density	Yield	Water	C/W	4K	10K	Soluble Alkali	Total Alkali
(lb/gal)	(ft^3/sk)	(gal/sk)	(g/mL)	(%BWOC)		(kg/m^3)	(kg/m^3)
14	1.33	4.86	2.32	5.10		1.53	7.54
14	1.39	5.24	2.15		8.43	1.42	6.99
13	1.49	5.19	2.17	7.99		1.43	7.05
13	1.60	5.82	1.94		13.56	1.28	6.31
12	1.69	5.60	2.01	11.66		1.33	6.53
12	1.87	6.60	1.71		20.48	1.13	5.56
11	1.95	6.15	1.83	16.48		1.21	5.95
11	2.27	7.71	1.46		30.31	0.96	4.75
10	2.32	6.89	1.64	23.09		1.08	5.33
10	2.88	9.41	1.20		45.40	0.79	3.90
9	2.84	7.97	1.41	32.69		0.93	4.58
8	3.67	9.69	1.16	47.93		0.77	3.77

Table 11—Alkali concentration of Type I cement slurries with ULHS

Cement: soluble alkali (Na_2O_e) - 0.179% Cement: total alkali (Na_2O_e) - 0.479%							
				ULHS Type			
Slurry Density	Yield	Water	C/W	4K	10K	Soluble Alkali	Total Alkali
(lb/gal)	(ft^3/sk)	(gal/sk)	(g/mL)	(%BWOC)		(kg/m^3)	(kg/m^3)
14	1.42	5.89	1.91		6.17	3.42	9.15
13	1.54	5.95	1.89	6.73		3.38	9.05
12	1.92	7.27	1.55		18.49	2.77	7.42
11	2.02	6.94	1.62	15.52		2.90	7.76
10	2.94	10.15	1.11		43.97	1.99	5.32
9	2.94	8.83	1.28	32.3		2.29	6.13
7	5.39	13.86	0.81	46.97		1.45	3.88

It should be emphasized that the data in the tables are calculated values based on simple slurry formulations.

We plan to design actual experiments under downhole conditions to ascertain any potential reactivity between ULHS and various levels of alkali content in lightweight cement slurries.

Software Program

To assist in designing cement slurries made with ULHS, a software program is being created. The program does not simulate cement jobs and fluid dynamics. Instead, the program focuses on the static final placement of the fluids (i.e., the slurry composition and slurry properties such as yield and density).

As suggested by project participants the foamed cement portion of the software program has been removed. Most service companies have a program that deals with foamed cement.

A beta version of the program will be distributed to the project participants near the end of July. This will give the participants a chance to test the program to see if there are any glitches.

Plans for Final Project Quarter

- Field Job

A field job using ULHS in a cement slurry is planned for the middle of July. The candidate well is located in Natrona County, Wyoming, on land owned by Rocky Mountain Oilfield Testing Center. The cementing application is for the production casing with a total depth of 5,900 feet. The ULHS slurry will cover from 4,150 to 2,635 ft. The cement that will be used is TXI Lightweight. The planned slurry design will contain 25% BWOC ULHS (6K), 0.2% BWOC proprietary retarder, and 7.57 gal/sk water for a design density of 10.0 lb/gal.

- Software Program

A beta version of the ULHS slurry design program will be distributed to the project participants near the end of July. This will give the participants a chance to test the program to see if there are any glitches. Any suggestions or comments about the program should be e-mailed to Fred Sabins.

- Annular Seal Testing

This project will also utilize other test methods to evaluate each of the three lightweight cement systems in their ability to maintain a seal under downhole stresses. An annular seal model will be used to measure bulk permeability across a cement system that has been stressed from temperature or pressure cycling. As with previous testing, a pipe-in-pipe and pipe-in-soft configuration will simulate high and low restraints, respectively. **Figure 7** is a schematic of the pipe-in-soft configuration of the annular seal model.

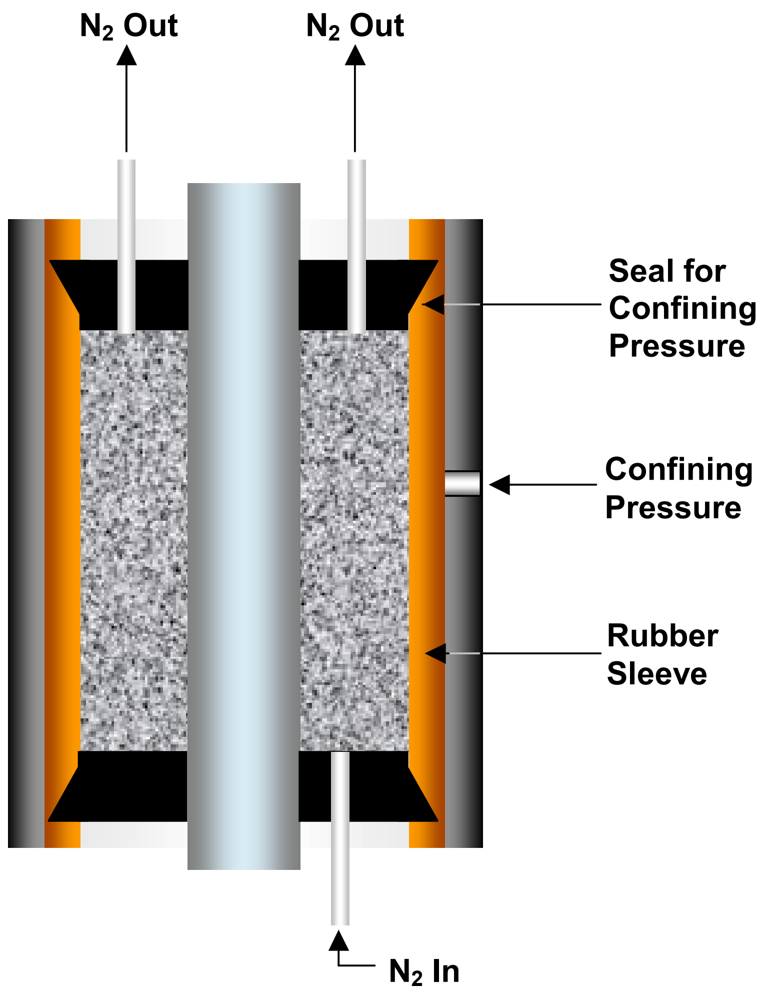

Figure 7—Cross section of annular seal model for pipe-in-soft configuration

The inner pipe of the model will be the main conduit for the stressing medium. For instance, the inner pipe can contain heated fluids while the remainder of the system is at a different temperature; this simulates the hotter formation fluids that can be experienced during production. The inner pipe of the model can also be pressured up to 5,000 psi, simulating casing pressure testing which is believed by many to lead to loss of annular seal because of stresses placed on the cement due to the expanding and contracting casing.

The annular seal testing will be performed after each time the interior conduit pipe is pressurized. For the temperature cycling, the annular seal testing will be done after each temperature cycle.

In the pipe-in-soft configuration, the rubber sleeve surrounding the cement is able to withstand 25 psi. During the annular seal test, pressure can then be applied to the outside of the rubber sleeve, allowing the sleeve to make a fluid-tight seal on the outside of the cement. Pressurized nitrogen gas (<25 psi) can then be applied axially across the cement and the only paths for fluid flow is through cement or along the interface between the cement and the inner pipe. Any exiting nitrogen flow rate can be monitored and measured.

Conclusions

- In general, pressure cycling did not detrimentally affect the shear bond strength of the lightweight cement systems cured in a pipe-in-pipe configuration.

- Drillout testing revealed no significant faults with the ULHS or foamed cement systems.

- Preliminary expansion testing showed some expansion associated with neat TXI Lightweight cement and a slurry with TXI Lightweight cement and ULHS.

- Analysis testing of alkali content of ULHS slurries showed that there might be a potential for ASR. Investigations into ASR of ULHS cement slurries are continuing.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
OD—outer diameter
psi—pound per square inch
rev—revolution
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

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Appendix A—Quality Control Testing

TXI Lightweight Cement

TXI Information		CSI Information				Free Fluid			Rheology										
Cmt Type	Production Date	Date Received	CSI Log#	Bucket Opened	Test Date	Water Conc. (%bwoc)	mL	% by volume	Water Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
LW	09/18/00	11/06/00	C-108 B-1	11/07/00	11/15/00	105	2	0.8	75	80	57	50	42	38	33	22	12	13	120
LW	09/18/00	11/06/00	C-108 B-2	12/05/00	01/04/01	105	2	0.8	75	80	58	52	45	38	32	21	13	13	125
LW	09/18/00	11/06/00	C-108 B-11	06/24/01	06/26/01	105	2	0.8	75	80	60	55	47	39	21	20	15	15	127
LW	09/18/00	11/06/00	C-108 B-12	07/03/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-7	09/05/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-14	09/24/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-13	12/04/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-15	01/22/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-16	05/15/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
LW	09/18/00	11/06/00	C-108 B-18	02/25/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	45°F Strengths			60°F Strengths			80°F Strengths		120°F Strengths		Thickening Time			
Cmt Type	CSI Log#	Test Date	Conc. (%bwoc)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 70 Bc	Time to 100 Bc
LW	C-108 B-1	11/15/00	75.0	24	2.0	166	24	1.0	254	24	523	24	1579	5	6	2:02	2:20
LW	C-108 B-2	01/04/01	75.0	24	2.0	161	24	1.0	221	24	441	24	1225	5	5	2:00	2:17
LW	C-108 B-11	06/26/01	75.0	24	2.0	158	---	---	---	24	501	---	---	5	9	1:57	2:18
LW	C-108 B-12	08/14/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-7	09/10/01	75.0	---	---	---	---	---	---	---	---	---	---	5	6	1:57	2:17
LW	C-108 B-14	10/16/01	75.0	---	---	---	---	---	---	---	---	---	---	5	4	2:07	2:26
LW	C-108 B-14	11/13/01	75.0	---	---	---	---	---	---	---	---	---	---	5	5	2:05	2:25
LW	C-108 B-14	12/20/01	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:03	2:22
LW	C-108 B-13	01/11/02	75.0	---	---	---	---	---	---	---	---	---	---	5	8	1:58	2:12
LW	C-108 B-15	02/08/02	75.0	---	---	---	---	---	---	---	---	---	---	5	7	2:05	2:15
LW	C-108 B-18	03/04/02	75.0	---	---	---	---	---	---	---	---	---	---	5	13	2:11	2:27
LW	C-108 B-18	04/09/02	75.0	---	---	---	---	---	---	---	---	---	---	5	23	1:54	2:16
LW	C-108 B-16	05/16/02	75.0	---	---	---	---	---	---	---	---	---	---	5	19	2:00	2:12
LW	C-108 B-18	06/26/02	75.0	---	---	---	---	---	---	---	---	---	---	5	24	1:53	2:10

TXI Class H Cement

TXI Information		CSI Information				Water	Free Fluid		Rheology									
Cmt Type	Prod. Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	mL	% by volume	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	1.9	0.8	80	89	72	53	45	37	16	10	---	---
Class H	09/27/00	11/06/00	C-108 A-1	11/06/00	11/21/00	38.0	3.0	1.2	80	85	70	53	45	38	14	8	9	19
Class H	09/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	3.0	1.2	80	95	80	60	51	42	20	12	15	26
Class H	09/27/00	11/06/00	C-108 A-3	02/22/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-4	06/26/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-6	07/20/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-7	08/27/01	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-8	01/14/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Class H	09/27/00	11/06/00	C-108 A-10	06/11/02	---	---	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths		140°F Strengths		Thickening Time		
Cement Type	CSI Log#	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Sch #	Initial Bc	Time to 100 Bc
Class H	C-108 A-1	11/07/00	38.0	8	524	8	2088	---	---	---
Class H	C-108 A-1	11/29/00	38.0	8	480	8	2249	5	12	2:03
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1617	---	---	---
Class H	C-108 A-1	02/22/01	38.0	---	---	8	1550	---	---	---
Class H	C-108 A-2	01/11/01	38.0	8	1201	8	1964	5	7	1:54
Class H	C-108 A-2	01/12/01	38.0	8	1039	8	1756	---	---	---
Class H	C-108 A-2	02/12/01	38.0	8	424	8	1717	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1567	---	---	---
Class H	C-108 A-3	02/22/01	38.0	---	---	8	1580	---	---	---
Class H	C-108 A-4	06/29/01	38.0	---	---	---	---	5	17	2:00
Class H	C-108 A-6	08/13/01	38.0	---	---	---	---	5	15	1:50
Class H	C-108 A-7	09/06/01	38.0	---	---	---	---	5	19	2:00
Class H	C-108 A-3	10/09/01	38.0	---	---	---	---	5	12	1:53
Class H	C-108 A-3	11/13/01	38.0	---	---	---	---	5	13	1:50
Class H	C-108 A-3	12/21/01	38.0	---	---	---	---	5	14	1:45
Class H	C-108 A-3	01/11/02	38.0	---	---	---	---	5	13	2:00
Class H	C-108 A-8	02/08/02	38.0	---	---	---	---	5	28	1:55
Class H	C-108 A-8	03/05/02	38.0	---	---	---	---	5	14	1:55
Class H	C-108 A-8	04/04/02	38.0	---	---	---	---	5	24	2:00
Class H	C-108 A-8	05/15/02	38.0	---	---	---	---	5	22	1:50
Class H	C-108 A-10	06/25/02	38.0	---	---	---	---	5	26	1:50

TXI Type I Cement

TXI Information		CSI Information				Water	Rheology									
Cement Type	Production Date	Date Received	CSI Log #	Bucket Opened	Test Date	Conc. (%bwoc)	Temp (°F)	300 RPM	200 RPM	100 RPM	60 RPM	30 RPM	6 RPM	3 RPM	10 sec G.S.	10 min G.S.
Type I	09/27/00	11/06/00	C-113 A-1	11/09/00	11/17/00	46.0	80	75	62	48	40	33	17	10	10	19
Type I	09/27/00	11/06/00	C-113 A-2	11/20/00	11/20/00	46.0	80	80	65	49	40	34	17	10	10	19
Type I	09/27/00	11/06/00	C-113 A-3	12/04/00	12/05/00	46.0	80	78	64	50	40	32	16	10	10	19
Type I	09/27/00	11/06/00	C-113 A-4	01/09/01	01/09/01	46.0	80	80	65	52	40	33	17	11	10	20
Type I	09/27/00	11/06/00	C-113 A-5	11/09/00	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-1	03/20/01	03/20/01	46.0	80	77	63	51	39	32	17	10	10	20
Type I	03/10/01	03/19/01	C-189 A-5	06/01/01	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-8	07/11/01	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-6	10/16/01	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-17	08/30/01	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-11	01/17/02	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-12	02/17/02	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-13	02/28/02	---	---	---	---	---	---	---	---	---	---	---	---
Type I	03/10/01	03/19/01	C-189 A-14	03/27/02	---	---	---	---	---	---	---	---	---	---	---	---
Type I	04/19/02	05/02/02	C-418-A	05/02/02	---	---	---	---	---	---	---	---	---	---	---	---
Type I	04/19/02	05/02/02	C-418-B	06/19/02	---	---	---	---	---	---	---	---	---	---	---	---

CSI Information			Water	100°F Strengths				45°F Strengths			60°F Strengths			80°F Strengths		Thickening Time			
Cement Type	CSI Log #	Test Date	Conc. (%bwoc)	Time (Hr)	CS (psi)	Time (Hr)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	$CaCl_2$ (%bwoc)	CS (psi)	Time (Hr)	CS (psi)	Test Date	Sch #	Int. Bc	Time to 100 Bc
Type I	C-113 A-1	11/17/00	46.0	---	---	---	---	---	---	---	---	---	---	24	1646	11/15/00	4	9	2:17
Type I	C-113 A-2	11/27/00	46.0	8	754	24	2607	24	2	737	24	1	1194	24	1689	01/05/01	4	8	2:21
Type I	C-113 A-2	02/12/01	46.0	---	---	---	---	---	---	---	---	---	---	24	2022	---	---	---	---
Type I	C-113 A-3	12/05/00	46.0	---	---	24	2585	---	---	---	---	---	---	---	---	---	---	---	---
Type I	C-113 A-4	01/17/01	46.0	8	729	24	2527	24	2	1042	---	---	---	---	---	01/17/01	4	4	2:09
Type I	C-113 A-5	02/15/01	46.0	8	931	24	2568	---	---	---	---	---	---	---	---	---	---	---	---
Type I	C-113 A-5	02/22/01	46.0	---	---	24	2334	---	---	---	---	---	---	---	---	---	---	---	---
Type I	C-113 A-5	02/22/01	46.0	---	---	24	2590	---	---	---	---	---	---	---	---	---	---	---	---
Type I	C-113 A-5	02/22/01	46.0	---	---	24	2250	---	---	---	---	---	---	---	---	---	---	---	---
Type I	C-189 A-1	03/20/01	46.0	8	916	24	2364	---	---	---	24	1	1238	24	1737	03/20/01	4	12	1:42
Type I	C-189 A-5	06/29/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/29/01	4	10	1:37
Type I	C-189 A-8	08/15/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	08/15/01	4	6	1:50
Type I	C-189 A-17	09/12/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	09/12/01	4	6	2:00
Type I	C-189 A-6	10/16/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	10/16/01	4	7	1:41
Type I	C-189 A-6	11/13/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	11/13/01	4	7	1:53
Type I	C-189 A-6	12/21/01	46.0	---	---	---	---	---	---	---	---	---	---	---	---	12/21/01	4	6	1:46
Type I	C-189 A-11	01/14/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	01/14/02	4	8	1:42
Type I	C-189 A-12	02/11/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	02/11/02	4	15	1:40
Type I	C-189 A-13	03/04/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	03/04/02	4	14	2:10
Type I	C-189 A-14	04/02/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	04/02/02	4	21	1:46
Type I	C-418-A	05/03/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	05/03/02	4	27	2:15
Type I	C-418-B	06/25/02	46.0	---	---	---	---	---	---	---	---	---	---	---	---	06/25/02	4	32	2:00

Appendix B—Laboratory Procedures for Foamed Cement

The working draft of ISO 10426-4[1] outlines the recommended practices for the atmospheric generation and testing of foamed cement slurries and their corresponding unfoamed base slurries. The procedures discussed in this appendix and used for this project were borrowed from ISO 10426-4.

B.1 Preparing Unfoamed Base Slurry

B.1.1 Calculation of Base Cement With and Without Surfactants

Because the final slurry for foamed cement contains surfactant(s), these materials cannot be added to the base slurry for initial mixing. This will require that the density of the base slurry be adjusted to compensate for the later addition of the surfactant(s) prior to foaming.

Example: Slurry Design: Class G Cement + 0.2 gal/sk Surfactant

Base slurry density	=	14.5 lb/gal	
Surfactant weight	=	10 lb/gal	

Base Slurry Calculations:		Weight	Volume
	Cement	94 lb	3.59 gal
	Surfactant	2 lb (0.2 gal * 10 lb/gal)	0.2 gal
	Water	55.39 lb	6.65 gal
	Total	151.39 lb	10.44 gal

Calculation of True Weight % Contributions:			
	Cement	62.1 %	(94/151.39)
	Surfactant	1.3 %	(2/151.39)
	Water	36.6 %	(55.39/151.39)

Slurry without Surfactants:		Weight	Volume
	Cement	94 lb	3.59 gal
	Water	55.39 lb	6.65 gal
	Total	149.39 lb	10.24 gal

Slurry Density without Surfactants: 149.39/10.24 = 14.59 lb/gal

B.2 Equipment

B.2.1 Blender Container

A special blending container is required for preparing foamed cement at ambient pressure in the laboratory. (A typical blending container is shown in Figure B.1) The blending container is similar to the one used for standard slurry preparation except that it has a threaded cap with an O-ring seal. The cap has a small hole (approx. ¾-in. diameter) in the center fitted with a removable plug that has an O-ring seal.

B.2.2 Multi-Blade Assembly

The multi-blade assembly is what is used during this project. The multi-blade or stacked-blade assembly is constructed of a series of assemblies, each blade corresponding to the requirements of ISO 10426-2[2], clause 5. The assembly consists of five (5) standard blades attached to a central shaft, and spaced equally throughout the mixing container. A typical assembly is shown in Figure B.1.

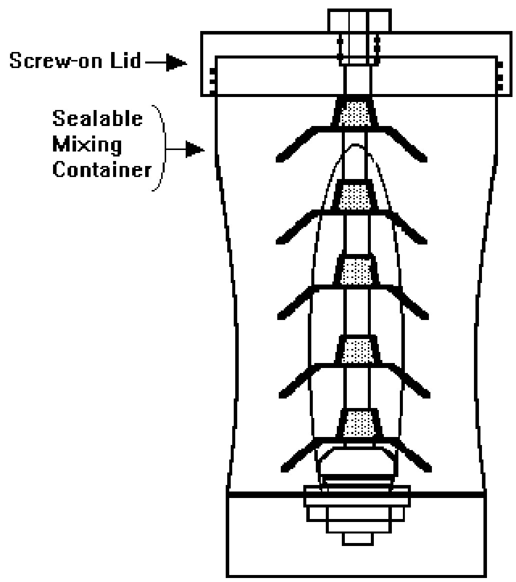

Fig. B.1—Example of a typical blending container

B.3 Container Volume

Accurate determination of the volume of the blending container is critical to this procedure. The calculations for slurry volume and foamed cement density are based on this volume determination. Weigh the clean, dry, blending container (including mixing assembly, screw-on lid and screw-in plug for the lid). Remove the screw-on lid from the mixing container and then remove the screw-in plug from the lid. Fill the mixing container with water and then screw the lid on tightly. Pour additional water into the hole in the lid for the plug until the container is completely filled, and then screw the plug tightly into the lid. Wipe the excess water that exits from the plug's vent hole, and then weigh the container again. The weight of the water inside the container is then divided by the density of the water to determine an accurate volume for the mixing container.

B.4 Preparing Base Cement Slurry

This method assumes that the base slurry as described in Section B.1.1 is being prepared in a separate mixing container, and this slurry is then to be weighed into the mixing container described in Section B.2.1. To prepare sufficient volume may require multiple mixes with the standard mixing procedure.

Base slurries containing all additives except foaming surfactant(s) should be prepared according to ISO 10426-2[2],clause 5. When possible, the temperature of the cement sample, additives, and mix water should be within ± 2°C (3°F) of the respective temperatures recorded from the well site. The temperature of the mixing container should approximate that of the mix water being used in the slurry design. The mixing device should be calibrated annually to a tolerance of ± 3.3 rev/s (200 rpm) at 66.7 rev/s (4,000 rpm) and ± 8.3 rev/s (500 rpm) at 200 rev/s (12,000 rpm).
As required, the density of the unfoamed cement slurry can be determined by methods found in ISO 10426-2[2], clause 6.

B.5 Determining Slurry Volumes and Weights

B.5.1 Slurry Volume

Determine the volume of unfoamed cement slurry to be mixed. The total volume of unfoamed cement slurry should include the volume of the surfactant(s) to be added to the slurry. The surfactant(s) is to be added after the initial mixing of the base slurry. The volume of unfoamed slurry to be placed in the container may be determined by the following procedure.

When it is desired to foam a slurry with a specific amount of gas per unit volume of slurry (foam quality), the resultant density of the foamed slurry must be determined. This can be calculated by Equation 1.

$$FD = (100 - \%G) \div 100 \times UFDS \qquad (1)$$

Where:	FD	=	Foamed density of the slurry
	%G	=	Percentage of gas in final foamed slurry
	UFDS	=	Unfoamed slurry density with surfactant(s)

When a desired foamed slurry density is known or after calculating it with Equation 1, determine the grams of cement slurry including surfactant(s) that is to be placed into the foam blender to prepare the foamed slurry. This can be calculated by Equation 2.

$$GUFS = CV \times FD \qquad (2)$$

Where:	GUFS	=	Grams of unfoamed slurry including surfactant(s) to be placed into the foam mixer
	CV	=	Container volume of foam mixer (mL)
	FD	=	Foamed density of the slurry (g/mL)

Example:	Container volume	=	1170 mL
	Base slurry density	=	14.5 lb/gal (1.74 g/mL)
	Foamed cement density	=	10.0 lb/gal (1.2 g/mL)
	Unfoamed slurry weight	=	1170 mL × 1.2 g/mL = 1404 g

B.5.2 Surfactant(s) and Slurry Weight

The surfactant(s) weight is determined by taking the unfoamed slurry weight and multiplying by the percent by weight of surfactant(s). The slurry weight is determined by taking the unfoamed slurry weight and subtracting the surfactant(s) weight. This can be calculated by Equation 4.

$$GS = GUFS \times (\%Surfactant/100) \quad (3)$$

Where: GS = Grams of surfactants (total) to place into the foam mixer with the unfoamed slurry without surfactant(s)
GUFS= Total grams unfoamed slurry prepared in Section B.1

$$GUSM = GUFS - GS \quad (4)$$

Where: GUSM = Grams of unfoamed slurry without surfactant(s) to be placed into the mixer.

Example: Unfoamed slurry weight = 1404.1 g
Percent by weight of surfactant = 1.3 %

Surfactant weight = 1404.1 × 0.013 = 18.5 g
Slurry weight = 1404.1 - 18.5 = 1385.6 g

B.6 Preparing the Atmospheric Foamed Slurry

Based on the volume calculated in Section B.5.1, weigh the appropriate amount of the prepared slurry into the special mixing container. Add the calculated amount of surfactant(s). The final weight of the cement slurry and added surfactant(s) should be checked against the final desired base slurry density. Before foaming, verify that the total weight of the slurry and added surfactant(s) corresponds to the weight calculated in Section B.5.2.

B.6.1 Generating a Foamed Cement

Make sure the mixing container is sealed. Using the blade assembly described in Section B.2.2, the slurry should be mixed at the 12,000 rpm setting for 15 seconds. Because of the increase in slurry volume and viscosity, the maximum rpm of the blender could be less than 12,000 rpm. The maximum attainable rpm will depend on the power of the blender, slurry density, and foam quality. Record and report the final rpm of the mixer.

During the mixing, there will be a noticeable change in the sound (pitch) from the blender. After mixing, there may be some slight pressure in the mixing container because of temperature increases and energy imparted to the foam during the foaming process. Be careful when removing the top of the mixing container. After mixing, open the sampling port or container lid, and verify that the slurry completely fills the slurry-mixing container. If the slurry does not fill the mixing container at the end of the 15-second

mixing, it is doubtful the slurry will foam properly under field conditions. The slurry should be redesigned.

B.7 Atmospheric Testing of Foamed Cement Slurries

Because of the high air entrainment in a foamed cement slurry, it is necessary to modify some of the standard testing procedures to prevent obtaining erroneous test results.

B.7.1 Determining Foamed Slurry Density

The density of the foamed slurry should be determined by pouring it into a container with a large open top that has a known volume when completely filled. Weigh the container, pour the foamed slurry into the container, and level the top with a straight blade. Wipe the outside of the container clean, and weigh the container with the foamed slurry. The density of the foamed slurry in the container is determined by dividing the slurry mass by the container volume and converting to the appropriate density units.

NOTE: Downhole densities may be different than designed values depending on pressure and temperature conditions. Special software is used to predict downhole densities.

B.7.2 Determining Slurry Stability

B.7.2.1 Unset Slurry Stability

Evaluate the foam stability by pouring a sample of the foamed cement slurry into a container or graduated cylinder for 2 hours of continued evaluation. Cover or seal the top of the container to prevent drying or dehydration of the sample. Since the main purpose of this test is to check for settling and stability in the foamed slurry, the visual appearance of the foamed slurry (such as free fluid, settling, or bubbles concentrated in a specific area) must be noted. If desired, density measurements may be made of the foam at multiple locations in the cylinder after the 2-hour period. To determine the density of the slurry at various locations in the cylinder, a large syringe with a Tygon tube on it can be used to remove small portions from the top, middle, and bottom. The removed slurry can then be transferred to a smaller graduated cylinder to determine the weight of a known volume of the slurry. From there, the specific gravity and density can be determined.

Pour the foamed slurry into a standard 250-mL graduated cylinder that is used for free-fluid testing. Cover the top of the cylinder to prevent dehydration, place it onto the counter-top, and visually examine it during the 2-hour period. The cylinder cannot be cured at temperatures above the ambient temperature at which the foamed slurry was prepared because an increase in temperature will increase the bubble size and may have an effect on the slurry stability.

B.7.2.2 Set Slurry Stability

Check foam stability by curing samples until they are set for density gradient measurement throughout the sample. These may be cured in non-greased, covered 50.8-mm (2-in.) diameter, 101.6-mm (4-in.) tall cylinders or any appropriate covered container. Use of grease or other mold-release agents should be avoided as these materials may affect the stability of the foamed cement.

Cut or break the samples into sections, mark them from the top to the bottom, and measure the specific gravity of each section. The specimen should not be cut with a saw that uses water. The use of water may cause the specimen to absorb water and change the density of the specimen. Large variations in density from sample top to bottom are an indication of instability. When determining the specific gravity by Archimedes principal, it is recommended that a beaker of fresh water be placed on a scale and tared. The specimen is placed into a loop of fine string (or thread) and suspended in the water for the first measurement for determining the volume of the specimen (V). The volume of the specimen (mL) will be equal to the weight of the water displaced by the specimen when suspended in the water. The weight of the specimen being suspended in the water must be determined quickly to prevent the specimen from absorbing water and giving erroneous results. The specimen is then lowered to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W). The specific gravity (SG) is then determined by dividing the weight, W (in grams) by volume, V (in mL). The slurry density can also be determined ($SG \times 8.33 = lb/gal$).

Signs of foam instability include the following:
- More than a trace of free fluid.
- Bubble breakout noted by bubbles appearing on the surface of the sample.
- Excessive gap at the top of the specimen. Minor meniscus effects are normal.
- Visual signs of density segregation as indicated by streaking or light to dark color change from top to bottom.
- Large variations in density from sample top to bottom.

B.7.3 Determining Compressive Strength

The foamed cement slurry is poured into a curing mold that can be sealed. The sealing lid prevents the foamed slurry from expanding out of the curing mold as it is heated. This expansion can result in an undesired density decrease. The mold can be a standard 50.8-mm (2-in.) cube mold with a cover clamped to the top.

The sealed mold containing the foamed cement slurry is then placed into an atmospheric water bath, cured, and the strength is determined as specified by API. The temperature is normally limited to approximately 65°C (149°F), but can sometimes be increased to 90°C (194°F) if there is sufficient seal to prevent the slurry from expanding out of the curing mold.

B.8 Determining Other Tests on Base Unfoamed Slurry

A slurry that is foamed at atmospheric pressure should not be tested under pressure. Applying pressure to a foamed slurry prepared at atmospheric pressure will compress the foam, changing the density and gas ratio. This can also allow contamination when tested in a HPHT consistometer for thickening time.

For the following tests, the base unfoamed slurry without the surfactant(s) is prepared according to ISO 10426-2[2], clause 5. After the slurry is prepared, the mixer is stopped and the surfactant(s) added and stirred gently with a spatula to distribute it uniformly in the slurry. It is recommended the slurry be transferred gently from the mixing container to a beaker and back three times to ensure a uniform distribution. The use of a small amount of material for preventing/breaking air entrainment in slurries that are not foamed is permitted for these tests. Materials to prevent/break air entrainment should not be used in any foamed slurries.

B.8.1 Determining Thickening Time

Since the surfactant(s) will affect the thickening time, and the foam itself does not affect the thickening time of a cement slurry, the thickening time test is normally performed using a standard HPHT consistometer on the base unfoamed cement slurry containing the surfactant(s).

The thickening time test of the unfoamed slurry containing the surfactant(s) will be performed using the procedures in ISO 10426-2[2], clause 9.

B.8.2 Determining Fluid Loss

Fluid-loss tests performed with a foamed cement prepared at atmospheric pressure will not yield reliable results. The fluid loss values obtained from a foamed cement slurry will be slightly less than that of the base unfoamed cement slurry. The fluid loss of the base unfoamed cement is normally used as an indication of the fluid loss of the foamed cement slurry.

The static fluid-loss test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 10.

B.8.3 Determining Rheological Properties

With the concentration of gas in a foamed slurry changing continuously during pumping of the job, it is impractical to perform rheological testing at all the foam quality concentrations that are needed to model the frictional pressures during pumping of a foamed slurry. Use of a rotational viscometer will result in separation of the gas from the slurry, causing erroneous results. Correlations can be used to convert the rheological properties of the base unfoamed slurry to that of a foamed cement with varying foam qualities to simulate the job.

The rheological test of the unfoamed slurry containing the surfactant(s) is performed using the procedures in ISO 10426-2[2], clause 12.

References

[1] ISO 10426-4: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 4: Recommended Practice for Atmospheric Foam Cement Slurry Preparation," working draft 2001.
[2] ISO 10426-2: "Petroleum and Natural Gas Industries—Cements and Materials for Well Cementing, Part 2: Recommended Practice for Testing of Well Cements," 1998.

Appendix 8

Quarterly Report 8

Ultra-Lightweight Cement

Eighth Quarterly Technical Progress Report

July 1 to September 30, 2002

Fred Sabins

Issued October 31, 2002

DOE Award Number
DE-FC26-00NT40919

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report includes results from laboratory testing of ULHS systems along with other lightweight cement systems, including foamed and sodium silicate slurries. During this project quarter, a comparison study of the three cement systems examined the effect that cement drillout has on the three cement systems. Testing to determine the effect of pressure cycling on the shear bond properties of the cement systems was also conducted. This report discusses testing that will be performed for analyzing the alkali-silica reactivity of ULHS in cement slurries, as well as the results of Field Tests 1 and 2.

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Corrigendum

One of the cement types used in the project's tests has been inaccurately referred to as Class A in previous quarterly progress reports. The cement is actually Type I cement. Although Class A and Type I cements are very similar, they are different cements.

In previous progress reports, the "Class A" designation should be replaced with "Type I" when used to describe the cement being tested.

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water.

This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

Executive Summary

Laboratory testing during the eighth quarter was a continuation and extension of testing conducted previously. Tests were performed for comparing the performance of slurries containing ULHS to that of foamed and sodium silicate cement systems. Comparison studies examined shear bond strength after pressure-cycling conditions.

Two field tests were designed and conducted to test the slurry's performance in actual formations. The first field test was designed to ensure that the slurry could be easily blended, mixed, and pumped on location, in actual wells with little trouble. The second field test was designed to test the slurry's performance in a land-based well that closely resembled deepwater operations.

This report provides the following information:

- Field testing results
- Cement Quality –Control Program and QC program data (Appendix A)
- Description of the completed cement slurry software program used to calculate the amount of ULHS needed for specific densities
- Alkali-Silica Reactivity Testing description and procedures (Appendix E)
- On-Site Testing Summary of DOE Field Job 2 (Appendix B) and the Cement Testing Report for Field Job 2 (Appendix C)
- Preliminary Halliburton Job Recommendations (Appendix D)

Field Testing Result

The second field test was performed in the Rocky Mountains in a well operated by the DOE and Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming. The second field test well conditions were 5,765 ft TD, with a static temperature of 200°F and a bottomhole circulating temperature of 130°F. The previous well had been cemented with foam cement. These wells typically have problems with lost circulation and require high-strength cement and good zone isolation. This well required one hundred barrels of the ultra-lightweight cement slurry (using 3M 6K ULHS beads). The slurry was mixed and pumped with no problems, and the ULHS beads showed no breakage after one hour of conditioning at the surface. Complete fluid returns were observed during the entire cementing job. This was verified through density measurements every ten minutes. Tables 1 through 4 in Appendix B provide collected data.

Ultrasonic logs performed on the well after the cement operation showed good bonding to both pipe and formation (Fig. 1). In Figure 1, the callout entitled Good Pipe Bond shows that the amplitude of the ring of the pipe was very low indicating good coupling of the pipe. The second callout, Good Formation Bond, provides an estimation of the quality of the cement bond to the formation. In this case, the variable formation signal indicates a good cement formation bond. The third callout, High Impedence, High Compressive Strength, Good Bond, indicates that the impedence values of the cement measured were high as evidenced by the dark color (the darker the color, the higher the cement strength).

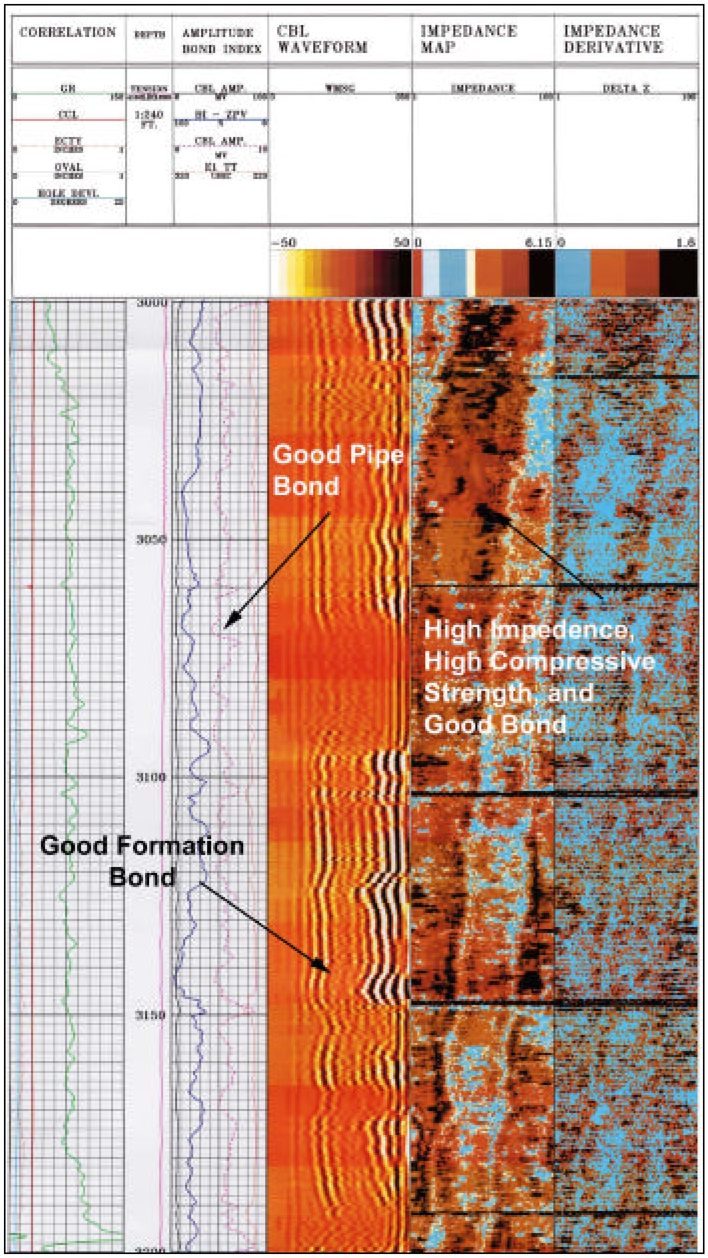

Figure 1—CBL and ultrasonic log for 10 lb/gal ULHS slurry

A summary of the field test parameters and results for Field Test 2 is shown in Table 1.

Table 1—Field Test 2 Parameters and Results

County	Natrona County, Wyoming
TD	5,765 ft
Hole Size	8 3/4 in.
Production Casing	7 in.
Slurry Density	10 lb/gal
Lead Cement	ULHS w/ TXI Lighweight
Tail Cement	TXI Lightweight
Static Temperature	200°F
Bottomhole Circulating Temperature	130°F

Software Program

To assist in designing cement slurries made with ULHS, a software program was developed to calculate the amount of ULHS beads required for specific densities. The program does not simulate cement jobs and fluid dynamics. Instead, the program focuses on the static final placement of the fluids (i.e., the slurry composition and slurry properties such as yield and density).

The software program uses an inputted water requirement to calculate the amount of beads needed in the slurry.

The program has been distributed to the project participants. Fig. 2 through Fig. 5 show the screens included in the program interface.

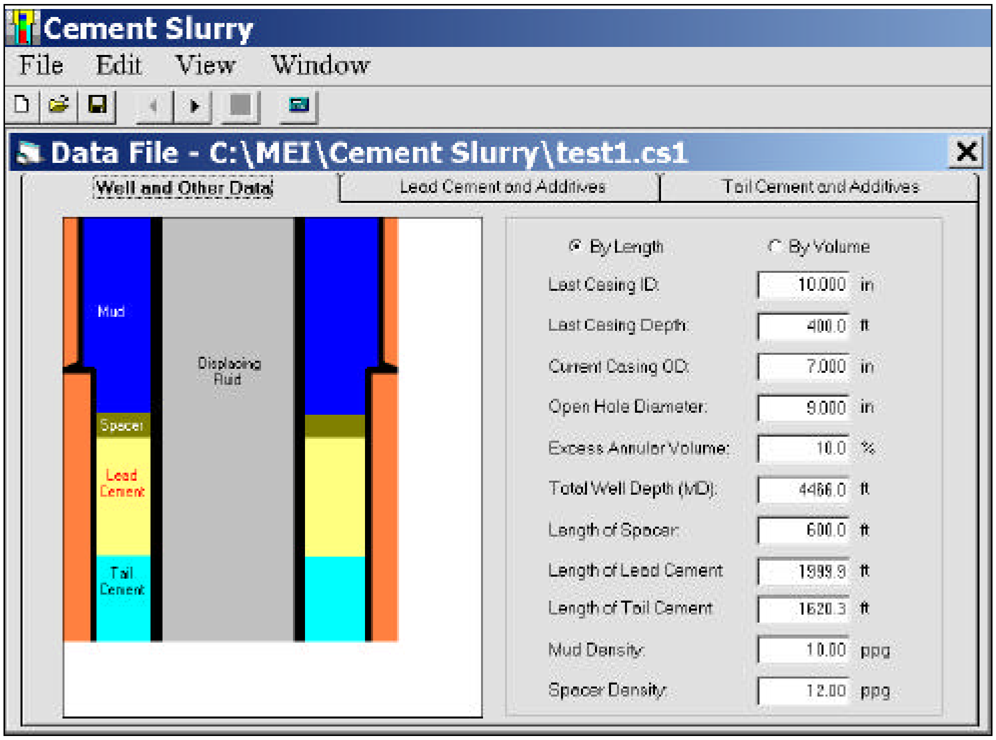

Figure 2—General well information

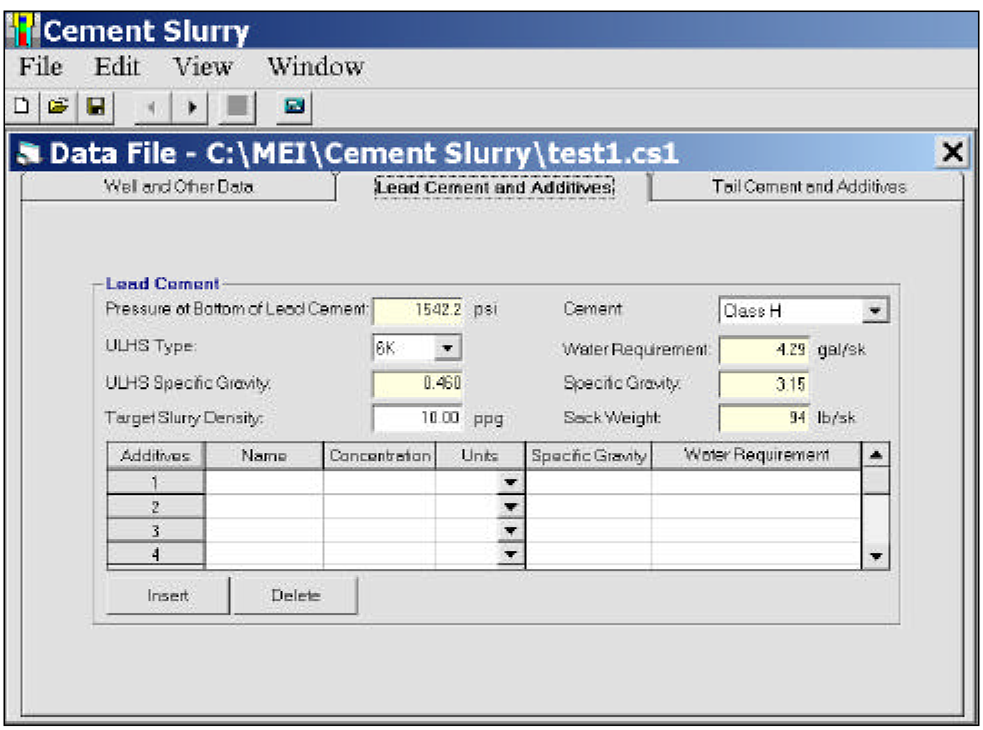

Figure 3—Lead cement parameters

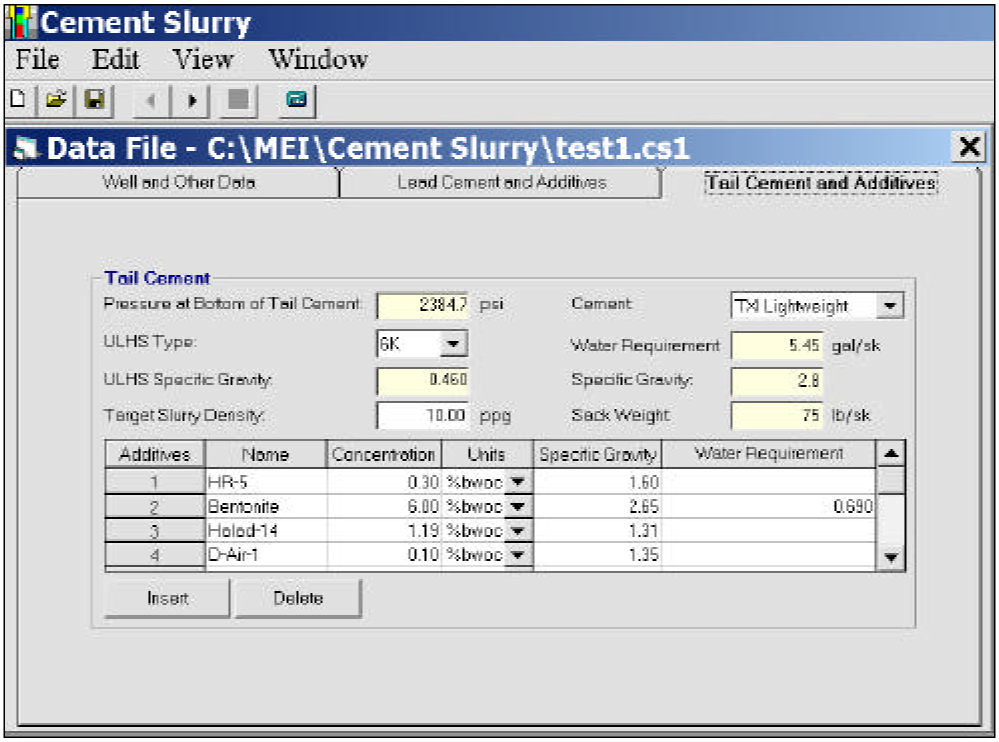

Figure 4—Tail cement parameters

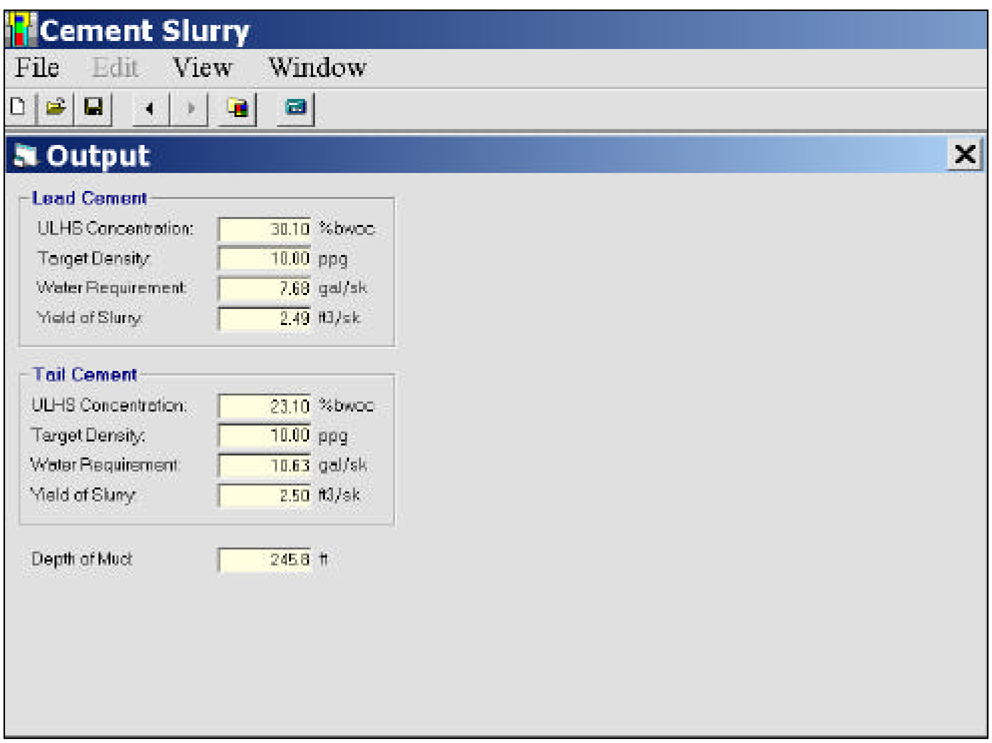

Figure 5—Output screen containing job design requirements

Alkali-Silica Testing

Approval was made for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oil well cements, and conduct long-term tests to verify if ASR is occurring and when and how it manifests itself. Appendix D provides the proposed testing program.

Conclusions

1. A field job was successfully completed using the ULHS in Natrona County, Wyoming.
2. Ultrasonic and sonic logs performed on the well after the cement operation showed good cement bond to pipe, good cement bond to formation, and high compressive strengths.
3. A computer program was developed to assist in slurry design of ULHS cement systems.
4. A recommended procedure and testing protocol was developed for Alkali-Silica Reactivity of ULHS slurries.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Recommended Practice 10B: “Recommended Practices for Testing Well Cements,” 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

Appendix A—Quality Control Testing

Class A

TXI Provided Information		CSI Information				CSI Thickening Time					
Cmt Class	Mill Production Run Date	Date Received	CSI Log #	Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	15'-30' Bc	100 Bc	Pass/ Fail
Type I	9/25 to 9/27/00	11/06/00	C-113 A-1	11/09/00	11/15/00	46.0	4	9	10	2:17	**Pass**
Type I	9/25 to 9/27/00	11/06/00	C-113 A-2	11/20/00	01/05/01	46.0	4	8	11	2:21	**Pass**
Type I	9/25 to 9/27/00	11/06/00	C-113 A-3	12/04/00	01/09/01	46.0	4	4	**ran**	**out**	**of sample**
Type I	9/25 to 9/27/00	11/06/00	C-113 A-4	01/09/01	01/17/01	46.0	4	4	6	2:09	**Pass**
Type I	9/25 to 9/27/00	11/06/00	C-189-A-8	07/11/01	08/15/01	46.0	4	6	8	1:50	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-17	08/30/01	09/12/01	46.0	4	6	8	2:00	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	10/16/01	46.0	4	7	11	1:41	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	11/13/01	46.0	4	7	13	1:53	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-6	10/16/01	12/21/01	46.0	4	6	11	1:46	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-11	01/17/02	01/14/02	46.0	4	8	15	1:42	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-12	02/17/02	02/11/02	46.0	4	15	17	1:40	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-13	02/28/02	03/04/02	46.0	4	14	12	2:10	**Pass**
Type I	9/25-9/27/00	11/06/00	C-189-A-14	03/27/02	04/02/02	46.0	4	21	19	1:46	**Pass**
Type I	4/19-4/21/02	05/02/02	C-418-A	05/02/02	05/03/02	46.0	4	27	28	2:15	**Pass**
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	06/25/02	46.0	4	32	30	2:00	**Pass**
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	07/24/02	46.0	4	29	28	1:59	**Pass**
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	08/08/02	46.0	4	29	28	1:57	**Pass**
Type I	4/19-4/21/02	05/02/02	C-418-B	06/19/02	09/24/02	46.0	4	29	28	1:59	**Pass**

Lightweight

TXI Provided Information			CSI Information				CSI Thickening Time					
Cmt Class	Mill Production Run Date	Grind	Date Received	CSI Log #	Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	70 Bc	100 Bc	Pass/ Fail
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-1	11/07/00	11/15/00	75.0	5	6	2:02	**2:20**	
LW	9/15 to 9/18/00	62	11/06/00	C-108 B-2	12/05/00	01/05/01	75.0	5	5	2:00	**2:17**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-12	07/03/01	08/14/01	75.0	5	7	2:03	**2:22**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-7	09/05/01	09/10/01	75.0	5	6	1:57	**2:17**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	10/16/01	75.0	5	4	2:07	**2:26**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	11/13/01	75.0	5	5	2:05	**2:25**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-14	09/24/01	12/21/01	75.0	5	7	2:03	**2:22**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-13	12/04/01	01/11/02	75.0	5	8	1:58	**2:12**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-15	01/22/02	02/08/02	75.0	5	7	2:05	**2:15**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	03/04/02	75.0	5	13	2:11	**2:27**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	04/09/02	75.0	5	23	1:54	**2:16**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-16	05/15/02	05/16/02	75.0	5	19	2:00	**2:12**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	06/26/02	75.0	5	24	1:53	**2:10**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	07/26/02	75.0	5	23	1:59	**2:09**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	08/22/02	75.0	5	23	2:05	**2:15**	
LW	9/15 to 9/18/00	62	11/06/00	C-108-B-18	02/25/02	09/12/02	75.0	5	23	2:00	**2:10**	

Class H

TXI Information		CSI Information				CSI Thickening Time						CSI 8hr					CSI 8hr Strengths				
Cmt Class	Prod. Date	Date Received	CSI Log #	Date Bucket Opened	Test Date	% H_2O	Sch #	Int Bc	15'-30' Bc	100 Bc	Pass/ Fail	Time Hrs	Temp °F	Old	Str psi 1.565	Pass/ Fail	Time Hrs	Temp °F	Old	Str psi 1.565	Pass/ Fail
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/07/00	38.0	5	**ran**	**out**	**of sample**		8	100	335	**524**	**Pass**	8	140	1334	**2087.71**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	11/29/00	38.0	5	12	13	2:03	**Fail**	8	100	307	**480**	**Pass**	8	140	1437	**2248.91**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/11/01	38.0	5	7	13	1:54	**Pass**	8	100	768	**1201.92**	**Pass**	8	140	1255	**1964.08**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	01/12/01	38.0	5					8	100	664	**1039.16**	**Pass**	8	140	1122	**1755.93**	**Pass**
H	9/27/00	11/06/00	C-108 A-2	11/06/00	02/12/01							8	100	271	**424**	**Pass**	8	140	1097	**1716.81**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01												8	140		**1617**	**Pass**
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01												8	140		**1567**	**Pass**
H	9/27/00	11/06/00	C-108 A-1	11/06/00	02/22/01												8	140		**1550**	**Pass**
H	9/27/00	11/06/00	C-108 A-3	02/22/01	02/22/01												8	140		**1580**	**Pass**
H	9/27/00	11/06/00	C-108 A-6	07/20/01	08/13/01	38.0	5	15	20	1:50	**Pass**										
H	9/27/00	11/06/00	C-108 A-7	08/27/01	09/06/01	38.0	5	19	17	2:00	**Pass**										
H	9/27/00	11/06/00	C-108 A-3	02/22/01	10/09/01	38.0	5	12	15	1:53	**Pass**										
H	9/27/00	11/06/00	C-108 A-3	02/22/01	11/13/01	38.0	5	13	20	1:50	**Pass**										
H	9/27/00	11/06/00	C-108 A-3	02/22/01	12/20/01	38.0	5	14	21	1:45	**Pass**										
H	9/27/00	11/06/00	C-108 A-3	02/22/01	01/11/02	38.0	5	13	17	2:00	**Pass**										
H	9/27/00	11/06/00	C-108 A-8	01/14/02	02/08/02	38.0	5	28	19	1:55	**Pass**										
H	9/27/00	11/06/00	C-108 A-8	01/14/02	03/05/02	38.0	5	18	18	1:55	**Pass**										
H	9/27/00	11/06/00	C-108 A-8	01/14/02	04/04/02	38.0	5	24	27	2:00	**Pass**										
H	9/27/00	11/06/00	C-108 A-8	01/14/02	05/15/02	38.0	5	22	22	1:50	**Pass**										
H	9/27/00	11/06/00	C-108 A-10	06/11/02	06/25/02	38.0	5	26	27	1:50	**Pass**										
H	9/27/00	11/06/00	C-108 A-10	06/11/02	07/25/02	38.0	5	24	28	1:49	**Pass**										
H	9/27/00	11/06/00	C-108 A-10	06/11/02	08/09/02	38.0	5	24	28	1:45	**Pass**										
H	9/27/00	11/06/00	C-108 A-10	06/11/02	09/19/02	38.0	5	24	28	1:52	**Pass**										

Appendix B—On-Site Testing Summary of DOE Field Job #2

A 10 ppg, TXI Lightweight ULHS lead cement slurry was pumped as the lead slurry. The Tail slurry was a 13.5 ppg TXI Lightweight cement slurry mixed with 1% HALAD- 9. As seen in Table1, no changes in rheological properties occurred except for an increase in temperature after the slurry began to mix inside the RCM. The slurry was mixed on the RCM for an hour and rheologies were taken initially every five minutes; but after no change was noticed the sampling time was extended to every 10 minutes. The consistent rheologies indicated that no shearing of ULHS had occurred.

The rheologies shown in Tables 1 through 4 are much lower than the rheologies shown in Halliburton's lab report in Appendix C. We are uncertain of what caused this discrepancy.

Table 1.

Summary of Viscosity Change as a Result of Shearing in RCM

Lead: TXI Lightweight Cement + 25% ULHS + 0.3% HR-5 + 0.5% HALAD-9 + 7.57gps Water + 0.20%CFR-3

Time (minutes)	Temperature (°F)	Rheological Properties 300	200	100	60	30	20	10	6	3	PV	YP
0	91.7	86	60	34	26	18	14	12	10	10	78	8
5	93.5	100	70	40	28	18	14	12	10	10	90	10
15	93.5	96	64	38	26	18	16	10	10	10	87	9
20	94.1	90	64	40	28	18	14	10	10	8	75	15
30	94.5	92	62	36	24	16	14	10	10	8	84	8
40	94.3	90	62	38	26	18	14	10	10	8	78	12
50	94.2	82	60	36	26	18	14	10	10	8	69	13
60	94.3	86	60	38	26	16	14	10	10	8	72	14

Table 2 below lists the rheological properties of lead slurry sampled in the flow line as it was being pumped into the well. The slurry was pumped at a rate of 4 bpm. The slurries viscosity remained the same as those samples taken from the RCM through the first 10 minutes of sampling.

Table 2

Summary of Viscosity Change as Slurry was Pumped into Well

Lead: TXI Lightweight Cement + 25% ULHS + 0.3% HR-5 + 0.5% HALAD-9 + 7.57gps Water + 0.20% CFR-3

Time (minutes)	Temperature (°F)	300	200	100	60	30	20	10	6	3	PV	YP
0	90.1	96	70	42	30	20	20	16	14	14	81	15
5		90	64	36	20	16	14	10	10	8	81	9
10	87.8	72	50	30	22	16	14	10	10	8	63	9
15	90.9	76	42	30	24	16	14	10	10	10	69	7

Pressurized Mud Balance was used during the job to verify density and record any changes that might occur during blending and agitation. Table 3 indicates time required to mix cement and achieve density of 10.0 ppg.

Table 3

Time	Density
16:15	**10.6 ppg**
16:25	**10.1 ppg**
16:40	**10.0 ppg**

Table 4 indicates time in blender agitating prior to pumping slurry downhole.

Table 4.

16:55	**9.9 ppg**
17:05	**10.0 ppg**
17:10	**10.0 ppg**
17:20	**10.0 ppg**
17:30	**10.0 ppg**
17:45	**10.0 ppg**
17:50	**10.0 ppg**
18:00	**10.0 ppg**
18:15	**10.0 ppg**
18:30	**10.0 ppg**
18:35	**10.0 ppg**
18:45	**10.0 ppg**

The cement remained in the blender for 1 hour and 50 minutes prior to pumping without any change in density. Aeration of slurry caused loss of prime to centrifugal pump twice during agitation period. This is a normal phenomenon when no additive is used to prevent foaming of slurry.

Job Log

Halliburton	Job Log		TICKET # 1953511	TICKET DATE 10/18/02
REGION NORTH AMERICA LAND	NWA / COUNTRY WESTERN		BDA / STATE DENVER, CO	COUNTY NATRONA
MBU ID / EMPL #	H.E.S EMPLOYEE NAME		PSL DEPARTMENT ZONAL ISOLATION	
LOCATION CASPER, WY	COMPANY RMOTC		CUSTOMER REP / PHONE CLAUD DICKEY	
TICKET AMOUNT	WELL TYPE		API/UWI #	
WELL LOCATION NATRONA, WY	DEPARTMENT CEMENTING SERVICES 10003		JOB PURPOSE CODE	
LEASE / WELL # DOE	Well No. 41-2-X-3	SEC / TWP / RNG		

Date	Time	Rate	Volume	N2 Rate	Pressure (psi)		Job Description / Remarks
mo/dy/yr		(bpm)	(bbl)(gal)	(scfm)	tbg/csg	bksd	
7-19-02	1400						ARRIVE ON LOCATION
	1420						BLOW OFF CEMENT INTO FIELD BIN
	1500						RIG UP SWEDGE AND CIRCULATE WITH 9.0 PPG MUD
	1545						RIG UP HES EQUIPMENT
	1630						MIX AND CIRCULATE 94 BBLS LEAD CEMENT
	1745						SAFET MEETING WITH RIG CREW
	1800						REMOVE SWEDGE AND STAB PLUG CONATINER
	1823	5			4000		PRESSURE TEST LINES
	1826	5	10		200		PUMP WATER SPACER
	1828	5	20		200		PUMP SUPERFLUSH
	1832	5	10		250		PUMP WATER SPACER
	1835	5	94		250		PUMP LEAD CEMENT
							10 PPG 2.11 CUFT/SK 7.57 GAL/SK
	1844	2	27		150		CATCH CEMENT SAMPLE
	1850	2	55		100		CATCH CEMENT SAMPLE
	1855	2	80		150		CATCH CEMENT SAMPLE
	1900	5	119		290		PUMP TAIL CEMENT
							13.5 PPG 1.25 CUFT/SK 6.06 GAL/SK
	1922						WASH PUMPS AND LINES
	1923						DROP TOP PLUG
	1924	7	226		90		PUMP DISPLACEMENT

Halliburton

Ticket Number	Company	Lease Name	Well No.	Date	
1953511	RMOTC	DOE	41-2-X-3	10/18/02	2

Date	Time	Rate	Volume	N2 Rate	Pressure (psi)		Job Description / Remarks
mo/dy/yr		(bpm)	(bbl)(gal)	(scfm)	tbg/csg	bksd	
7-19-02							
	1946	7	140		240		CAUGHT CEMENT
	1956	5	200		800		CONTINUE DISPLACEMENT
							GOOD LIFT, FULL RETURNS
	1958	2	212		900		SLOW RATE ON DISPLACEMENT
	2008	2	224.5		1200		BUMP PLUG
							CHECK FLOATS
	2009						FLOATS HELD
	2015						END JOB

Job Chart


DHole Density (lb/gal) A
PS Pressure (psi) B
PS Total (bbl) D
PS Rate (bpm) C
(lb/gal)
Pressure (psi)
Rate (bpm)
Volume (bbl)
18:20 7/19/2002
18:40
19:00
19:20
19:40
20:00 7/19/2002
Time
Stages
1 Pump Spacer 18:19:14
2 Pump Spacer 18:26:21
3 Pump Spacer 1 18:28:09
4 Pump Spacer 2 18:29:45
5 Pump Lead Cement 18:32:13
6 Pump Lead Cement 18:35:01
7 Catch Cement Sample 18:43:42
8 Catch Cement Sample 18:50:28
9 Catch Cement Sample 18:54:32
10 Pump Tail Cement 18:57:31
11 Pump Shoe Cement 19:19:17
12 Wash Pumps and Lines 19:22:40
13 Pump Displacement 19:22:40
14 Caught Cement 19:45:06
15 Pump Displacement 20:03:07
16 End Job 20:11:19
Customer: RMOTC
Well Description: DOE 41-2-X-3
Job Date: 7-19-02
UWI: 7" Production Casing
Ticket #: 1953511
HALLIBURTON
OptiCem RT v2.3.0
22-Jul-02 08:01

Appendix C—Halliburton Cement Test Report

HALLIBURTON

CEMENT TEST REPORT
HALLIBURTON ENERGY SERVICES
ROCKY MOUNTAIN NWA LABORATORY
EVANSVILLE, WY

Date: 19 Jul 02

Report: RMOTC/CSI, C02-0211

To: Brian Carty
- Halliburton Energy Services
- Casper, Wyoming

PURPOSE

The purpose of this work was to determine the thickening times and rheologies of the submitted slurry pilot designs and bulk plant blends using the conditions listed below.

SCOPE AND PROCEDURE

All tests were performed according to modified API Spec 10.
Re: worksheet # 1077, 1078, 1082, 1083

WELL INFORMATION AND TESTING CONDITIONS

Company	-	RMOTC/CSI
Well Name	-	DOE 41-2-X-3
Job Type	-	Casing
District	-	Casper
State	-	Wyoming
Depth	-	5700 feet
BHST	-	200 degrees F
BHCT	-	130 degrees F
BHP	-	3500 psi

Respectfully submitted,

Nancy K. Lang
HALLIBURTON ENERGY SERVICES

CC: Casper Cementing

LEAD PILOT DESIGN #1

TXI Lightweight	#/sk	75.00
ULHS Beads	#/sk	18.75
Halad 9	% bwc	0.50
CFR-3	% bwc	0.20
HR-5	% bwc	0.30
Lab Tap Water	gal/sk	7.57
Slurry Weight	#/gal	10.00
Slurry Volume	ft3/sk	2.11

THICKENING TIME TEST

Initial Viscosity:	13 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	5:28

RHEOLOGY TESTS

RPM	SURF.
600	350
300	216
200	140
100	84

LEAD BULK PLANT BLEND #3

TXI Lightweight	#/sk	75.00
ULHS Beads	#/sk	18.75
Halad 9	% bwc	0.50
CFR-3	% bwc	0.20
HR-5	% bwc	0.30
Submitted Water	gal/sk	7.57
Slurry Weight	#/gal	10.00
Slurry Volume	ft3/sk	2.11

THICKENING TIME TEST

Initial Viscosity:	25 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	6:25

RHEOLOGY TESTS

RPM	SURF.	110 F	130 F
600	460	370	366
300	282	240	228
200	198	160	156
100	110	88	86

TAIL PILOT DESIGN **#2**

TXI Lightweight	#/sk	75.00
Halad 9	% bwc	1.00
Submitted Water	gal/sk	6.02
Slurry Weight	#/gal	13.50
Slurry Volume	ft3/sk	1.25

THICKENING TIME TEST

Initial Viscosity:	8 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	3:24

RHEOLOGY TESTS

RPM	SURF.
600	214
300	124
200	94
100	60

TAIL BULK PLANT BLEND **#4**

TXI Lightweight	#/sk	75.00
Halad 9	% bwc	1.00
CFR-3	% bwc	0.40
Submitted Water	gal/sk	6.02
Slurry Weight	#/gal	13.50
Slurry Volume	ft3/sk	1.25

THICKENING TIME TEST

Initial Viscosity:	4 Bc
Final Temperature:	130 F
Final Pressure:	3500 psi
Time to Temperature:	0:33
Time to 70 Bc:	3:39

RHEOLOGY TESTS

RPM	SURF.	110 F	130 F
600	154	138	126
300	92	84	80
200	66	60	56
100	40	36	34

Appendix D—Preliminary Halliburton Job Recommendations

Appendix D contains the preliminary recommendation received from Halliburton. The well data and slurry composition shown in this appendix are different than what was actually performed on the job. Although this information is preliminary, it provides the details for volume calculations and critical well parameters. In addition, the well number shown below is wrong and should be DOE 41-2-X-3.

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Job Information ***Tensleep Completion***

DOE 25-1-X-14

Surface Casing	0 - 725 ft (MD)
Outer Diameter	9.625 in
Inner Diameter	8.921 in
Linear Weight	36 lb/ft
Casing Grade	J-55
Job Excess	0 %
Tensleep Production Hole	725 - 5900 ft (MD)
Inner Diameter	10.540 in
Job Excess	10 %
Tensleep Production Casing	0 - 5900 ft (MD)
Outer Diameter	7.000 in
Inner Diameter	6.366 in
Linear Weight	23 lb/ft
Casing Grade	J-55
Job Excess	0 %
Mud Weight	0 lbm/gal
BHCT	0 degF

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Calculations **Tensleep Completion**

Spacer:

151.00 ft * 0.3387 ft^3/ft * 10 %	= 56.25 ft^3
Total Spacer	= 56.15 ft^3
	= 10.00 bbl

Spacer:

301.00 ft * 0.3387 ft^3/ft * 10 %	= 112.13 ft^3
Total Spacer	= 112.29 ft^3
	= 20.00 bbl

Spacer:

151.00 ft * 0.3387 ft^3/ft * 10 %	= 56.25 ft^3
Total Spacer	= 56.15 ft^3
	= 10.00 bbl

Cement : (1515.00 ft fill)

1515.00 ft * 0.3387 ft^3/ft * 10 %	= 564.37 ft^3
Total Lead Cement	= 564.37 ft^3
	= 100.52 bbl
Sacks of Cement	= 270 sks

Cement : (1748.00 ft fill)

1748.00 ft * 0.3387 ft^3/ft * 10 %	= 651.17 ft^3
Tail Cement	= 651.17 ft^3
	= 115.98 bbl

Shoe Joint Volume: (44.00 ft fill)

44.00 ft * 0.221 ft^3/ft	= 9.73 ft^3
	= 1.73 bbl
Tail plus shoe joint	= 660.90 ft^3
	= 117.71 bbl
Total Tail	= 530 sks

Total Pipe Capacity:

5900.00 ft * 0.221 ft^3/ft	= 1304.11 ft^3
	= 232.27 bbl

Displacement Volume to Shoe Joint:

Capacity of Pipe - Shoe Joint	= 232.27 bbl - 1.73 bbl
	= 230.54 bbl

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Job Recommendation ***Tensleep Completion***

Fluid Instructions

Fluid 1: Water Spacer

Water Spacer		Fluid Density:	8.34 lbm/gal
		Fluid Volume:	10 bbl

Fluid 2: Spacer Sweep

Super Flush		Fluid Density:	9.20 lbm/gal
42 lbm/bbl	Fresh Water (Base Fluid)	Fluid Volume:	20 bbl

Fluid 3: Water Spacer

Water Spacer		Fluid Density:	8.34 lbm/gal
		Fluid Volume:	10 bbl

Fluid 4: Lead Cement

TXI Lightweight		Fluid Weight	10 lbm/gal
75 lbm/sk	TXI Lightweight (Cement-api)	Slurry Yield:	2.09 ft^3/sk
25 %	Spherelite (Light Weight Additive)	Total Mixing Fluid:	7.57 Gal/sk
0.2 %	Halad(R)-9 (Low Fluid Loss Control)	Top of Fluid:	2637 ft
		Calculated Fill:	1515 ft
		Volume:	100.51 bbl
		Calculated Sacks:	270 sks
		Proposed Sacks:	270 sks

Fluid 5: Tail Cement

TXI Lightweight		Fluid Weight	13.50 lbm/gal
75 lbm/sk	TXI Lightweight (Cement-api)	Slurry Yield:	1.25 ft^3/sk
0.2 %	Halad(R)-9 (Low Fluid Loss Control)	Total Mixing Fluid:	6.10 Gal/sk
		Top of Fluid:	4152 ft
		Calculated Fill:	1748 ft
		Volume:	117.71 bbl
		Calculated Sacks:	530 sks
		Proposed Sacks:	530 sks

Fluid 6: Water Spacer

Fresh Water Displacement		Fluid Density:	8.34 lbm/gal
		Fluid Volume:	230.54 bbl

The Cement and Hollow Beads will be Customer Supplied.

Appendix E—Alkali-Silica Reactivity (ASR) Testing

Objective

The goals of this project are to study the long-term effects of the alkali-silica reaction in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR.

Alkali-silica reactivity (ASR) is a chemical reaction that occurs between alkali and reactive silica present in cement and concrete mixes. When this reaction occurs, a gel is formed that absorbs available water and increases internal pressure, eventually causing the cement to fracture. This fracturing renders the cement vulnerable to several hazardous materials that can severally weaken the structure of the cement matrix causing it to fail.

Testing Procedures

A variation of the Length Change of Hardened Hydraulic-Cement Mortar and Concrete (ASTM C157-93) methods was used to test expansion in the slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) methods were used to determine a change in the tensile strength of specimens as a result of ASR. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and 6 months. For statistical purposes, nine replicates of each slurry are made.

Test Slurry Composition

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal will be used. Ultra-light hollow sphere (ULHS) slurries with similar bead concentrations and a density of 9.0 lb/gal will also be used. Several 0.5% sodium chloride slurries will be used to evaluate accelerated ASR.

Neat Slurries (Baseline)

- Class H cement mixed with 4.3 gal of fresh water per sack to achieve a density of 16.4 lb/gal
- TXI Lightweight cement mixed with 6.0 gal of fresh water per sack to achieve a density of 13.5 lb/gal

Ultra-Light Hollow Sphere (ULHS) Slurries

- Class H cement plus 42.14% BWOC 3M 6K (6,000 psi) beads mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal

- TXI Lightweight cement plus 37.19% BWOC 3M 6K (6,000 psi) beads mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Salt Slurries

- Class H cement plus 0.5% BWOC NaCl mixed with 4.3 gallons of fresh water sack for a density of 16.4 lb/gal
- TXI Lightweight cement plus 0.5% BWOC NaCl mixed with 6.0 gallons of fresh water per sack for a density of 13.5 lb/gal
- Class H cement with 42.14% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- TXI Lightweight cement with 37.19% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Testing Conditions

- Application No. 3 – 128°F / 174°F (BHCT/BHST)
- Slurries were tested for a minimum of 200 days.

Mixing Procedures

Prepare a ULHS slurry as follows.

1. Weigh the appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry according to Appendix A of API RP 10B.
3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place this slurry in a Waring blender and mix at 4,000 rpm for 15 seconds. Then, return each specimen to lime-saturated water.

Alkali-Silica Reactivity (ASR) Testing for Expansion

Curing the Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made. Cure each test specimen in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
    - Never strike or jar a specimen during removal.
    - Never exert pressure directly against the gage studs.
    - Make sure the gage stud holder remains attached to the stud during specimen removal.

Important—To avoid damaging the specimens during removal from the molds, it may be necessary to leave the specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimens are within ±1/2 hour of the same age at the time the initial comparator reading is performed.

2. Mark specimens for identification or positioning as required with a soft graphite pencil, a graphite liquid that deposits graphite without binder, or waterproof, indelible ink. Never use any other writing instrument.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.
4. When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Apparatus

Molds for cement specimen curing have one section and are constructed as shown in Fig. 6. Molds for test specimens used in determining the length change of cement pastes and mortars produce 1 × 1 × 11 ¼-in. prisms with a 10-in. gage length. The gage length is the nominal length between the innermost ends of the gage studs. The parts of the molds should fit tightly and firmly together when assembled, and their surfaces should be smooth and free of pits.

The molds are made of steel not readily attacked by the cement paste, mortar, or concrete. The sides of the molds should be sufficiently rigid to prevent spreading or warping. For the molds shown in Fig. 6, the tolerance on dimension A is ±0.03 in. Each end plate of the mold is equipped to hold properly in place during the setting period.

The gage studs are of American Iron and Steel Institute (AISI) 3 Type 316 stainless steel. To prevent restraint of the gage studs before the specimen is removed, the device for holding the gage studs in position is arranged such that it can be partially or completely released after the slurry compacts in the mold. The gage studs are set so their principal axes coincide with the principal axis of the test specimen. For the molds shown in Fig. D-1, gage studs extend into the specimen 0.625 ± 0.025 in. and the distance between the inner ends of the gage studs is 10.00 ± 0.10 in.. Ten inches is the gage length for calculating length change.

Test Measurement

The comparator for the molds shown in Fig. D-1 features a dial micrometer or other measuring device graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens. The terminals of the comparator are plane, polished, and heat-treated, and are fitted with collars held in place with set screws. The collars extend 0.062 ± 0.003 in. beyond the plane face of the terminal and have an inside diameter 0.02 in. greater than the average diameter of the portion of the gage studs that must fit into the collars.

The comparator must allow the checking of the measuring device against a reference bar at regular intervals. The reference bar has an overall length of 11 5/8 ±1/8 in. for the specimen in use. The bar is made of a steel alloy with a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end of the reference bar is fitted with heat-treated, hardened, and polished tips machined to the same shape as the contact end of the gage studs used in test specimens.

Reference Bar

Place the reference bar (Fig. D-2) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of immersion, blot the pins, place the bar in the comparator, read, and record the indication.
4. Return the bar to immersion and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to immersion, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:
L = change in length at *x* age, %
Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;
Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time
G = nominal gage length, 10 in.

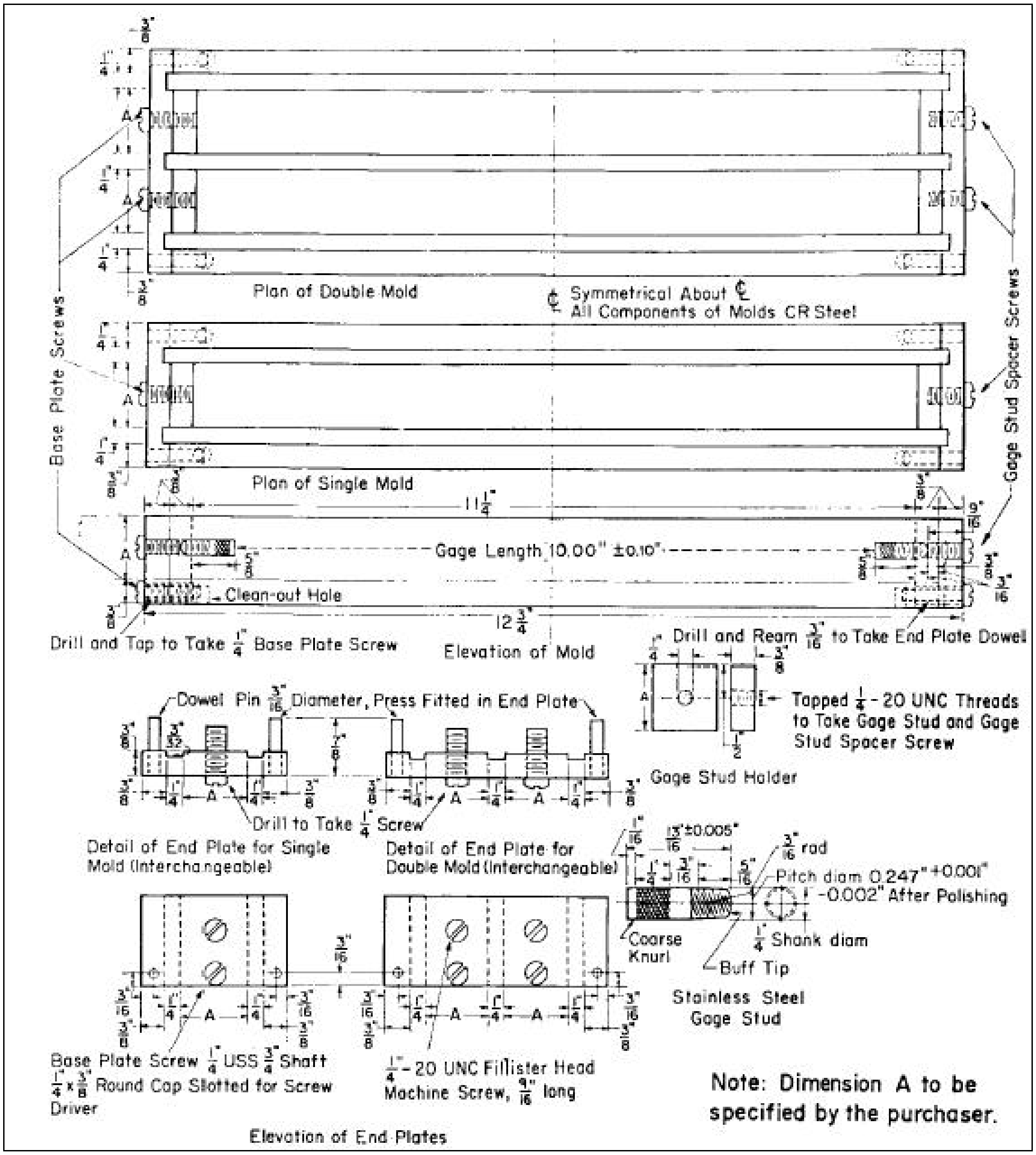


Figure D-1—Test specimen mold schematics

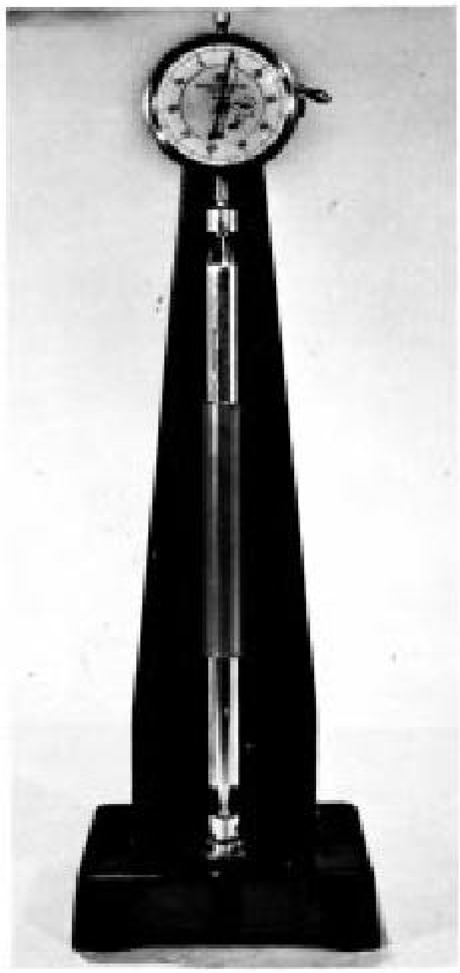


Figure D-2—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is placed in a 1.5 × 5-in. mold sealed at both ends.

Curing the Cement Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made.

Prepare the molds as follows.

1. Place slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Stir the remaining slurry by hand and place into additional molds and repuddle it.

3. Seal the molds and place them upright in a heated, circulating water bath at the appropriate curing temperature.
4. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.

Important—To avoid damaging the specimen during removal, it may be necessary to leave specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimen are within ±1/2 hour of the same age at the time the initial comparator reading is performed.

Test Measurement

After curing, the sample is extracted from the mold and cut into 1-in. ±1/8 in. sections in length. The density of each sample is measured before it is measured for tensile strength.

A ¼-in. section of the top surface of the sample is cut first. Next, the three 1-in.sections to be measured are cut. Each 1-in. ±1/8 in. section is identified as top, middle, and bottom and is measured for tensile strength in the test machine. The remaining sample pieces are discarded. Fig. D-3 shows a general schematic of how each specimen is oriented on its side during testing. The force applied to the specimens is automatically controlled and applied at a constant rate of approximately 0.025mm/hr. This testing is carried out at Westport Technology Center.

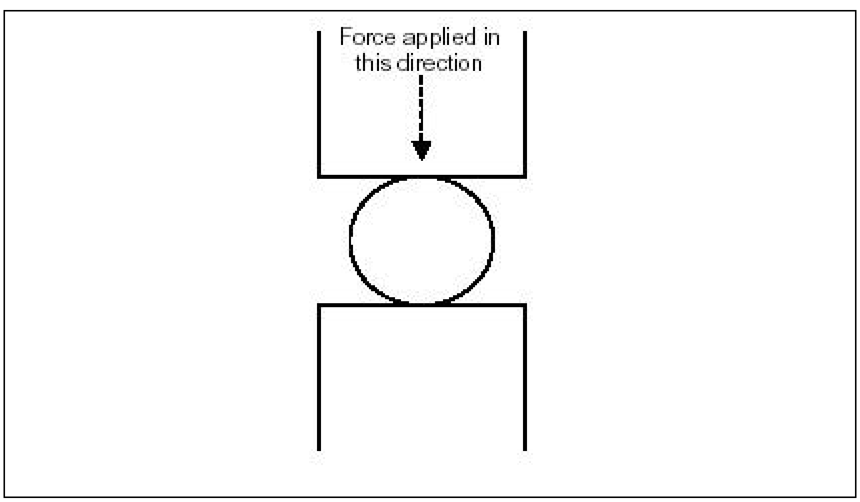


Figure D-3—Tensile strength Crush Diagram

Appendix 9

Quarterly Report 9

Ultra-Lightweight Cement

Ninth Quarterly Technical Progress Report

September 30 to December 31, 2002

Fred Sabins

Issued January 31, 2003

DOE Award Number
DE-FC26-00NT40919

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report discusses testing that was performed for analyzing the alkali-silica reactivity of ULHS in cement slurries. DOE joined the Materials Management Service (MMS)-sponsored joint industry project "Long-Term Integrity of Deepwater Cement under Stress/Compaction Conditions." Results of the project contained in two progress reports are also presented in this report.

Table of Contents

Introduction

Oil well cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water. This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field-testing.

The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile strengths of 8 different cement specimens will be tested. The initial casting of the expansion specimens was unsuccessful, so the procedure has been modified to correct the existing flaws so that the expansion specimens can be recast successfully.

The DOE recently joined a Materials Management Service project that contains 14 oil and well service companies as sponsors and focuses on the performance of low-density cements used for controlling shallow water flows in deep water drilling conditions. The focus of this MMS JIP is on low density and low temperature, and it fits in with lightweight cement project since both are concerned with long-term performance throughout the life of the well.

Executive Summary

Laboratory testing during the ninth quarter focused on evaluation of the alkali-silica reaction of 8 different cement compositions containing ULHS. The original laboratory procedure for measuring set cement expansion resulted in test specimen erosion that was unacceptable. This procedure has been modified and testing has been re-initiated.

This report provides the following information:

?? Alkali-Silica Reactivity Testing Progress
?? Presentation of MMS project data

Alkali-Silica Testing

Approval was made for a continuation of the current cooperative agreement with DOE. This extension consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oil well cements, and conduct long-term tests to verify if ASR is occurring and when and how it manifests itself. Compositions to be tested and test procedures in the ASR evaluation are listed in Appendix A.

ASR testing included preparation of tensile strength, compressive strength, and expansion specimens. The expansion specimens failed as they were originally poured. The ULHS cements experienced segregation and erosion while in the curing bath. All of the TXI lightweight cement specimens failed (broke) while in the curing bath, which may indicate expansion due to the alkali silicate reaction. The specimens were then recast with modified mold covers. Standard ASTM molds were used for all specimens with the exception of the TXI lightweight cement. The TXI lightweight cement used a non-standard volumetric expansion mold. While different specimen configurations are not directly comparable, two sets of other compositions were cast using each mold type to provide a comparison.

Preliminary compressive strength and tensile strength data were gathered. However, this testing was stopped when the expansion specimen failure was discovered, and this testing was re initiated also to be in sync with the expansion testing. It was decided to hold presentation of these initial data until the next report so that a more complete data suite would be available for analysis.

Contribution of the MMS Data

The data collected in the MMS JIP deals with the durability of various cements under thermal and pressure cycling. The major focus of the testing is the determination of the mechanical properties of the cement to obtain the durability. Cement compositions tested in the MMS project are outlined in Table 2. Reports 2 and 3 contain all of the data and are attached in Appendix B.

The major focus of current work is obtaining an accurate measurement of the Poisson's Ratio and the durability of the cement across soft formations during temperature and pressure cycling.

Conclusions

1. At this point in the project, usable ASR test specimens have been poured.
2. The testing regime is on schedule.
3. The MMS data will expand the database for the durability of lightweight cement.

1. List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
MMS—Minerals Management Service
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Recommended Practice 10B: "Recommended Practices for Testing Well Cements," 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

Appendix A—Alkali-Silica Reactivity (ASR) Testing

Objective

The goals of this project are to study the long-term effects of the alkali-silica reaction in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR.

Alkali-silica reactivity (ASR) is a chemical reaction that occurs between alkali and reactive silica present in cement and concrete mixes. When this reaction occurs, a gel is formed that absorbs available water and increases internal pressure, eventually causing the cement to fracture. This fracturing renders the cement vulnerable to several hazardous materials that can severally weaken the structure of the cement matrix causing it to fail.

Testing Procedures

A variation of the Length Change of Hardened Hydraulic-Cement Mortar and Concrete (ASTM C157-93) methods was used to test expansion in the slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) methods were used to determine a change in the tensile strength of specimens as a result of ASR. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and 6 months. For statistical purposes, nine replicates of each slurry are made.

Test Slurry Composition

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal will be used. Ultra-light hollow sphere (ULHS) slurries with similar bead concentrations and a density of 9.0 lb/gal will also be used. Several 0.5% sodium chloride slurries will be used to evaluate accelerated ASR.

Neat Slurries (Baseline)

- Class H cement mixed with 4.3 gal of fresh water per sack to achieve a density of 16.4 lb/gal
- TXI Lightweight cement mixed with 6.0 gal of fresh water per sack to achieve a density of 13.5 lb/gal

Ultra-Light Hollow Sphere (ULHS) Slurries

- Class H cement plus 42.14% BWOC 3M 6K (6,000 psi) beads mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- TXI Lightweight cement plus 37.19% BWOC 3M 6K (6,000 psi) beads mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Salt Slurries

- ?? Class H cement plus 0.5% BWOC NaCl mixed with 4.3 gallons of fresh water sack for a density of 16.4 lb/gal
- ?? TXI Lightweight cement plus 0.5% BWOC NaCl mixed with 6.0 gallons of fresh water per sack for a density of 13.5 lb/gal
- ?? Class H cement with 42.14% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- ?? TXI Lightweight cement with 37.19% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Testing Conditions

- ?? Application No. 3 – 128°F / 174°F (BHCT/BHST)
- ?? Slurries were tested for a minimum of 200 days.

Mixing Procedures

Prepare a ULHS slurry as follows.

1. Weigh the appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry according to Appendix A of API RP 10B.
3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place this slurry in a Waring blender and mix at 4,000 rpm for 15 seconds. Then, return each specimen to lime-saturated water.

Alkali-Silica Reactivity (ASR) Testing for Expansion

Curing the Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made. Cure each test specimen in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
   - ?? Never strike or jar a specimen during removal.
   - ?? Never exert pressure directly against the gage studs.
   - ?? Make sure the gage stud holder remains attached to the stud during specimen removal.

Important—To avoid damaging the specimens during removal from the molds, it may be necessary to leave the specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimens are within ±1/2 hour of the same age at the time the initial comparator reading is performed.

2. Mark specimens for identification or positioning as required with a soft graphite pencil, a graphite liquid that deposits graphite without binder, or waterproof, indelible ink. Never use any other writing instrument.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.
4. When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Apparatus

Molds for cement specimen curing have one section and are constructed as shown in Fig. 6. Molds for test specimens used in determining the length change of cement pastes and mortars produce 1 ? 1 ? 11 ¼-in. prisms with a 10-in. gage length. The gage length is the nominal length between the innermost ends of the gage studs. The parts of the molds should fit tightly and firmly together when assembled, and their surfaces should be smooth and free of pits.

The molds are made of steel not readily attacked by the cement paste, mortar, or concrete. The sides of the molds should be sufficiently rigid to prevent spreading or warping. For the molds shown in Fig. 6, the tolerance on dimension A is ±0.03 in. Each end plate of the mold is equipped to hold properly in place during the setting period.

The gage studs are of American Iron and Steel Institute (AISI) 3 Type 316 stainless steel. To prevent restraint of the gage studs before the specimen is removed, the device for holding the gage studs in position is arranged such that it can be partially or completely released after the slurry compacts in the mold. The gage studs are set so their principal axes coincide with the principal axis of the test specimen. For the molds shown in Fig. D-1, gage studs extend into the specimen 0.625 ± 0.025 in. and the distance between the inner ends of the gage studs is 10.00 ± 0.10 in. Ten inches is the gage length for calculating length change.

Test Measurement

The comparator for the molds shown in Fig. D-1 features a dial micrometer or other measuring device graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens. The terminals of the comparator are plane, polished, and heat-treated, and are fitted with collars held in place with set screws. The collars extend 0.062 ± 0.003 in.

beyond the plane face of the terminal and have an inside diameter 0.02 in. greater than the average diameter of the portion of the gage studs that must fit into the collars.

The comparator must allow the checking of the measuring device against a reference bar at regular intervals. The reference bar has an overall length of 11 5/8 ±1/8 in. for the specimen in use. The bar is made of a steel alloy with a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end of the reference bar is fitted with heat-treated, hardened, and polished tips machined to the same shape as the contact end of the gage studs used in test specimens.

Reference Bar

Place the reference bar (Fig. D-2) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of immersion, blot the pins, place the bar in the comparator, read, and record the indication.
4. Return the bar to immersion and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to immersion, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} ? 100$$

Where:
L = change in length at *x* age, %
Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;
Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time
G = nominal gage length, 10 in.

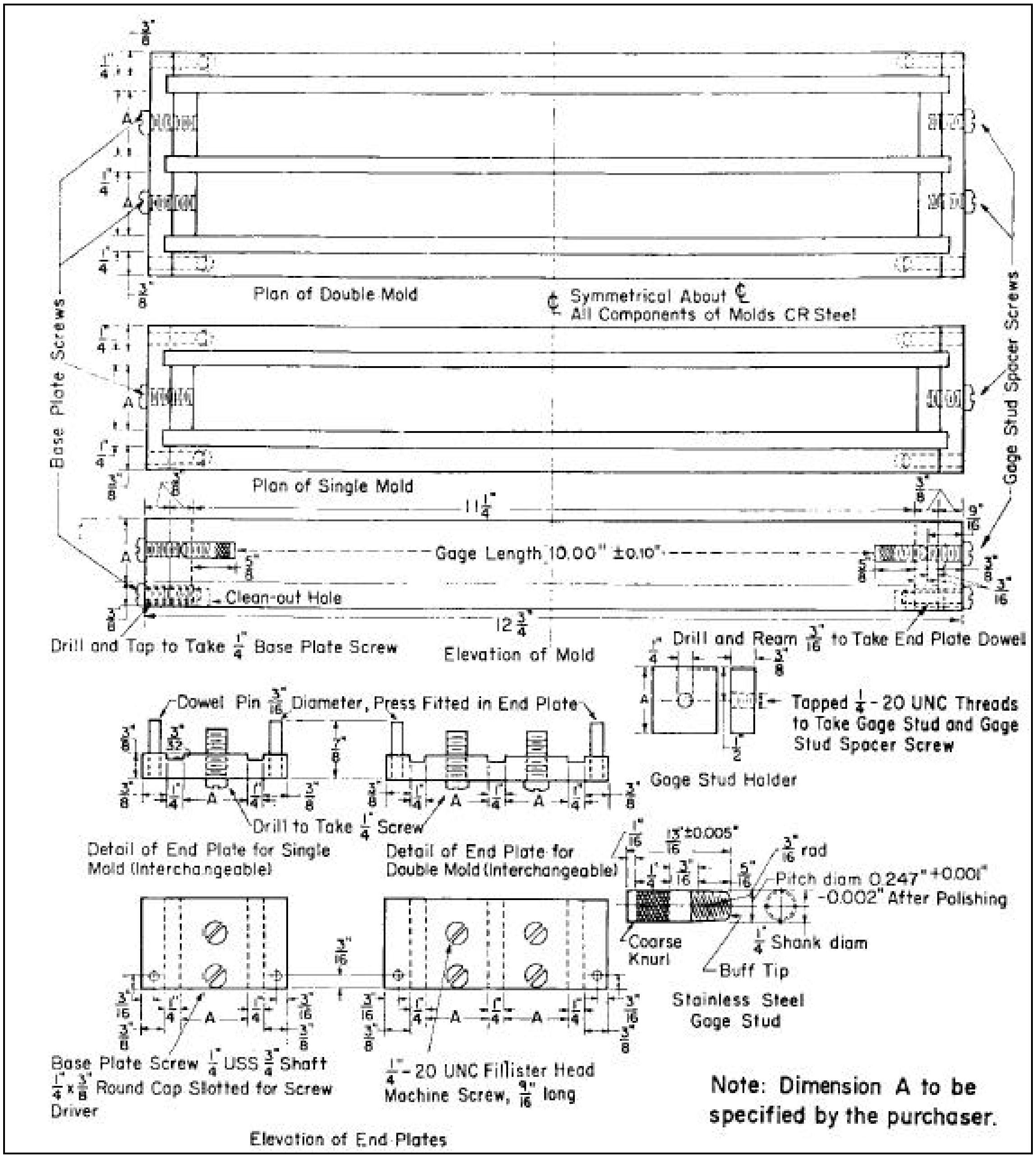
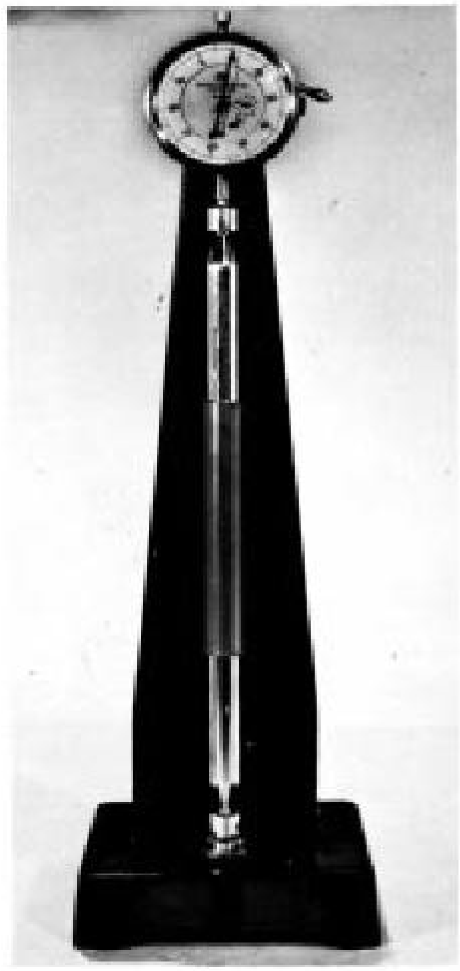


Figure D-1—Test specimen mold schematics



Type of Suitable Apparatus for Measurement of Length Changes

Figure D-2—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is placed in a 1.5 ? 5-in. mold sealed at both ends.

Curing the Cement Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made.

Prepare the molds as follows.

1. Place slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Stir the remaining slurry by hand and place into additional molds and repuddle it.

3. Seal the molds and place them upright in a heated, circulating water bath at the appropriate curing temperature.
4. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.

Important—To avoid damaging the specimen during removal, it may be necessary to leave specimens in the molds for more than 24 hours. This is especially true for certain slow-hardening cements. If the curing schedule must be extended, make sure that the same curing time is used for all other specimen to be compared, and that all comparison specimen are within ±1/2 hour of the same age at the time the initial comparator reading is performed.

Test Measurement

After curing, the sample is extracted from the mold and cut into 1-in. ±1/8 in. sections in length. The density of each sample is measured before it is measured for tensile strength.

A ¼-in. section of the top surface of the sample is cut first. Next, the three 1-in.sections to be measured are cut. Each 1-in. ±1/8 in. section is identified as top, middle, and bottom and is measured for tensile strength in the test machine. The remaining sample pieces are discarded. Fig. D-3 shows a general schematic of how each specimen is oriented on its side during testing. The force applied to the specimens is automatically controlled and applied at a constant rate of approximately 0.025mm/hr. This testing is carried out at Westport Technology Center.

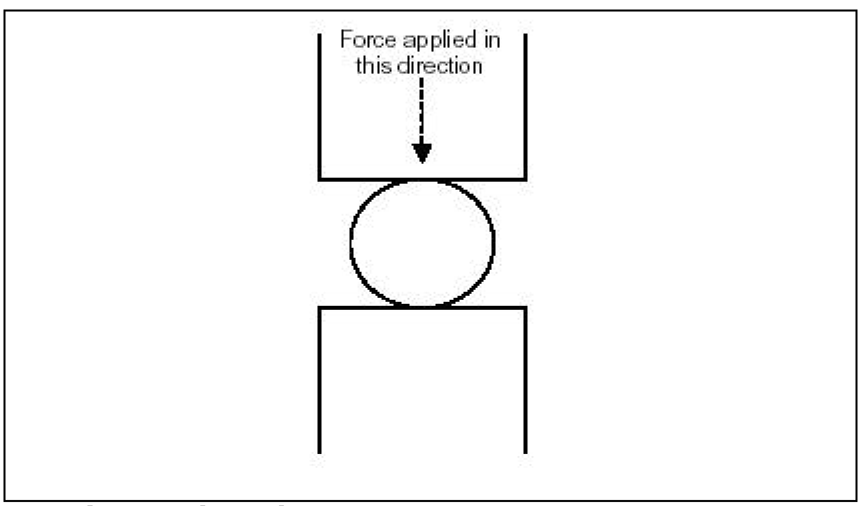


Figure D-3—Tensile Strength Crush Diagram

Appendix B

FINITE ELEMENT ANALYSIS OF
CEMENT SYSTEMS UNDER STRESS CONDITIONS

The following system configurations have been studied (as described in the MMS project report) using 3D finite element modeling (Fig.1):

1. Pipe-in-pipe (Inner Steel Pipe + Cement + Outer Steel Pipe)
2. Pipe-in-soft (Inner Steel Pipe + Cement + Outer Plastisol layer)

The following stress conditions have been studied:

1. Normal production operation
2. Internal casing pressure (Pressure cycling)
3. Subsidence, Compaction (Confining pressure)
4. Thermal stress (Temperature cycling)

Parametric study for a variety of cement types (Young's modulus and Poisson ratio) and cement thickness have also been performed.

Assumptions

1. The system can be modeled using linear elastic theory.
2. The composite system retains continuity at the interfaces (Fig.2).
3. The system is axi-symmetric because of the boundary conditions.
4. All materials are homogeneous and continuous.
5. Plastisol has the same material properties as that of rubber.
6. Plane stress condition is valid.

I. PIPE-IN-PIPE

1. Casing Pressure

Casing pressure is varied from 100 psi to 10000 psi.
Young's Modulus = 5000 psi
Poisson Ratio = 0.35
Confining Pressure = 0 psi
Cement Thickness = 1"
No temperature gradient.

Discussion

The principal stress and displacement profiles are shown in Fig.3 through Fig.7, for casing pressures of 100, 500, 1000, 5000 and 10,000 psi. In all the above cases, no confining pressure or temperature gradient is applied to isolate the effect of casing pressure on the stress distribution. As a result, most of the stress distribution is within the high modulus inner pipe. Comparatively, the cement layer in series with the inner pipe experiences reduced loads and hence smaller displacements. The axi-symmetry of the loading conditions uniformly stresses the composite system in the same direction, due to which no tensile forces are experienced.

2. Confining Pressure

Confining pressure is varied from 100 psi to 1000 psi.
Young's Modulus = 5000 psi
Poisson Ratio = 0.35
Casing Pressure = 500 psi
Cement Thickness = 1"
No temperature gradient.

Discussion

Discussion

The cement's Young's modulus is varied (1000, 3000, 5000 and 7000 psi) and the stress/displacement profiles are shown in Fig. 14 through Fig. 16. Due to the high modulus inner and outer pipes sandwiching the low modulus cement, very little stress variation is seen in the cement for different Young's moduli. The change in displacement fields is also marginal. However, if one of the adjacent layers is of comparable or lesser Young's modulus than the cement (as in the Pipe-in-Soft case), a significant stress contrast will be observed.

5. Poisson Ratio

Poisson Ratio is varied from 0.15 to 0.45.
Young's Modulus = 5000 psi
Confining Pressure = 500 psi
Casing Pressure = 500 psi
Cement Thickness = 1.5"
No temperature gradient.

Discussion

The cement's Poisson ratio is varied (0.15, 0.25, 0.35 and 0.45) and the stress/displacement profiles are shown in Fig. 17 through Fig. 19. As in the previous case, very little stress variation is seen within the cement layer itself. However, the arrest of continuity of plane stress is observed sharply at the interfaces. Negligible effect is felt due to an increase in Poisson ratio as it not the limiting property under these simulation conditions.

6. Thermal Stress

Young's Modulus = 5000 psi
Poisson Ratio = 0.35
Confining Pressure = 500 psi
Casing Pressure = 500 psi
Cement Thickness = 1"

Fig. 8 through Fig. 10 shows the stress and displacement fields for confining pressures of 100, 500 and 1000 psi. No temperature gradient is present. The high modulus inner and outer pipes reduce the effect of the load felt by the cement in each case, as a result of which very little stress variation is observed in the cement layer. Also, the compressive stress produces displacements in opposite directions at the two peripheries, with a stationary front in between.

3. Cement Thickness

Cement thickness is varied from 1” to 7.5”
Young’s Modulus = 5000 psi
Poisson Ratio = 0.35
Confining Pressure = 500 psi
Casing Pressure = 500 psi
No temperature gradient.

Discussion

Fig. 11 through Fig. 13 shows the stress and displacement fields for varying cement thickness (1, 3.5, 5.5 and 7.5”). No temperature gradient is included. Again, most of the stress variation is within the higher modulus inner and outer pipes. As the cement thickness is increased, the displacement values are observed to rise as a result of more flexible material present to accommodate the stress. This suggests that the cement may actually lose contact with the steel pipe at the interface and hence the annular seal, when large displacements are observed. It is required to study this system with appropriate large displacement interface elements with sufficient description of interface bonding.

4. Young’s Modulus

Young’s Modulus is varied from 1000 psi to 7000 psi.
Poisson Ratio = 0.35
Confining Pressure = 500 psi
Casing Pressure = 500 psi
Cement Thickness = 1.5”
No temperature gradient.

T_{out} = 68? F

T_{in} is varied from 80? F to 180? F.

Discussion

The stress and displacement profiles are shown in Fig.20 through Fig.23 for varying internal temperature (80, 110, 150 and 180? F). The thermal stress and the compressive stress act in opposite directions (especially near the outer boundary) and as a result, the net displacement is along the more dominant stress direction. As the internal temperature increases, the thermal stress dominates close to the inner boundary.

II. PIPE-IN-SOFT

1. Casing Pressure

Casing pressure is varied from 500 psi to 5000 psi.

Young's Modulus = 5000 psi

Poisson Ratio = 0.35

Confining Pressure = 500 psi

Casing Pressure = 500 psi

Cement Thic kness = 1"

Plastisol Thickness = 0.5"

No temperature gradient.

Discussion

Fig.24 through Fig.26 show the stress and displacement profiles for varying casing pressure (500, 1000 and 5000 psi). For the range of casing pressures considered here and the simulation conditions, significant variation is seen in the stress distribution due to an increase in the casing pressure. Most of the casing pressure load is transferred across the cement layer and consequently to the low modulus plastisol (soft formation).

PIPE-IN-PIPE

Fig.1. 3-D Finite element modeling

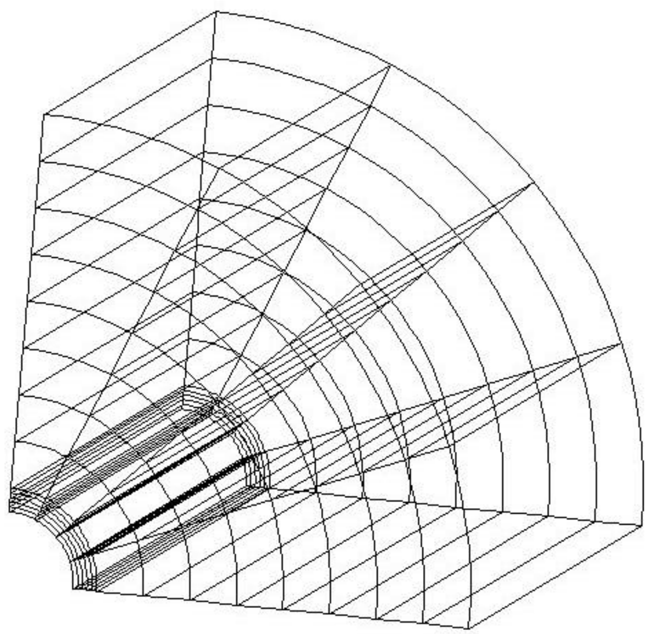


Fig.2. Total mesh displacement (normal operation)

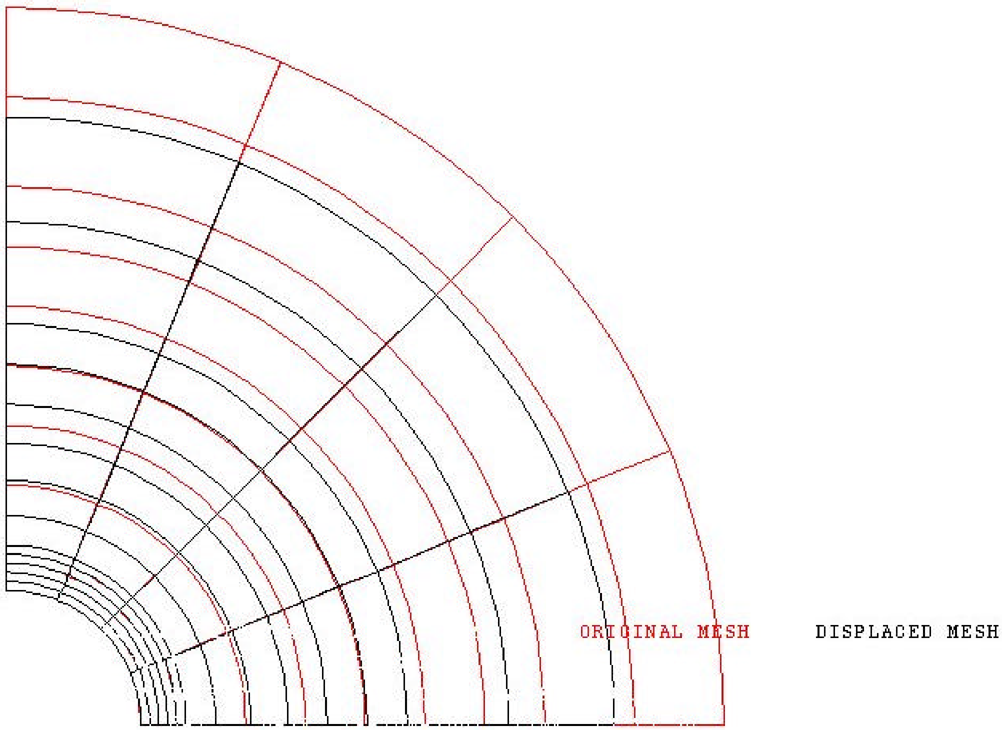

ORIGINAL MESH
DISPLACED MESH

Fig.3a First principal stress profile (Casing Pressure = 100 psi)

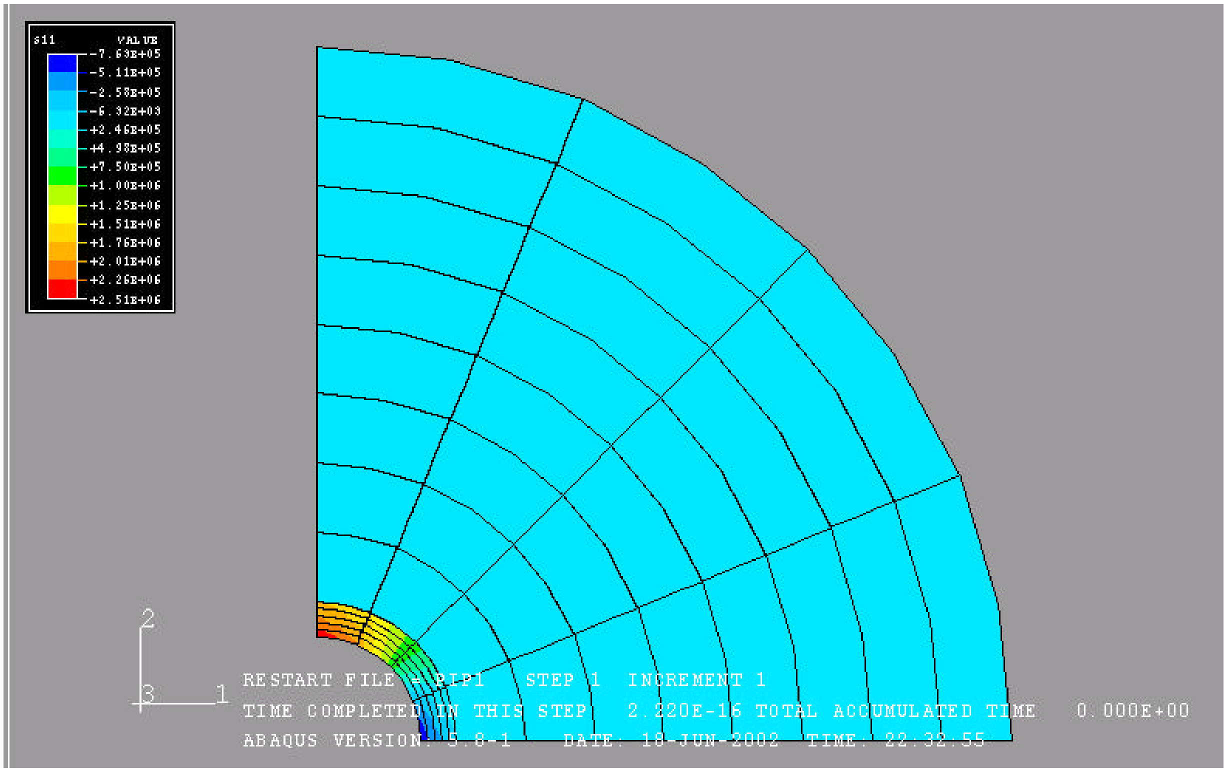


Fig.3b Second principal stress profile (Casing Pressure = 100 psi)

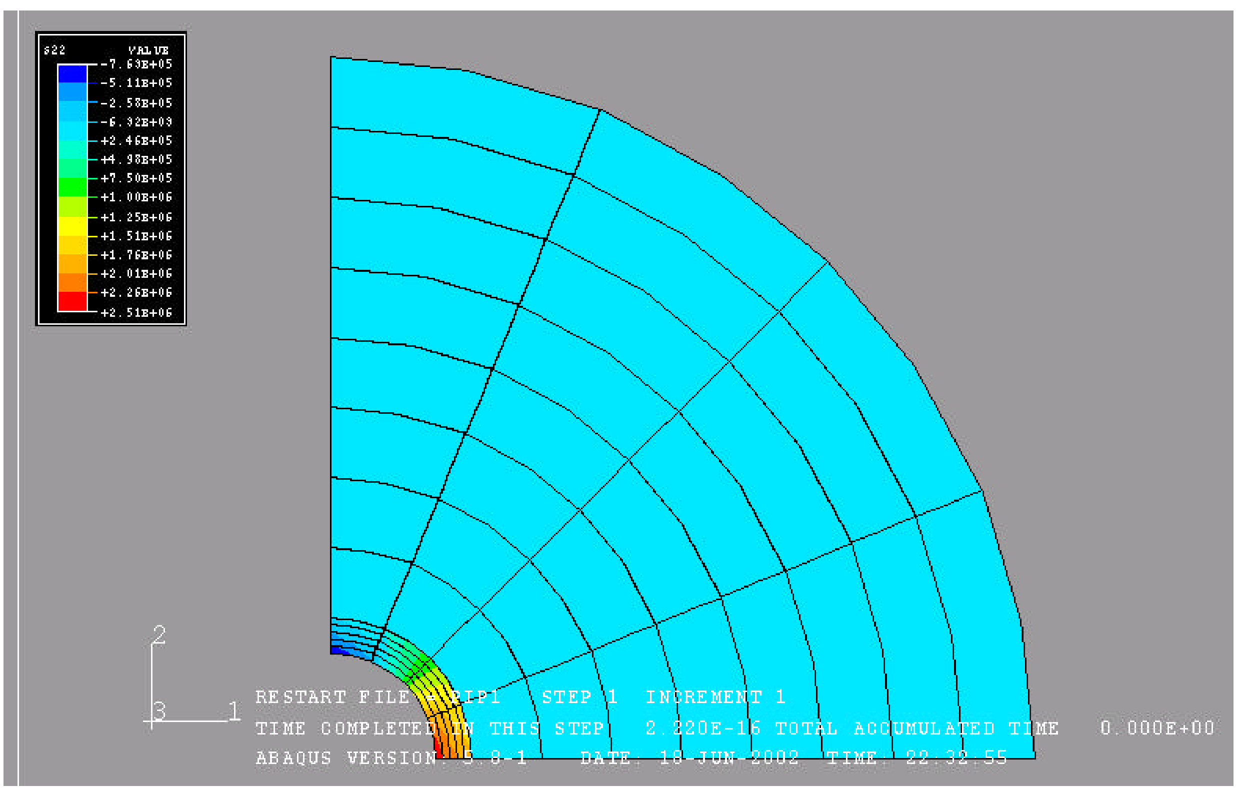


Fig.3c Horizontal displacement field (Casing Pressure = 100 psi)

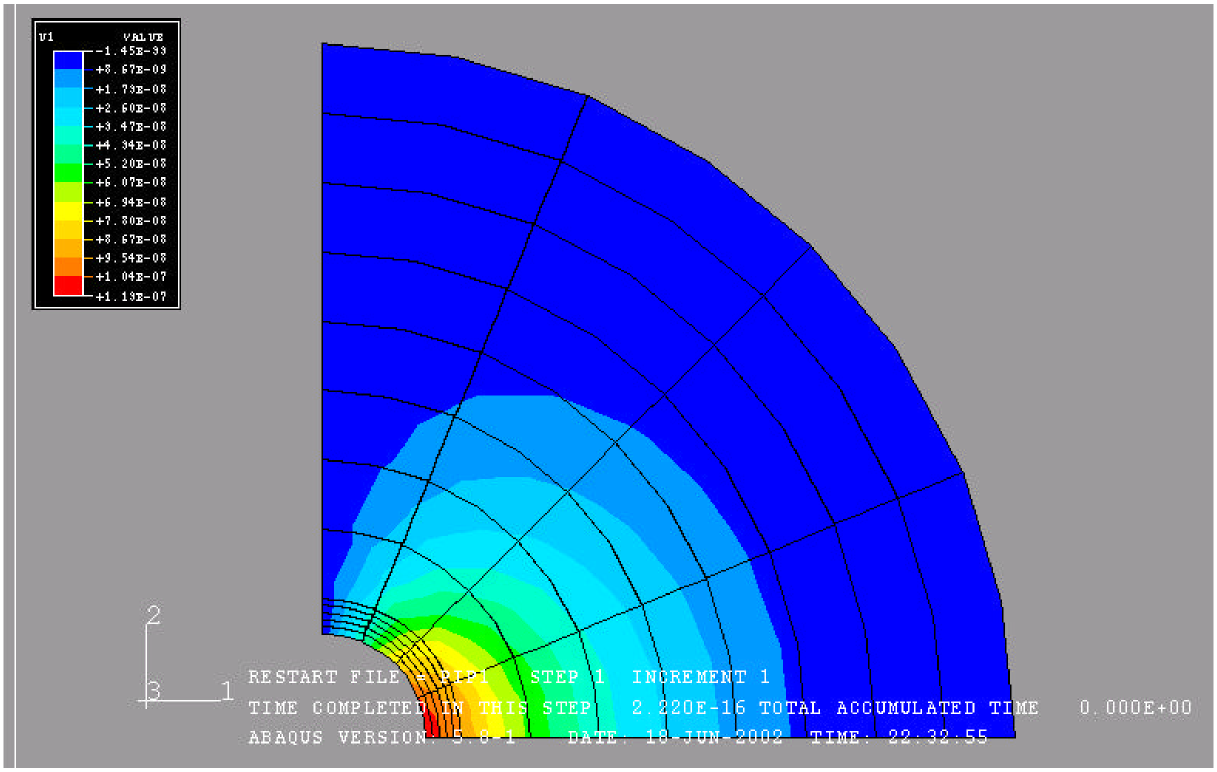


Fig.3d. Vertical displacement field (Casing Pressure = 100 psi)

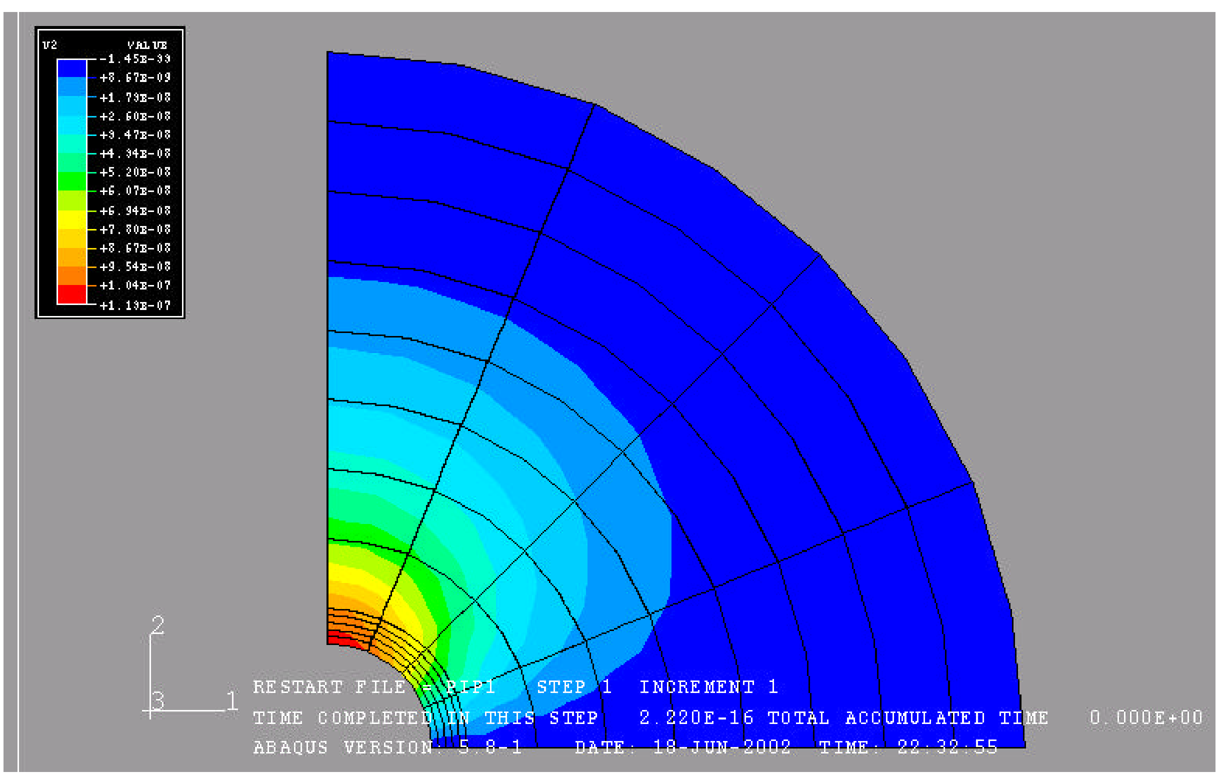


Fig.4a First principal stress profile (Casing Pressure =500 psi)

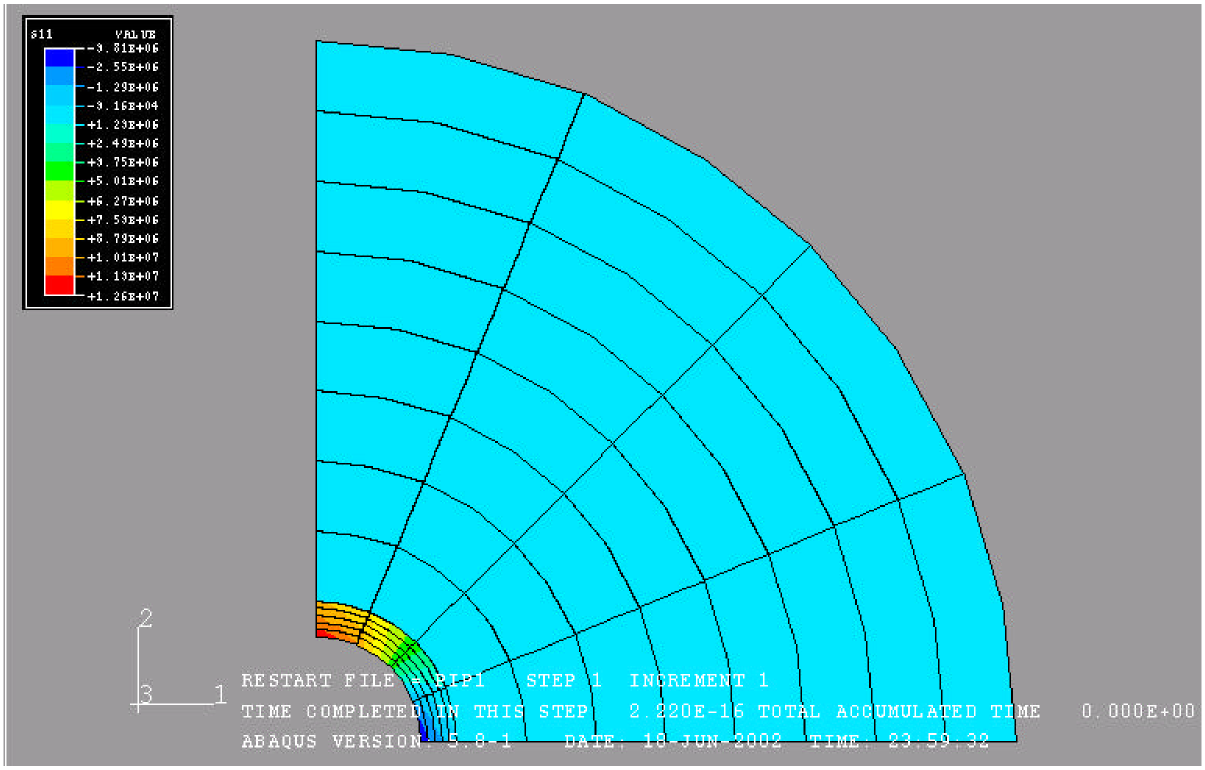


Fig.4b Second principal stress profile (Casing Pressure = 500 psi)

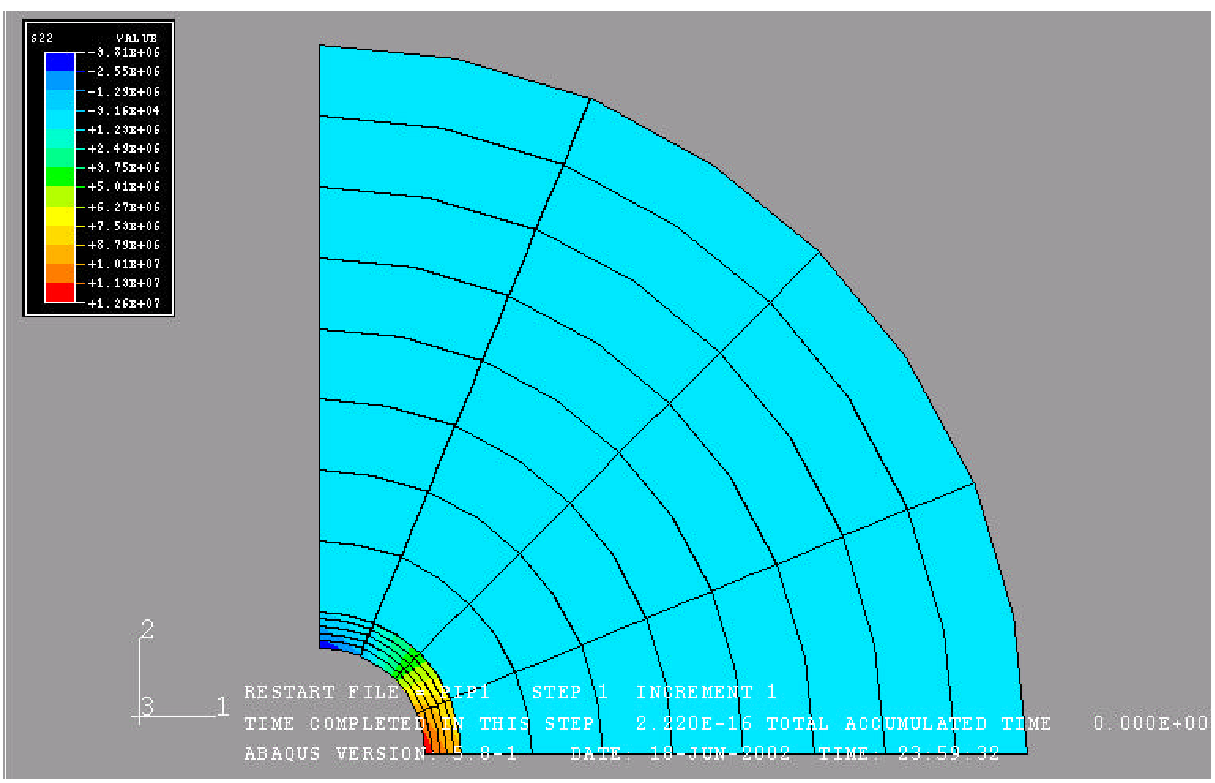


Fig.4c Horizontal displacement field (Casing Pressure = 500 psi)

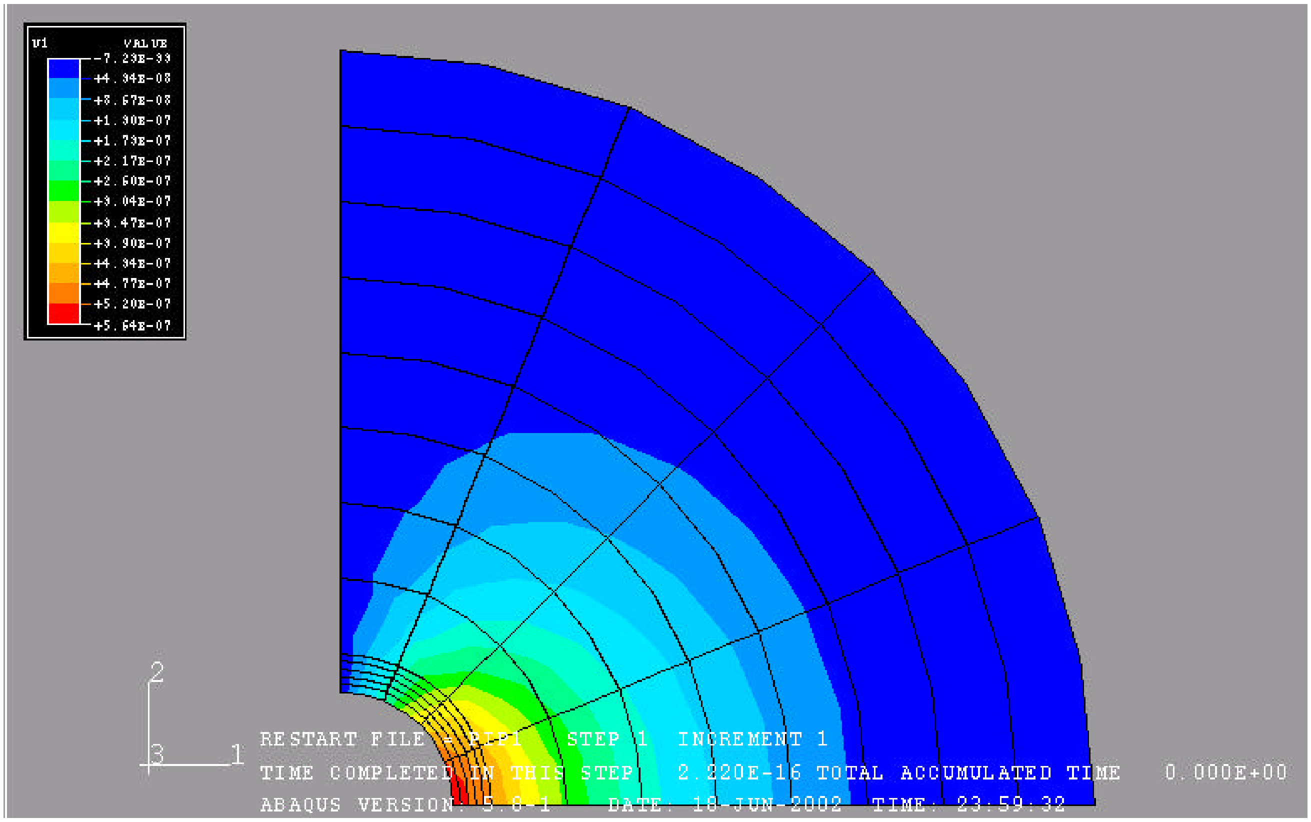


Fig.4d Vertical displacement field (Casing Pressure = 500 psi)

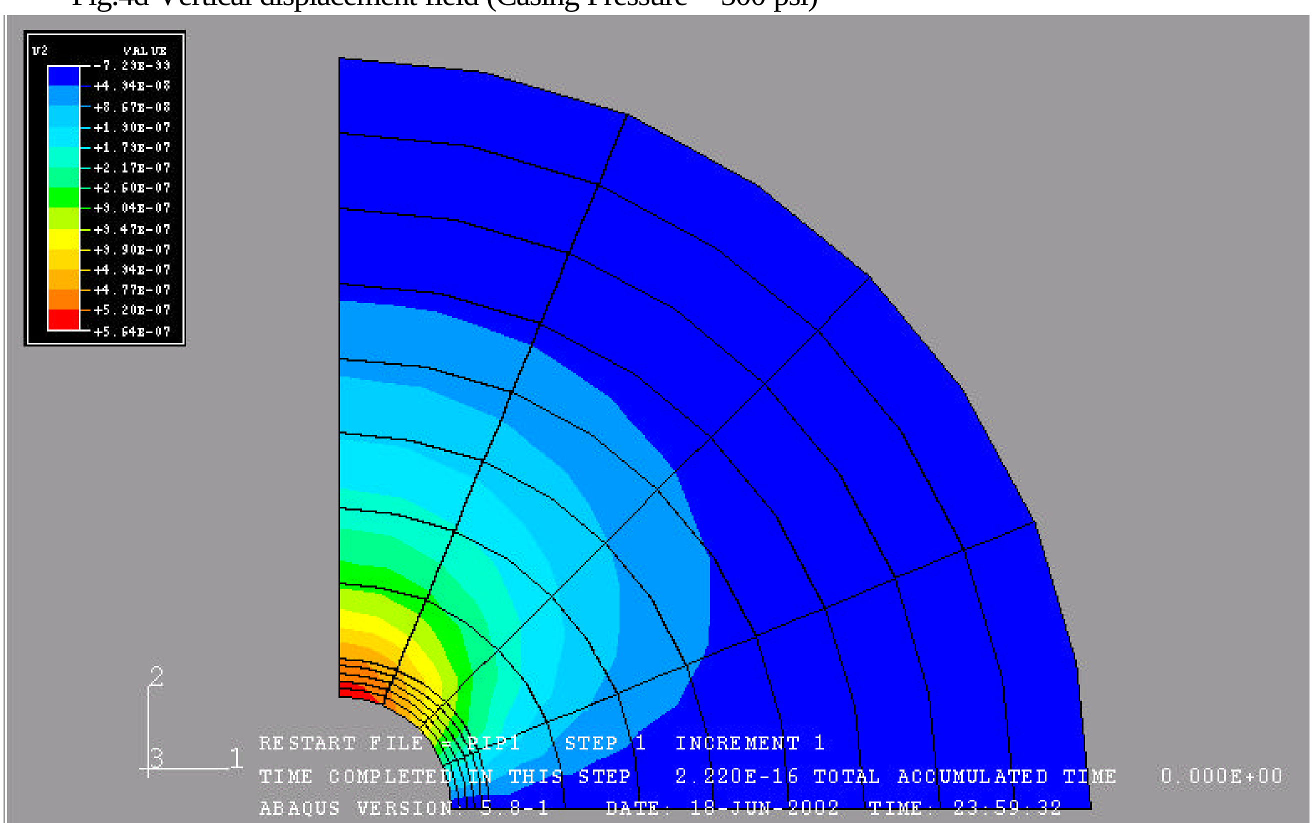


Fig.5a First principal stress profile (Casing Pressure = 1000 psi)

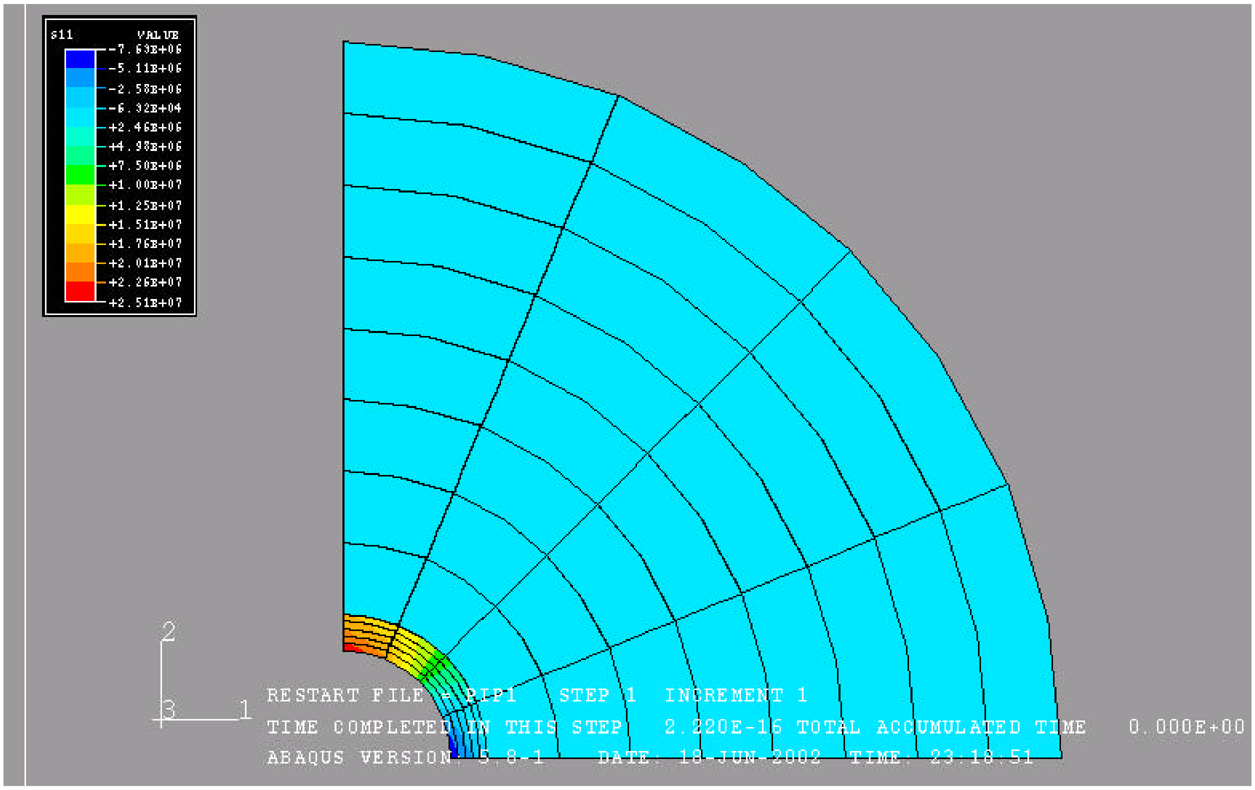


Fig.5b Second principal stress profile (Casing Pressure = 1000 psi)

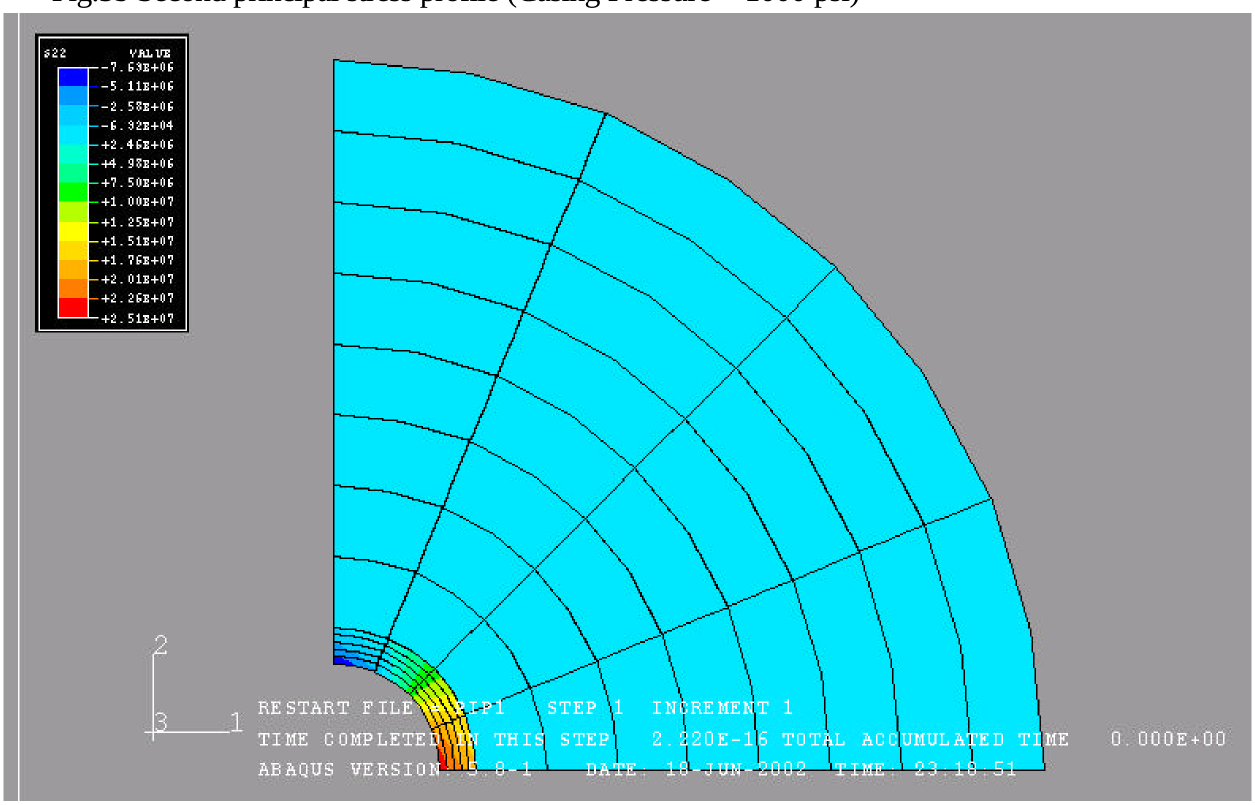


Fig.5c Horizontal displacement field (Casing Pressure = 1000 psi)

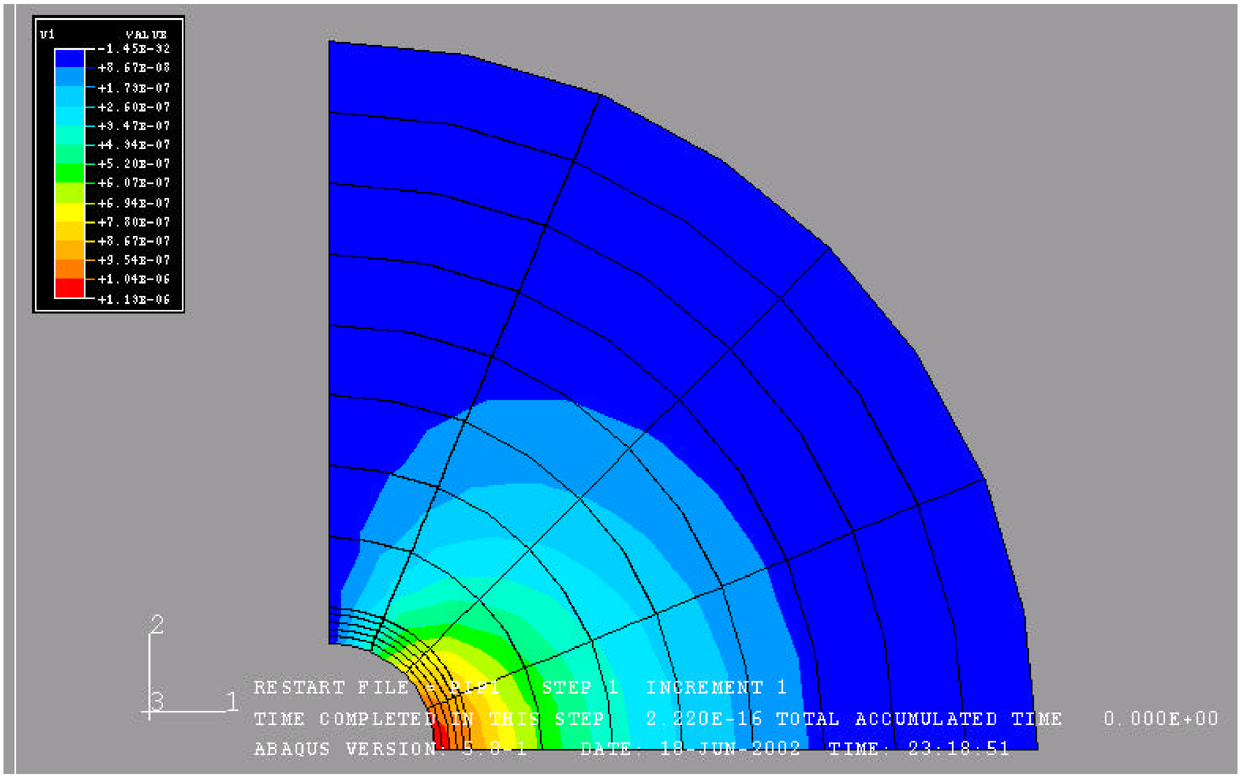


Fig.5d Vertical displacement field (Casing Pressure = 1000 psi)

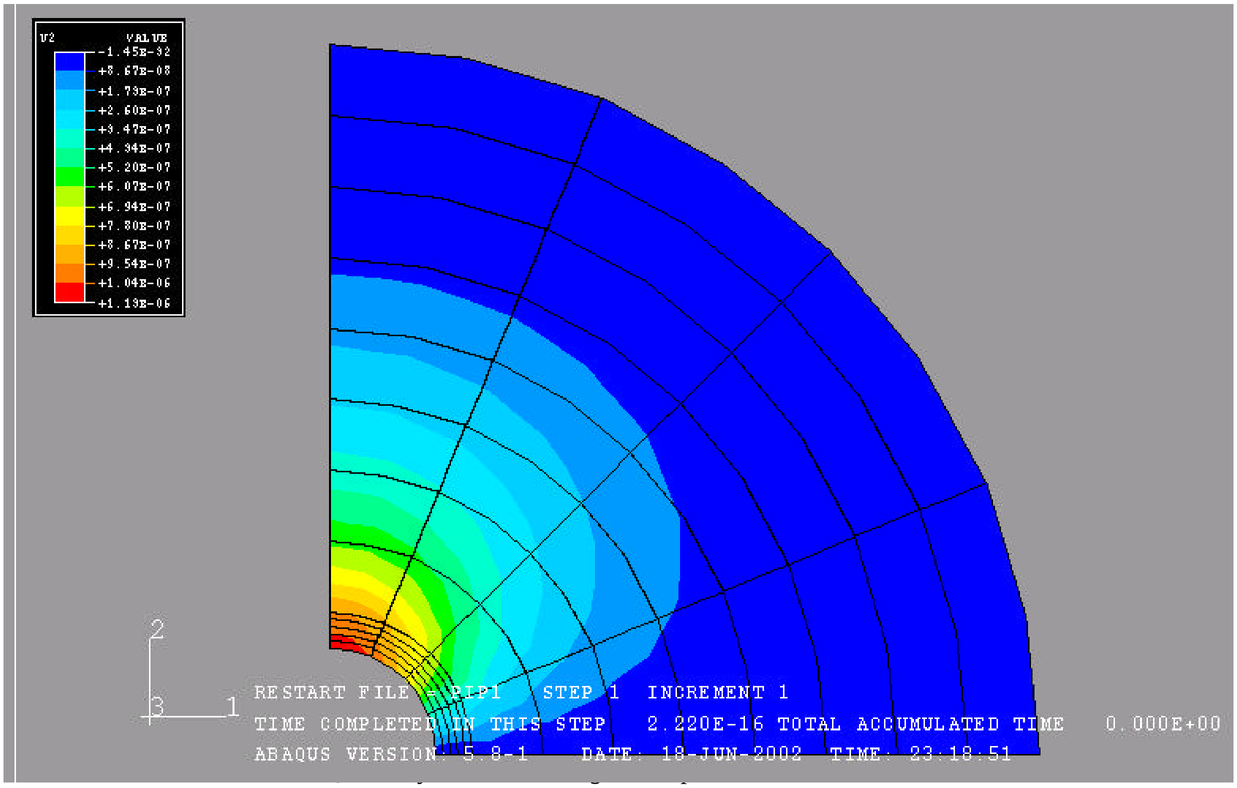


Fig.6a First principal stress profile (Casing Pressure = 5000 psi)

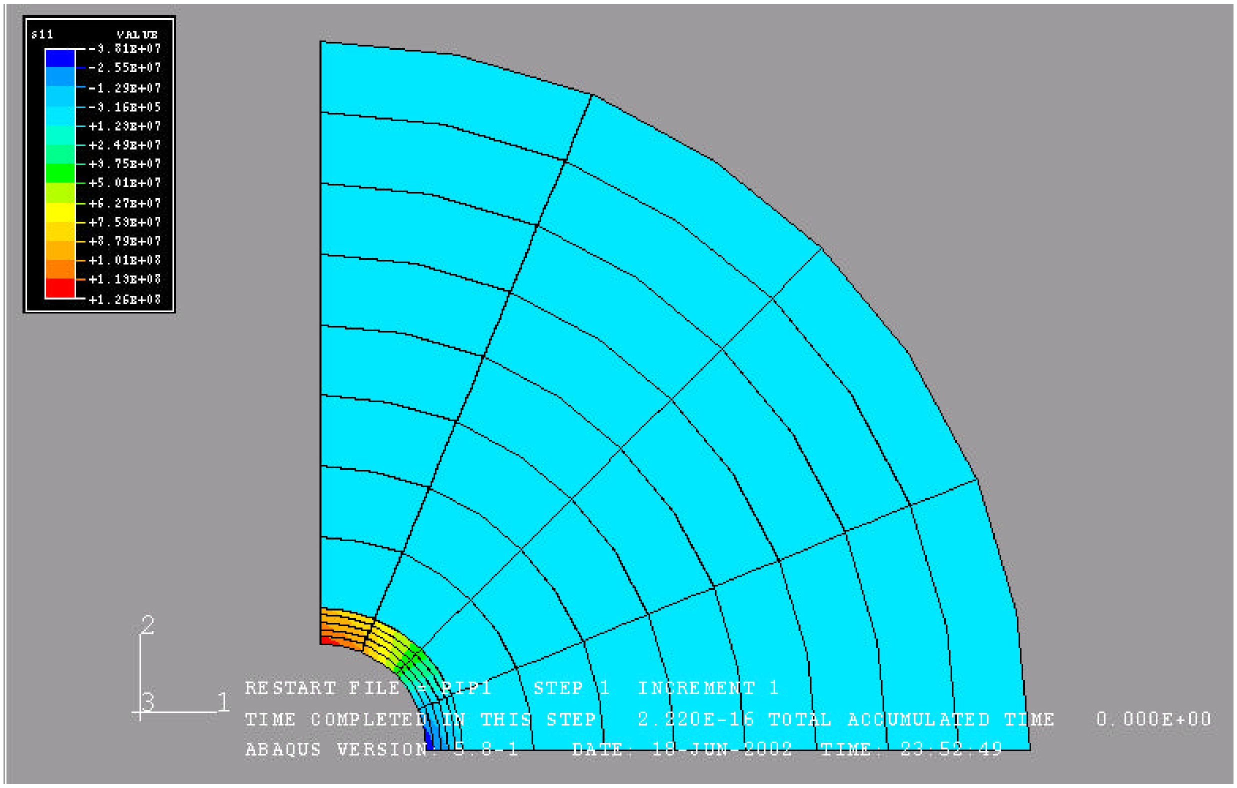


Fig.6b Second principal stress profile (Casing Pressure = 5000 psi)

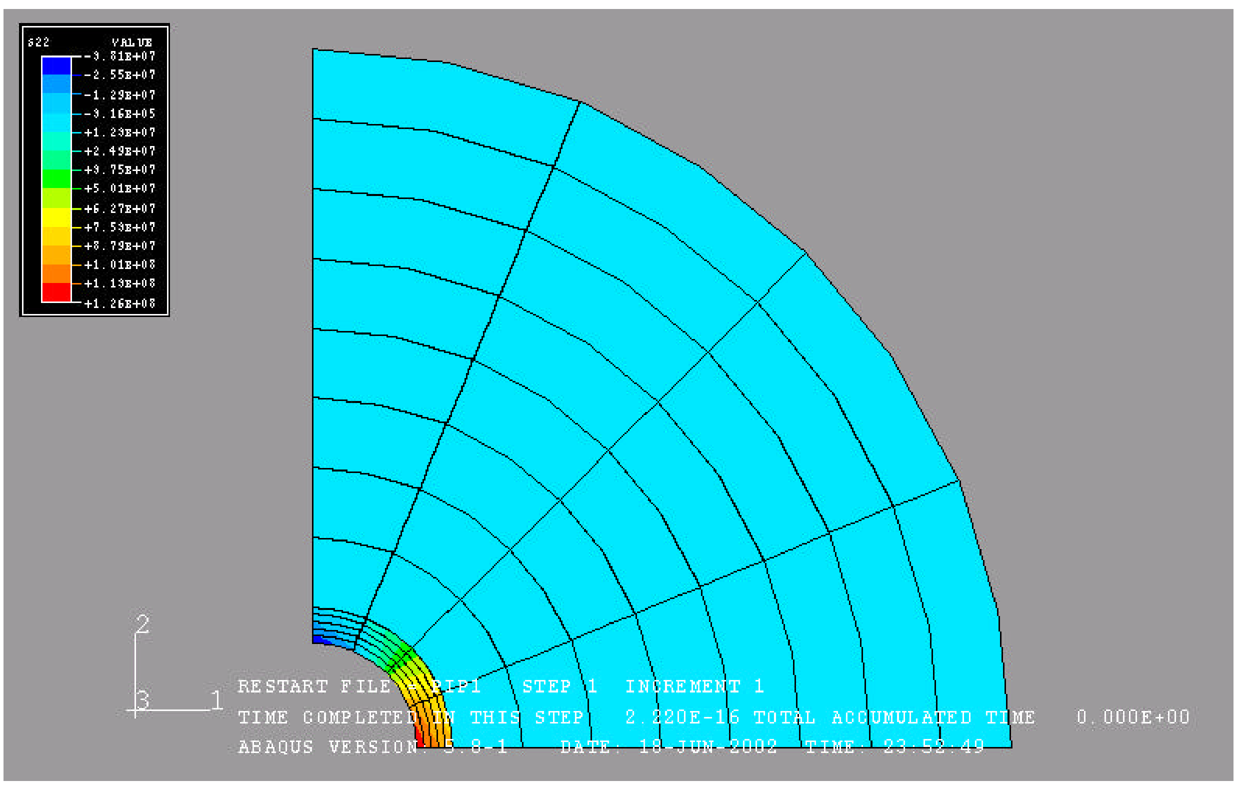


Fig.6c Horizontal displacement field (Casing Pressure = 1000 psi)

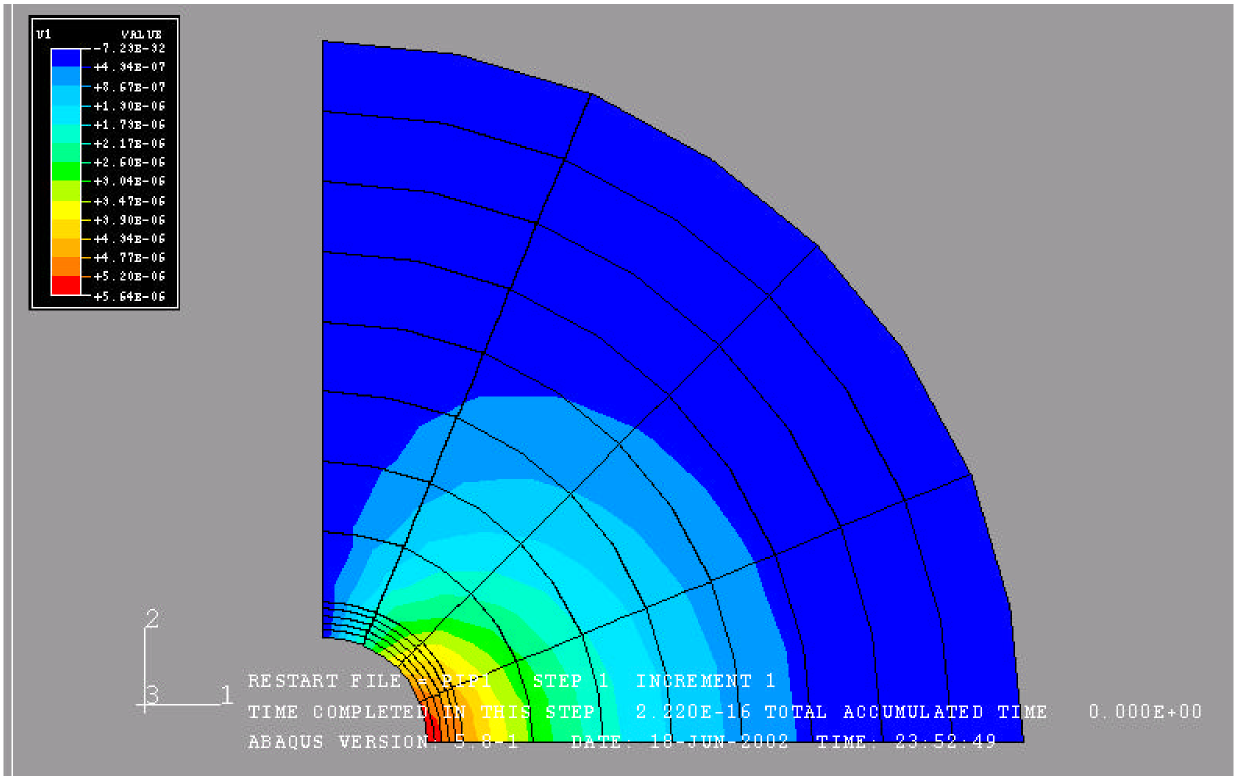


Fig.6d Vertical displacement field (Casing Pressure = 1000 psi)

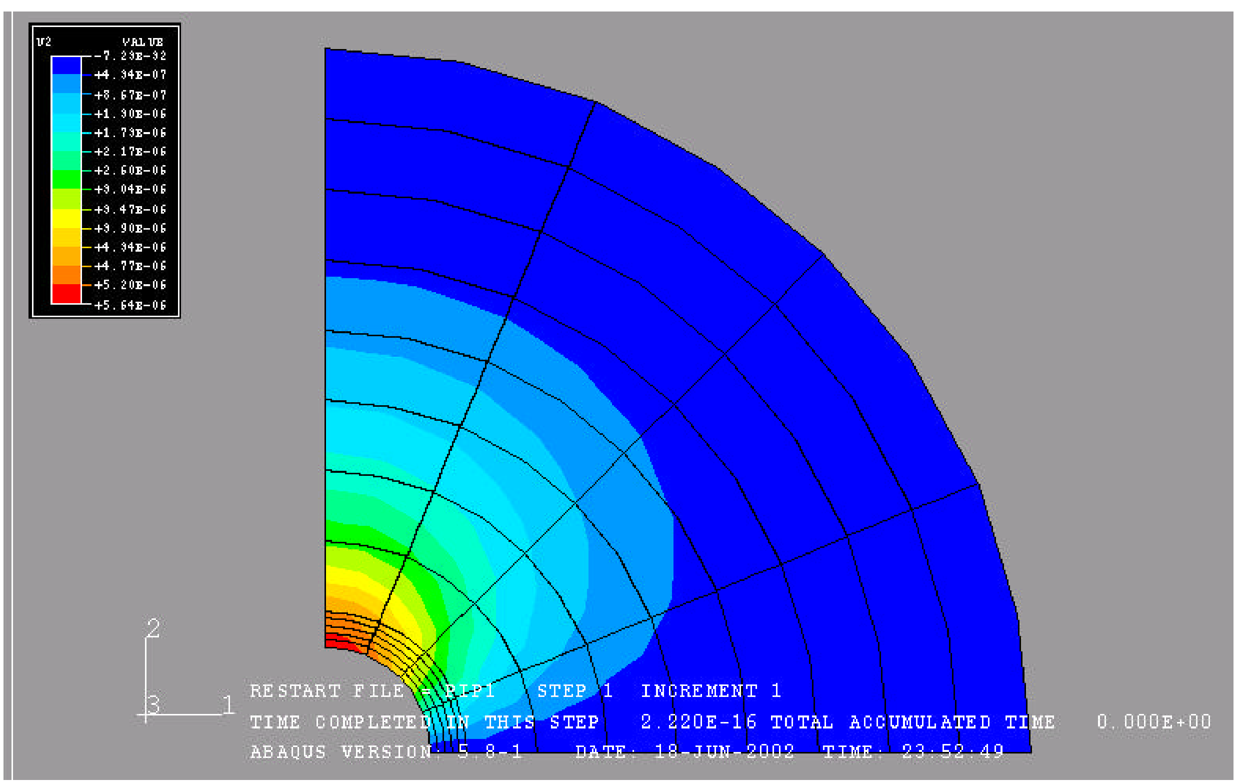


Fig.7a First principal stress profile (Casing Pressure = 10000 psi)

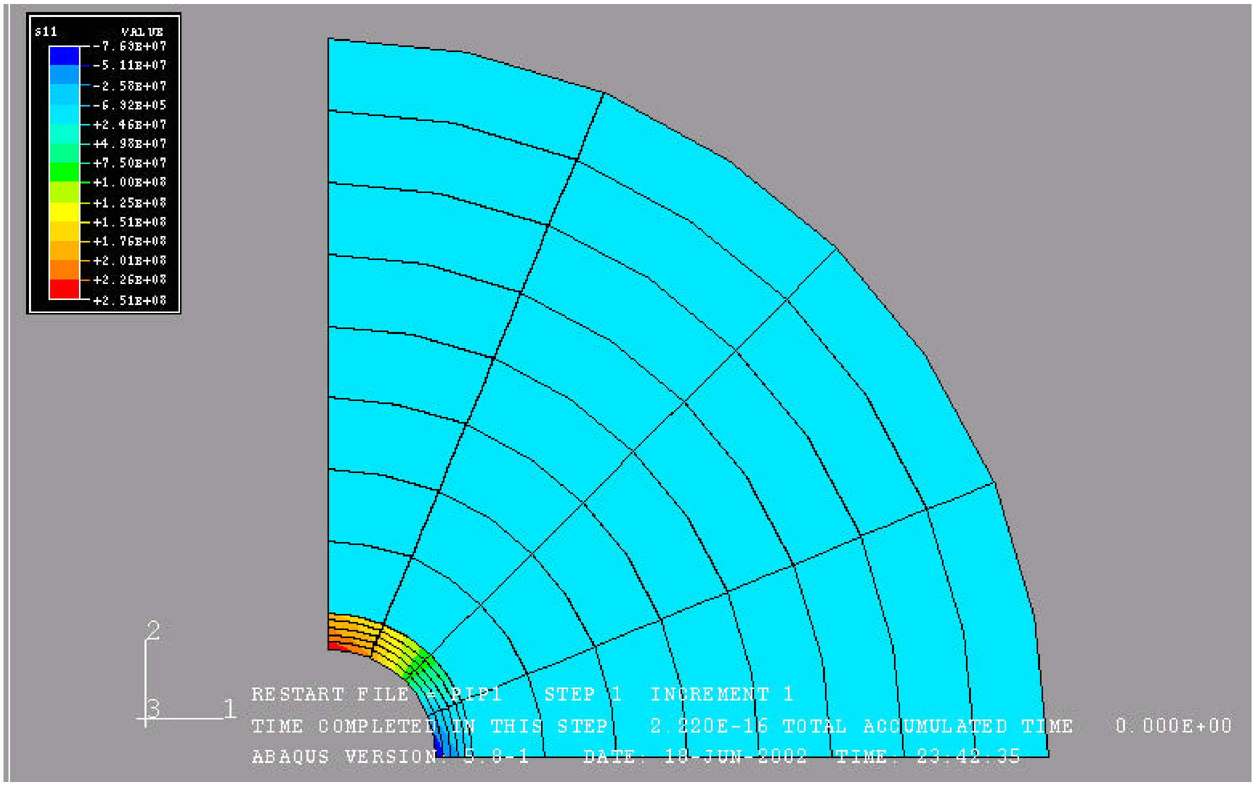


Fig.7b Second principal stress profile (Casing Pressure = 10000 psi)

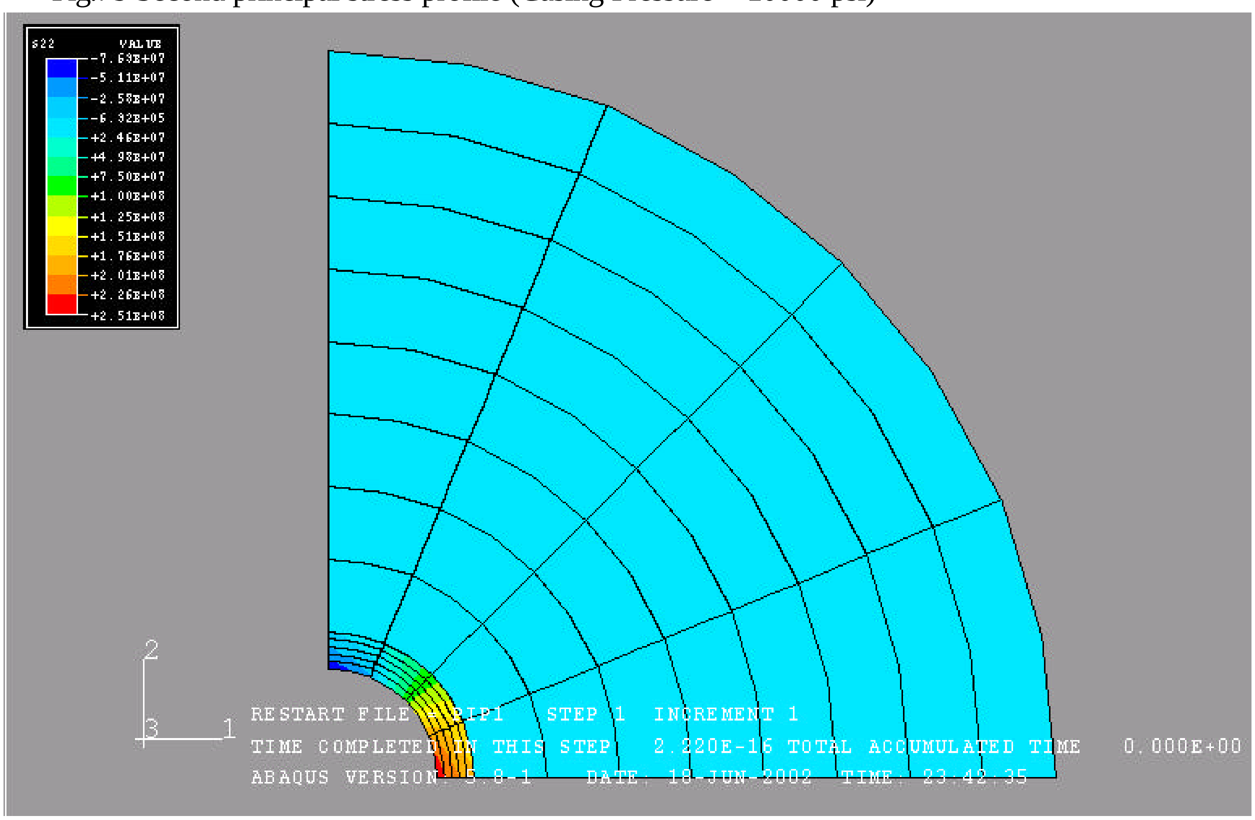


Fig.7c Horizontal displacement field (Casing Pressure = 10000 psi)

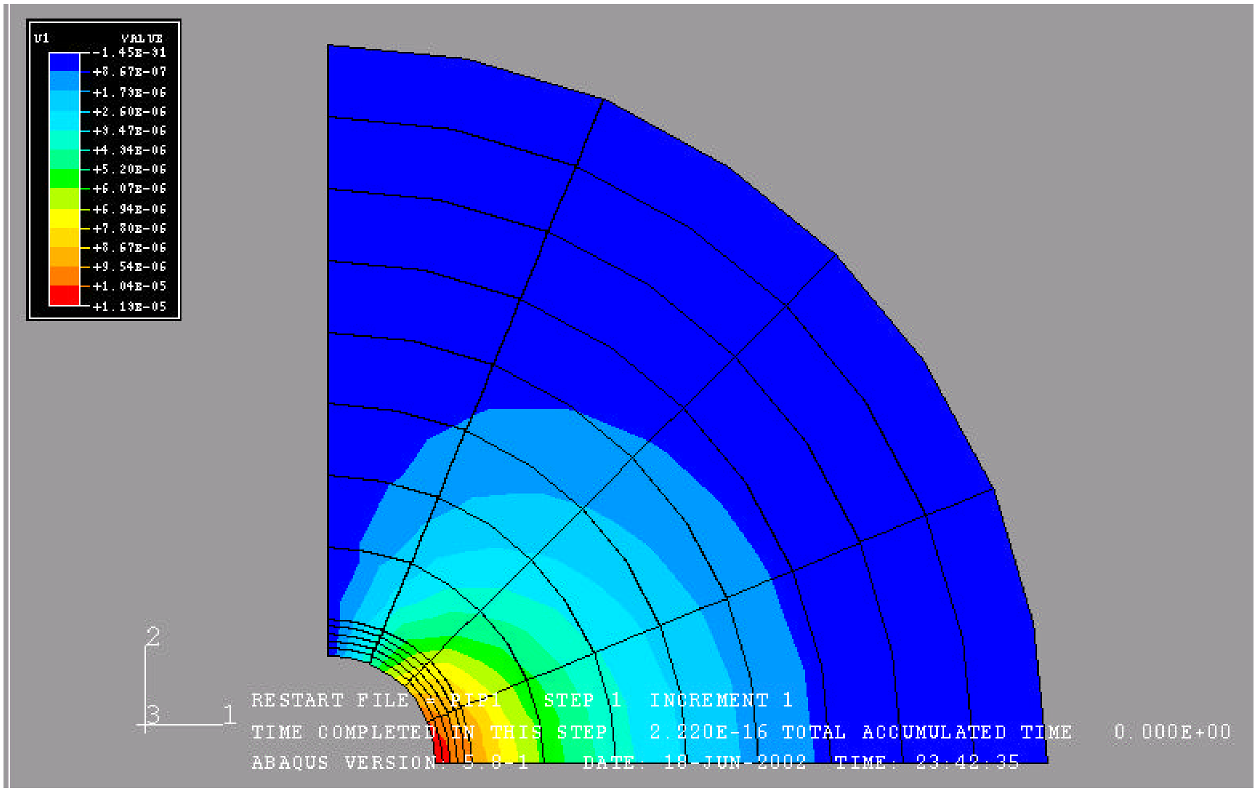


Fig.7d Vertical displacement field (Casing Pressure = 10000 psi)

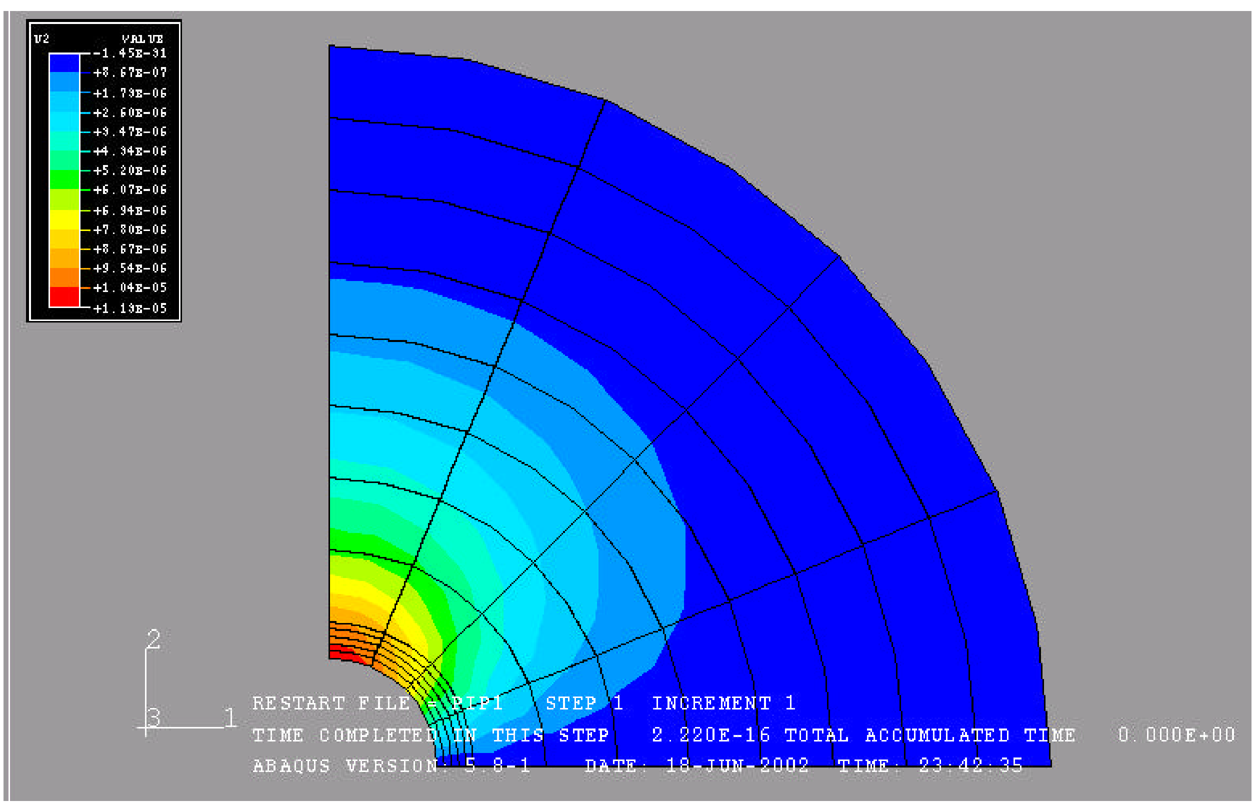


Fig.8a First principal stress profile (Confining Pressure = 100 psi)

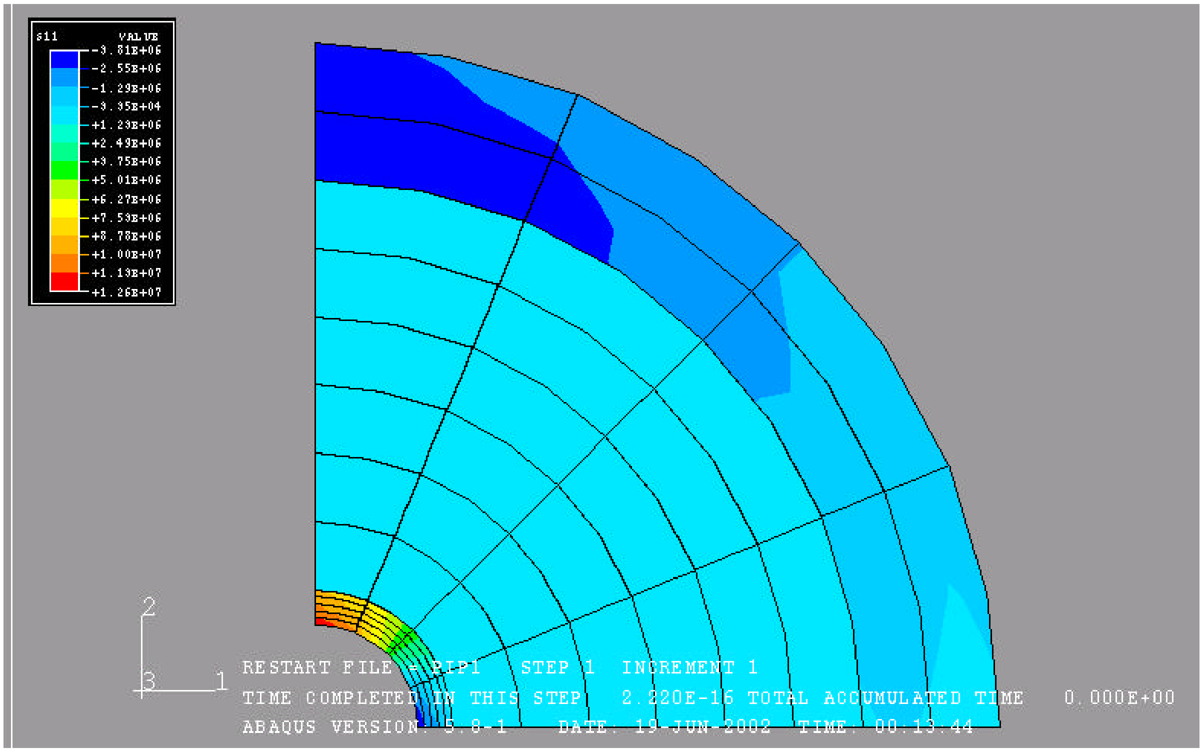


Fig.8b Second principal stress profile (Confining Pressure = 100 psi)

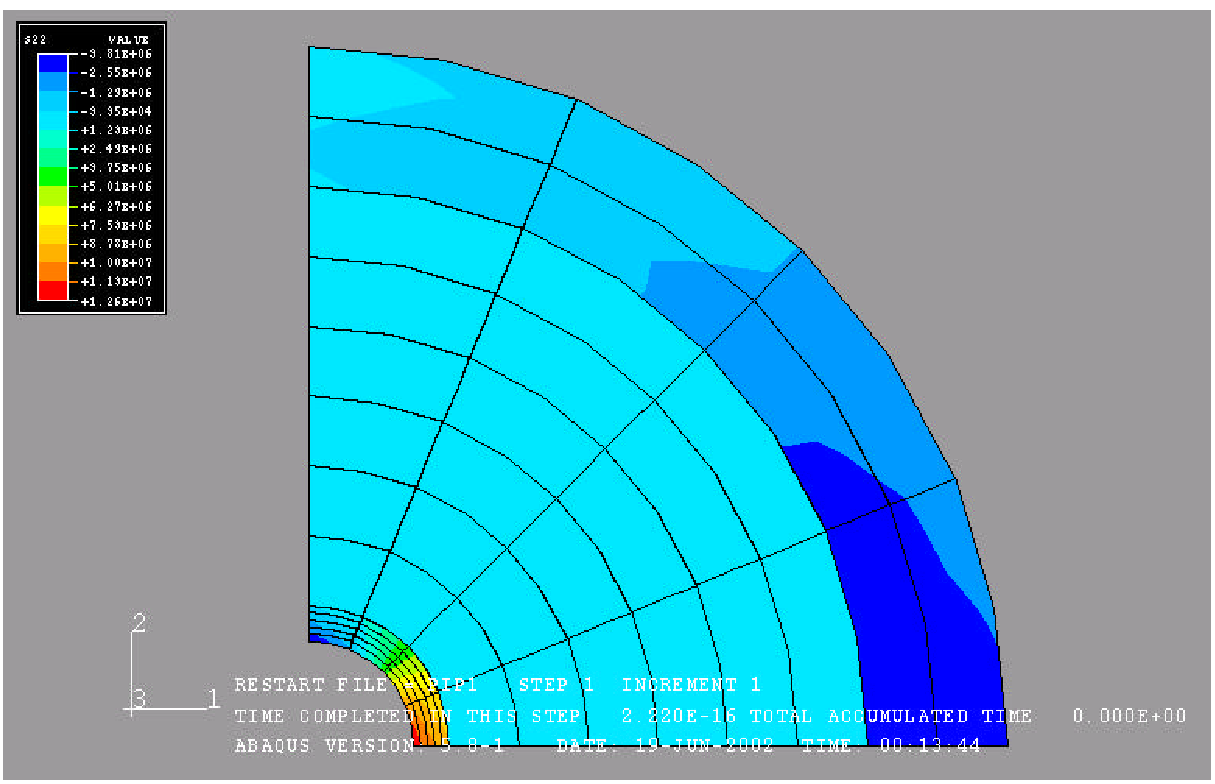


Fig.8c Horizontal displacement field (Confining Pressure = 100 psi)

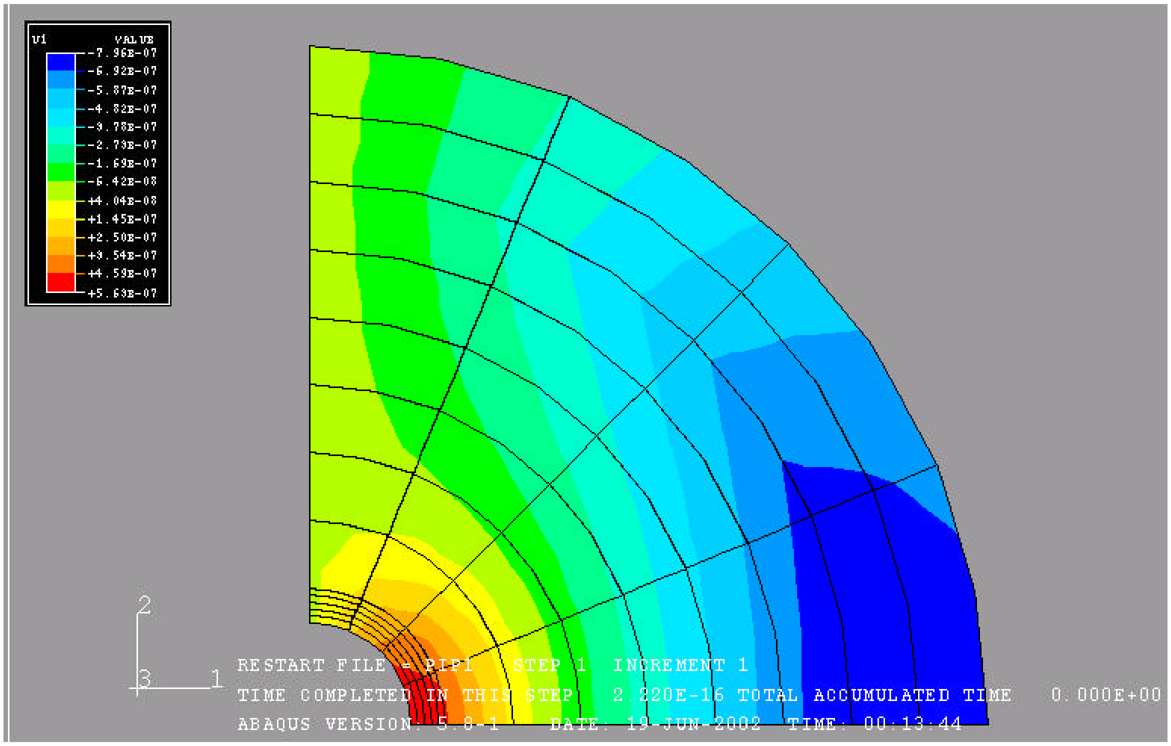


Fig.8d Vertical displacement field (Confining Pressure = 100 psi)

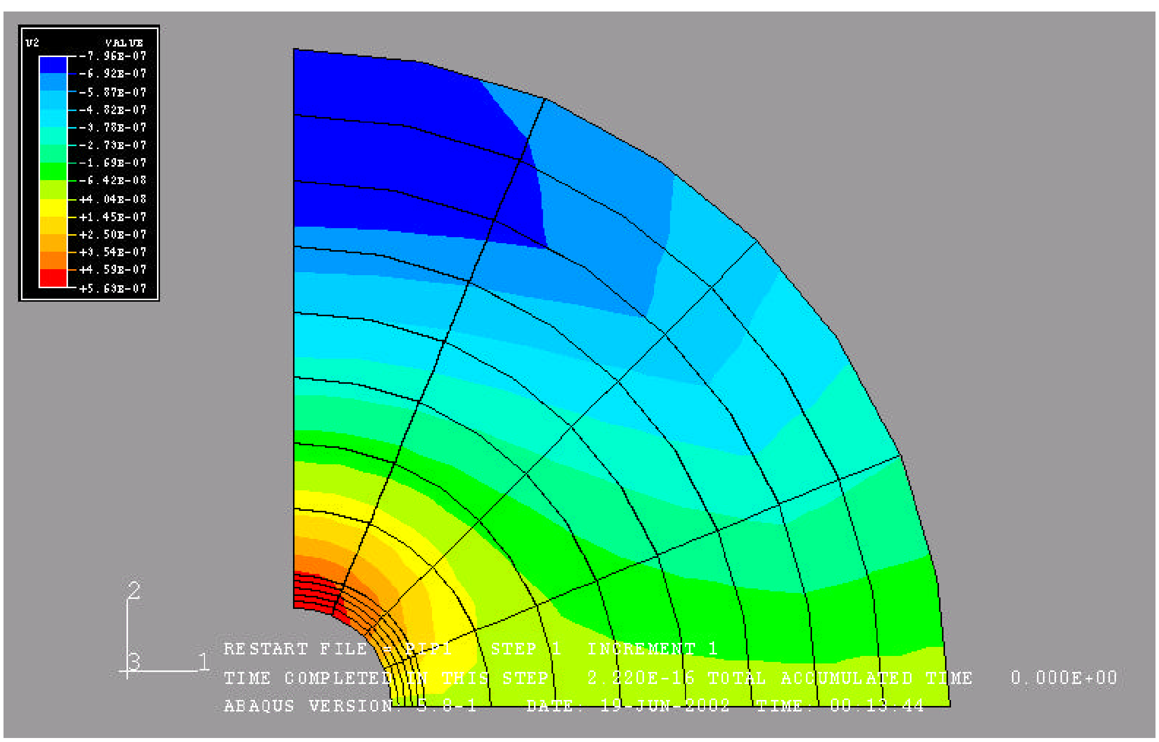


Fig.9a First principal stress profile (Confining Pressure = 500 psi)

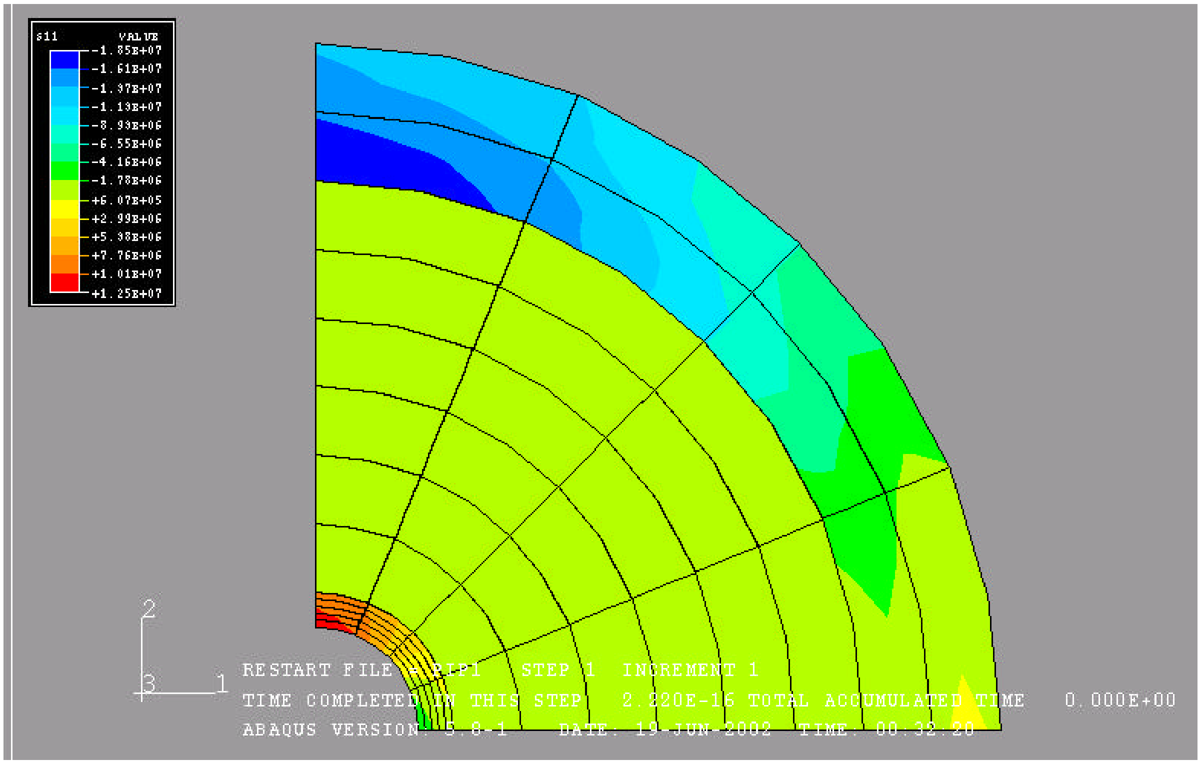


Fig.9b Second principal stress profile (Confining Pressure = 500 psi)

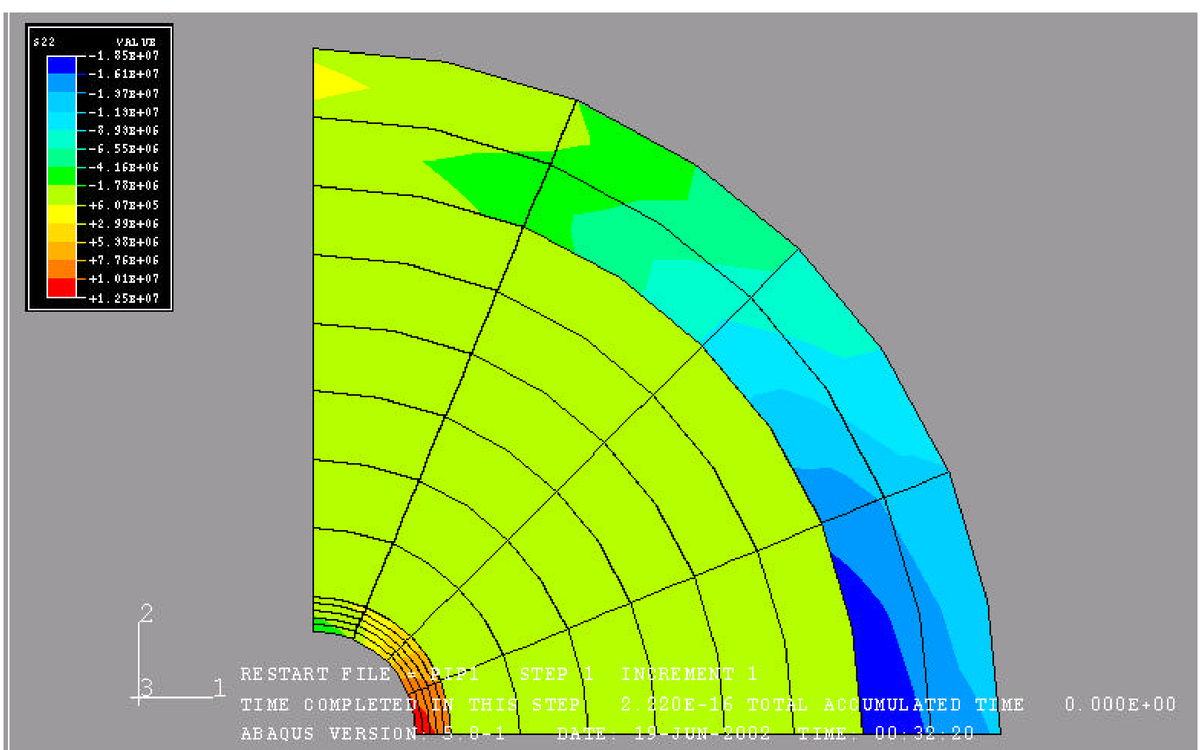


Fig.9c Horizontal displacement field (Confining Pressure = 500 psi)

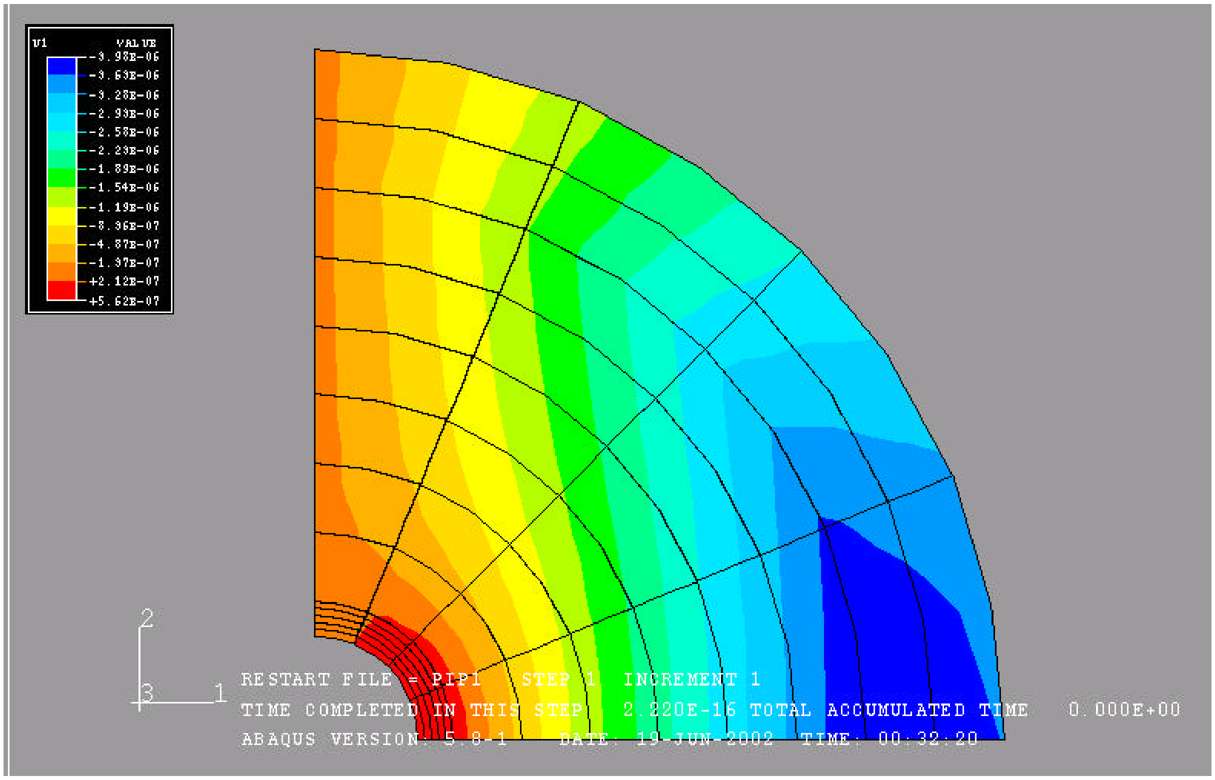


Fig.9d Vertical displacement field (Confining Pressure = 500 psi)

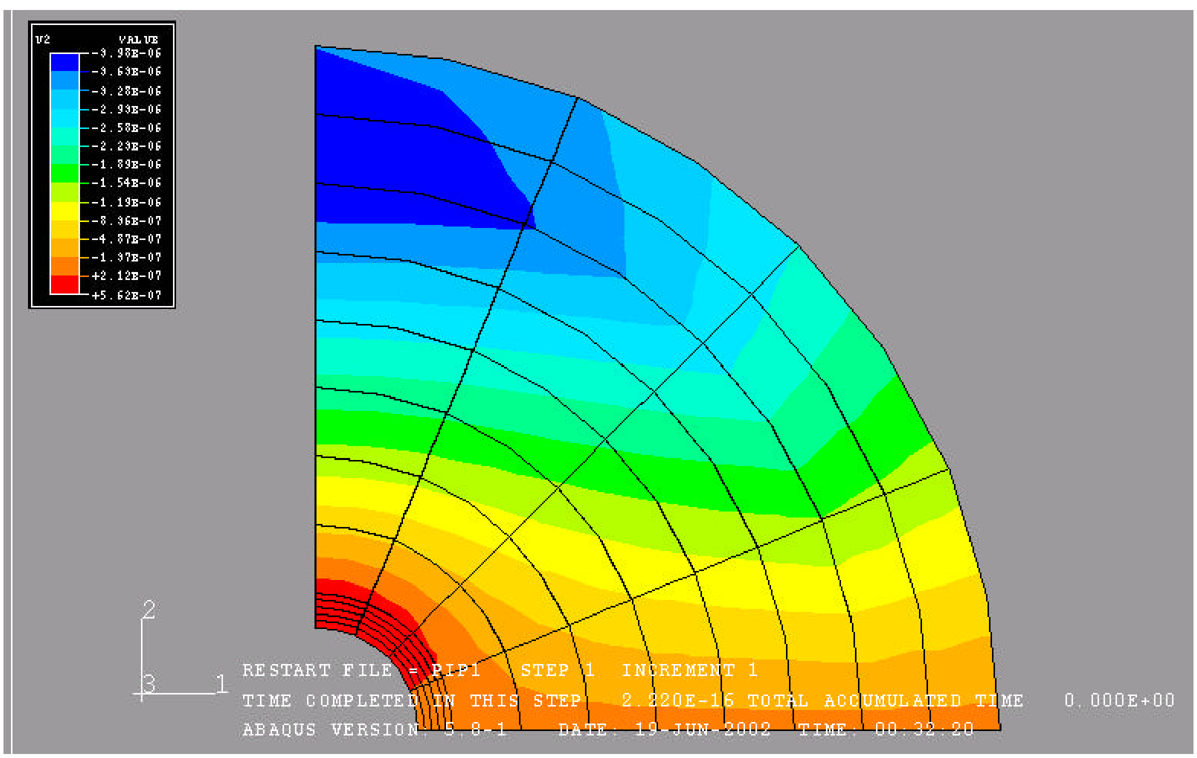


Fig.10a First principal stress profile (Confining Pressure = 1000 psi)

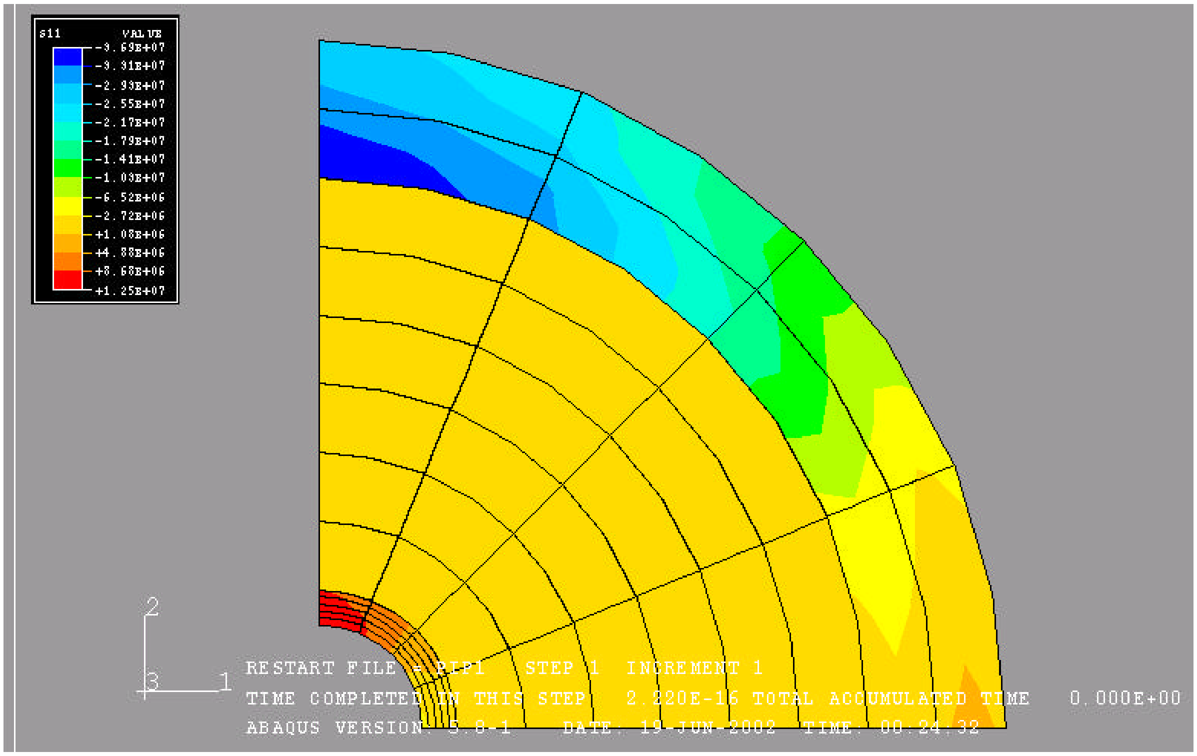


Fig.10b Second principal stress profile (Confining Pressure = 1000 psi)

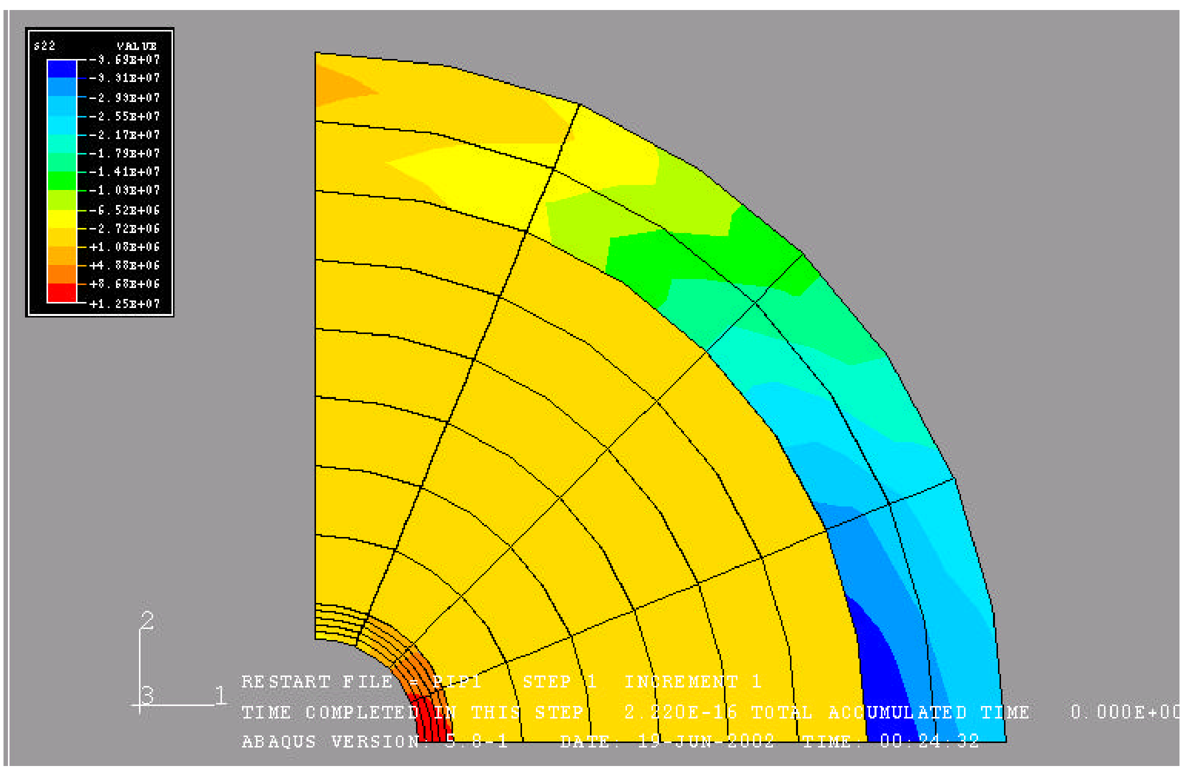


Fig.10c Horizontal displacement field (Confining Pressure = 1000 psi)

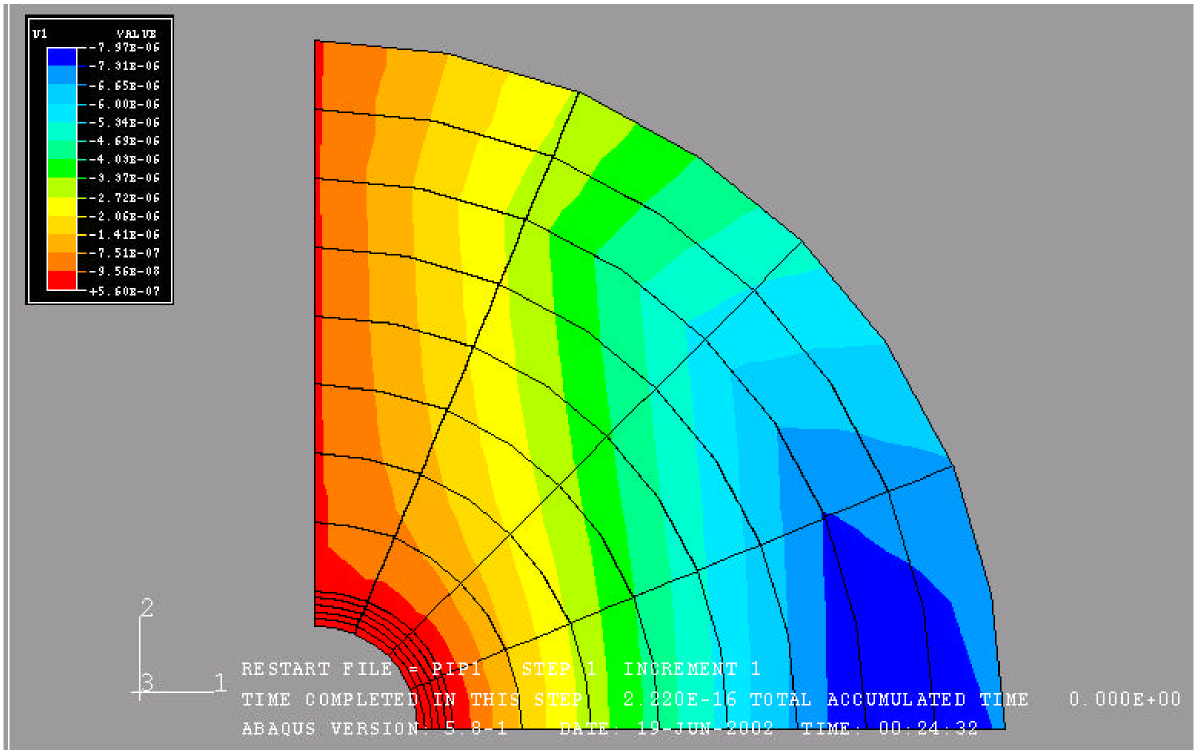


Fig.10d Vertical displacement field (Confining Pressure = 1000 psi)

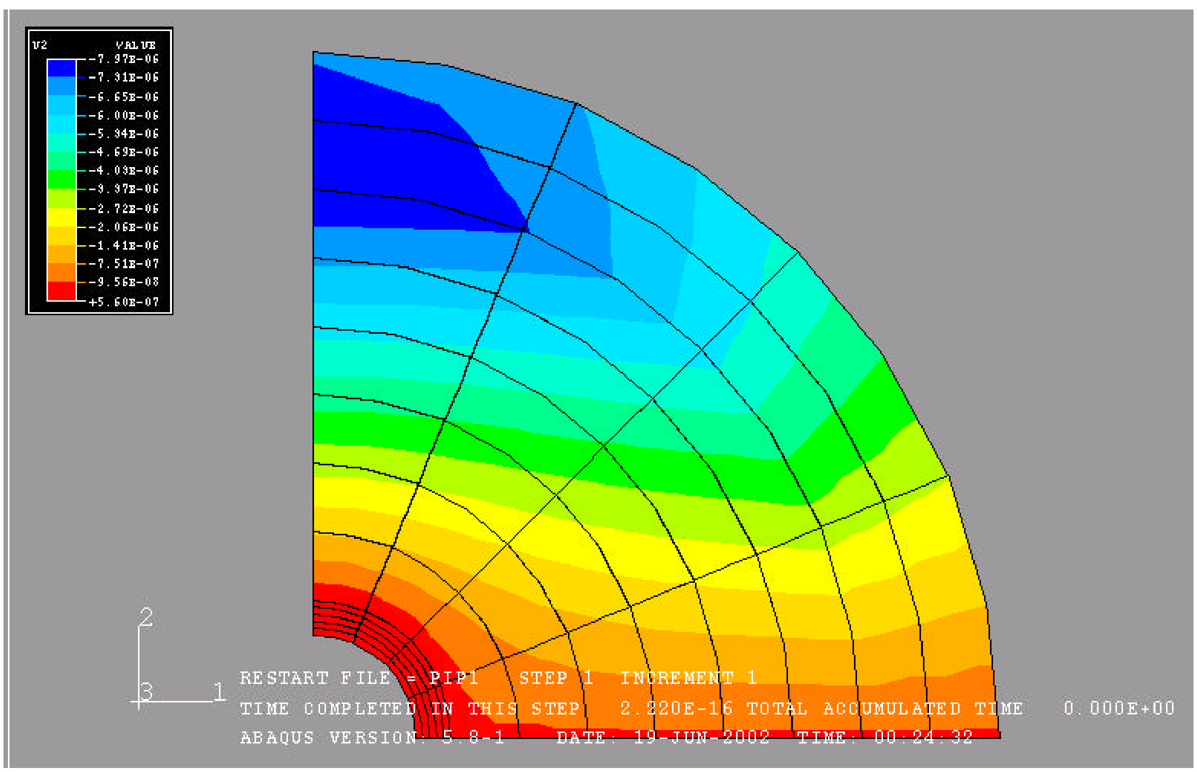


Fig.11a First principal stress profile (Cement Thickness = 3.5")

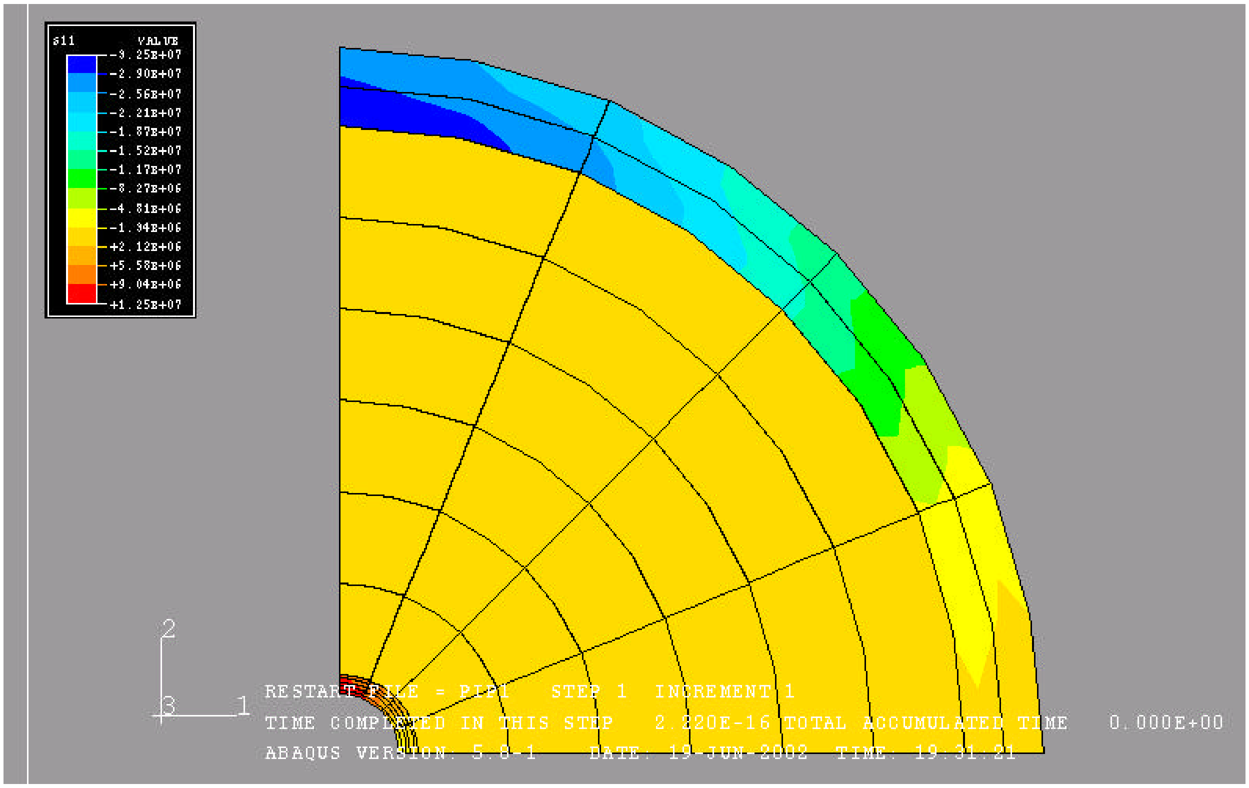


Fig.11b Second principal stress profile (Cement Thickness = 3.5")

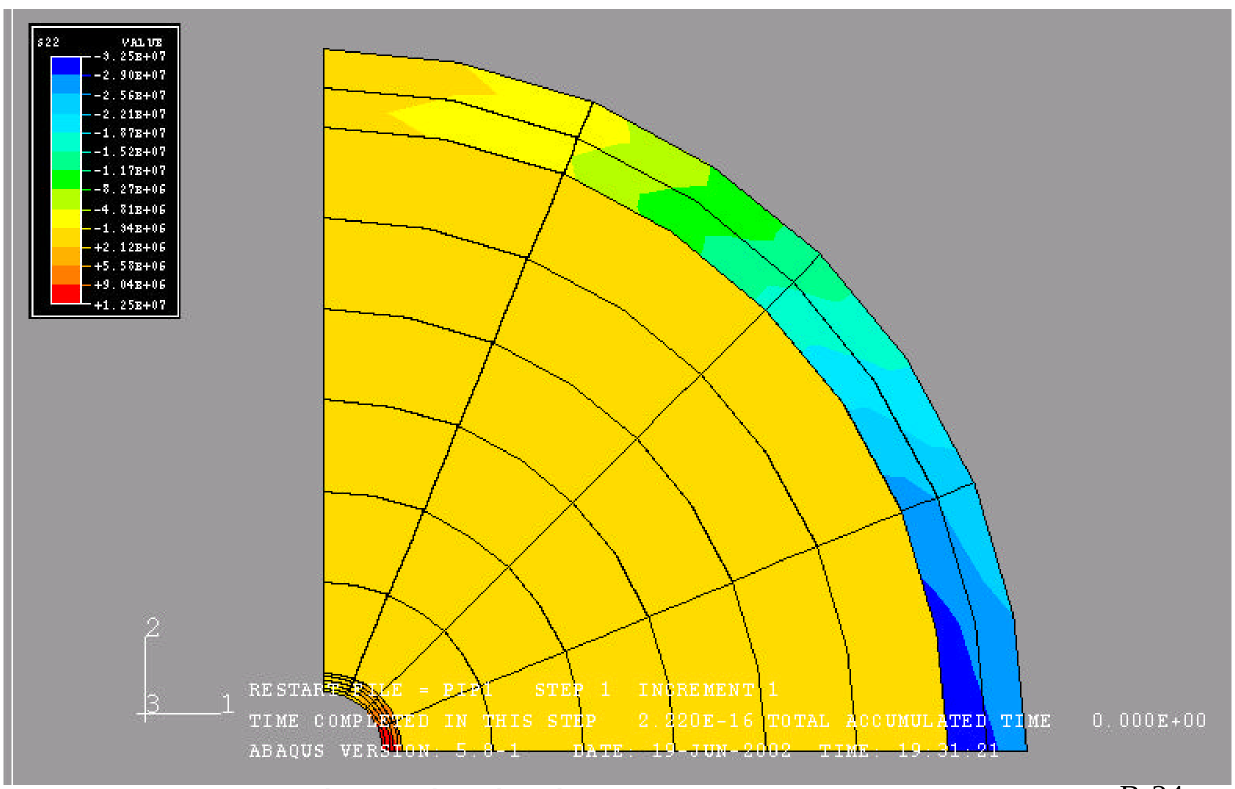


Fig.11c Horizontal displacement field (Cement Thickness = 3.5”)

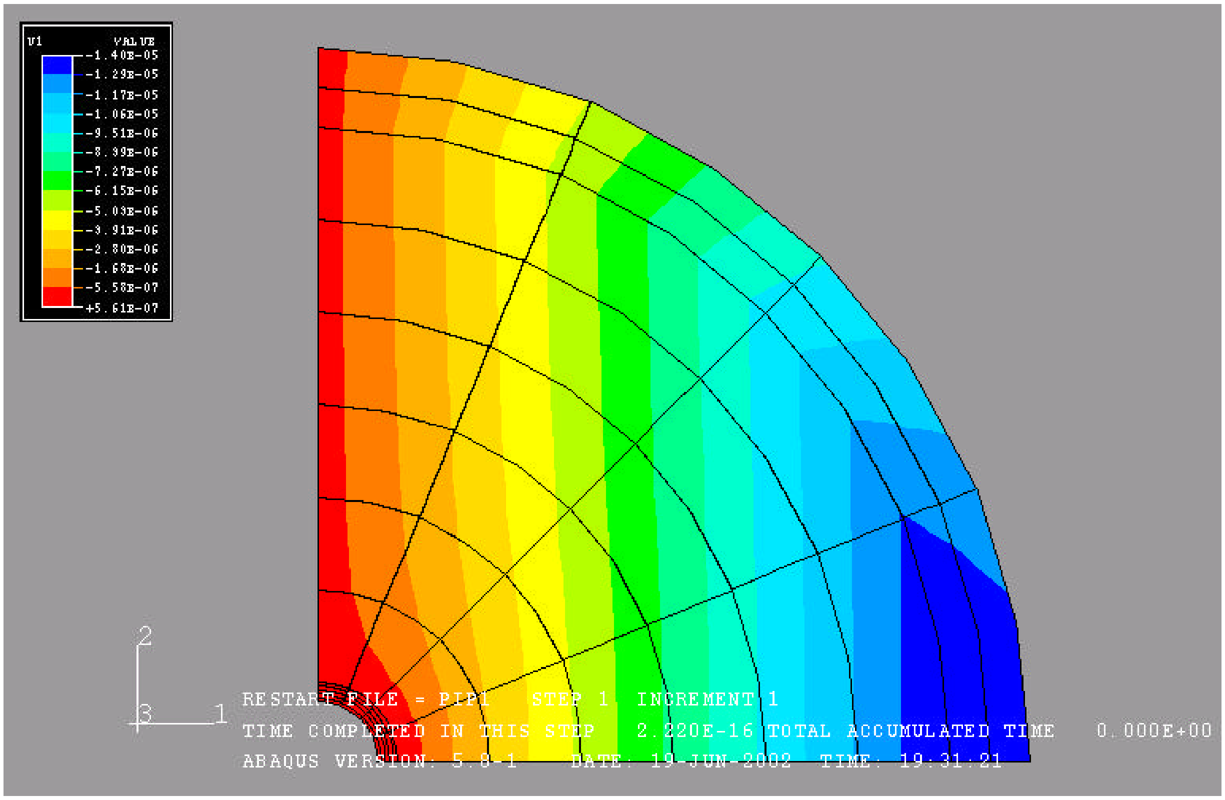


Fig.11d Vertical displacement field (Cement Thickness = 3.5”)

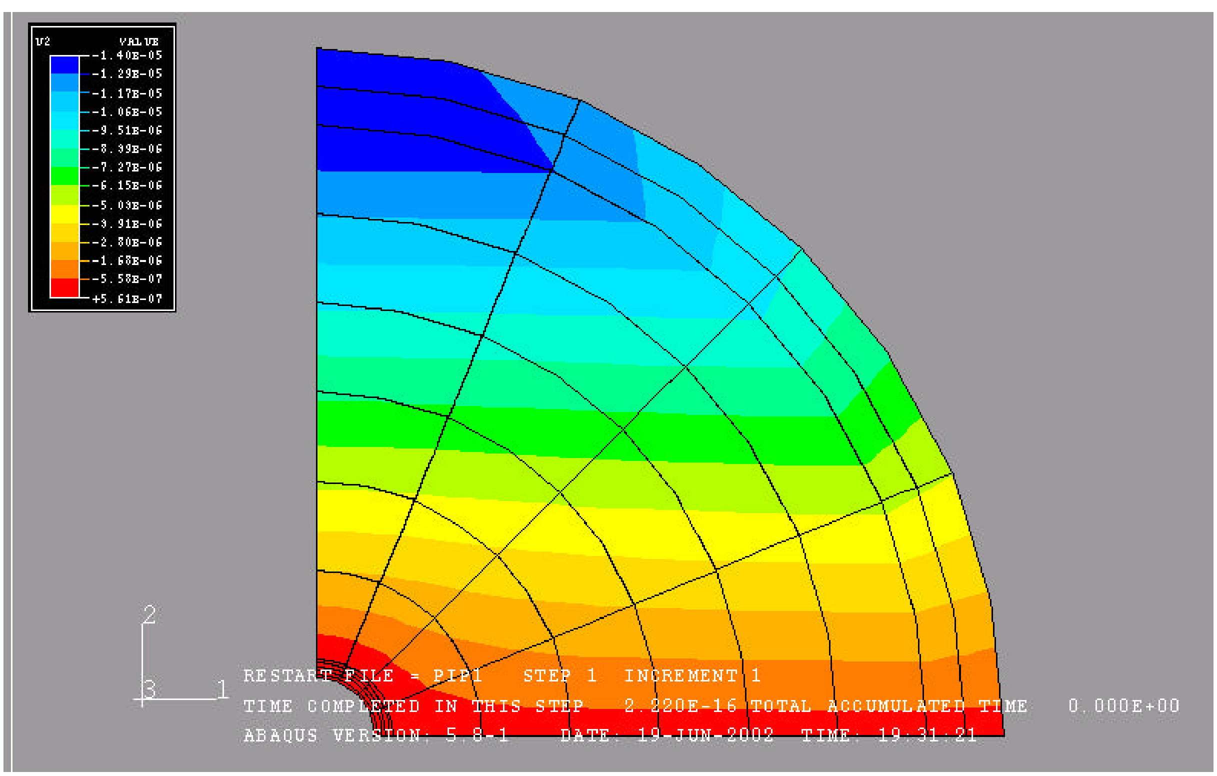


Fig.12a First principal stress profile (Cement Thickness = 5.5")

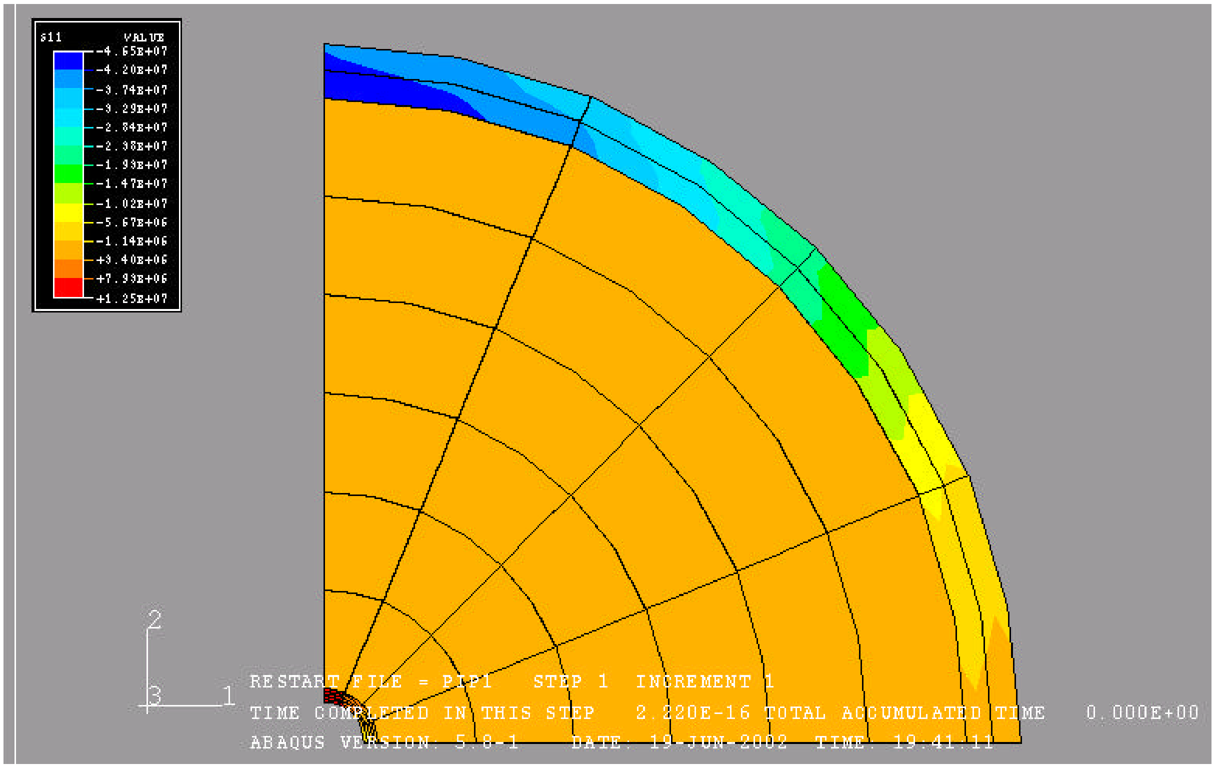


Fig.12b Second principal stress profile (Cement Thickness = 5.5")

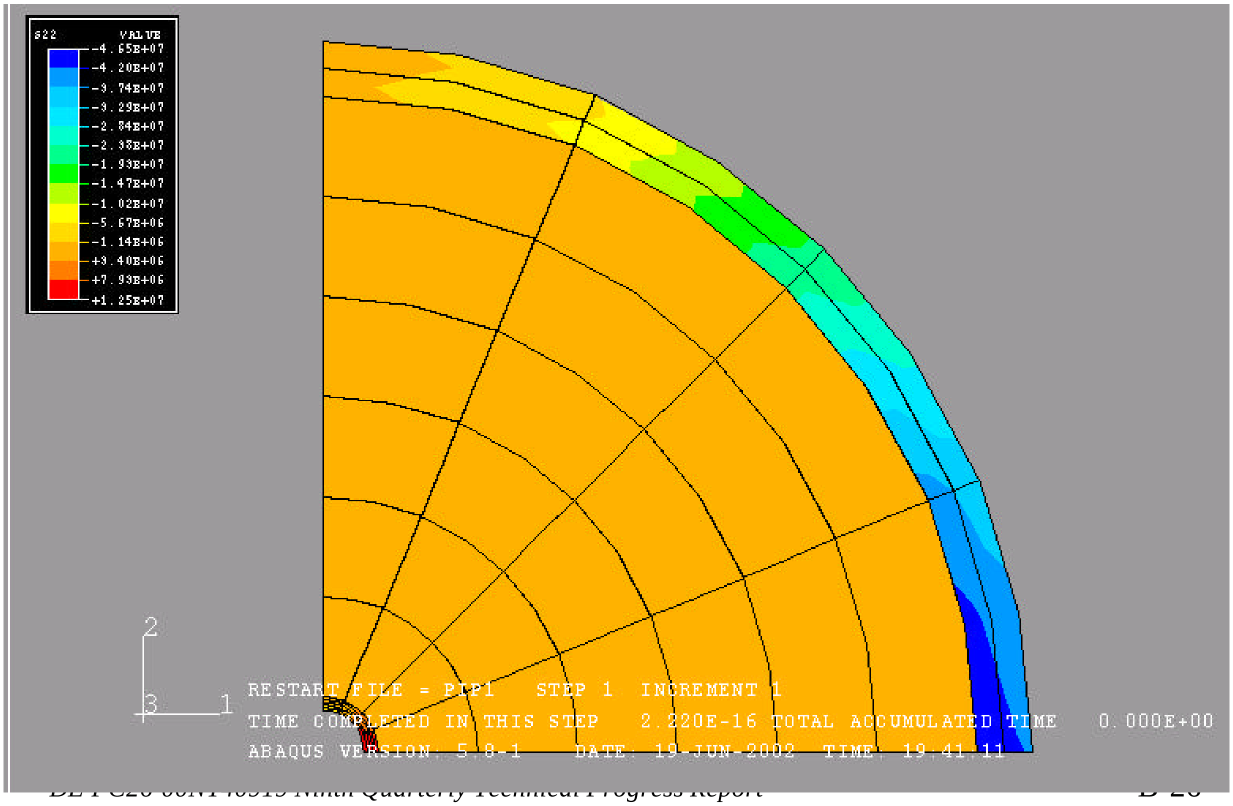


Fig.12c Horizontal displacement field (Cement Thickness = 5.5")

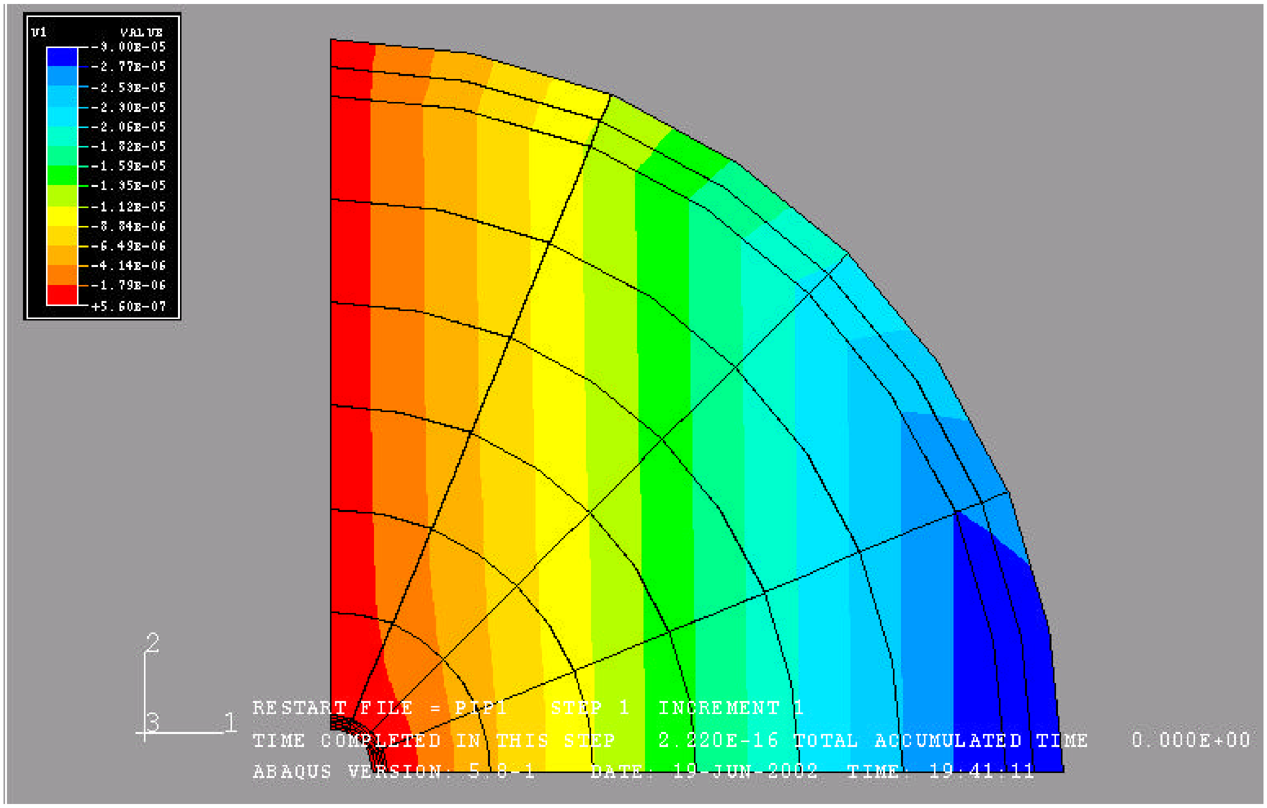


Fig.12d Vertical displacement field (Cement Thickness = 5.5")

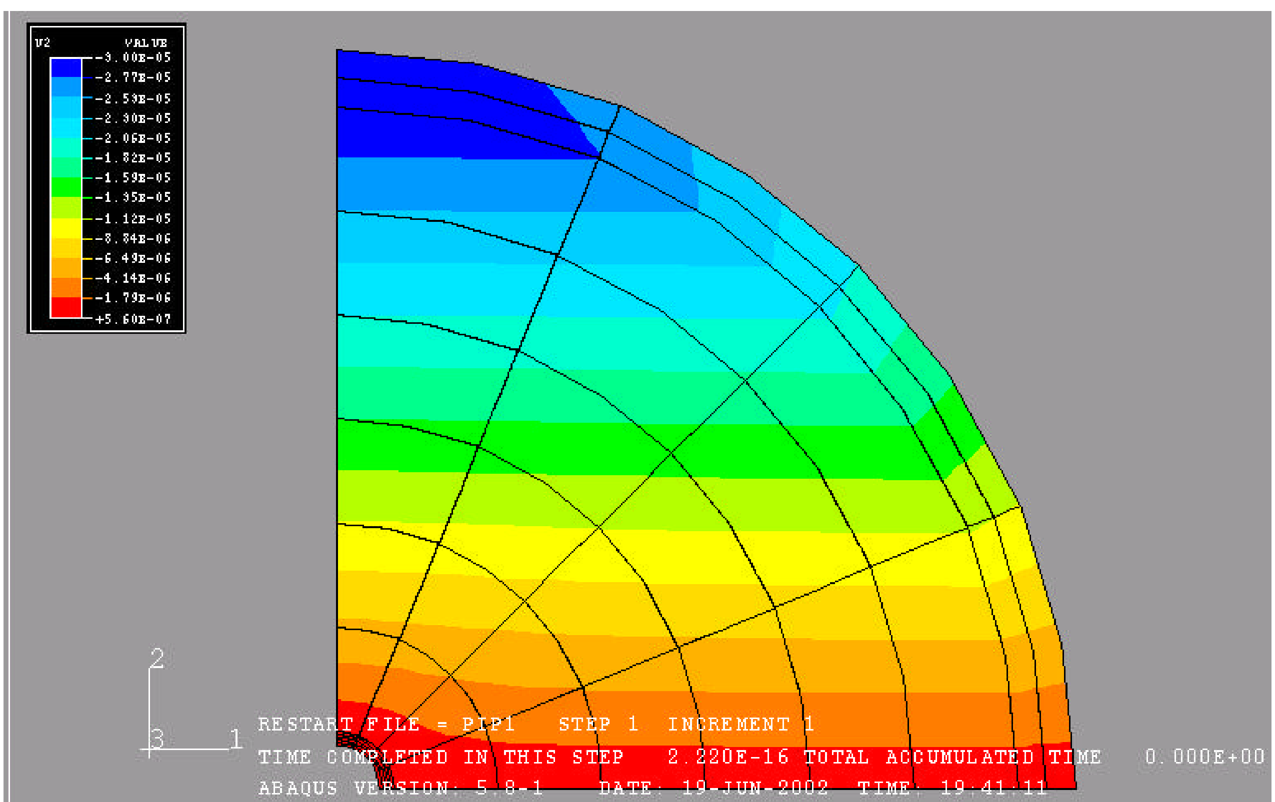


Fig.13a First principal stress profile (Cement Thickness = 7.5")

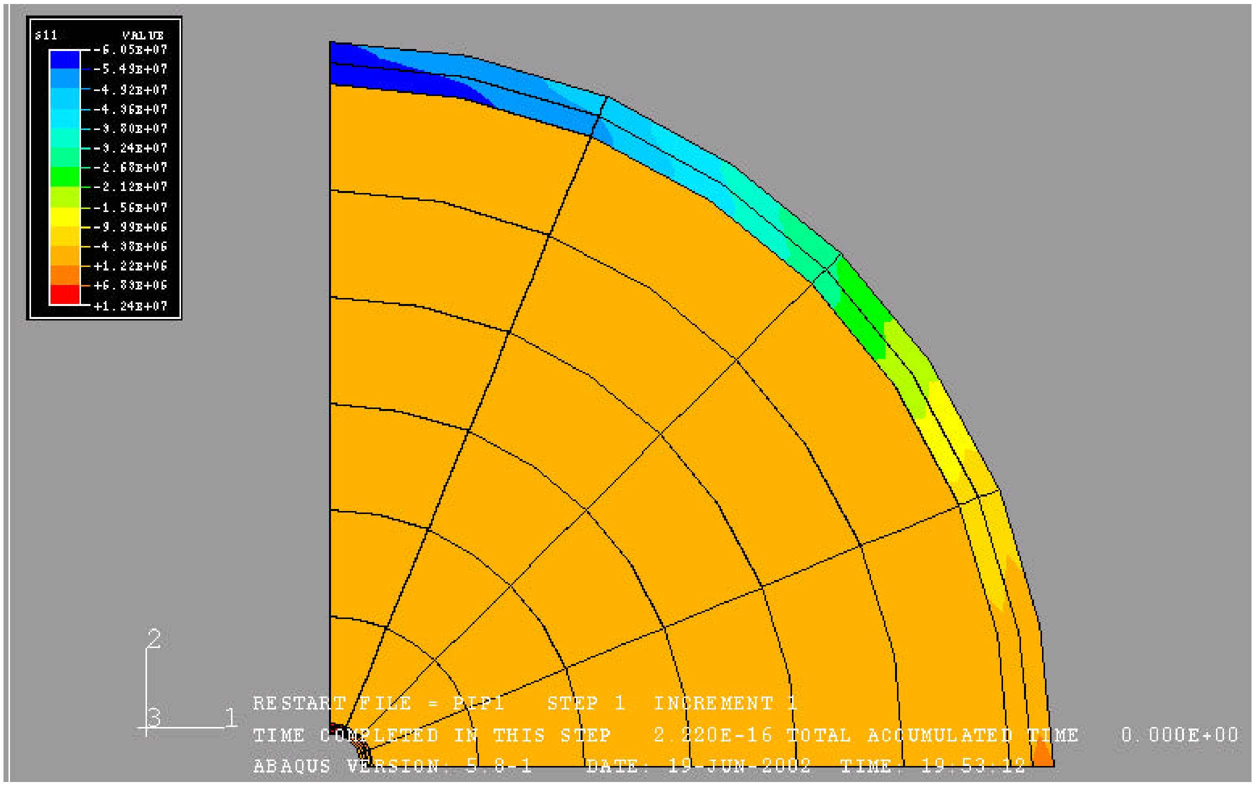
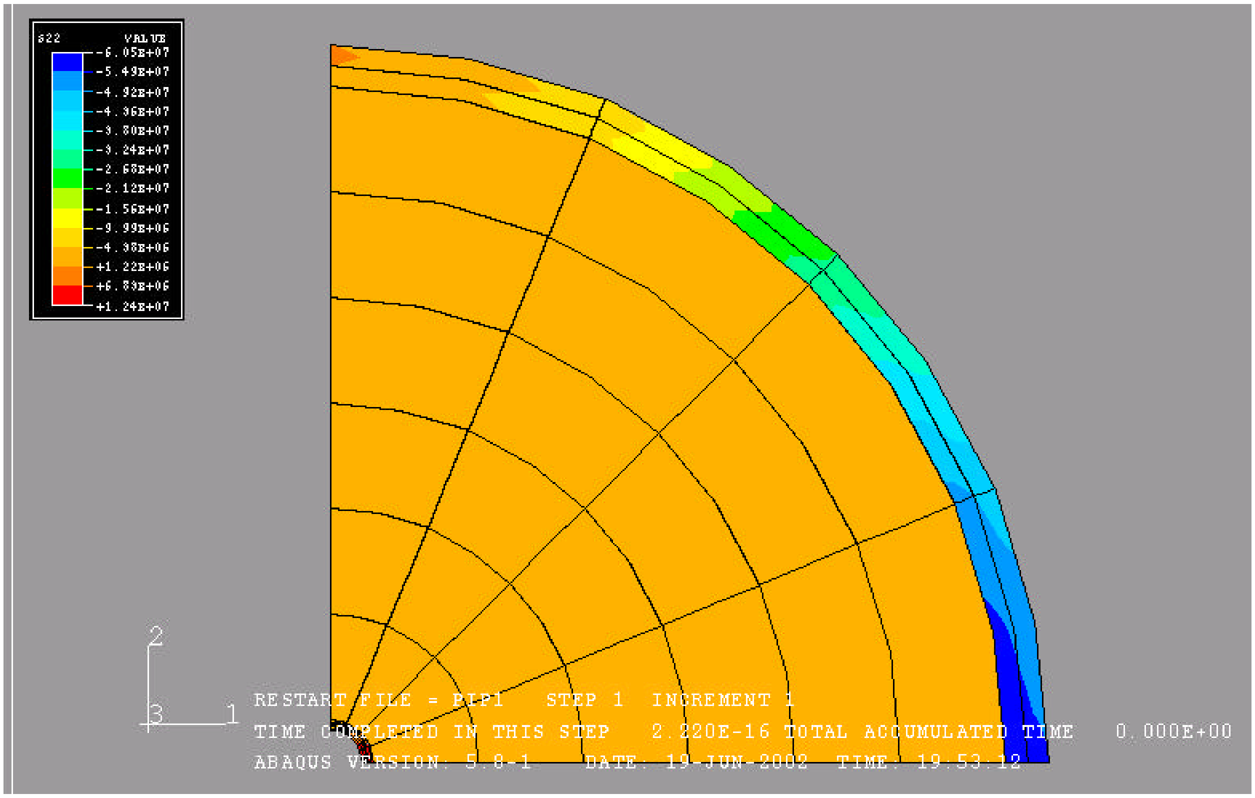


Fig.13b Second principal stress profile (Cement Thickness = 7.5")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-1.56E+07
-9.99E+06
-4.38E+06
+1.22E+06
+6.83E+06
+1.24E+07
2
3
1
RESTART FILE = PIP1 STEP 1 INCREMENT 1
TIME COMPLETED IN THIS STEP 2.220E-16 TOTAL ACCUMULATED TIME 0.000E+00
ABAQUS VERSION: 5.8-1 DATE: 19-JUN-2002 TIME: 19:53:12

Fig.13c Horizontal displacement field (Cement Thickness = 7.5")

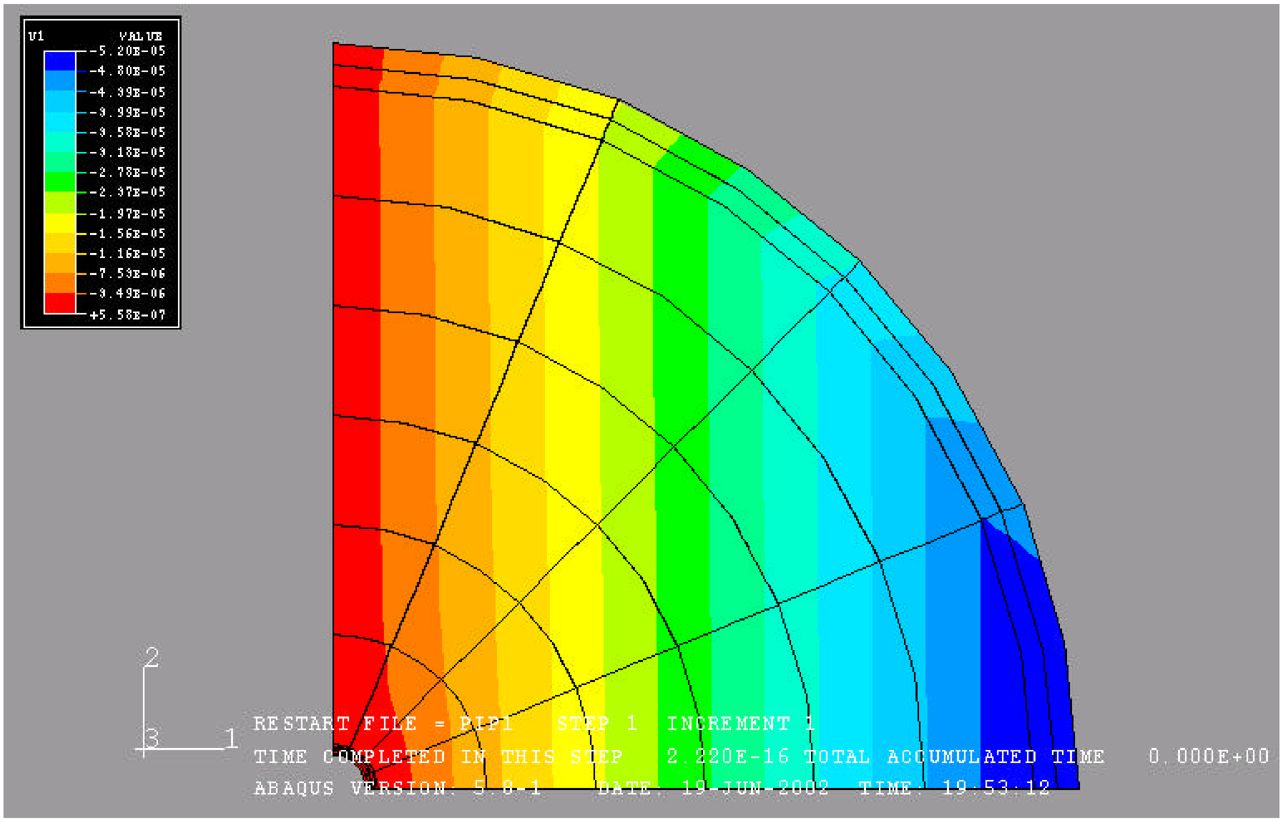


Fig.13d Vertical displacement field (Cement Thickness = 7.5")

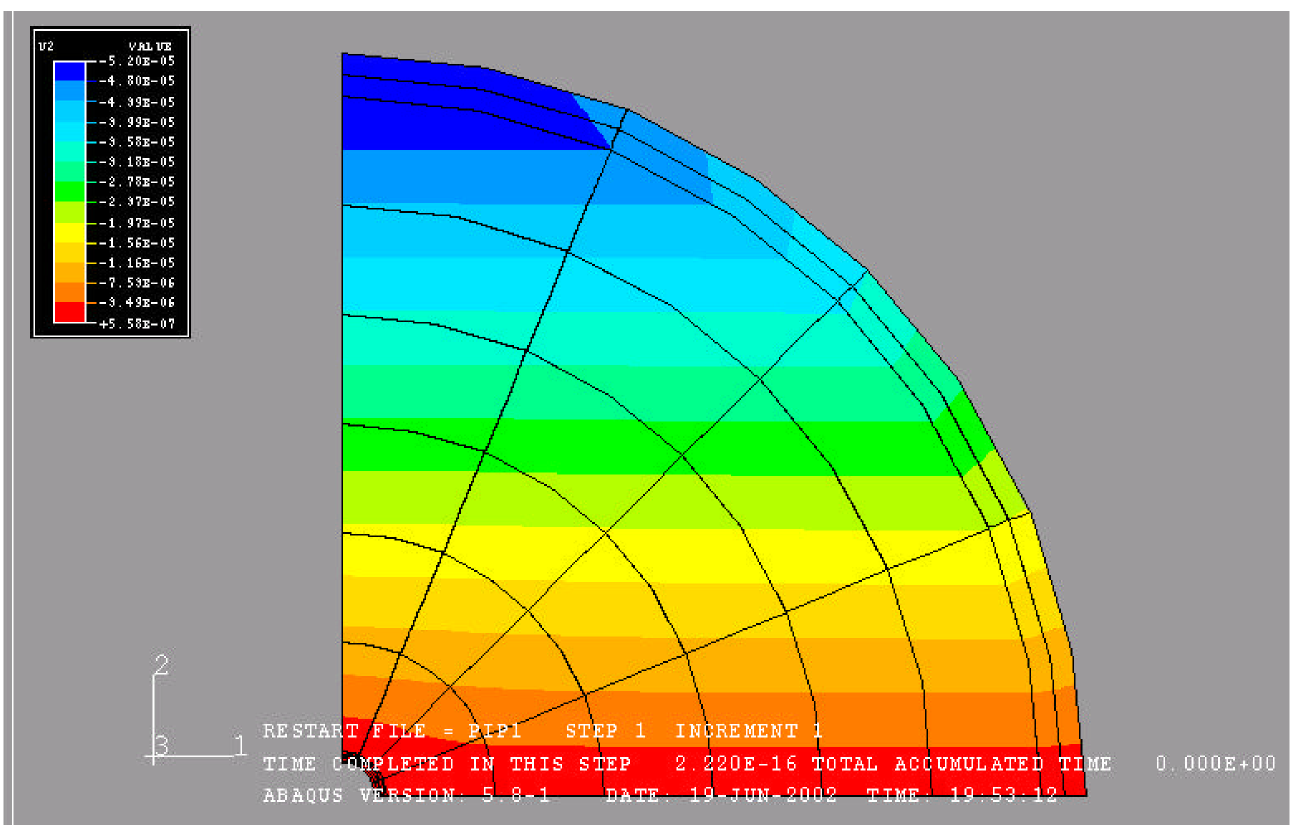


Fig.14a First principal stress profile (Young's Modulus = 1000 psi)

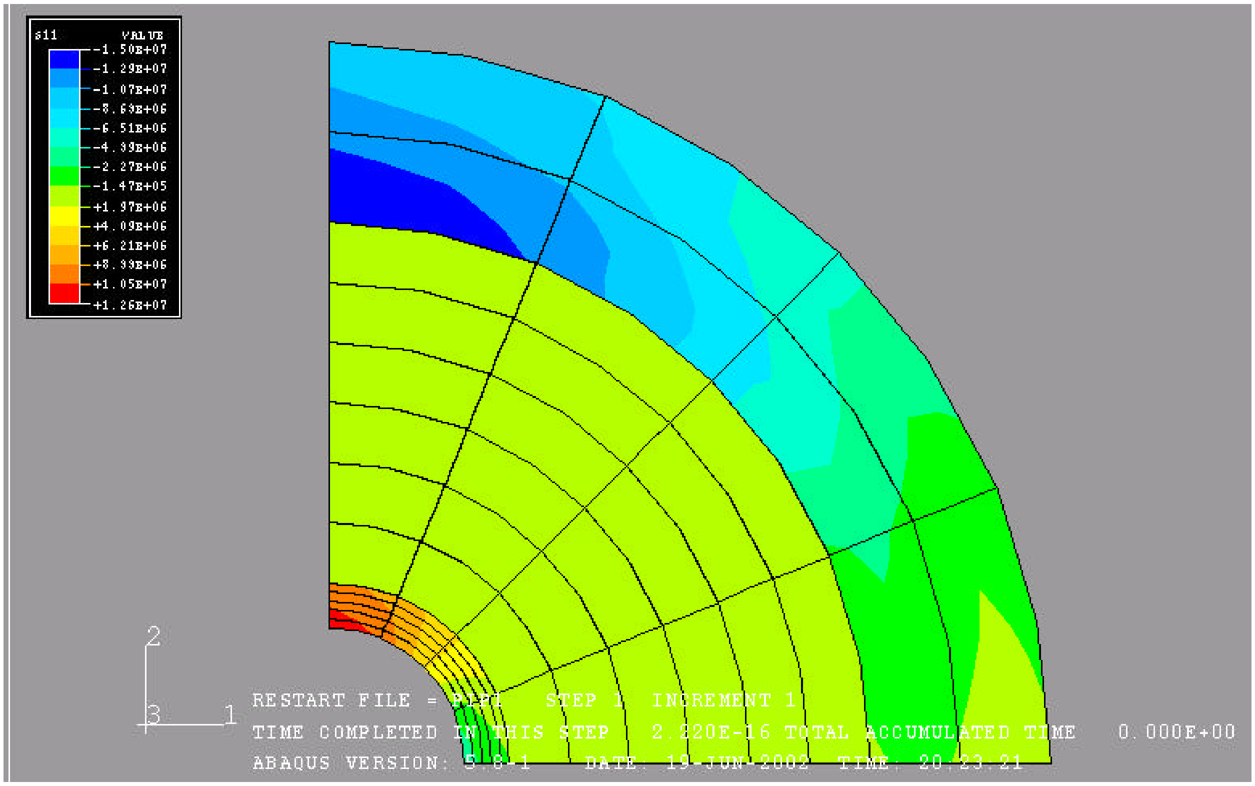


Fig.14b Second principal stress profile (Young's Modulus = 1000 psi)

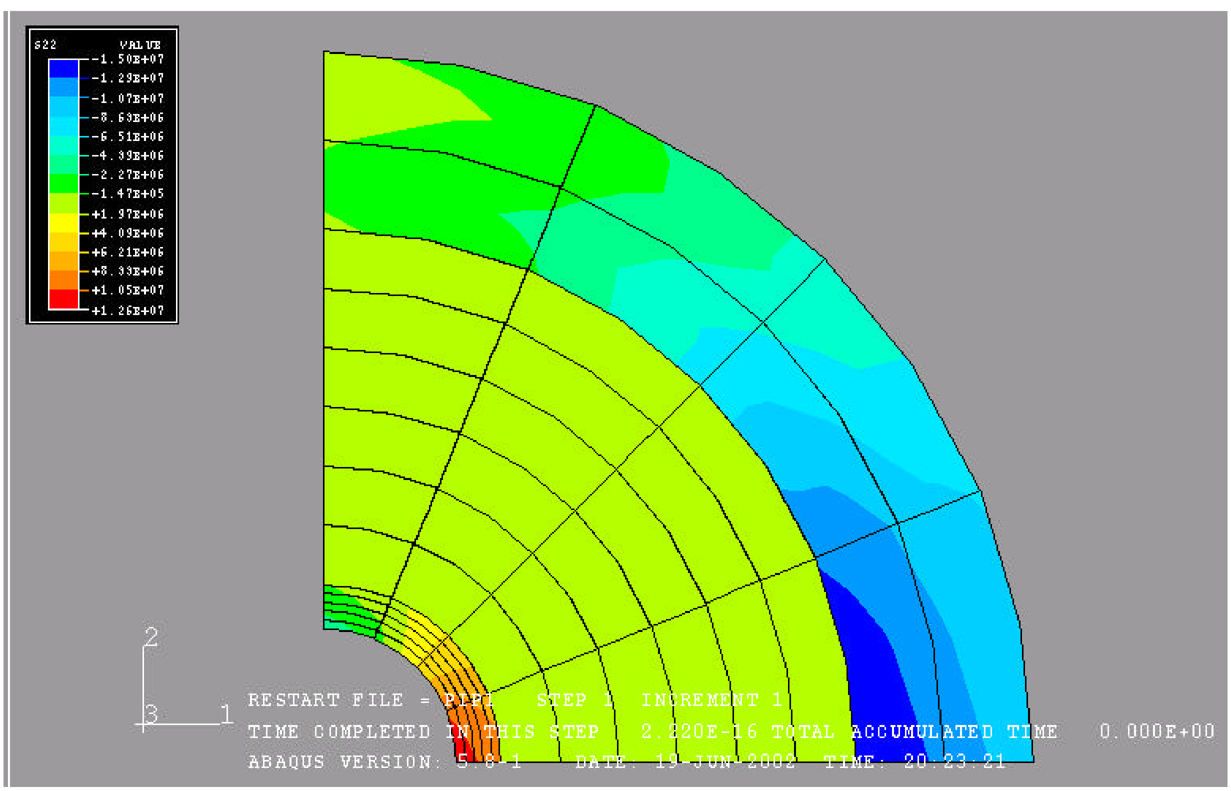


Fig.14c Horizontal displacement field (Young's Modulus = 1000 psi)

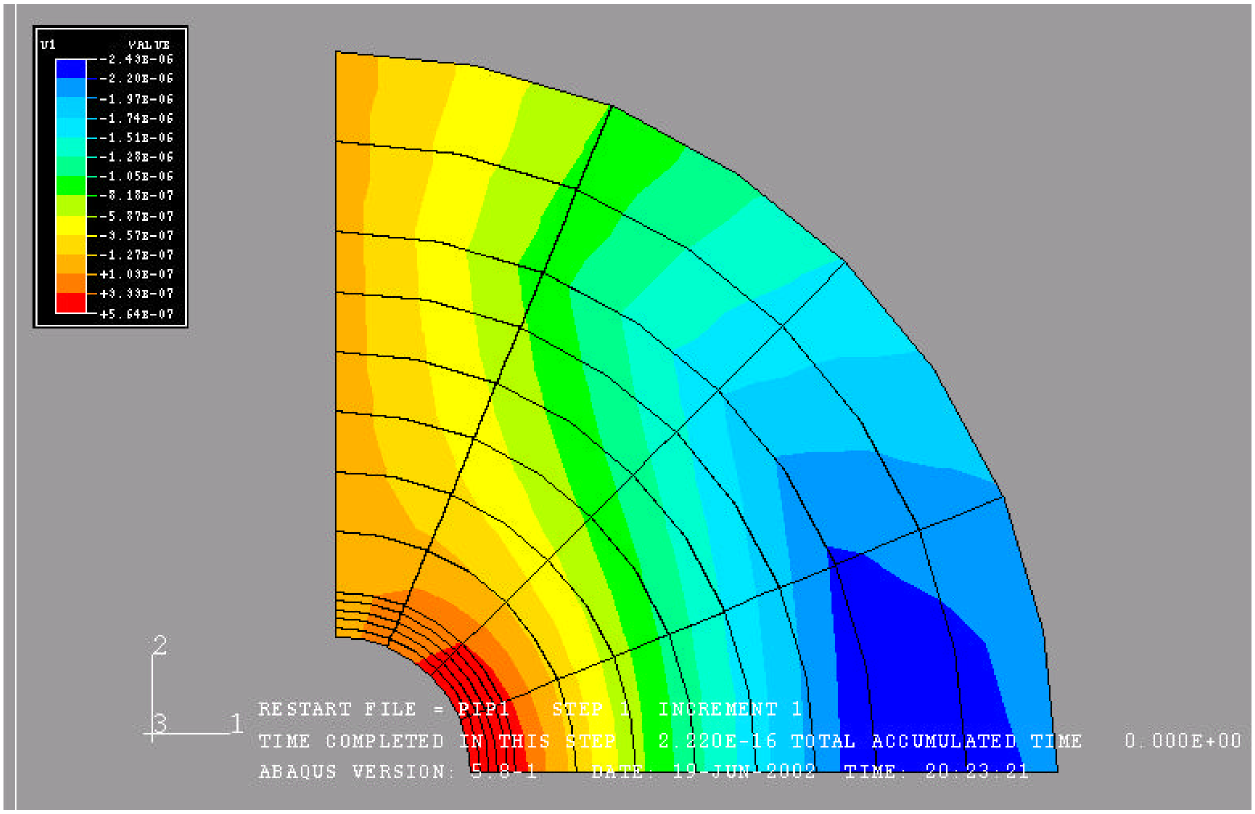


Fig.14d Vertical displacement field (Young's Modulus = 1000 psi)

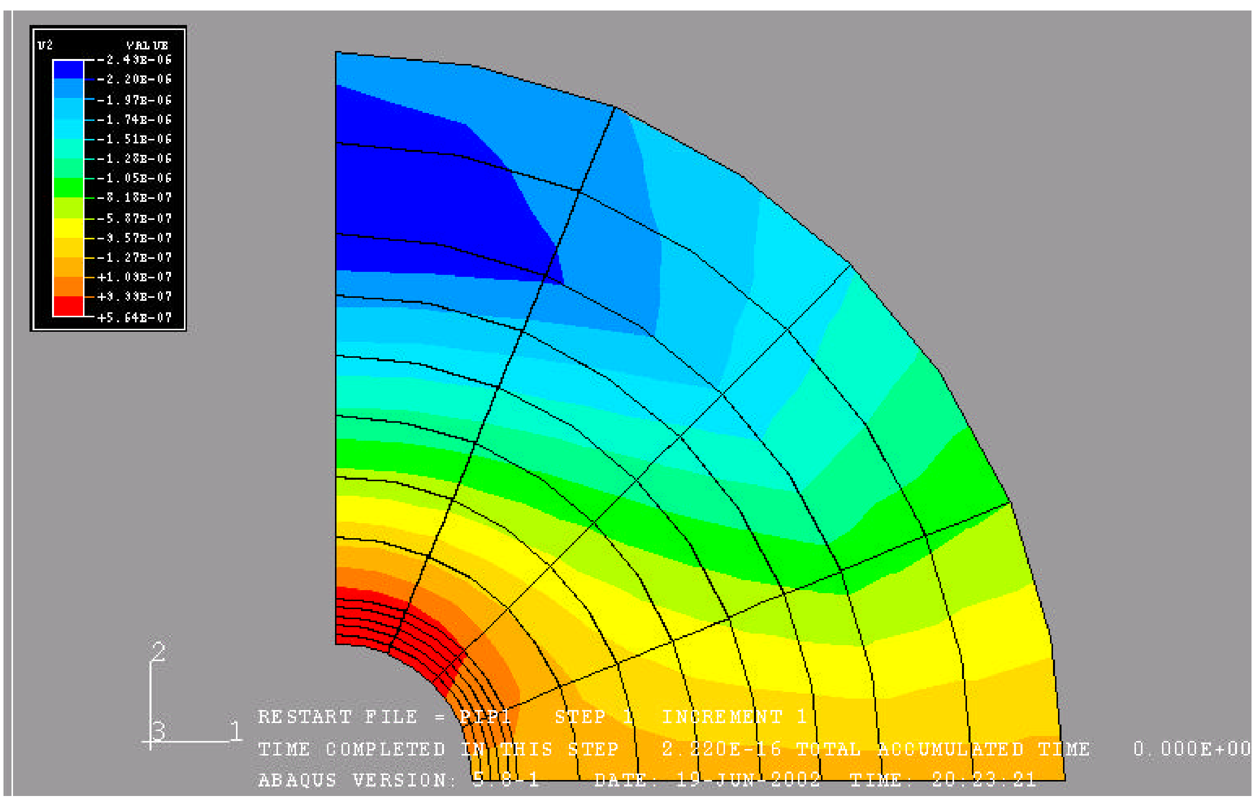


Fig.15a First principal stress profile (Young's Modulus = 3000 psi)

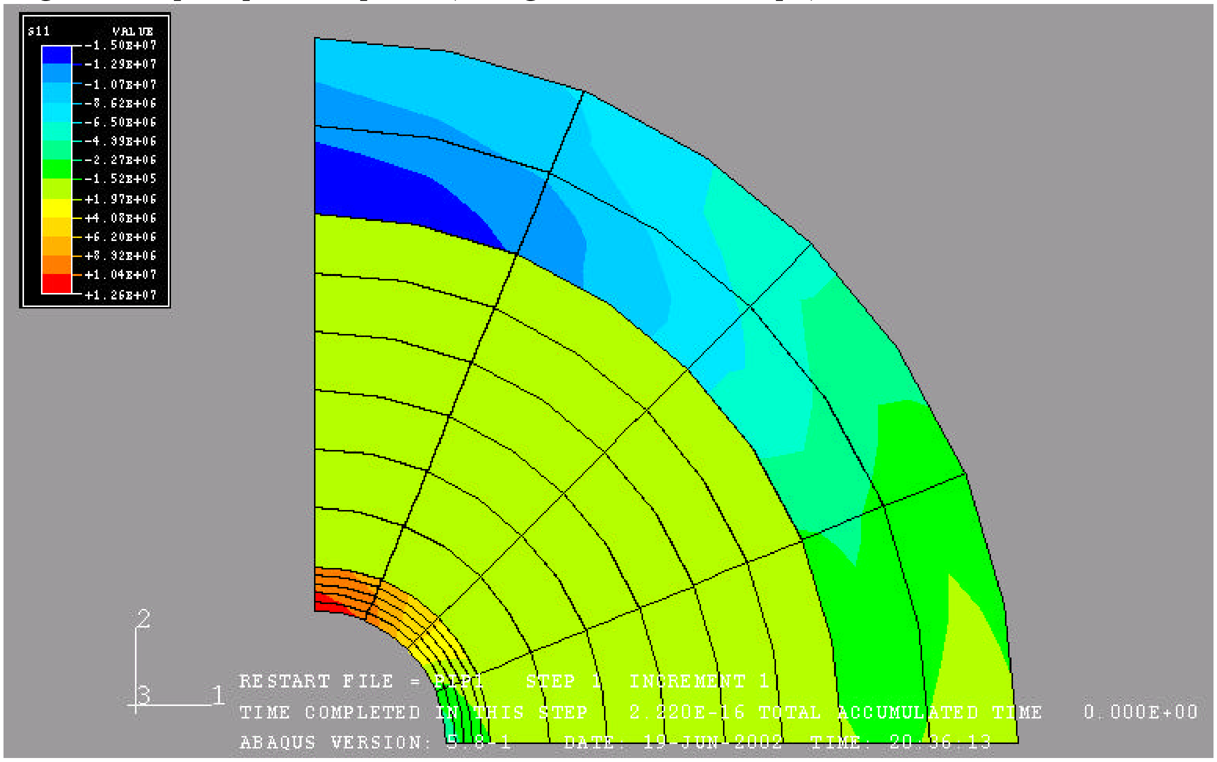


Fig.15b Second principal stress profile (Young's Modulus = 3000 psi)

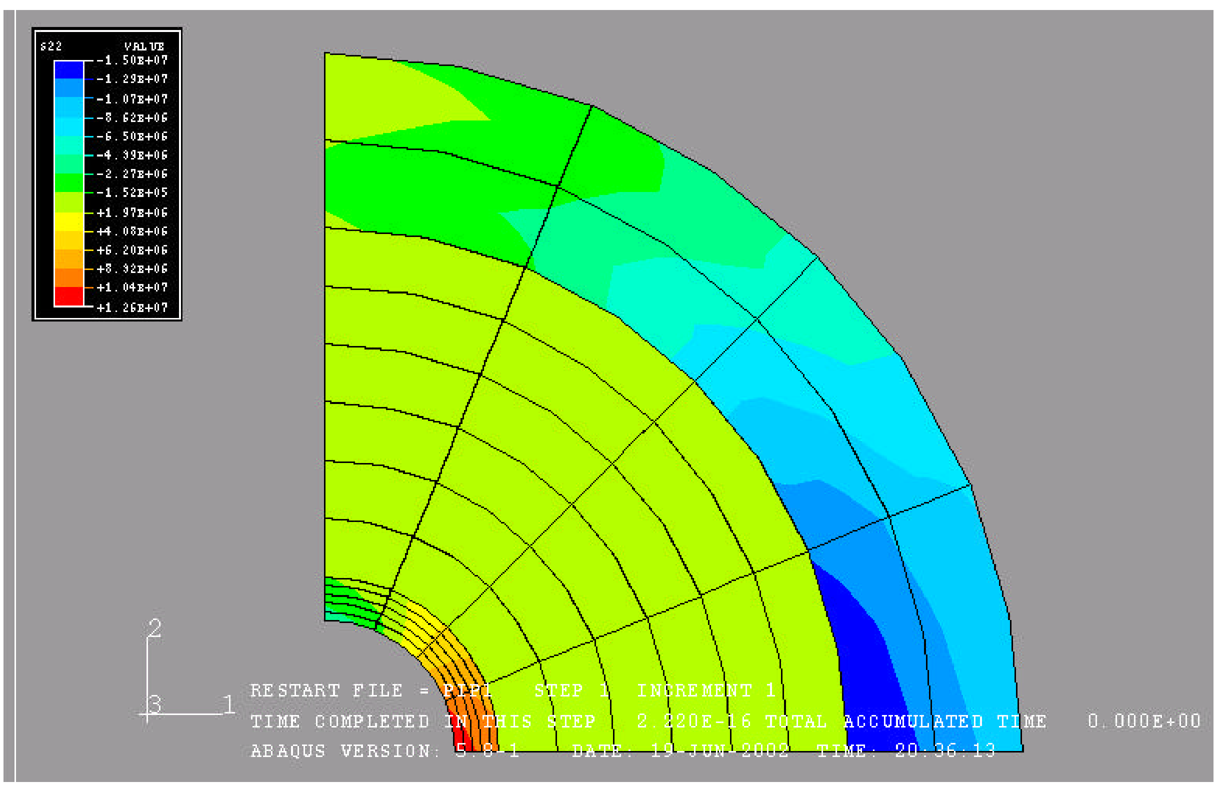


Fig.15c Horizontal displacement field (Young's Modulus = 3000 psi)

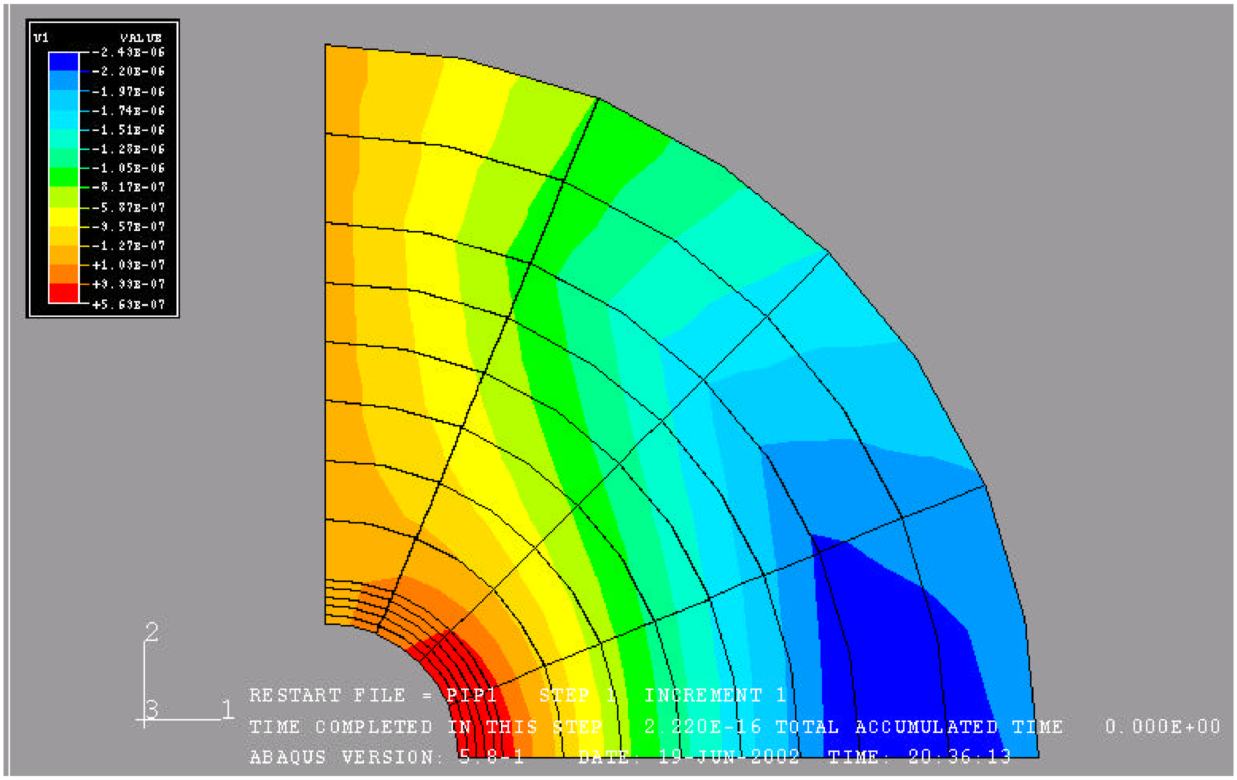


Fig.15d Vertical displacement field (Young's Modulus = 3000 psi)

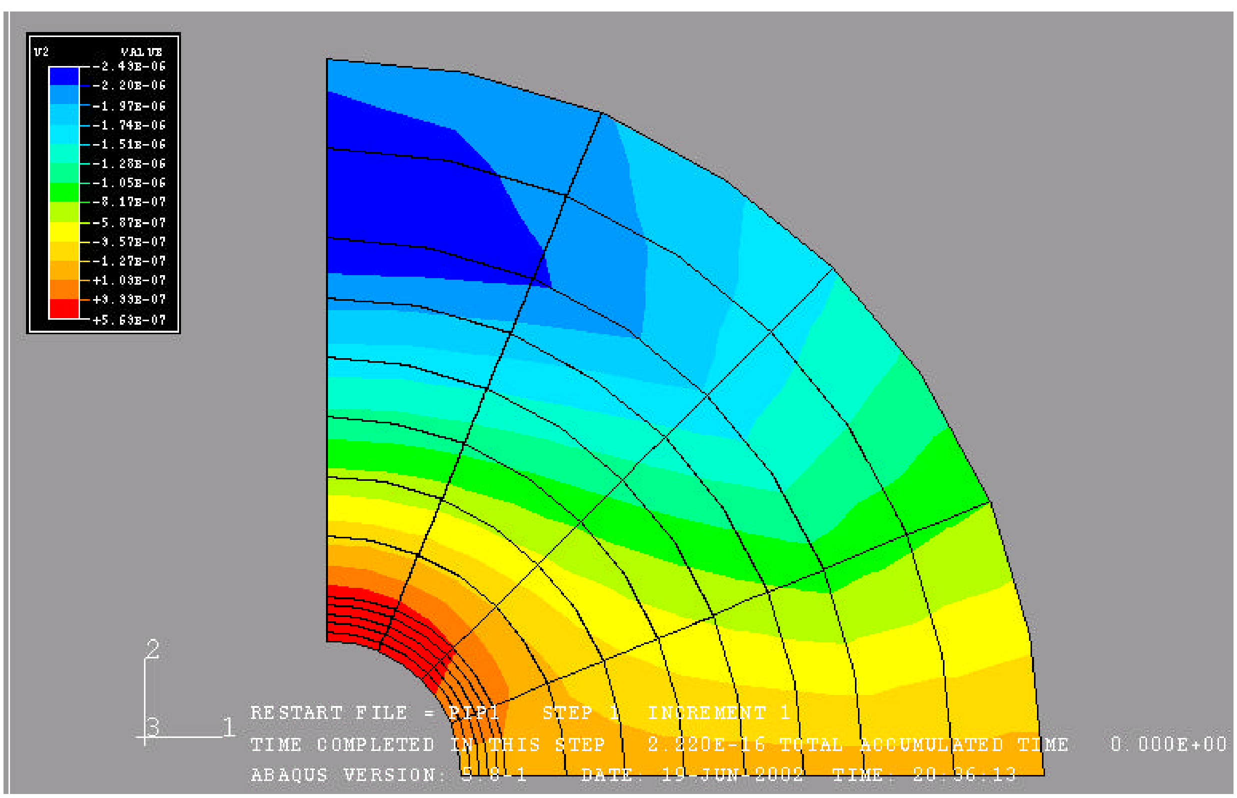


Fig.16a First principal stress profile (Young's Modulus = 5000 psi)

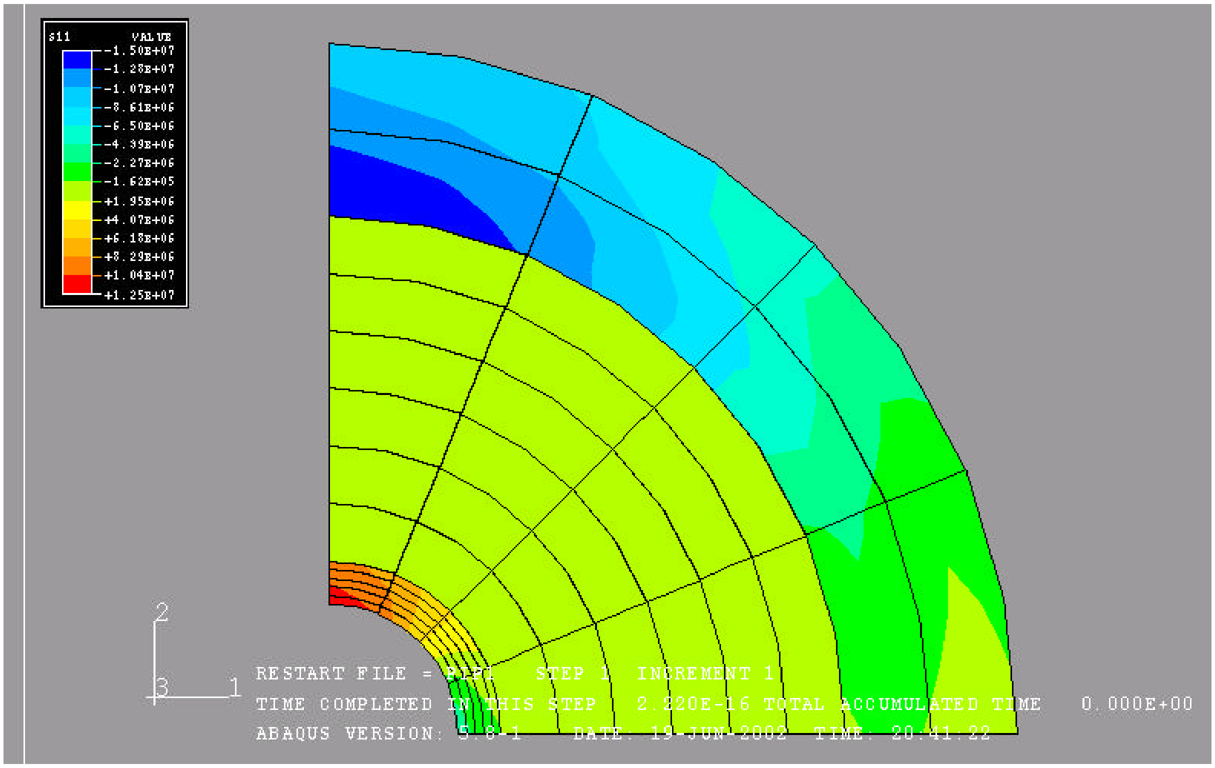


Fig.16b Second principal stress profile (Young's Modulus = 5000 psi)

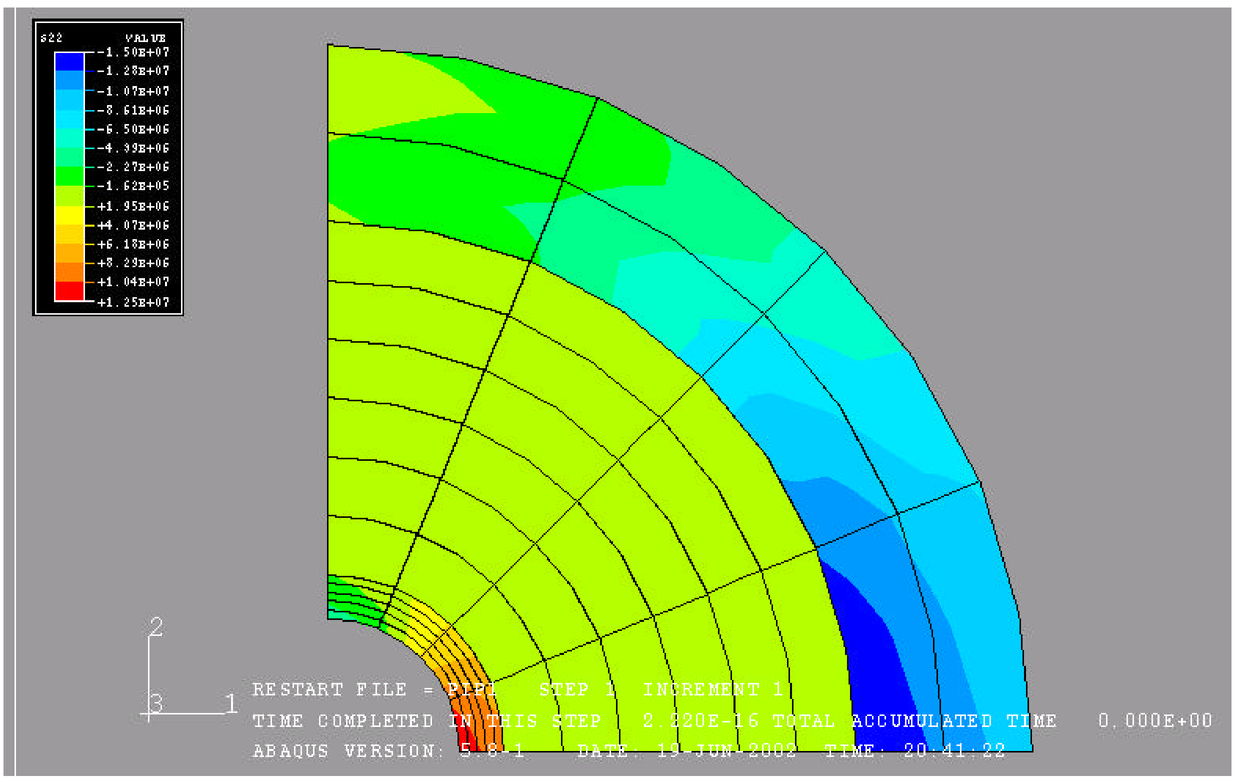


Fig.16c Horizontal displacement field (Young's Modulus = 5000 psi)

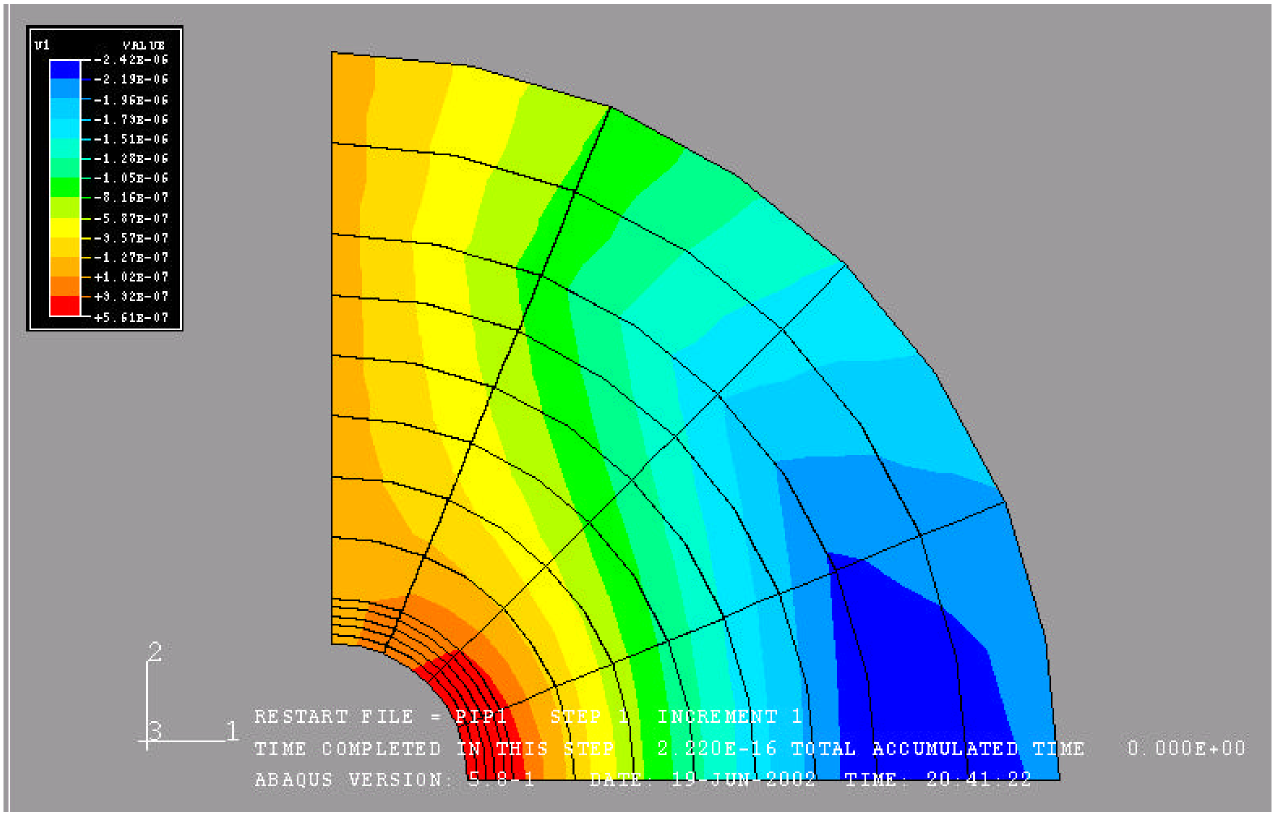


Fig.16d Vertical displacement field (Young's Modulus = 5000 psi)

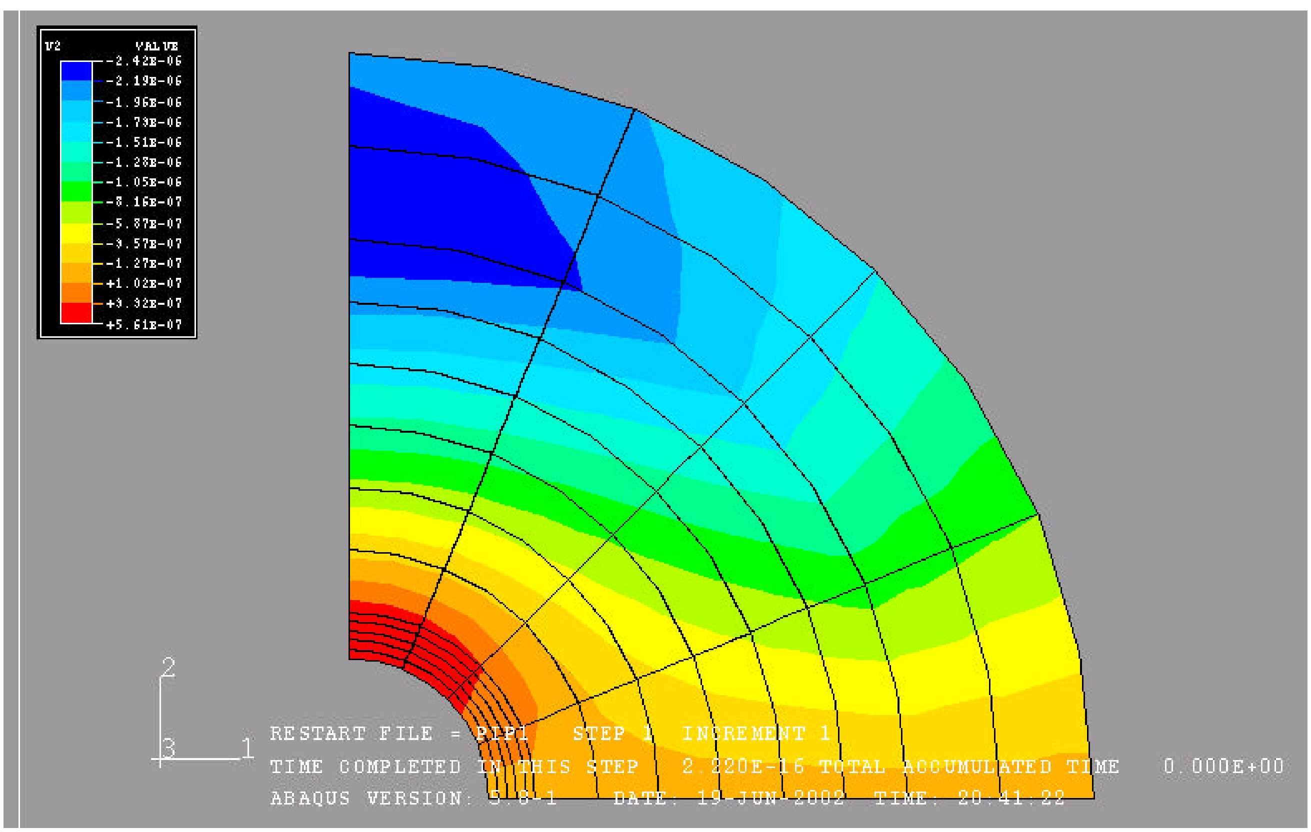


Fig.17a First principal stress profile (Poisson Ratio = 0.15)

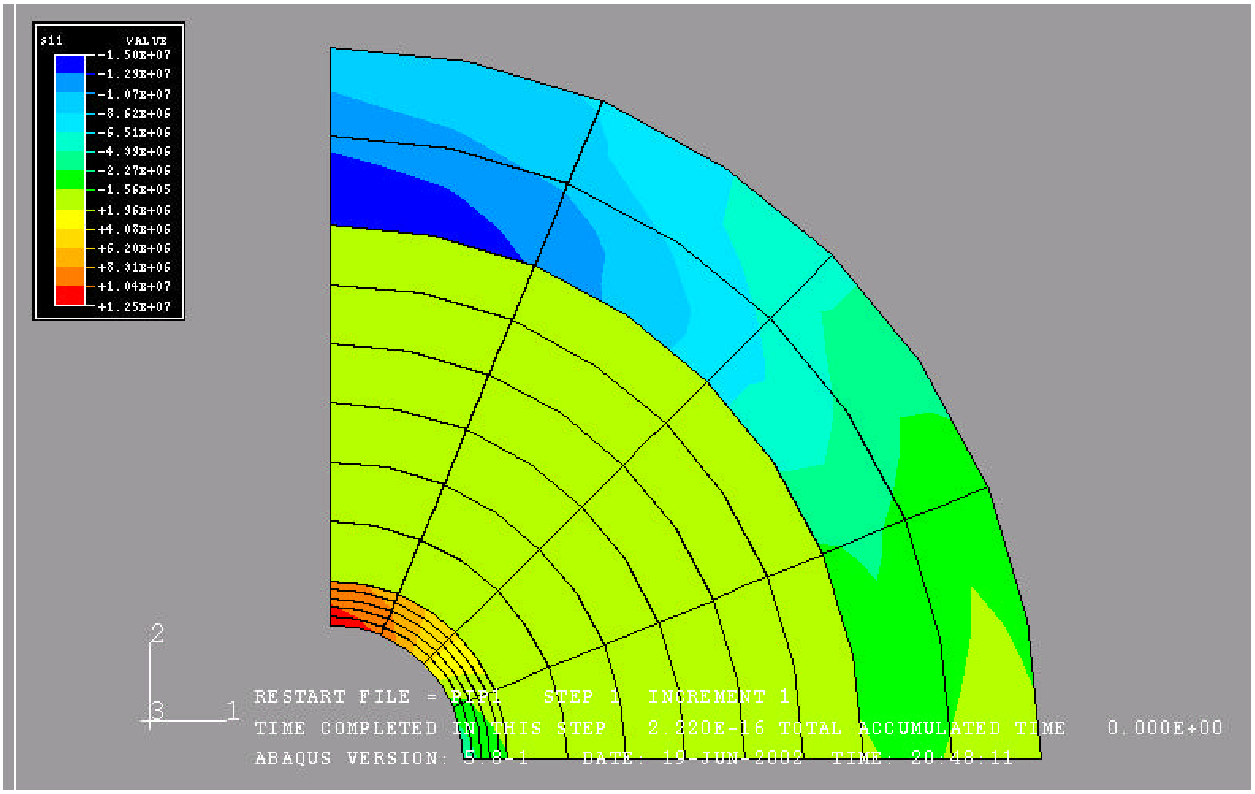


Fig.17b Second principal stress profile (Poisson Ratio = 0.15)

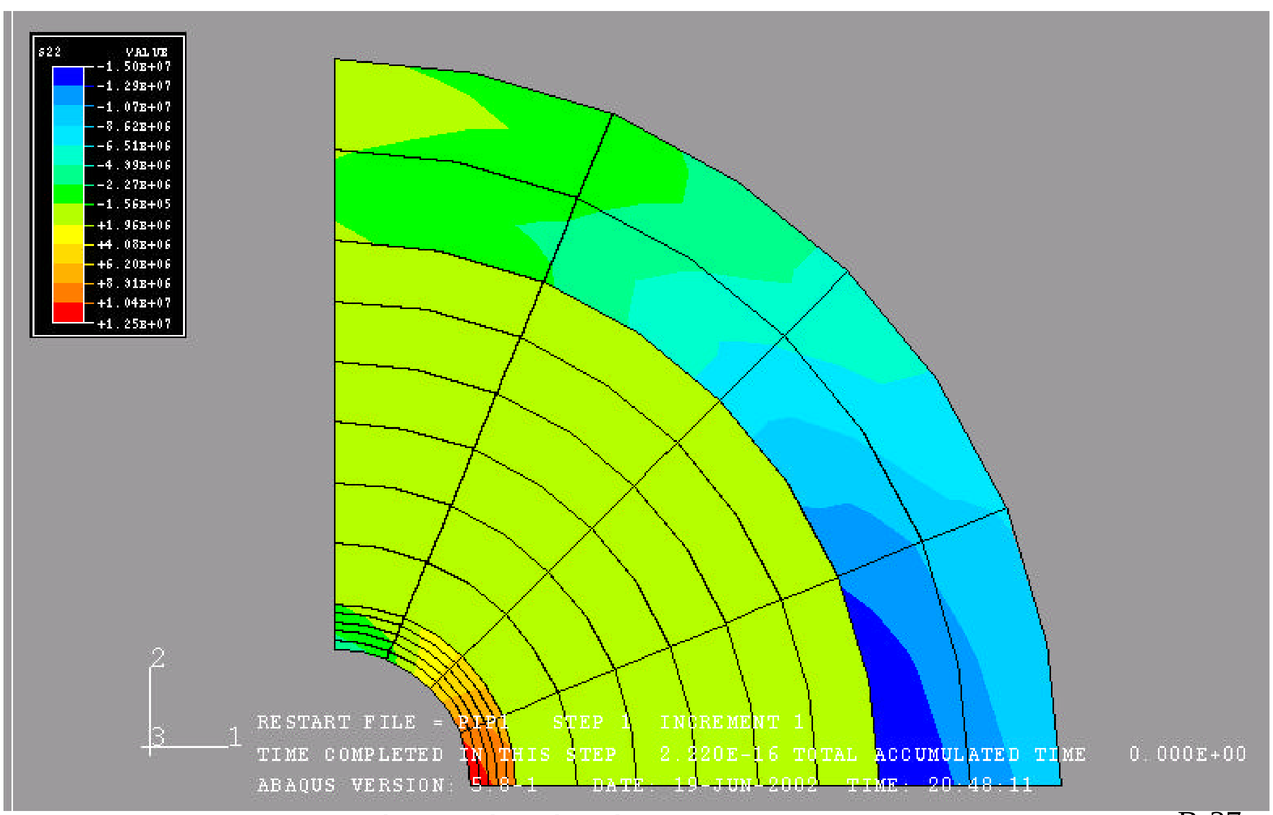


Fig.17c Horizontal displacement field (Poisson Ratio = 0.15)

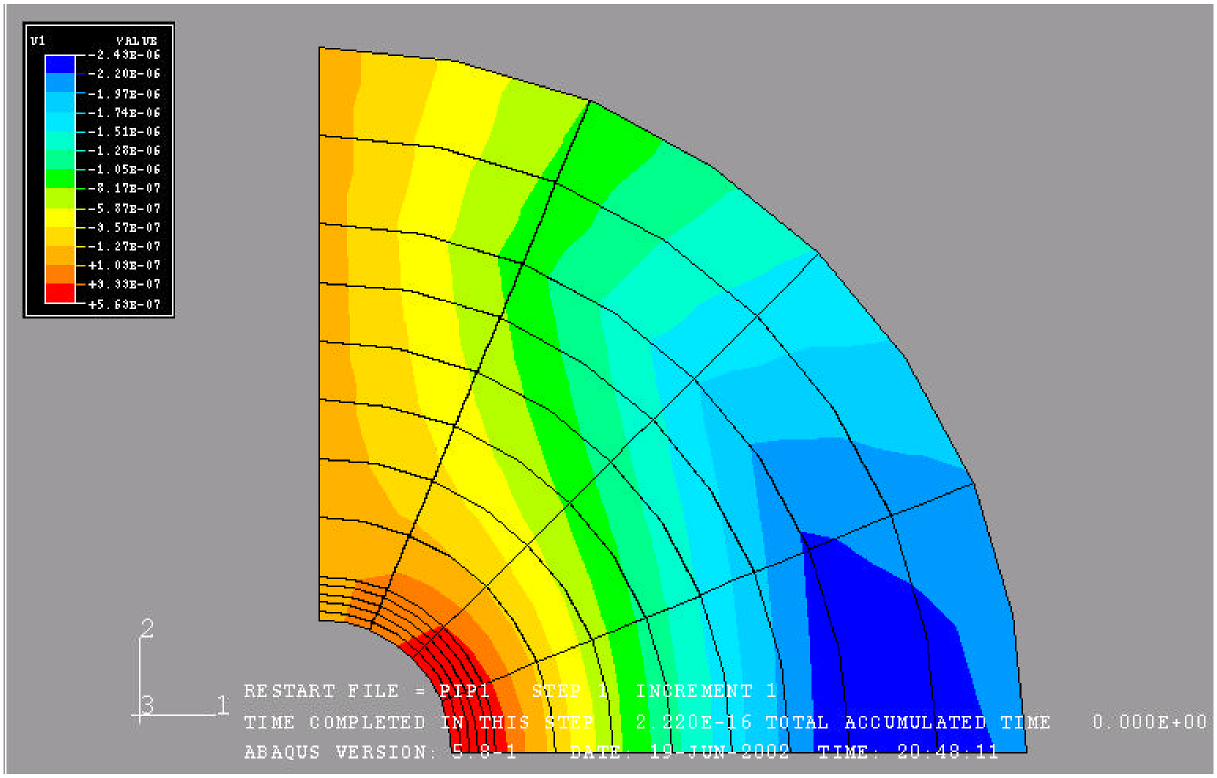


Fig.17d Vertical displacement field (Poisson Ratio = 0.15)

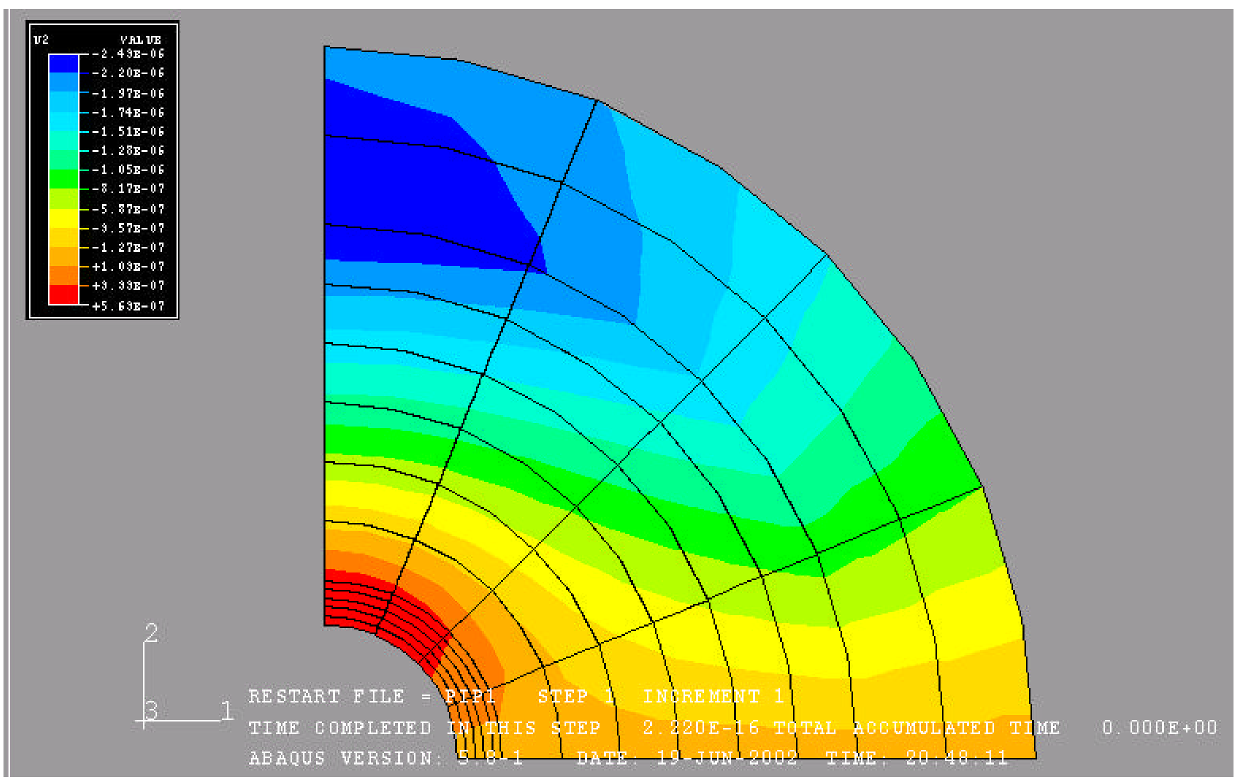


Fig.18a First principal stress profile (Poisson Ratio = 0.25)

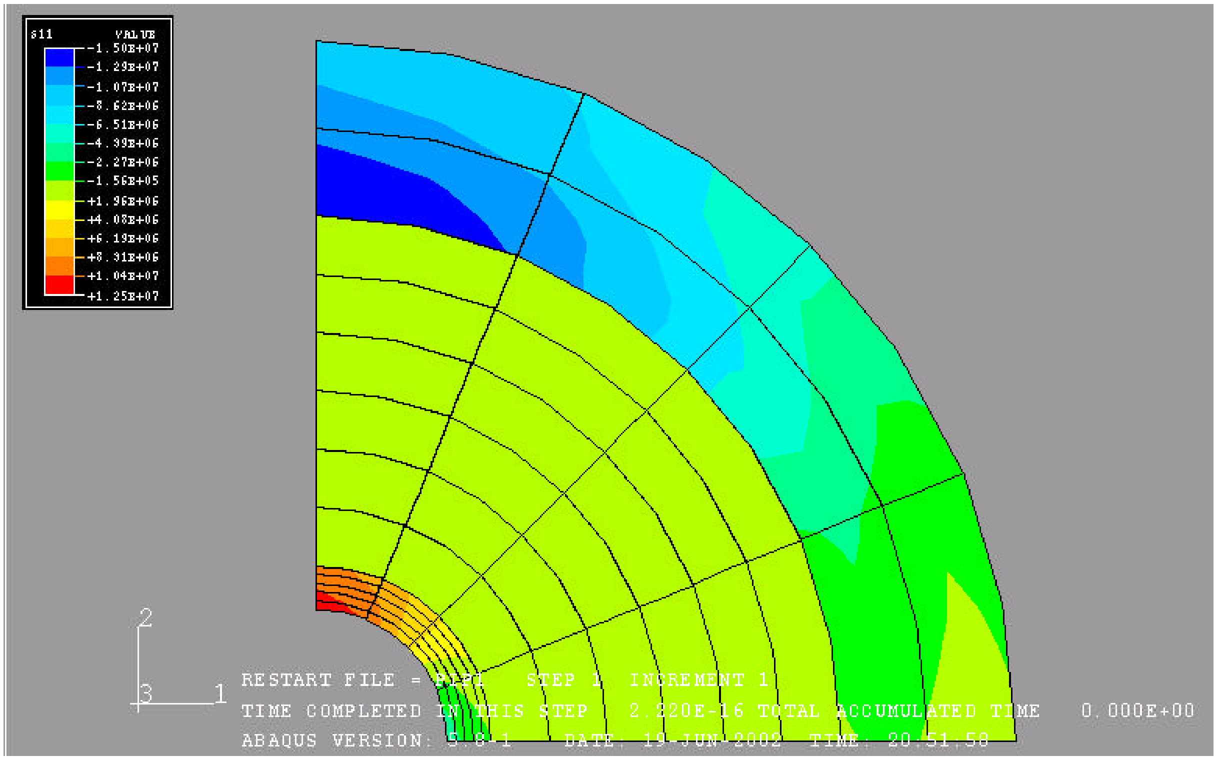


Fig.18b Second principal stress profile (Poisson Ratio = 0.25)

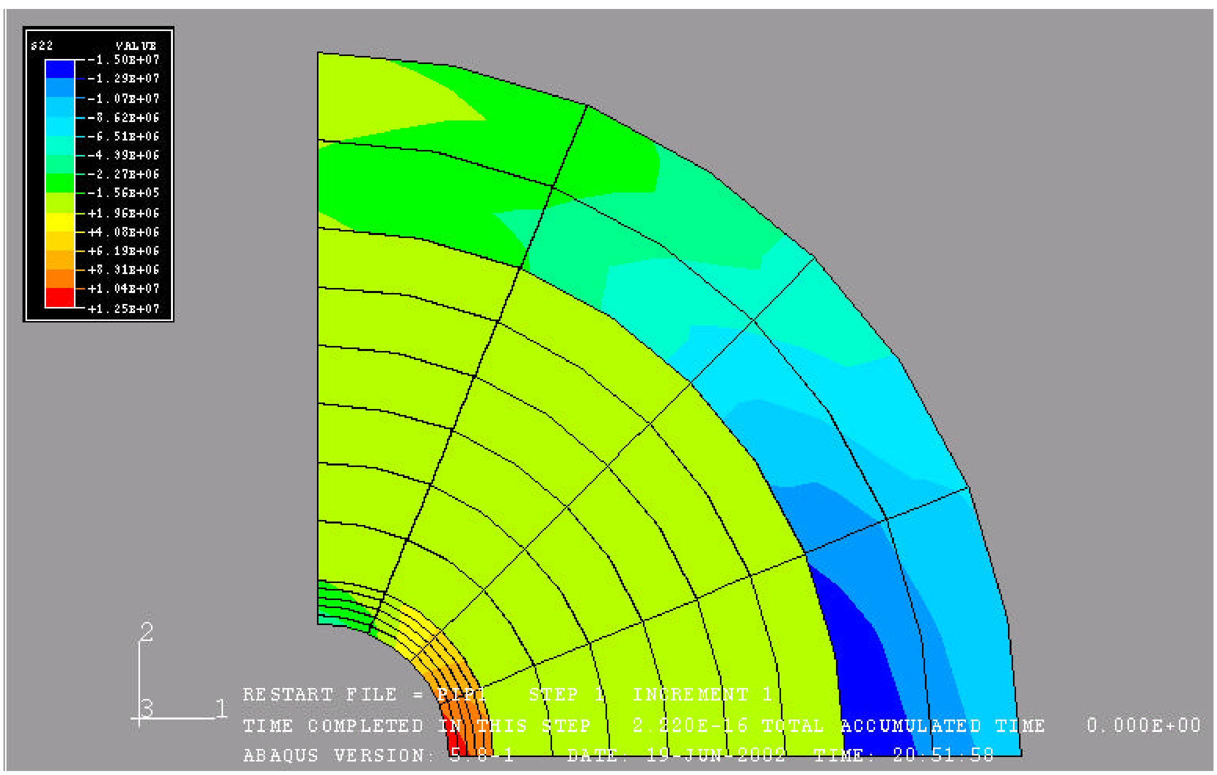


Fig.18c Horizontal displacement field (Poisson Ratio = 0.25)

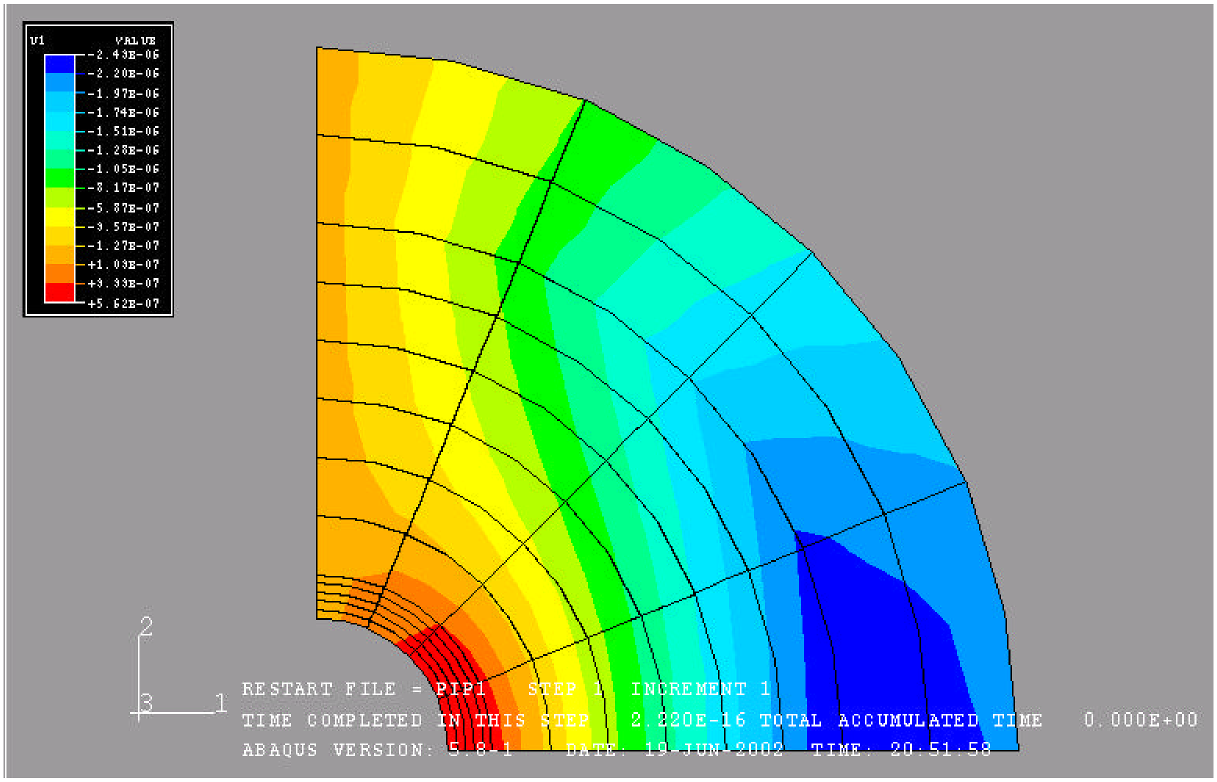
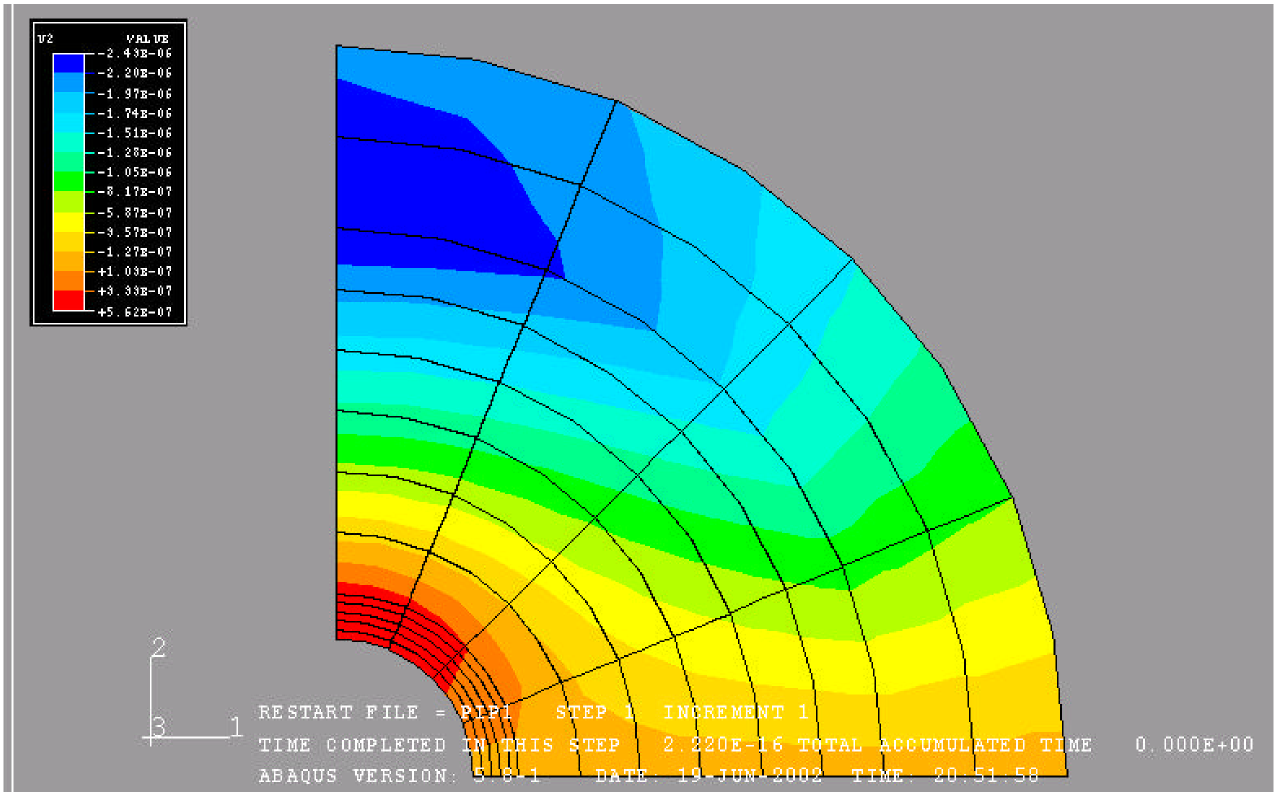


Fig.18d Vertical displacement field (Poisson Ratio = 0.25)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+3.33E-07
+5.62E-07
2
3
1
RESTART FILE = PIP1 STEP 1 INCREMENT 1
TIME COMPLETED IN THIS STEP 2.220E-16 TOTAL ACCUMULATED TIME 0.000E+00
ABAQUS VERSION: 5.8-1 DATE: 19-JUN-2002 TIME: 20:51:58

Fig.19a First principal stress profile (Poisson Ratio = 0.45)

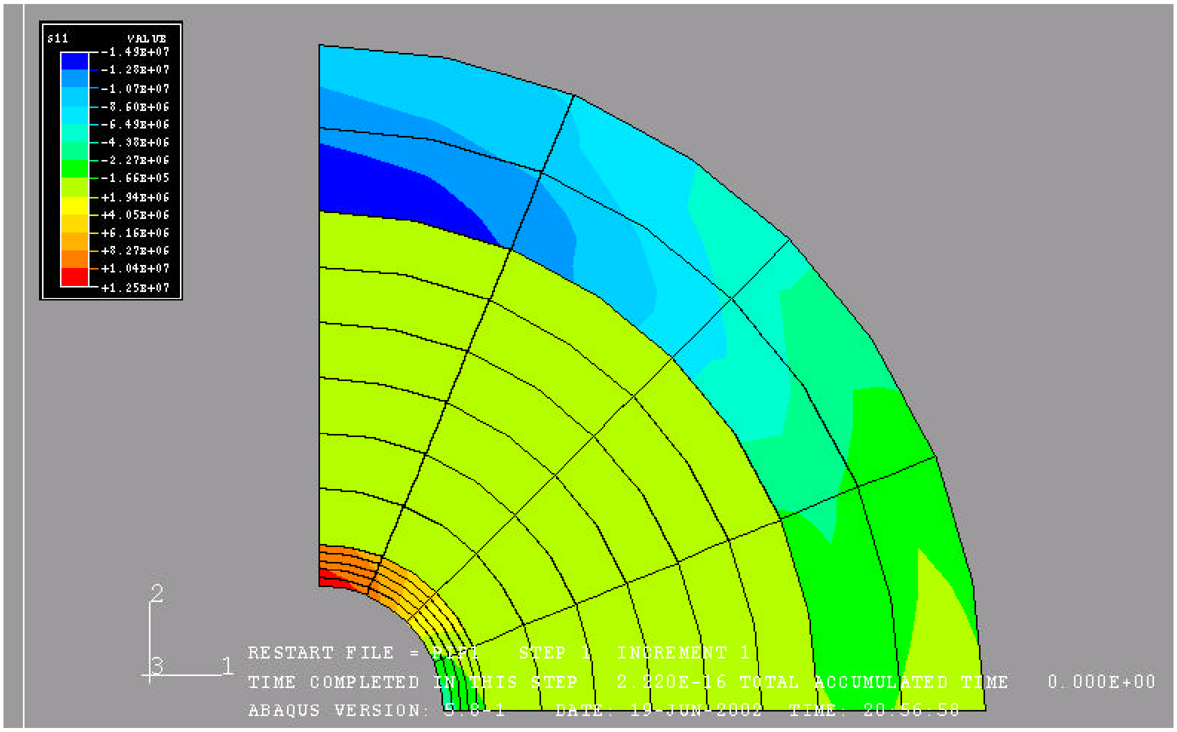


Fig.19b Second principal stress profile (Poisson Ratio = 0.45)

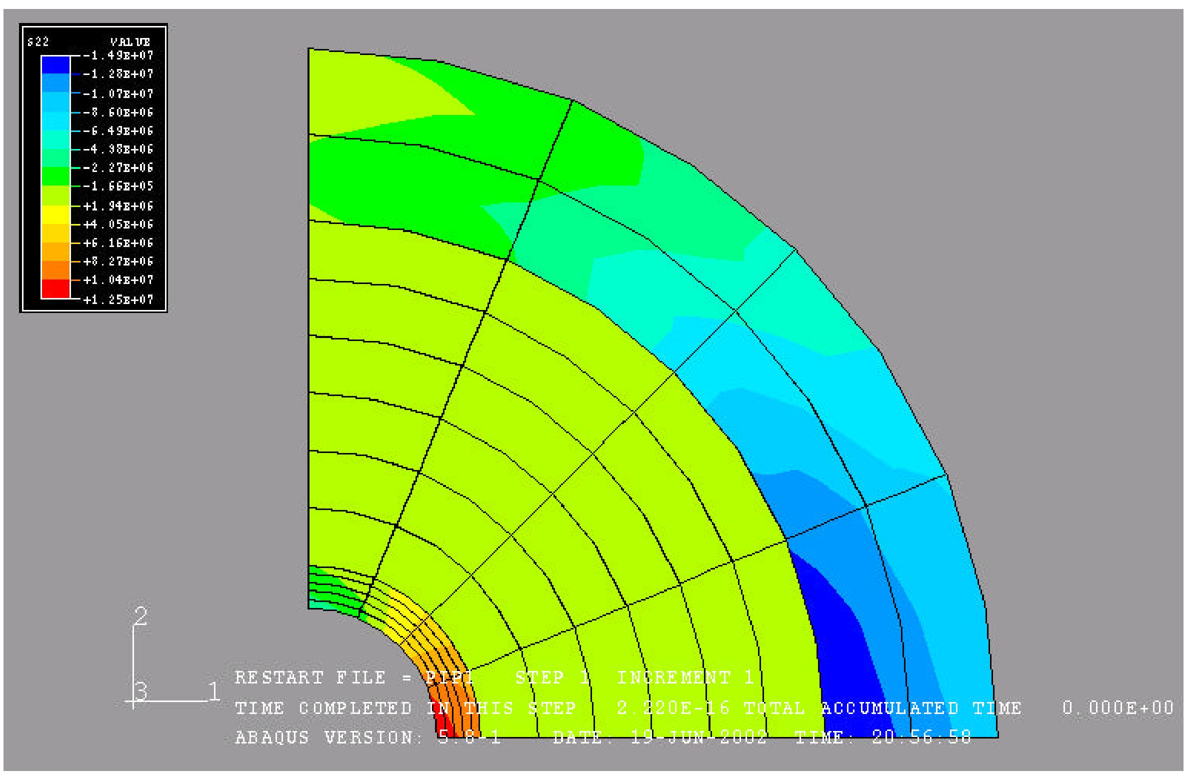


Fig.19c Horizontal displacement field (Poisson Ratio = 0.45)

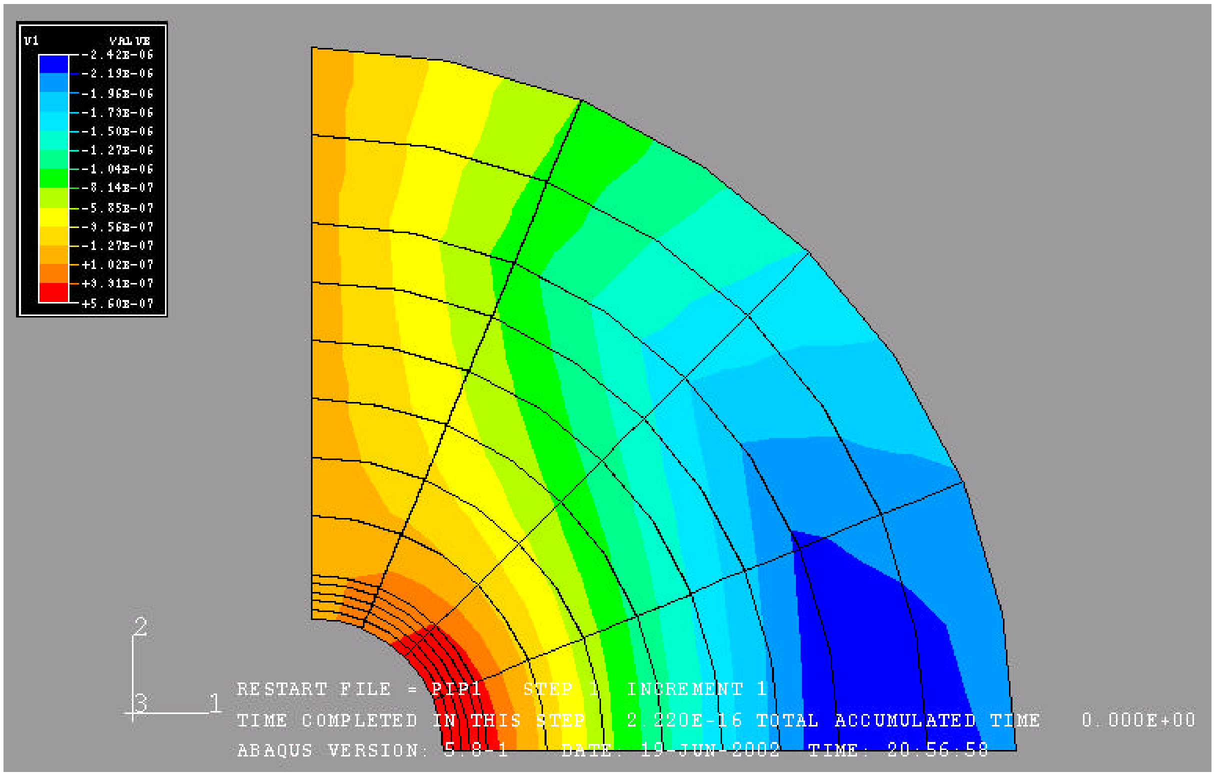


Fig.19d Vertical displacement field (Poisson Ratio = 0.45)

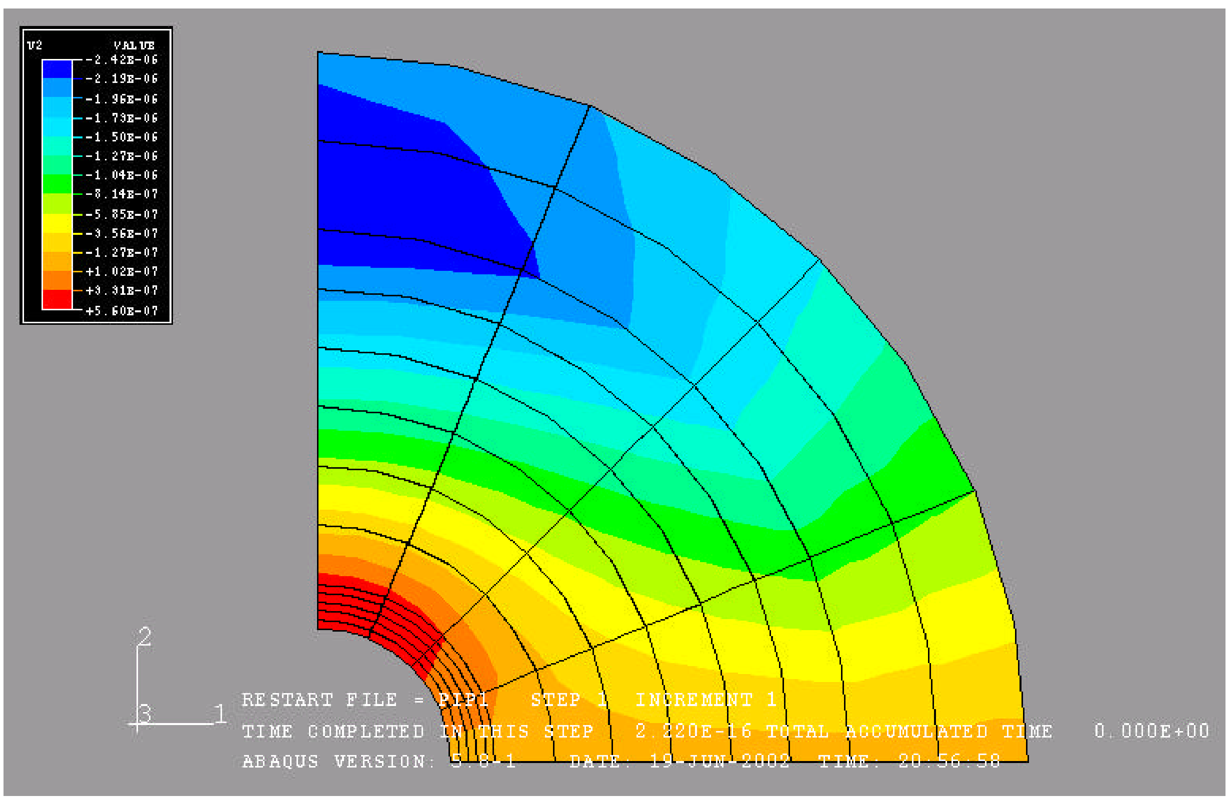


Fig.20a First principal stress profile (T_{in} = 80 F)

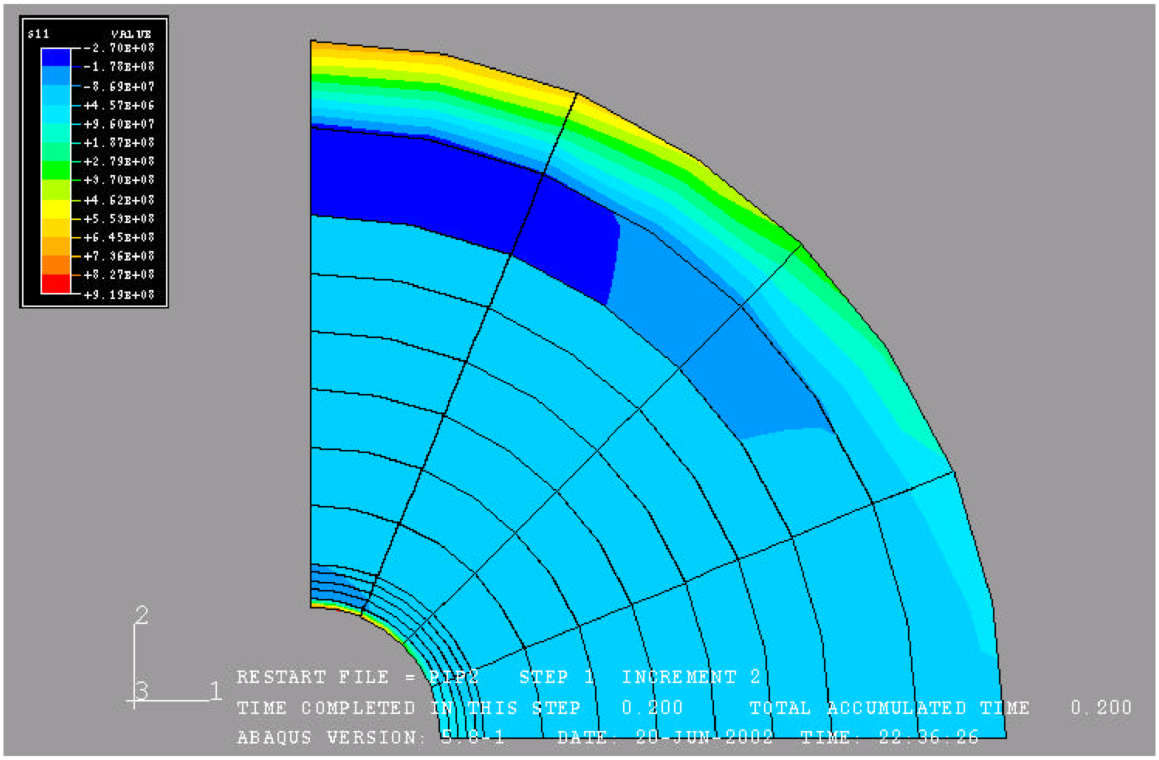


Fig.20b Temperature profile (T_{in} = 80 F)

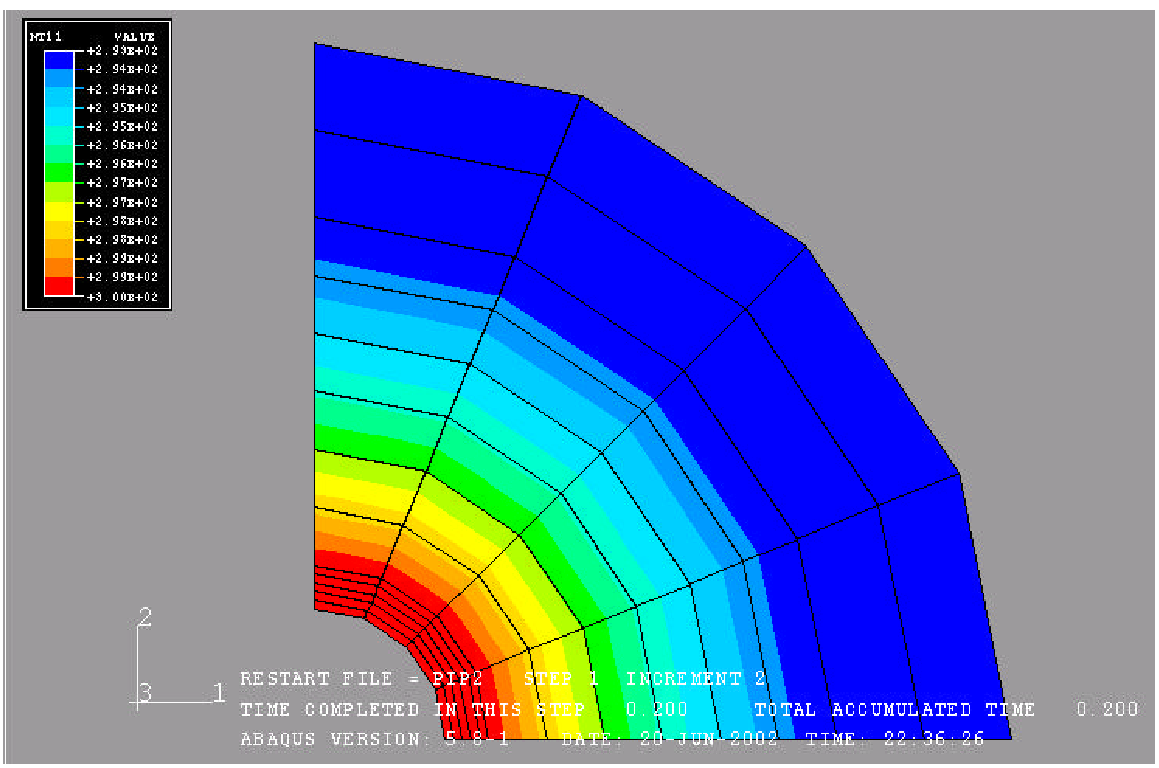


Fig.20c Horizontal displacement field (T_{in} = 80 F)

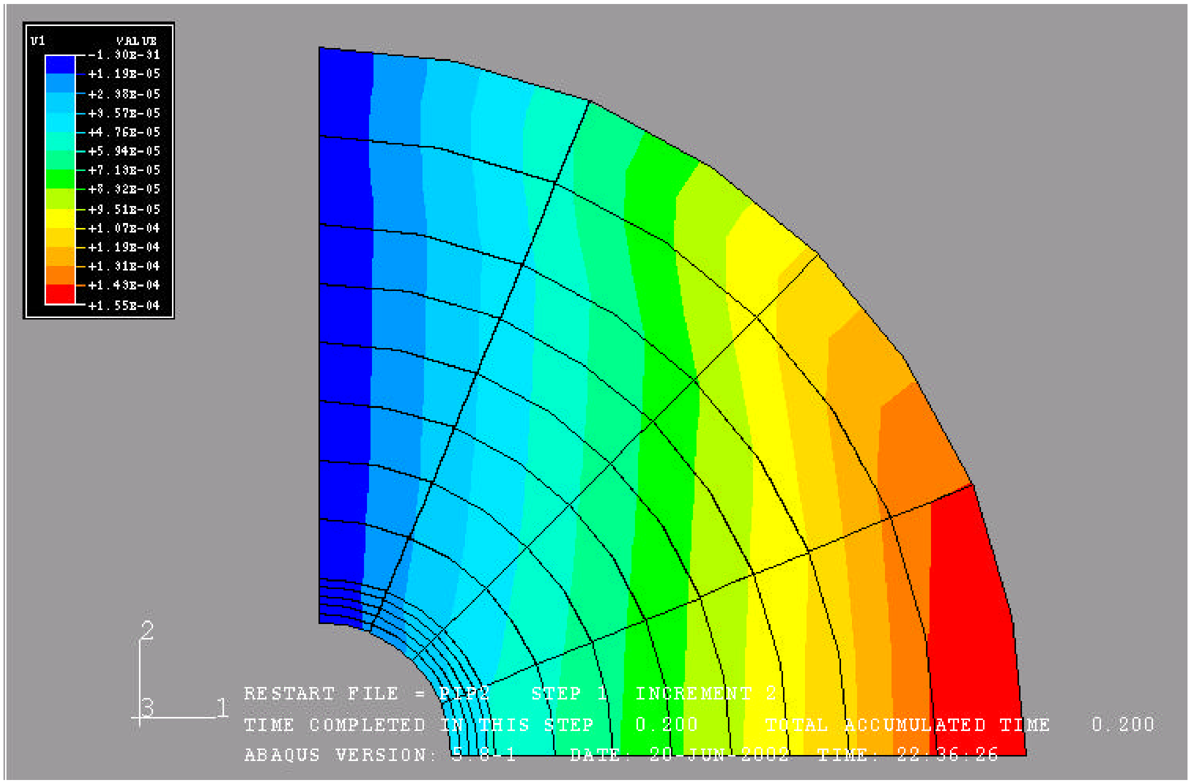


Fig.20d Vertical displacement field (T_{in} = 80 F)

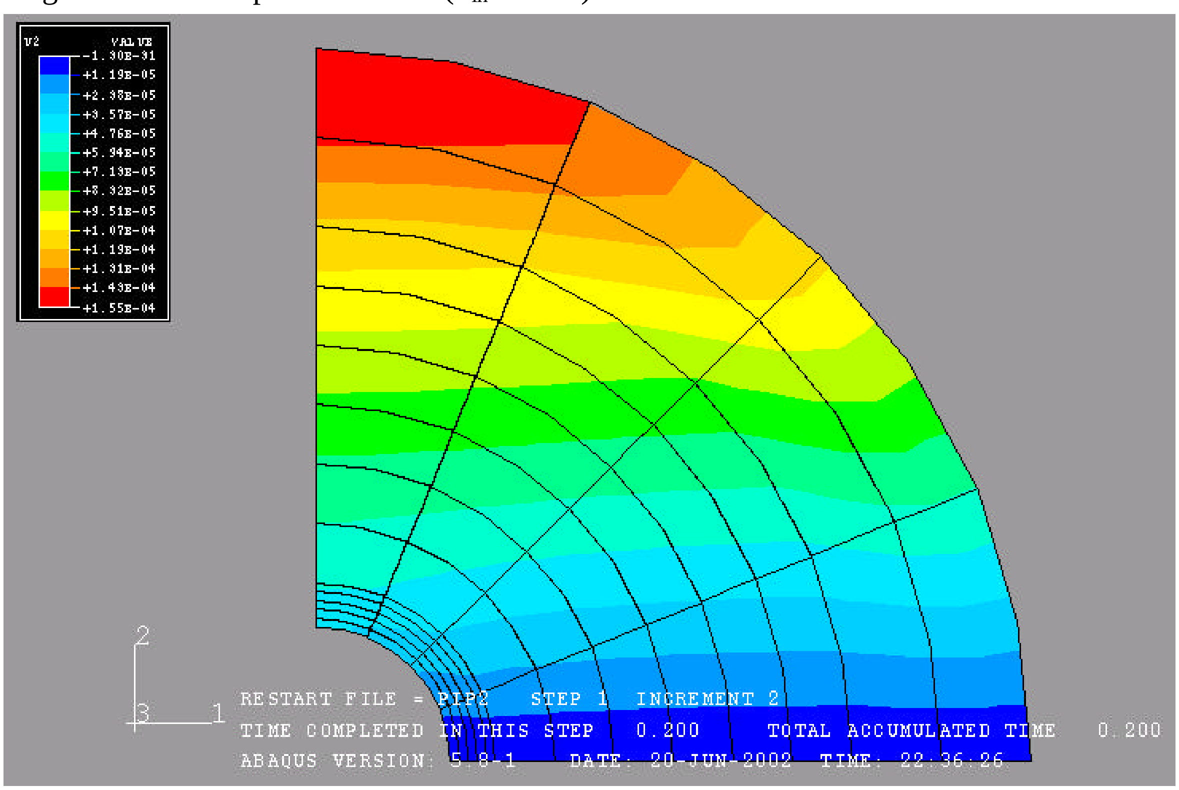


Fig.21a First principal stress profile (T_{in} = 110 F)

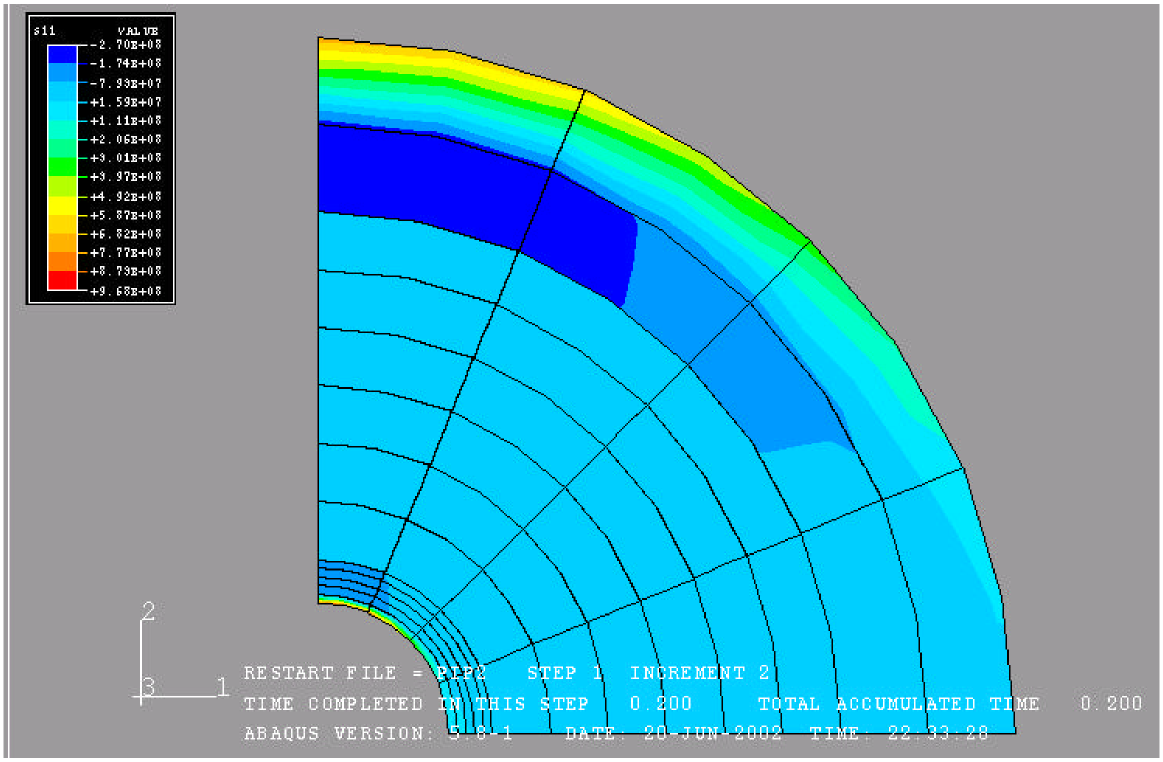


Fig.21b Temperature profile (T_{in} = 110 F)

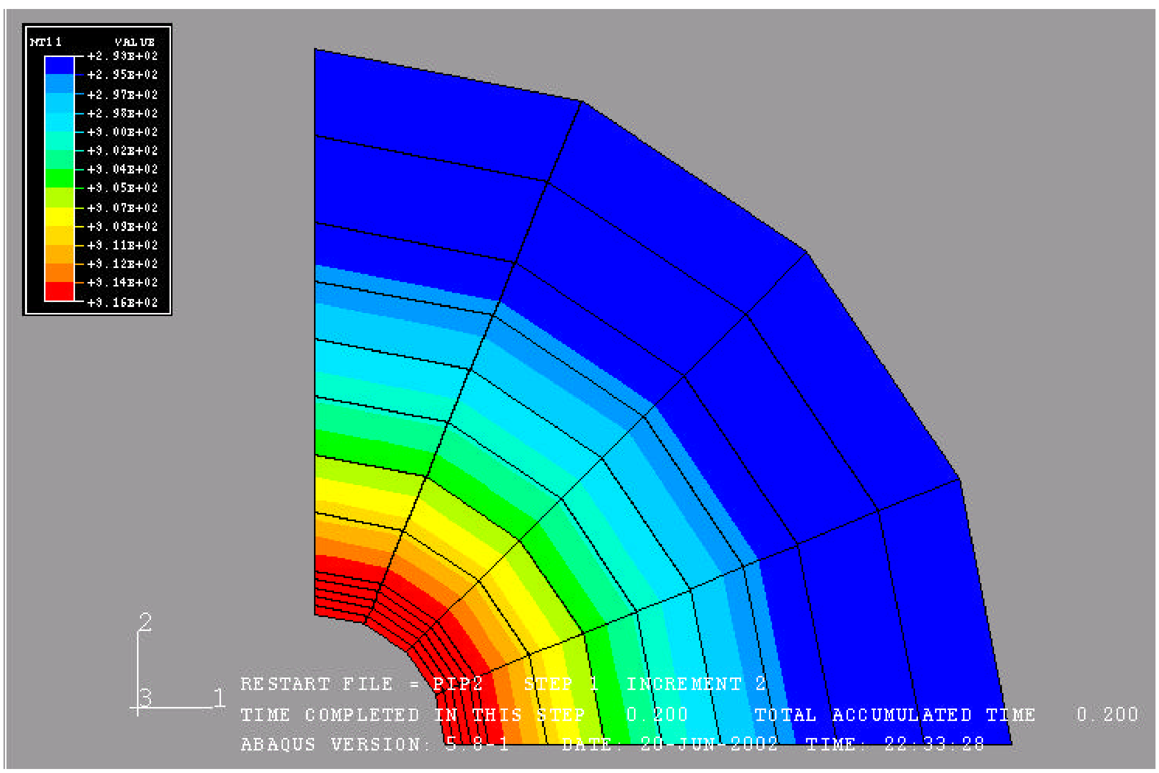


Fig.21c Horizontal displacement field (T_{in} = 110 F)

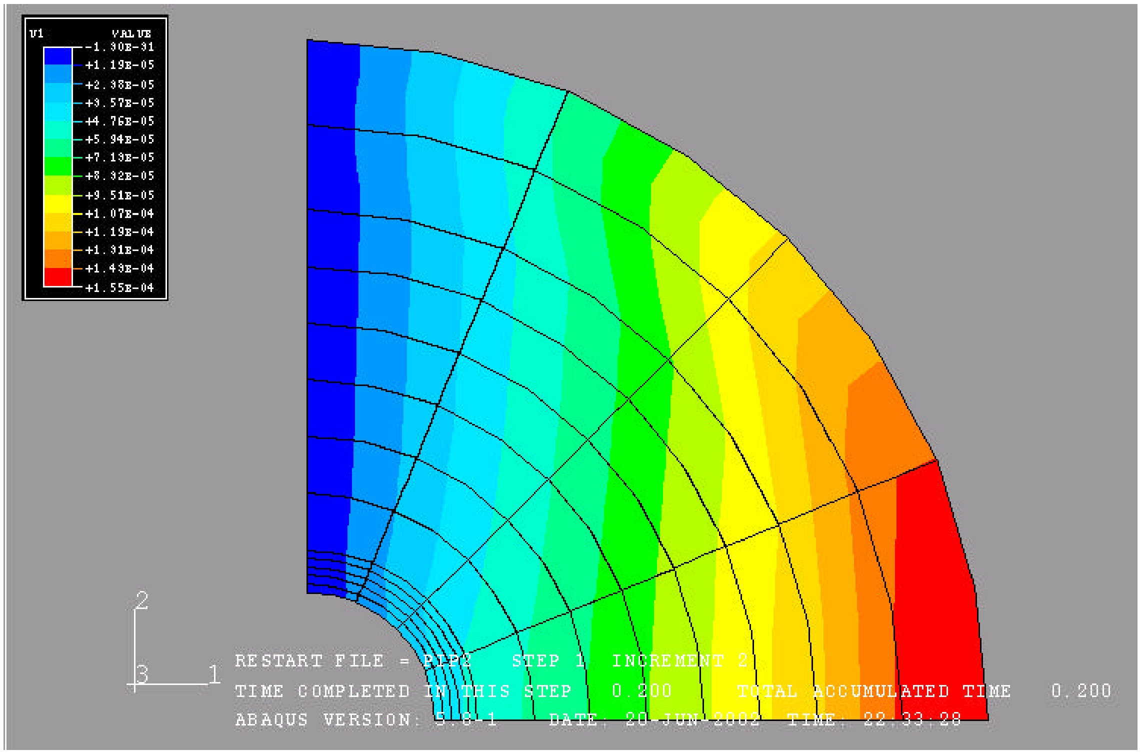


Fig.21d Vertical displacement field (T_{in} = 110 F)

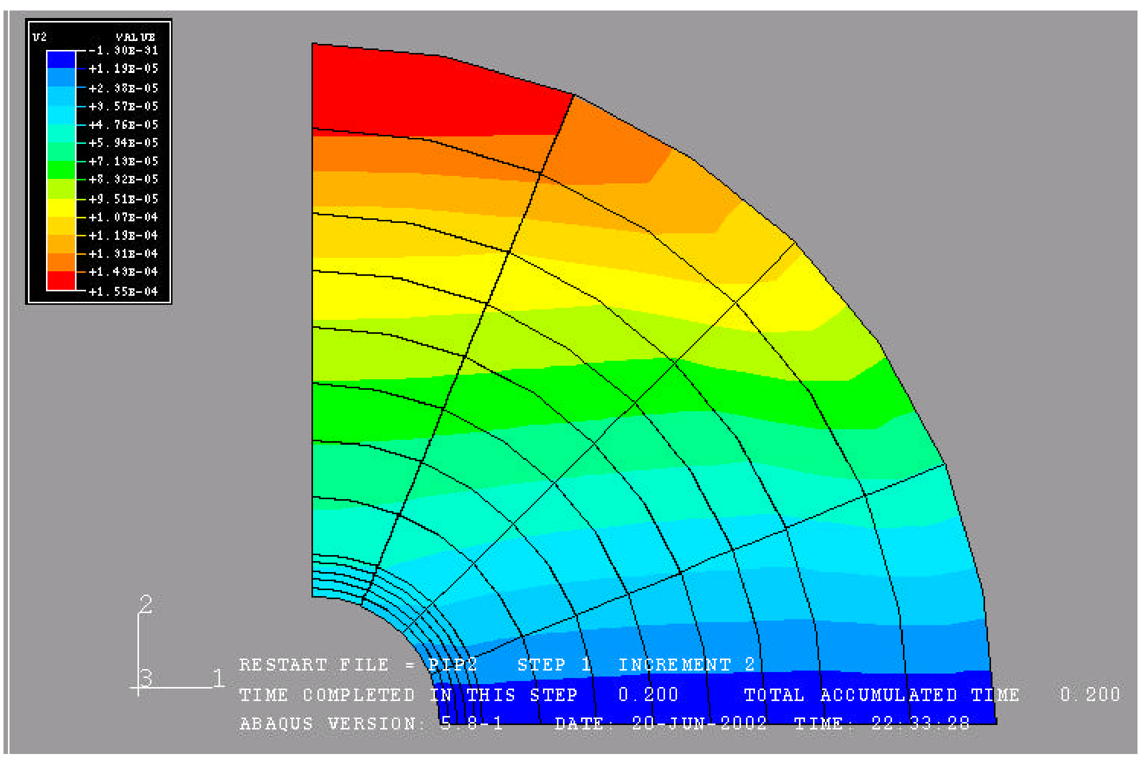


Fig.22a First principal stress profile (T_{in} = 150 F)

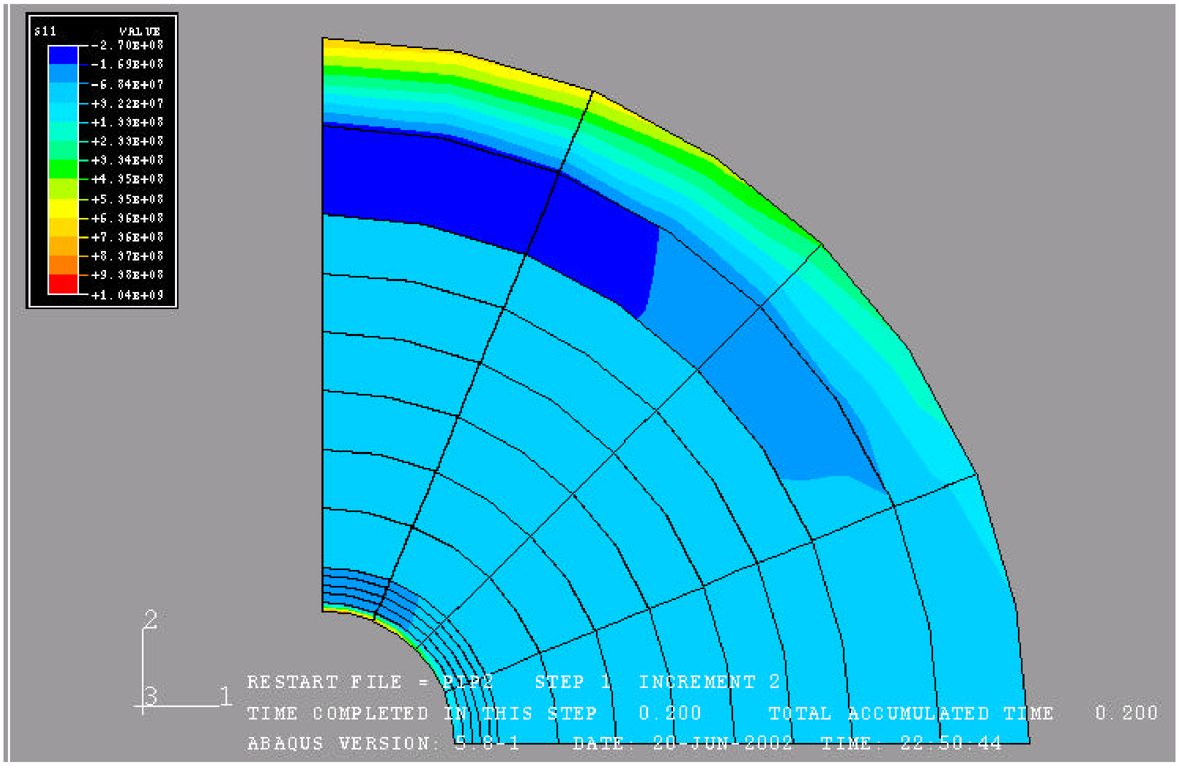


Fig.22b Temperature profile (T_{in} = 150 F)

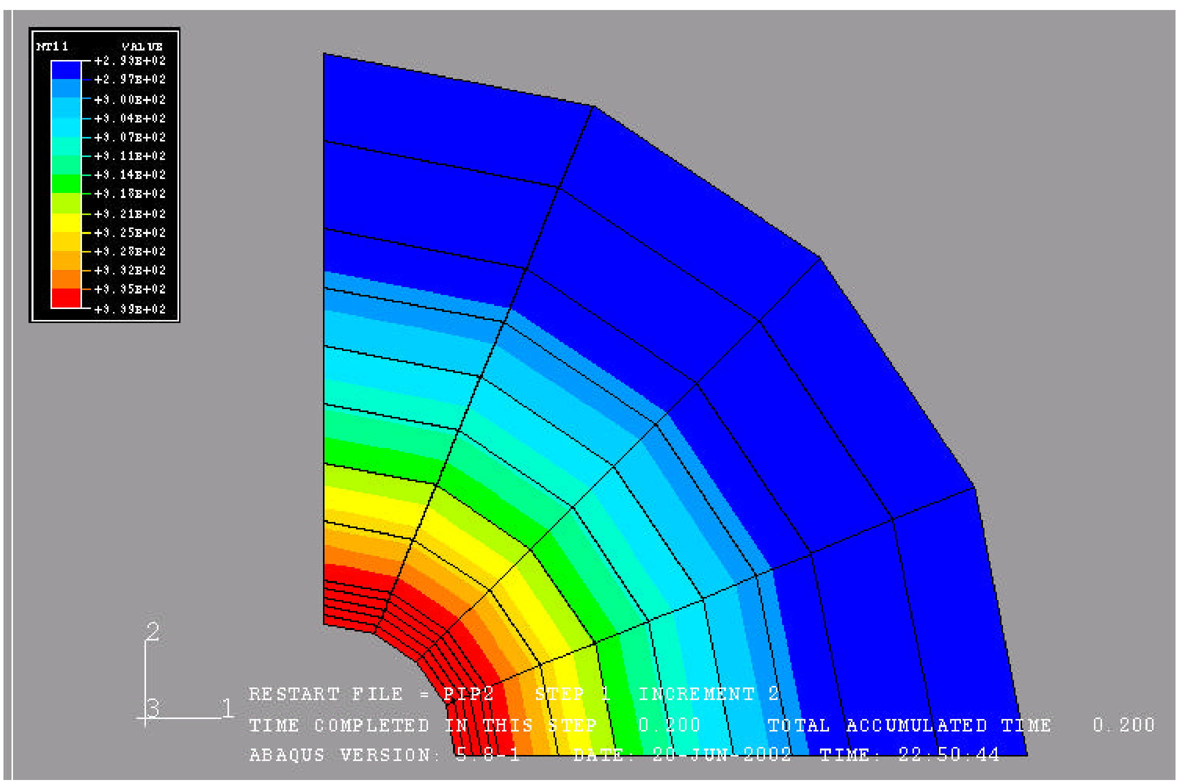


Fig.22c Horizontal displacement field (T_{in} = 150 F)

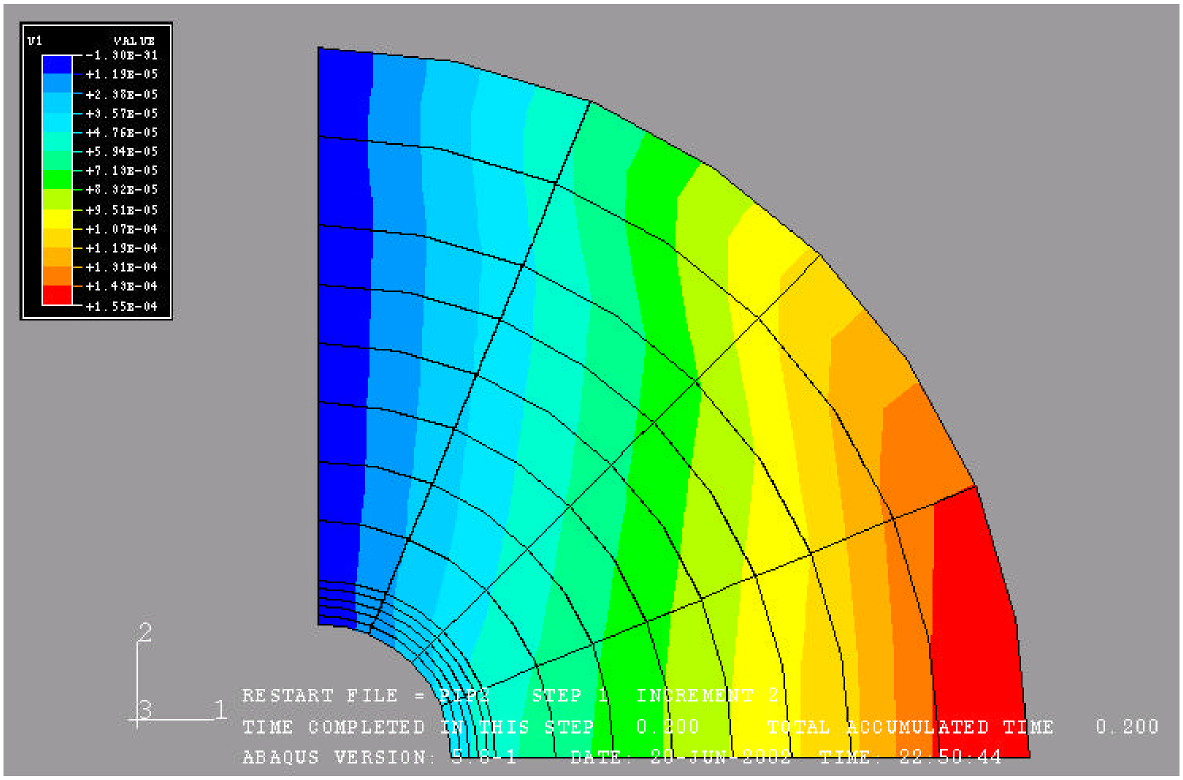


Fig.22d Vertical displacement field (T_{in} = 150 F)

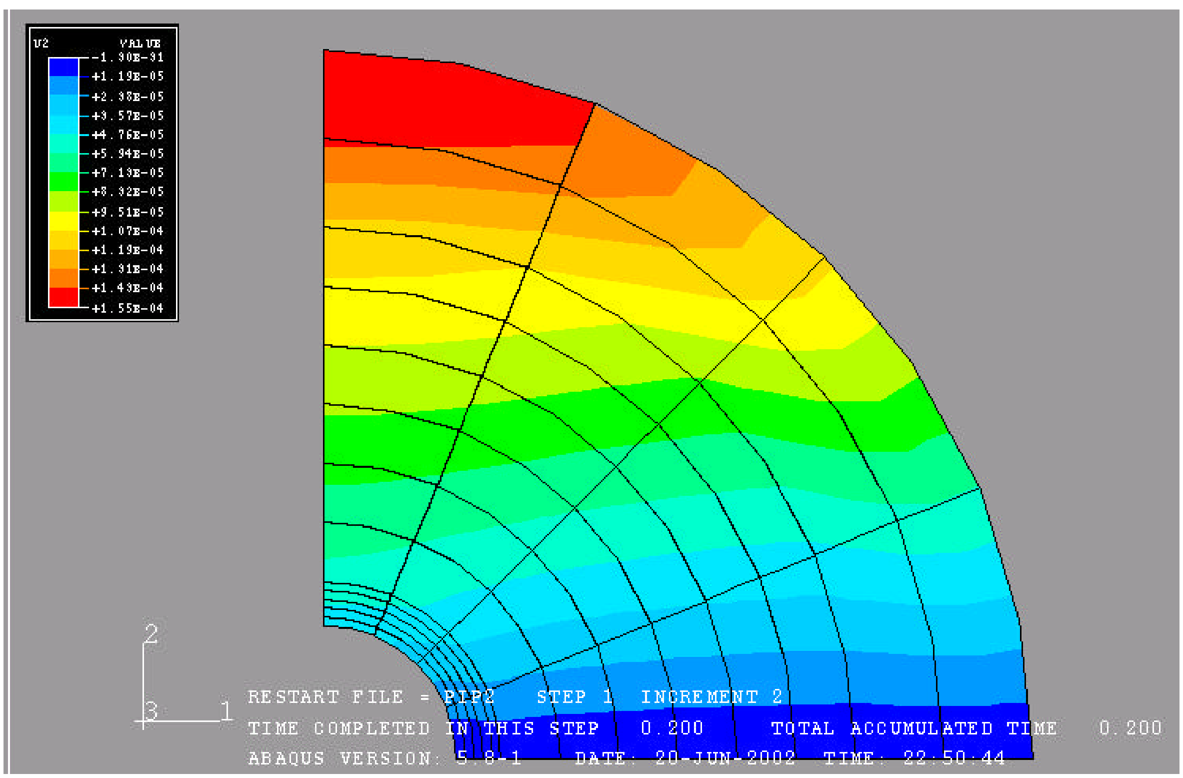


Fig.23a First principal stress profile (T_{in} = 180 F)

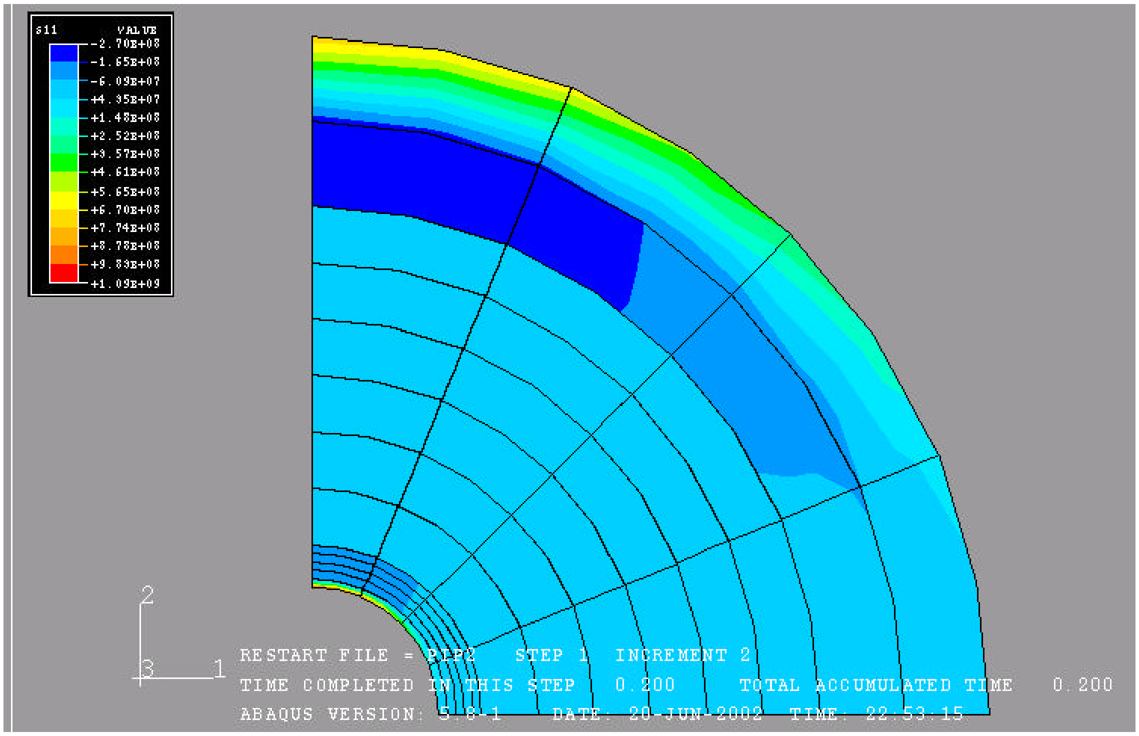


Fig.23b Temperature profile (T_{in} = 180 F)

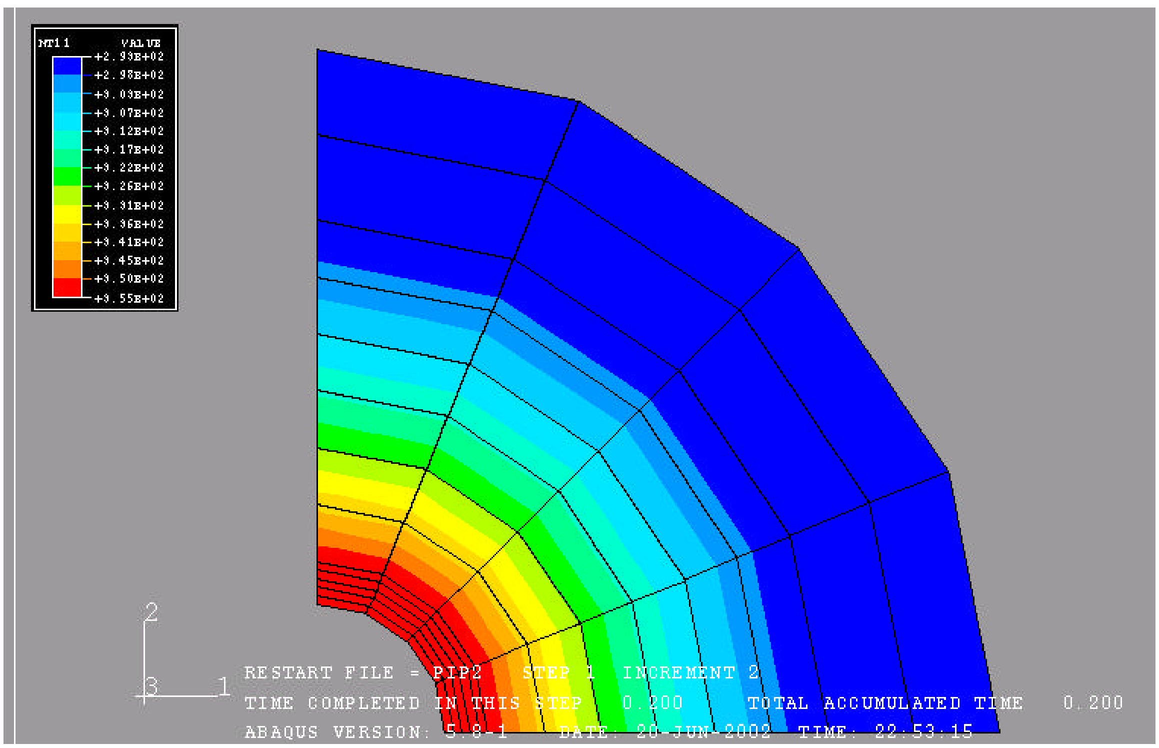


Fig.23c Horizontal displacement field (T_{in} =180 F)

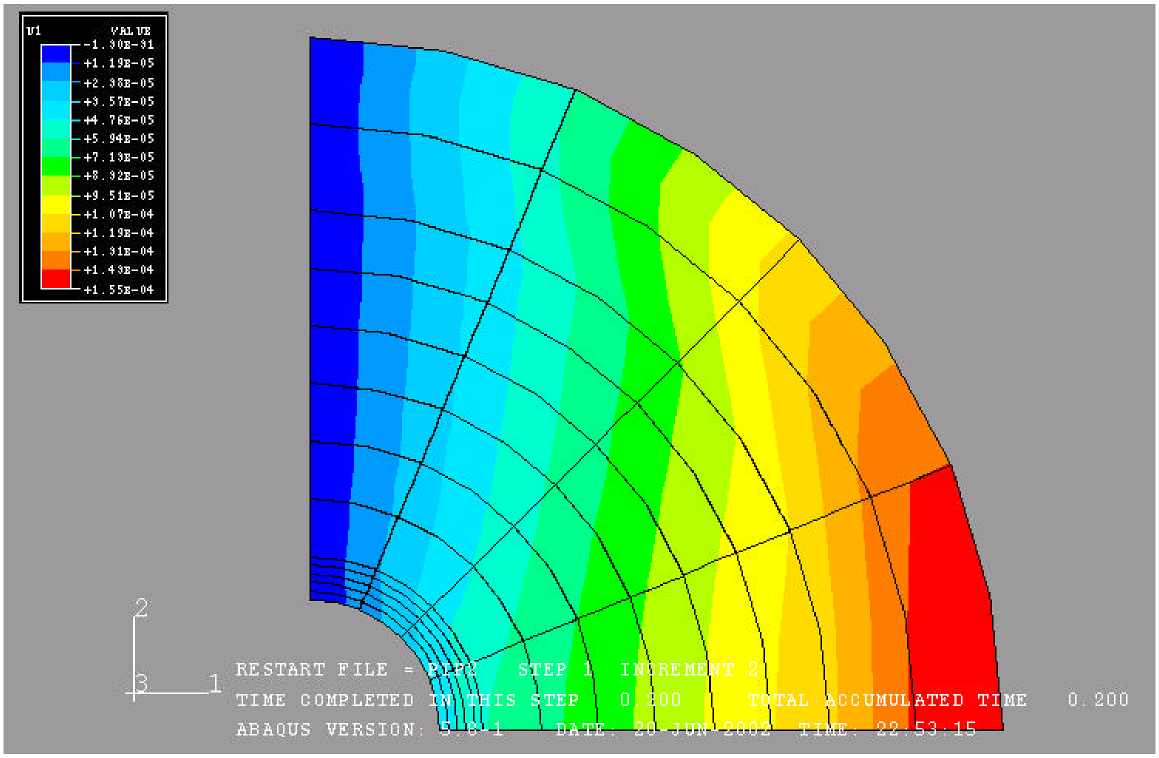


Fig.23d Vertical displacement field (T_{in} = 180 F)

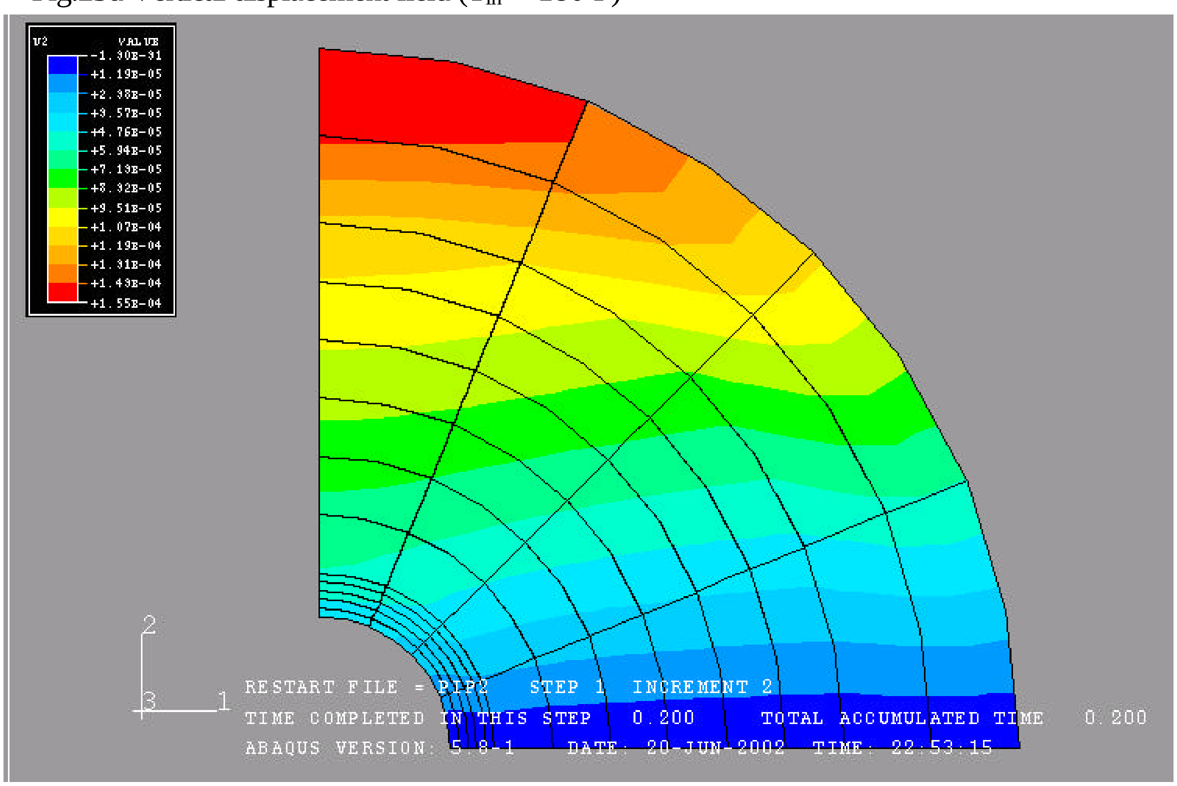


Fig.24a First principal stress profile (Casing Pressure = 500 psi)

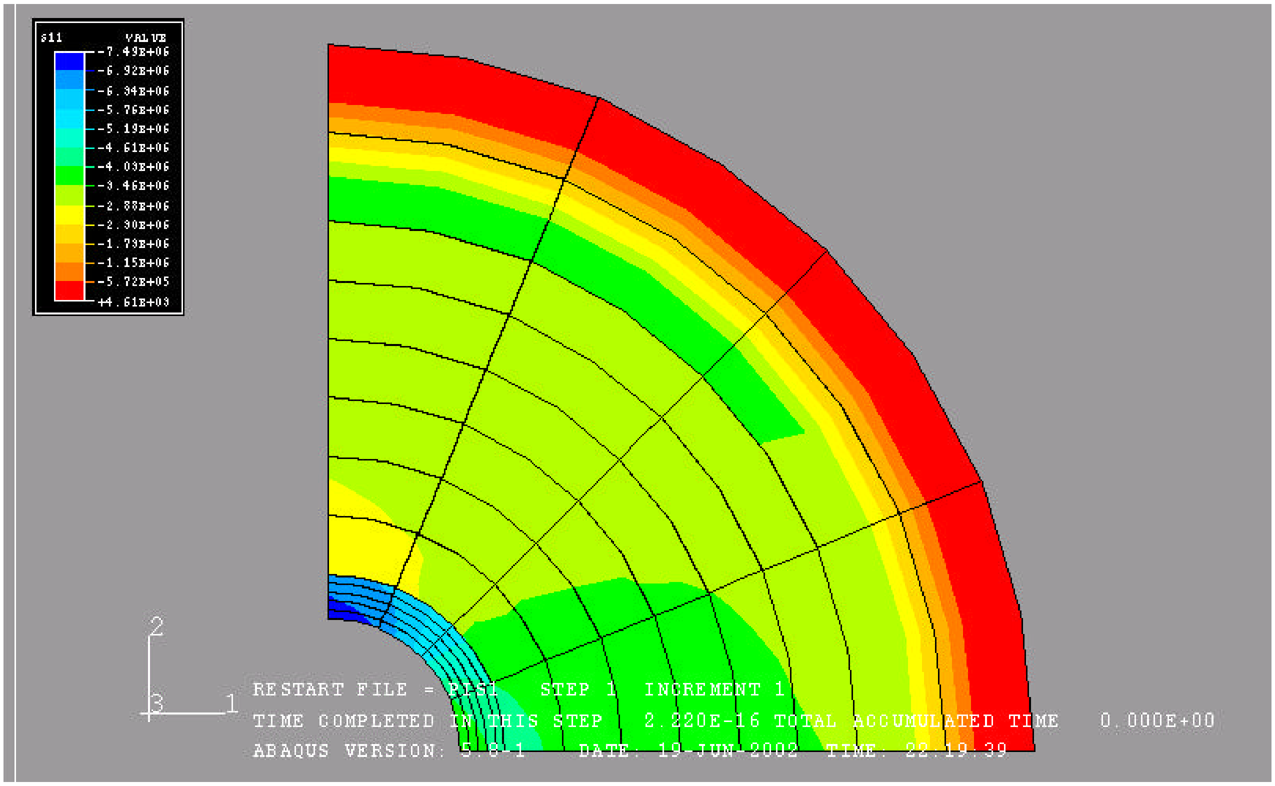


Fig.24b Second principal stress profile (Casing Pressure = 500 psi)

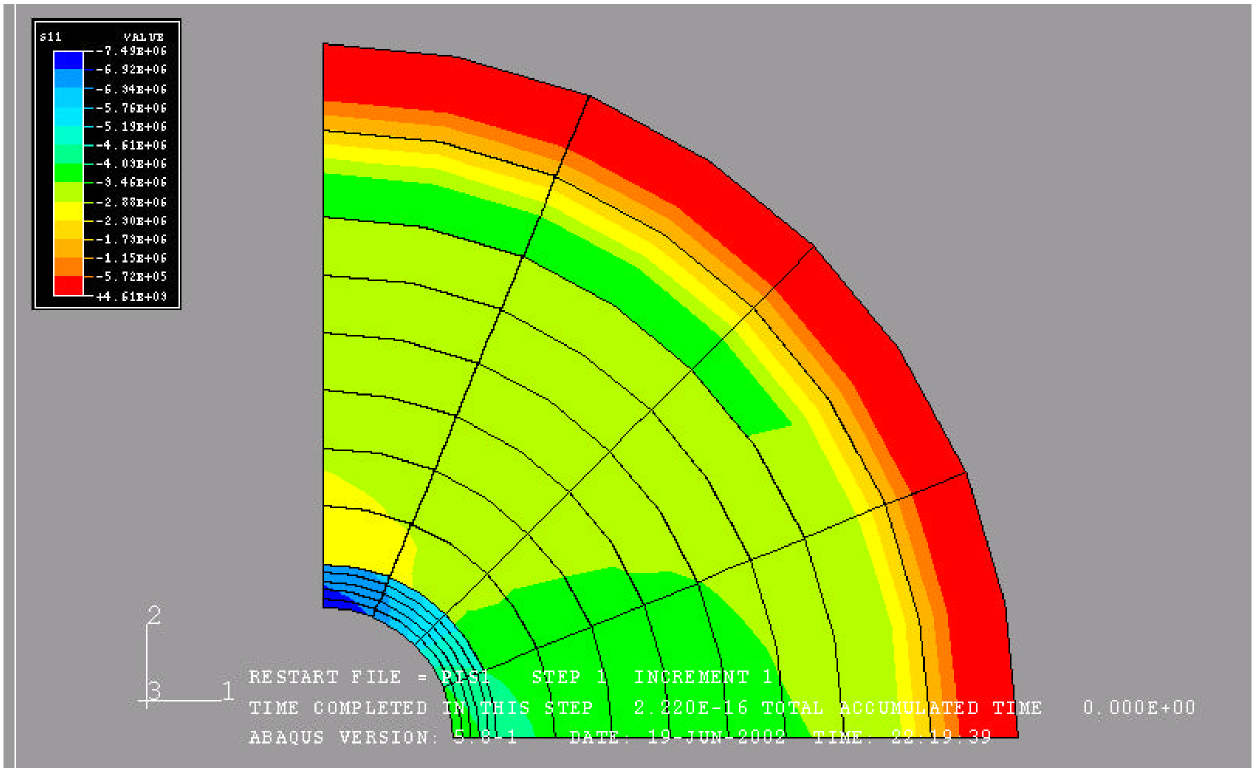

S11 VALUE
-7.49E+06
-6.92E+06
-6.34E+06
-5.76E+06
-5.19E+06
-4.61E+06
-4.03E+06
-3.46E+06
-2.88E+06
-2.30E+06
-1.73E+06
-1.15E+06
-5.72E+05
+4.61E+03
2
3
1
RESTART FILE = P1S1 STEP 1 INCREMENT 1
TIME COMPLETED IN THIS STEP 2.220E-16 TOTAL ACCUMULATED TIME 0.000E+00
ABAQUS VERSION: 5.8-1 DATE: 19-JUN-2002 TIME: 22:19:39

Fig.24c Horizontal displacement field (Casing Pressure = 500 psi)

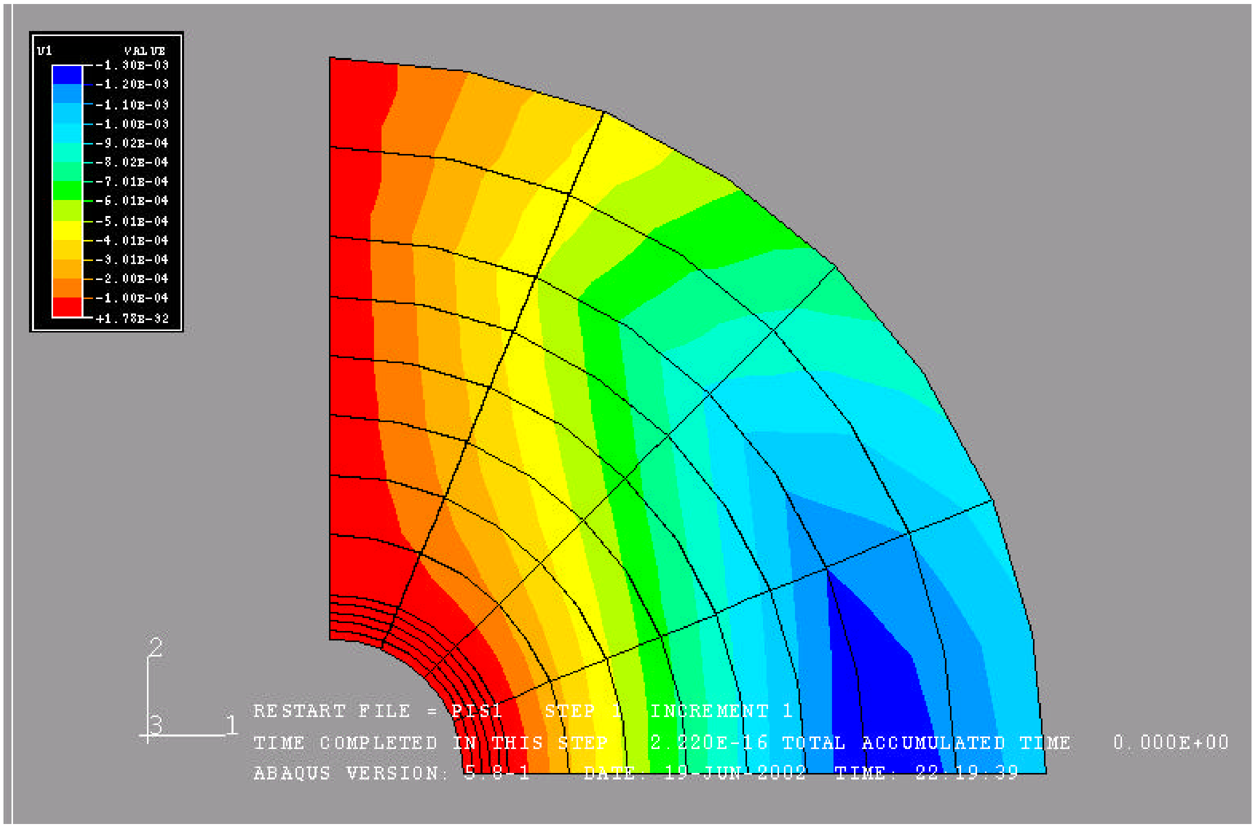


Fig.24d Vertical displacement field (Casing Pressure = 500 psi)

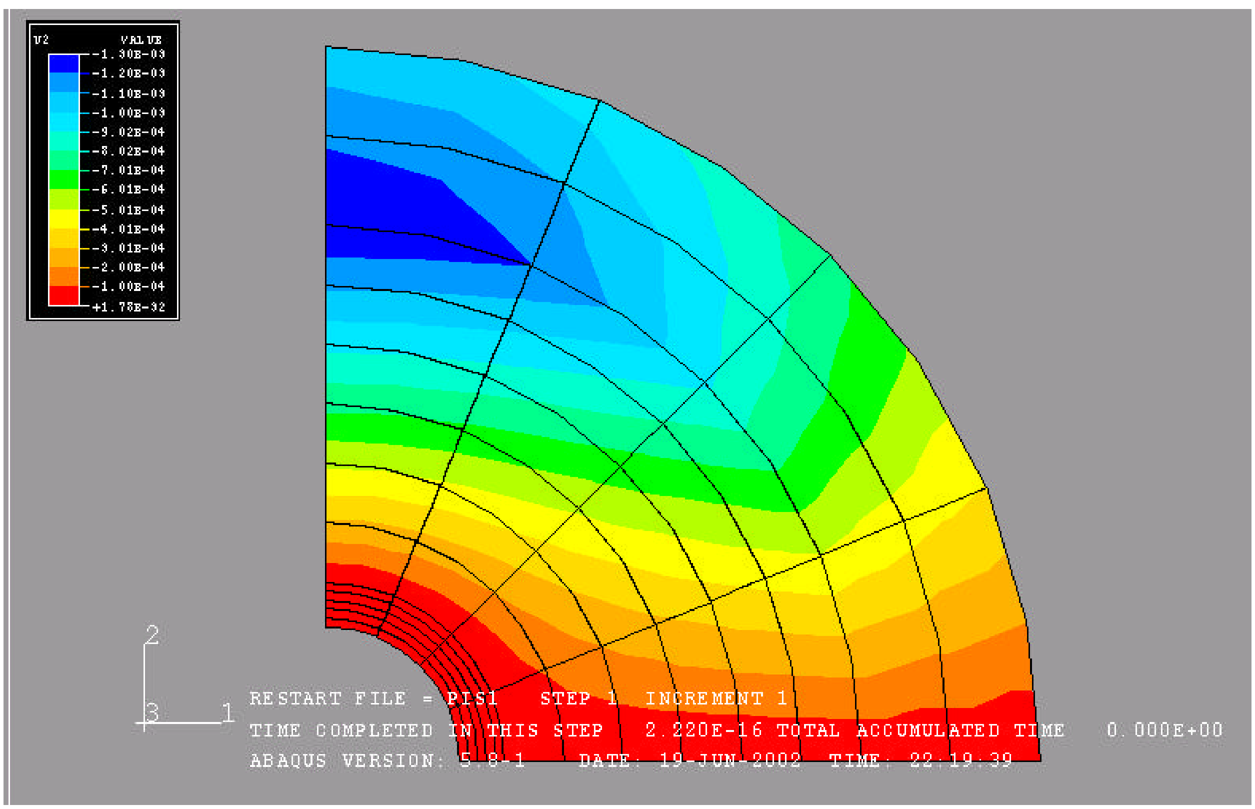


Fig.25a First principal stress profile (Casing Pressure = 1000 psi)

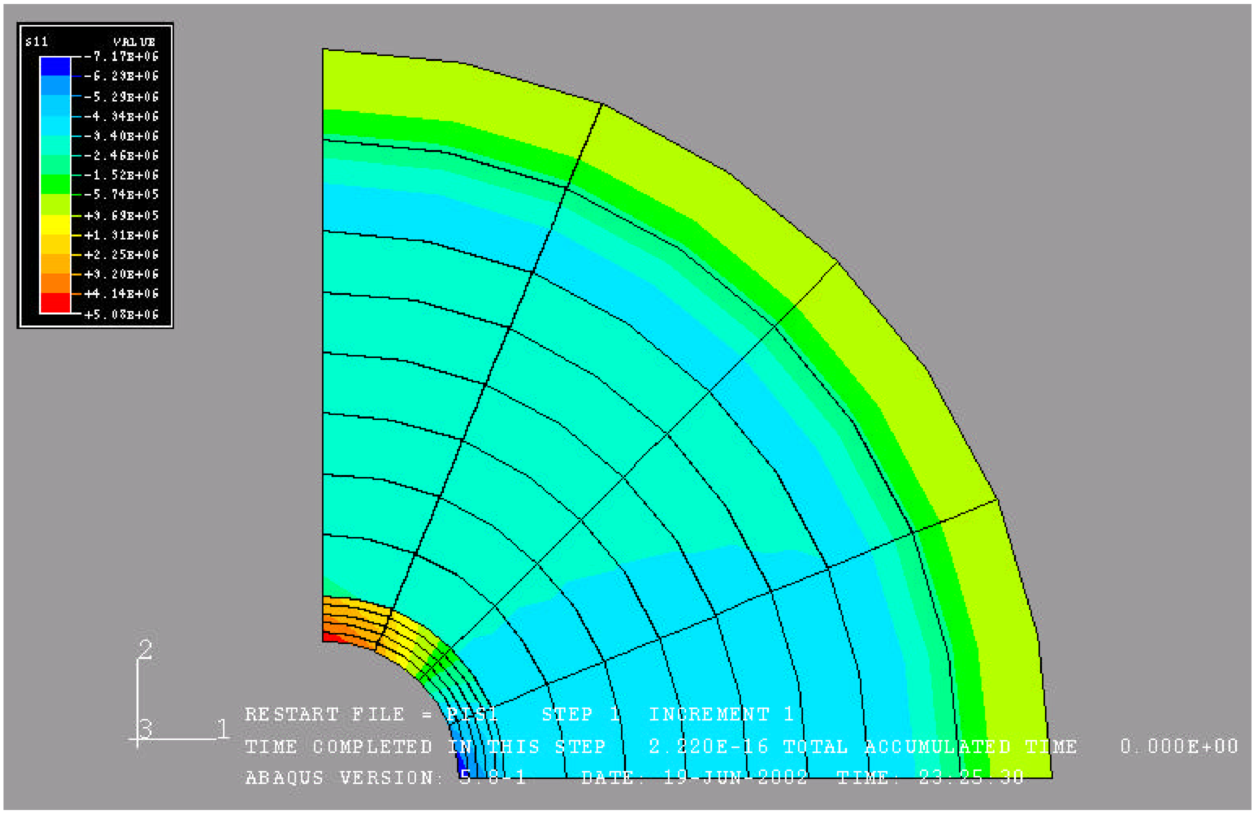


Fig.25b Second principal stress profile (Casing Pressure = 1000 psi)

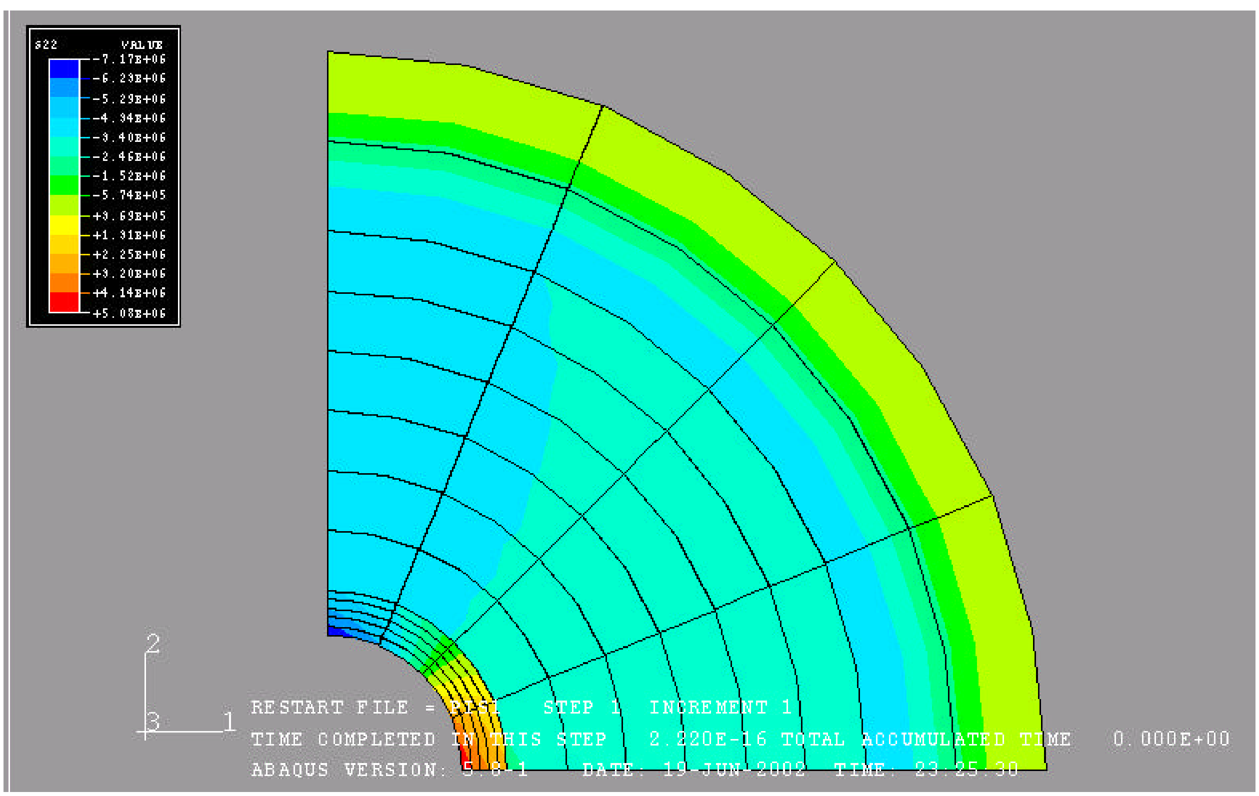


Fig.25c Horizontal displacement field (Casing Pressure = 1000 psi)

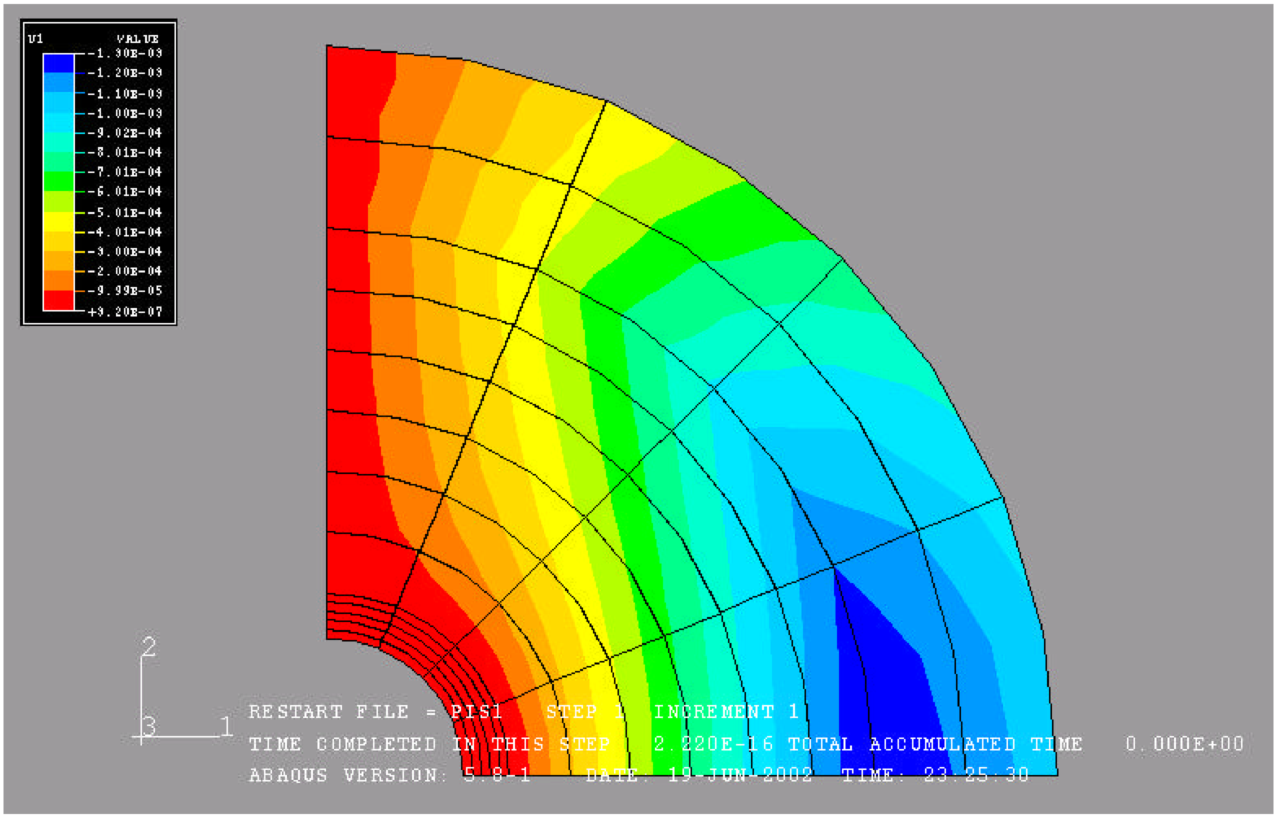


Fig.25d Vertical displacement field (Casing Pressure = 1000 psi)

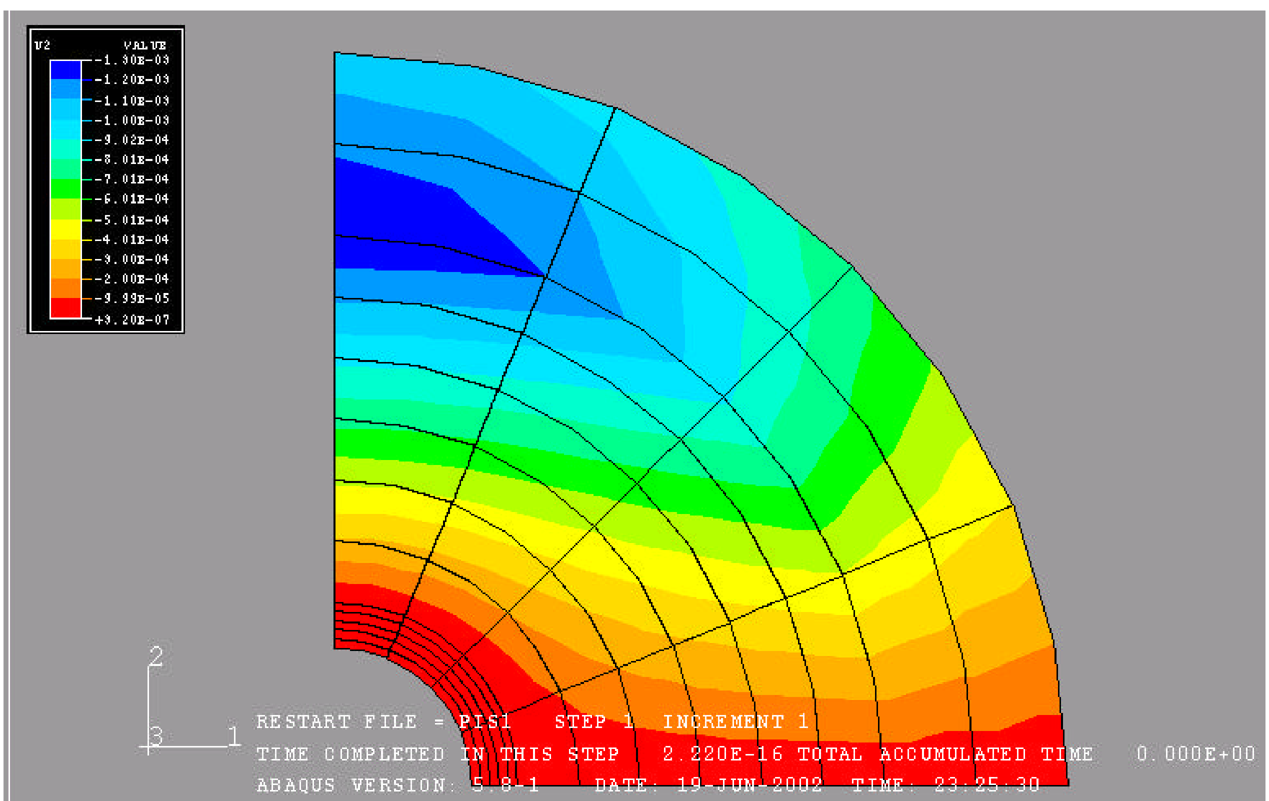


Fig.26a First principal stress profile (Casing Pressure = 5000 psi)

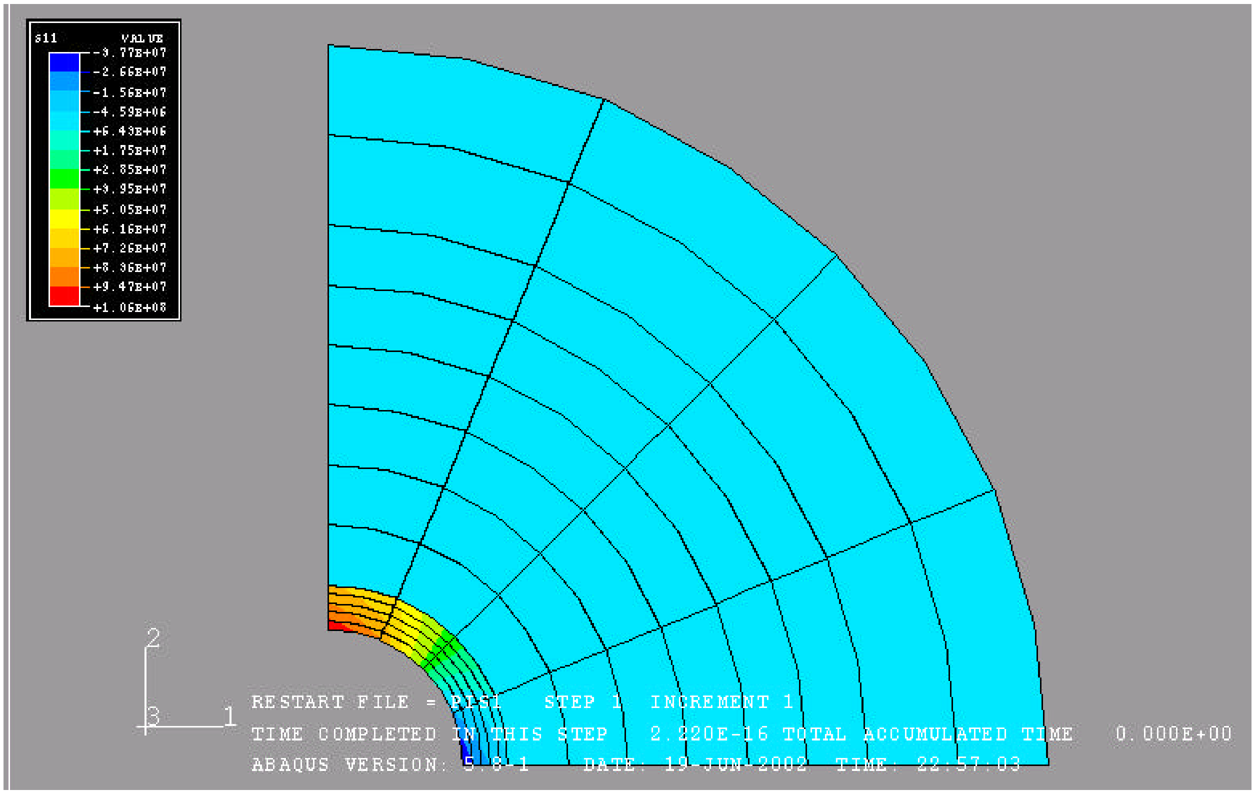


Fig.26b Second principal stress profile (Casing Pressure = 5000 psi)

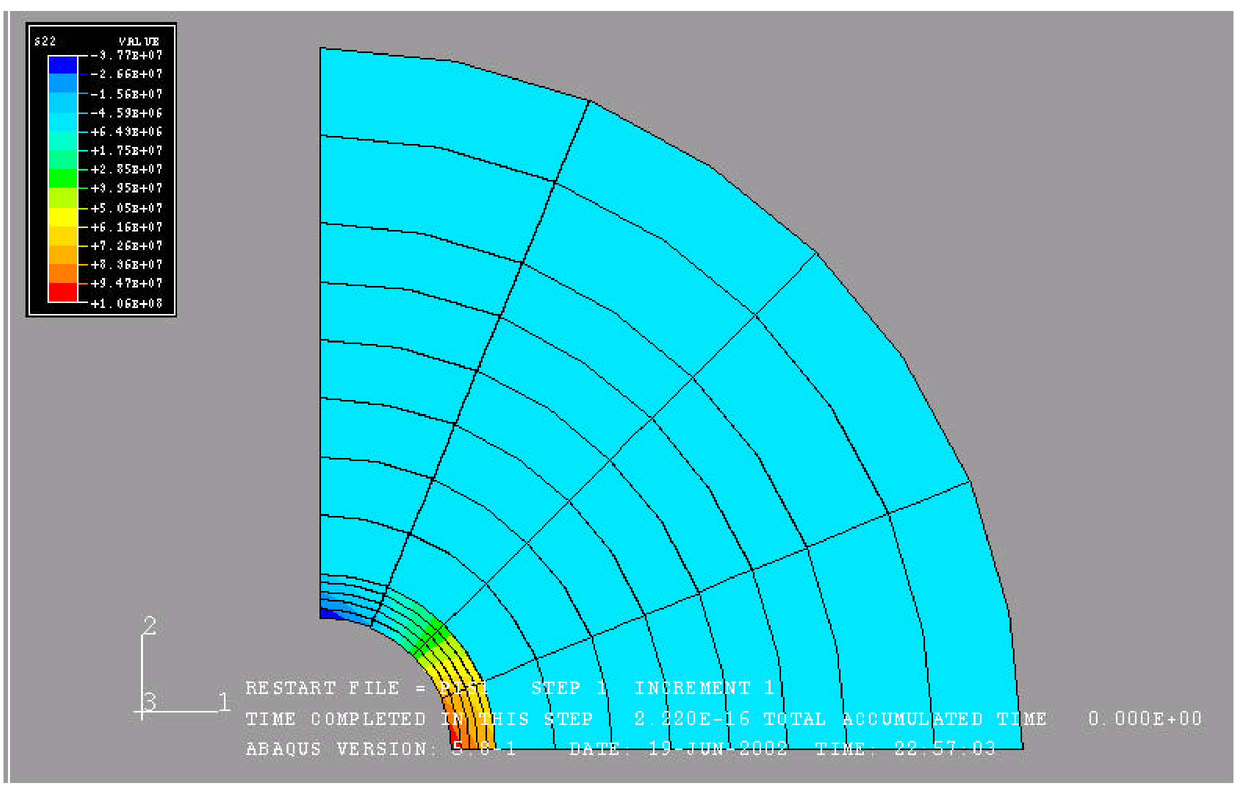


Fig.26c Horizontal displacement field (Casing Pressure = 5000 psi)

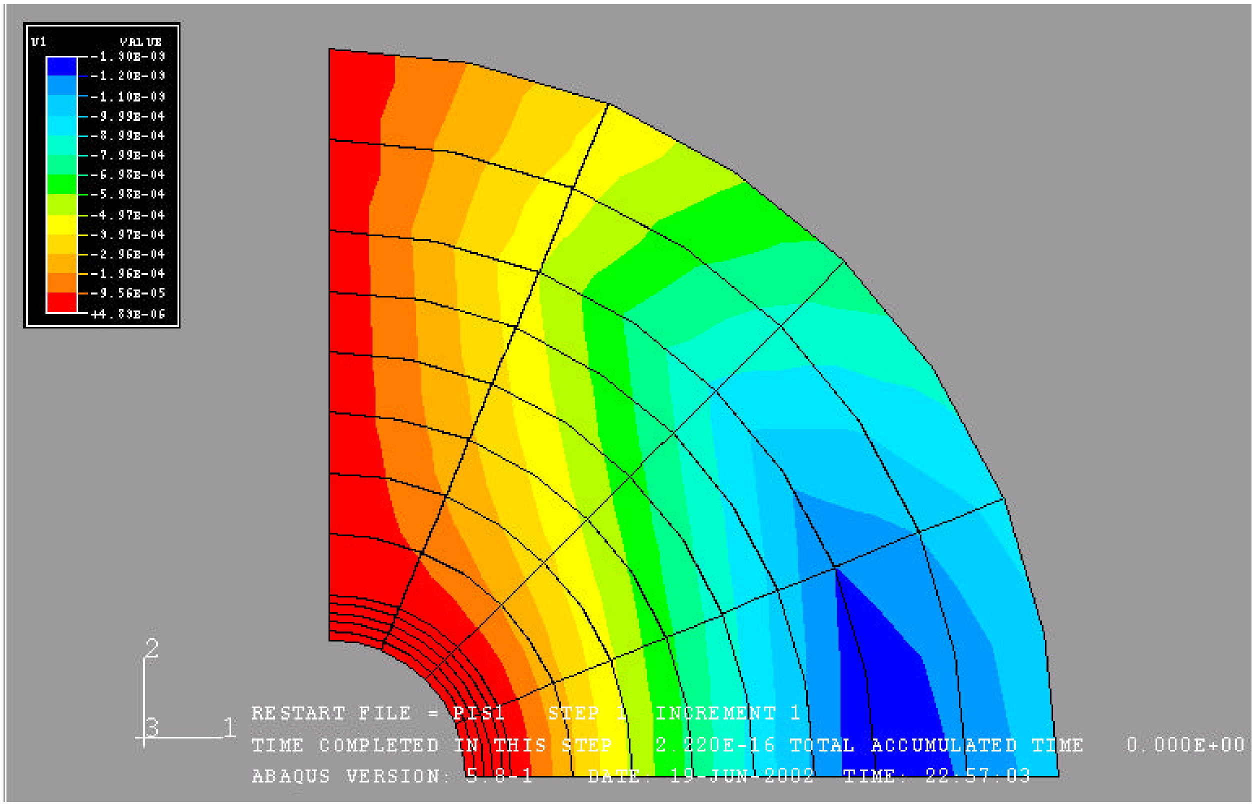
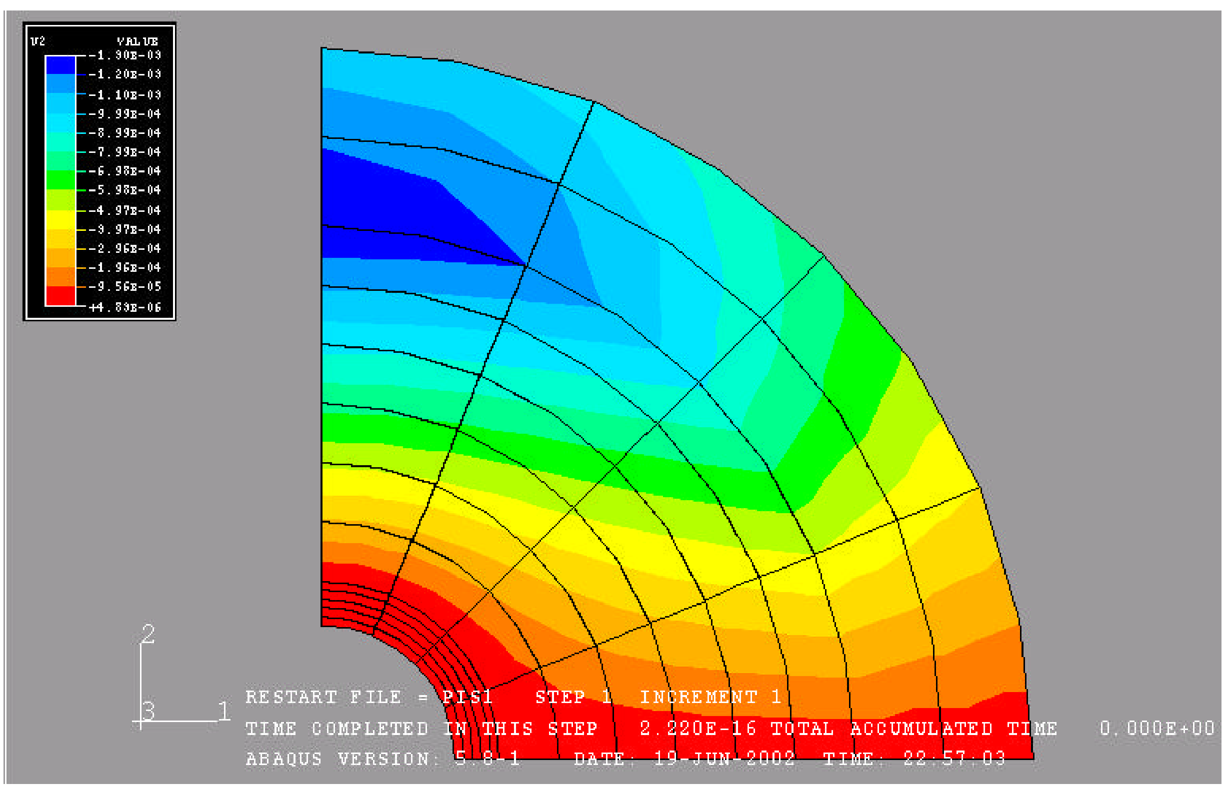


Fig.26d Vertical displacement field (Casing Pressure = 5000 psi)



MMS Project

Long-Term Integrity of Deepwater Cement Systems Under Stress/Compaction Conditions

Report 3

Issued November 27, 2002

CEMENTING SOLUTIONS, INC.

Cementing Solutions, Inc.

Table of Contents

Cementing Solutions, Inc.

Objectives

The overall objective of this research project is to determine the properties that affect cement's capability to a produce fluid-tight seal in an annulus and to develop correlations between cement properties and sealing performance under downhole conditions. The testing reported previously in progress reports 1 and 2 has helped to refine and confirm the test procedures that will be used for the remainder of the project.

Research conducted during this project period focused on continued measurement and correlation of cement mechanical properties, mechanical bond integrity of a cemented annulus, and mathematical simulation of stresses induced in a cemented annulus. Mechanical property testing included measurement of tensile strength and Young's Modulus measurements under various confining loads. Mechanical integrity testing included shear bond and annular seal testing on specimens cured under various cyclic curing schedules. Mathematical simulation of casing and cement stress and strain induced by thermal and pressure cycling was also performed during this project period.

Conventional Performance Testing

Composition

The compositions tested in this project are detailed in **Table 1** below.

Table 1—Cement Compositions for Testing

Comp. No.	Description	Cement	Additives	Water Requirement (gal/sk)	Density (lb/gal)	Yield (ft^3/sk)
1	Neat slurry	TXI Type 1	—	5.23	15.6	1.18
2	Neat slurry with fibers					
3	Foam slurry	TXI Type 1	0.03 gal/sk Witcolate 0.01 gal/sk Aromox C-12 1% CaCl	5.2	12.0	1.19
4	Bead slurry	TXI Type 1	13.19% K-46 beads	6.69	12.0	1.81
5	Latex slurry	TXI Type 1	1.0 gal/sk LT-D500	4.2	15.63	1.17
6	Latex fiber slurry	TXI Type 1	1.0 gal/sk LT-D500 3.5% carbon milled fibers 0.50% Melkrete	4.09	15.63	1.20
7	Class H with silica	Class H	35% coarse silica 0.6% retarding fluid loss additive	5.38	16.4	1.40
8	Class H with silica and fibers	Class H	35% coarse silica 0.6% retarding fluid loss additive 3.2% milled fibers	5.38	16.4	1.43

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Compressive Strength Testing

A summary of the compressive strength tests conducted was included in Report 2, and will not be repeated in this report. Please see Report 2 for a detailed description of these tests.

Report 2 discussed concerns about a possible discrepancy in compressive strength data provided by Westport and CSI. Compressive strength testing of representative compositions was conducted at Westport Laboratory to check the accuracy of CSI's test procedure. The results presented in **Table 2**, which represent the averages of three samples tested, indicate that data from the outside laboratory tracks closely with that of CSI.

Table 2—Comparison of Compressive Strengths

Location	Compressive Strength (psi) at 45°F	Compressive Strength (psi) at 80°F
Westport	1400	2015
CSI	1455	1920

Rock Properties Testing

Young's Modulus Testing

Composition 1 samples were cured in an unconfined condition (removed from mold after 24 hours and allowed to cure the remainder of the time outside of the mold) and tested at confining pressures of 0; 1,500; and 5,000 psi. The results are presented in **Table 3**.

Similar tests were conducted for Compositions 3 and 4 at confining pressures of 0, 500, and 1,000 psi, and for Composition 5 at confining pressures of 0, 250, and 500 psi. The results are presented in **Tables 4 through 6**.

Table 3—Composition 1, Compressive Young's Modulus

Confining Pressure (psi)	Effective Strength (psi)	Young's Modulus (psi)
0	8645	16.7 E 5
1500	8160	11.1 E 5
5000	8900	9.1 E 5

Table 4—Composition 3, Compressive Young's Modulus

Confining Pressure (psi)	Effective Strength (psi)	Young's Modulus (psi)
0	2885	5.8 E 5
500	3950	6.8 E 5
1000	4510	6.1 E 5

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Table 5—Composition 4, Compressive Young's Modulus

Confining Pressure (psi)	Effective Strength (psi)	Young's Modulus (psi)
0	5150	9.5 E 5
500	6000	8.1 E 5
1000	6150	1 E 5

Table 6—Composition 5, Compressive Young's Modulus

Confining Pressure (psi)	Effective Strength (psi)	Young's Modulus (psi)
0	3500	5.6 E 5
250	5250	8.9 E 5
500	6000	9.4 E 5

Figure 1—Young's modulus testing of Composition 2
(neat Type 1 with fibers)

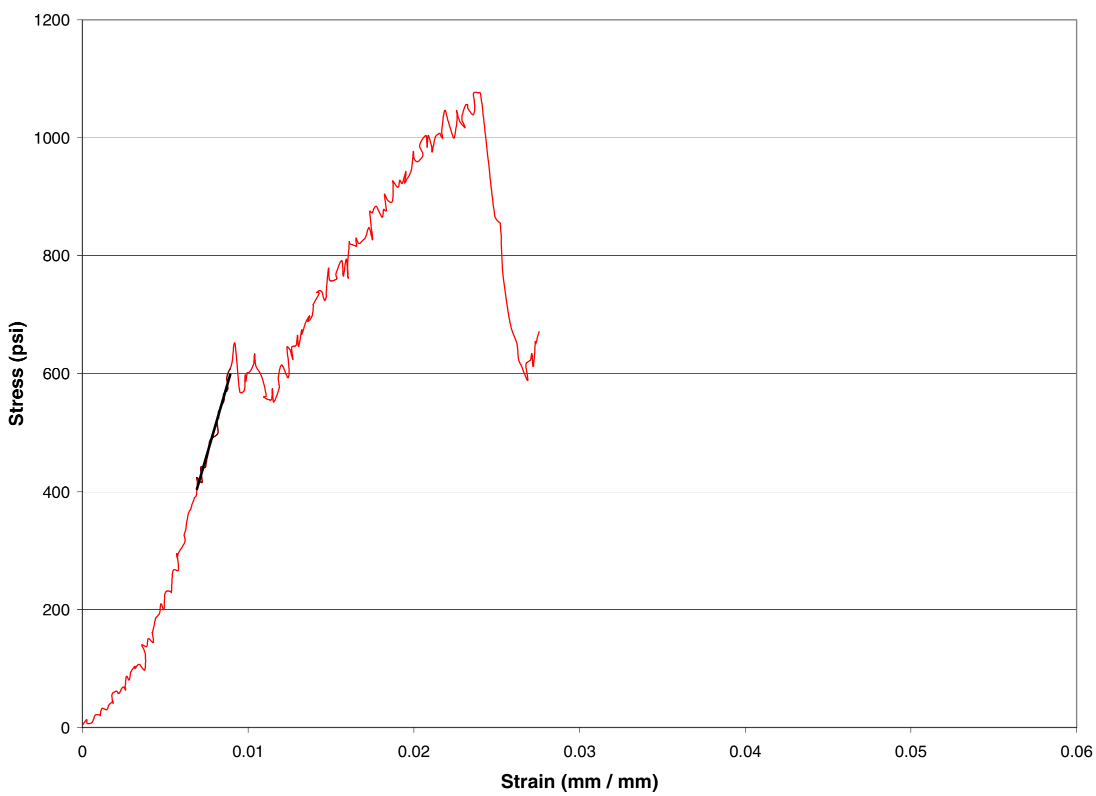

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Figure 2—Young's modulus testing of Composition 5 (Type I latex without fibers)

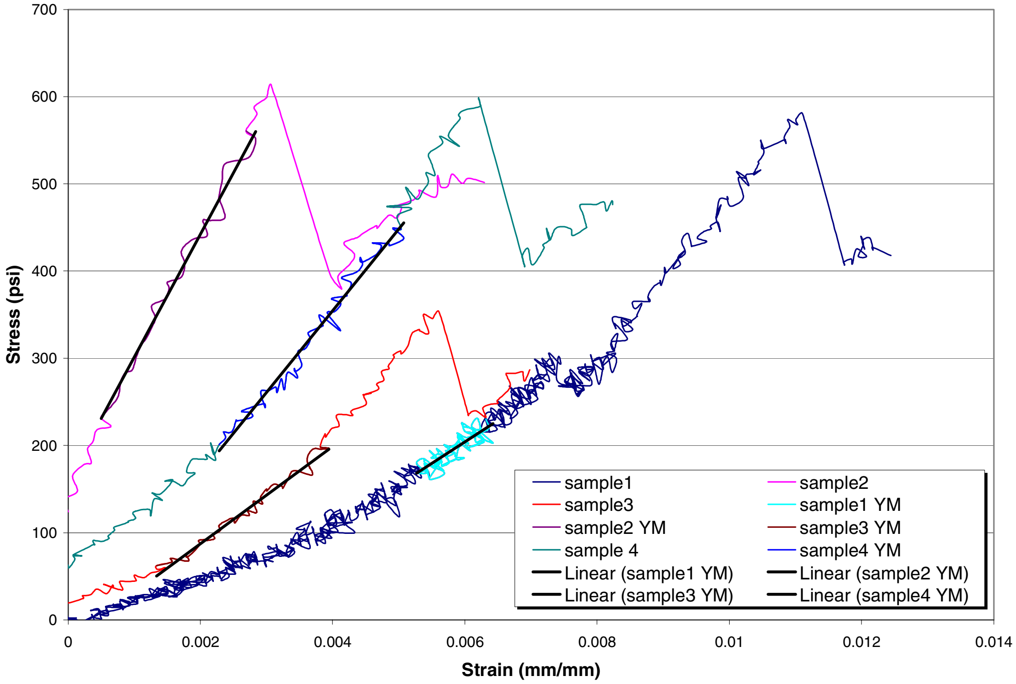
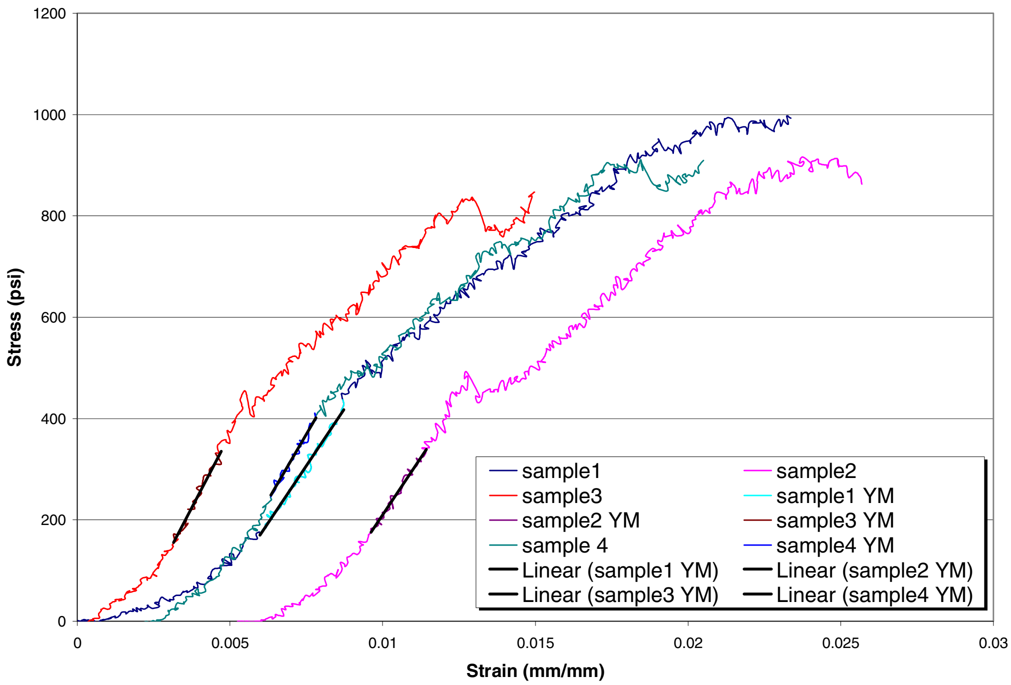


Figure 3—Young's modulus testing of Composition 6 (Type I latex with fibers)



Tensile Strength Testing

The data presented in **Table 7** indicate that the tensile strength of Composition 4 was significantly higher than that of the other compositions tested.

Table 7—Tensile Strength Comparison

Slurry	Tensile Strength (psi)
Composition 1	394* / 213**
Composition 2	1071
Composition 3	253
Composition 5	539
Composition 6	902

* Sample was cured outside the mold.

** Sample was cured in the mold.

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Hydrostatic Pressure Testing

The first hydrostatic pressure tests performed on a 10 lb/gal slurry (**Table 8**) were discussed in Report 2, and is being included in Report 3 for comparison purposes, as we present results obtained with a 12-lb/gal slurry (**Table 9**).

In both sets of tests, the initial sample was tested to failure. Subsequent cycle tests were performed with separate samples. The results are shown in Figures 4 through 9.

Table 8—Hydrostatic Cycles for 10-lb/gal Foam

Cycle No.	Hydrostatic (psi)	Young's Modulus (psi)
1 (initial)*	—	5.57E+05
2 (up)**	1000	3.38E+05
3 (down)**	100	6.71E+05
4 (up)**	1500	5.71E+05
5 (down)**	100	7.98E+05
6 (up)**	2000	6.68E+05
7 (down)**	100	8.49E+05***

* Initial sample taken to failure

** Tests performed on separate (not initial) samples

*** No deformation calculations performed for Cycle 7

Table 9—Hydrostatic Cycle for 12-lb/gal Foam

Cycle No.	Hydrostatic (psi)	Young's Modulus (psi)
1 (initial)*	—	8.24E+05
2 (up)**	600	1.30E+05

*Initial sample taken to failure

**Separate sample tested

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Figure 4—Young's modulus testing of 10-lb/gal foamed cement

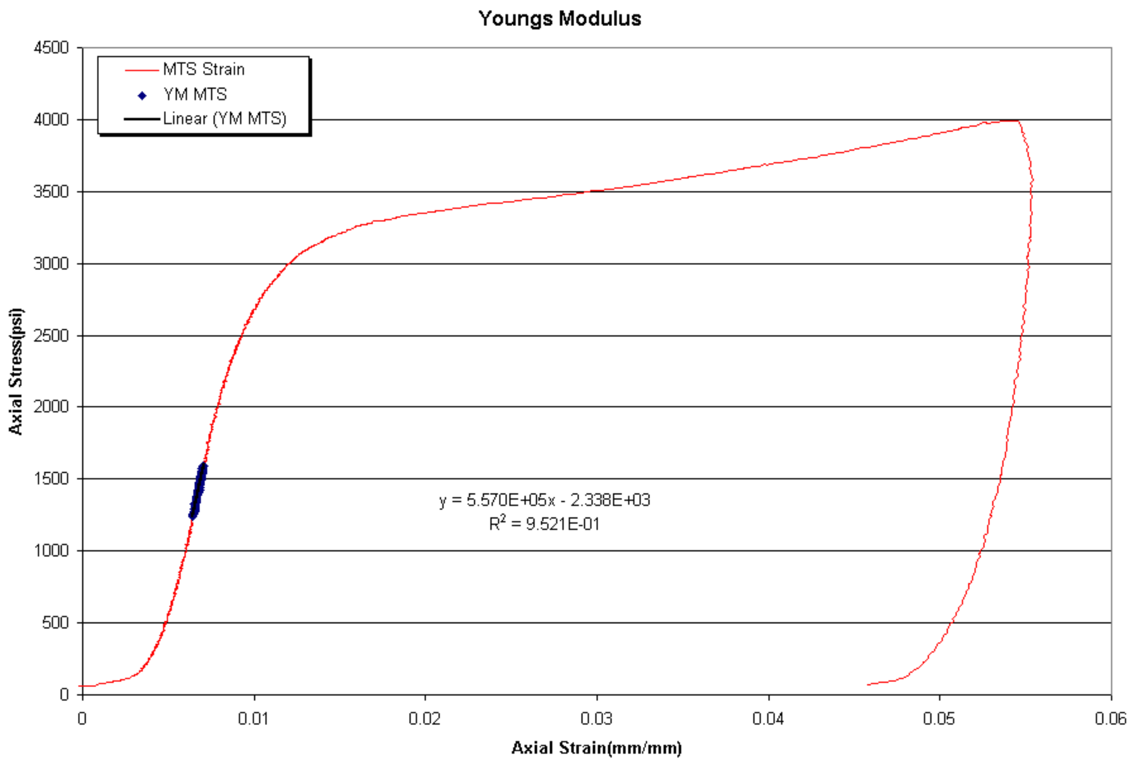

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Figure 5—Young's modulus testing of 10-lb/gal foamed cement during hydrostatic cycling

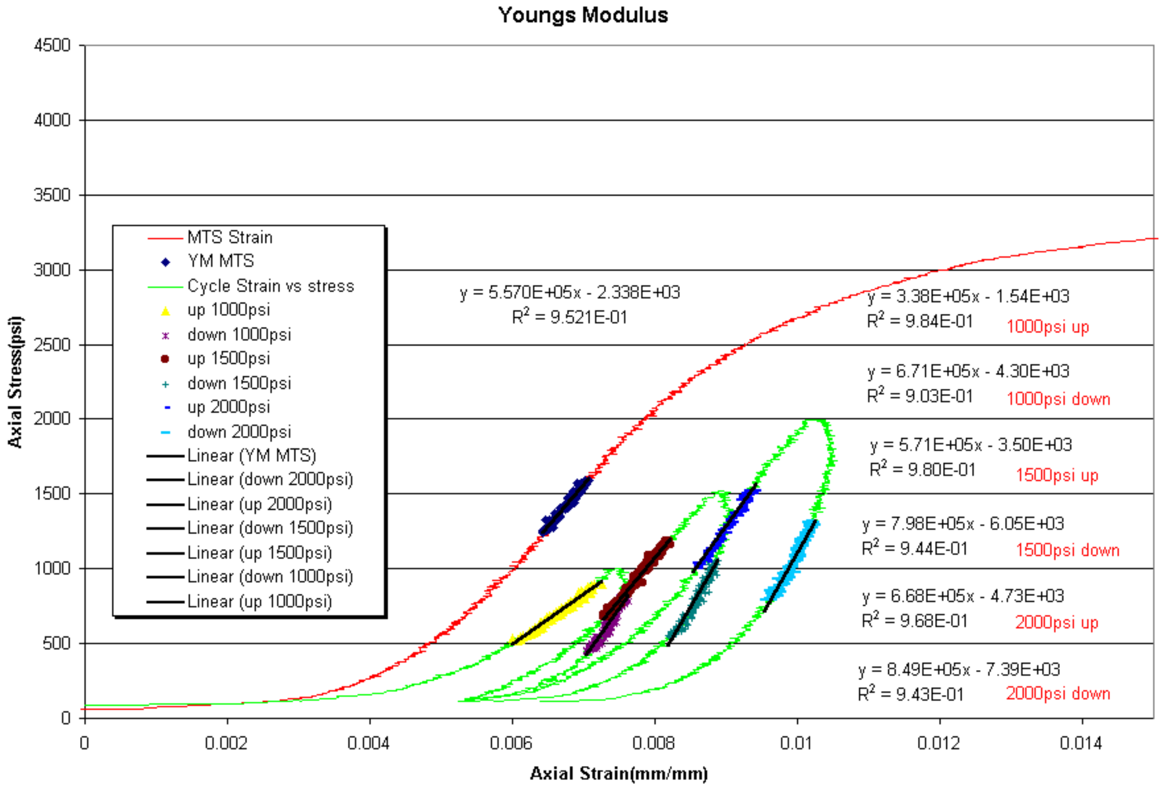

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Figure 6—Deformation of 10 lb/gal foamed cement during hydrostatic cycling

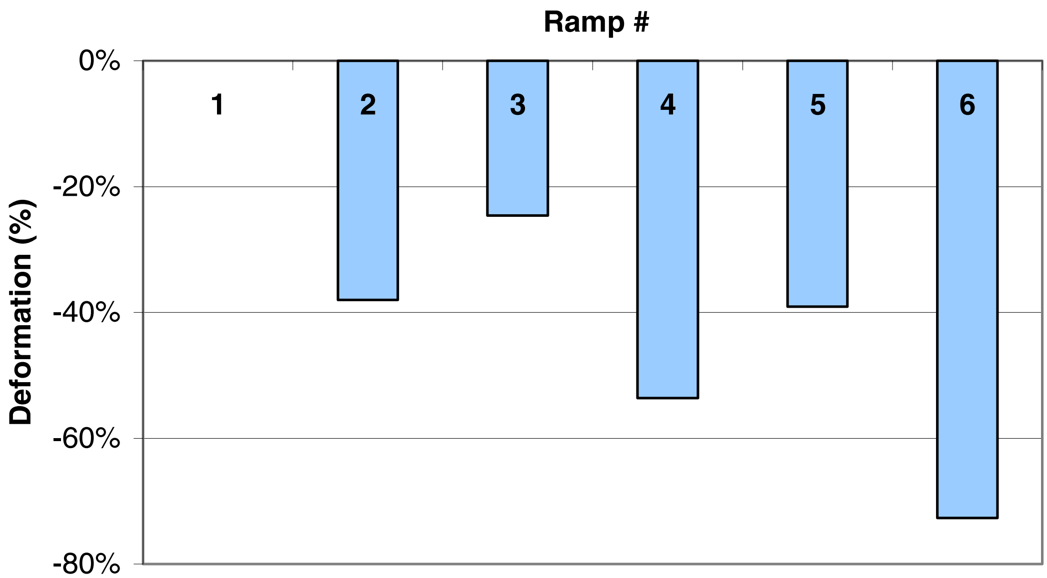

Figure 7— Young's modulus testing of 12-lb/gal foamed cement (Composition 2)

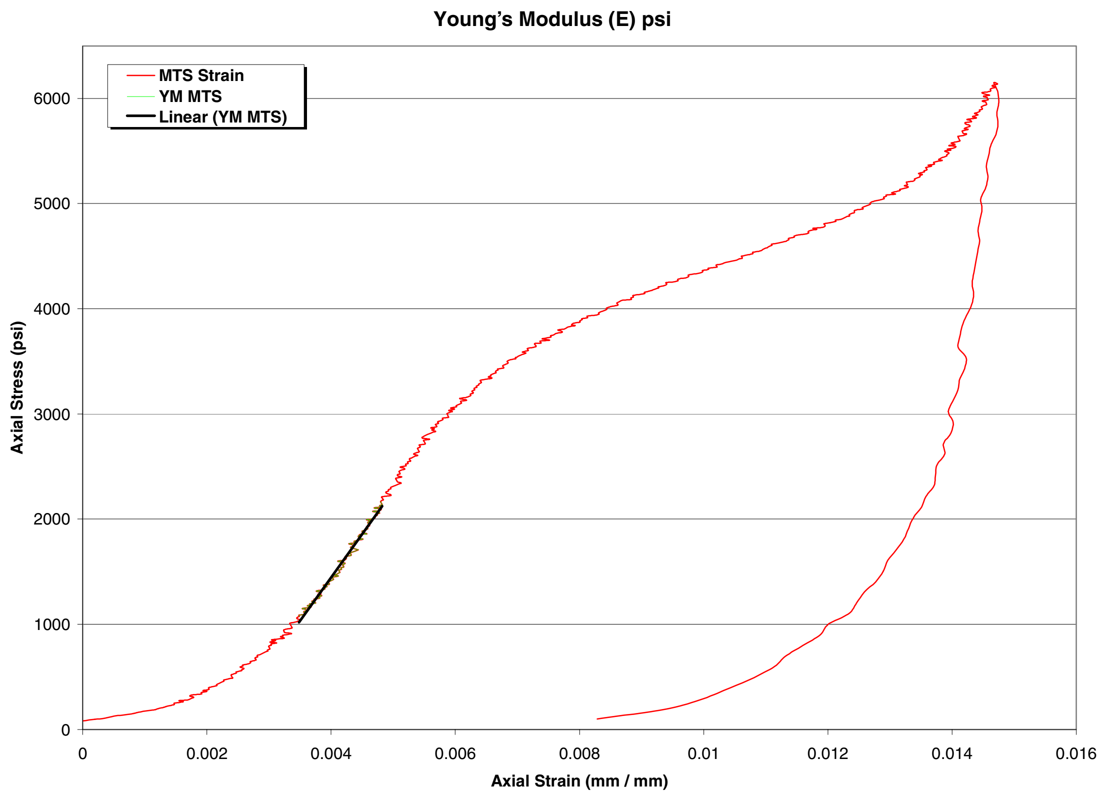

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Figure 8—Young's modulus testing of 12-lb/gal foamed cement (Composition 2) during hydrostatic cycling

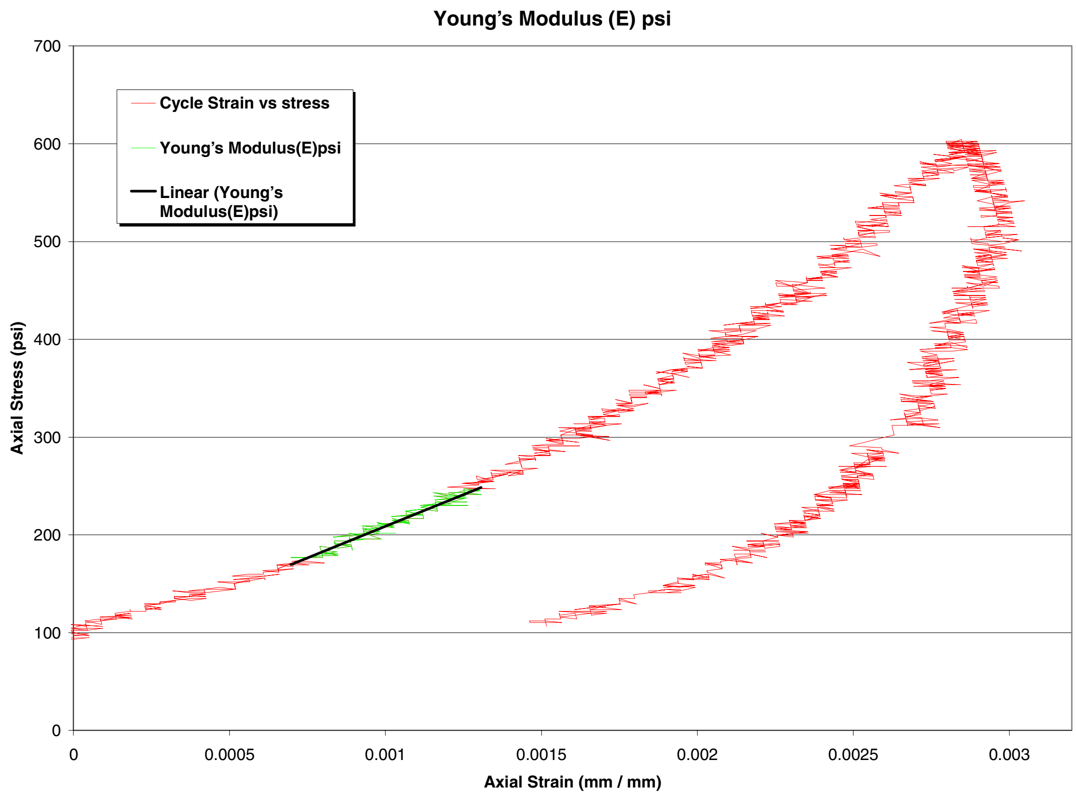

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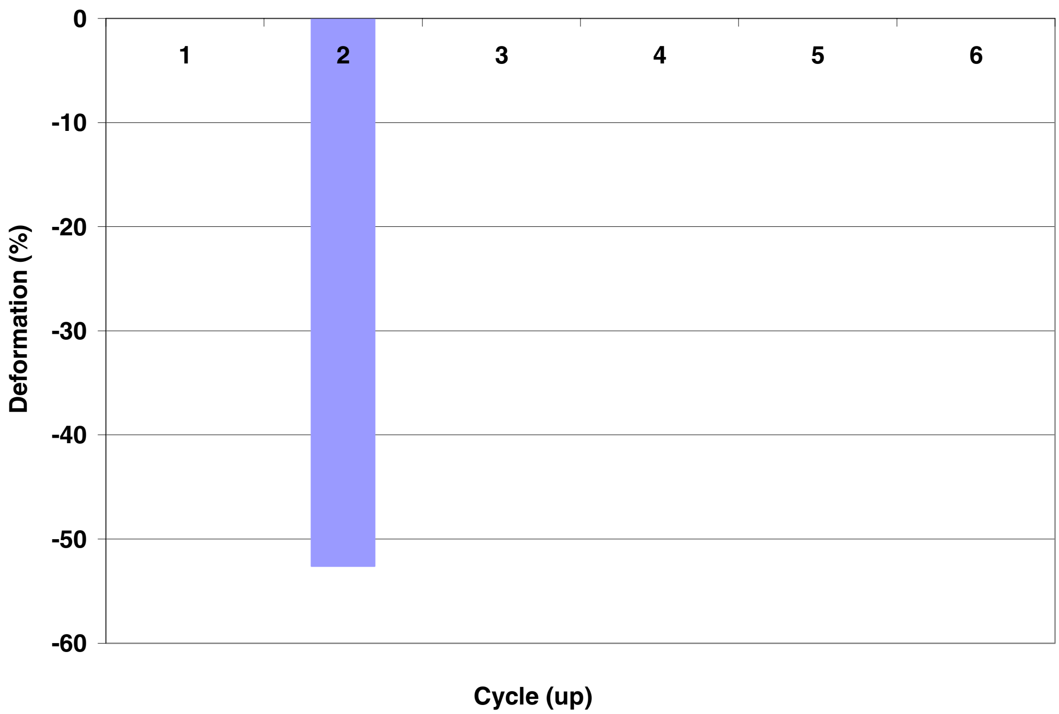
Figure 9—Deformation of 12-lb/gal foamed cement (Composition 2) during hydrostatic cycling



Chandler Engineering, Inc. Mechanical Properties Device

For comparison purposes, Chandler Engineering, Inc. and CSI have agreed to exchange data generated by two different systems – the rock mechanics system at Westport Laboratory and an acoustics-based system operated by Chandler. The same six slurries were tested in each device, and the comparative data is presented in **Tables 10 and 11**.

Initial results of Poisson's ratio testing on these lightweight cement compositions are not interpretable. The majority of tests yielded a negative Poisson's ratio, indicating a negative radial strain resulting from a positive axial strain. Several possible explanations for this phenomenon are under investigation. However, until the question is resolved, no Poisson's ratio data will be reported.

The Young's modulus values for latex cement with fibers, Class H cement, and Class H cement with fibers were not available at the time this report was prepared.

Like the UCA, Chandler's new analyzer measures the Young's modulus and compressive strength of a slurry as it cures at elevated temperatures and pressures, eliminating the potentially damaging effects of depressurization and cooling involved with traditional core testing. For more information on this device, see Appendix F.

Table 10—Chandler Device

Composition	Poisson's Ratio	Compressive Young's Modulus
1	0.20	2.3 E 6
4	0.31	1.5 E 6
5	0.39	1.4 E 6
6	0.19	2.5 E 6
7	0.24	2.2 E 6
8	0.25	2.3 E 6

Table 11—Rock Mechanics Data

Composition	Poisson's Ratio	Compressive Young's Modulus
1	—	1.7 E 6
4	—	9.5 E 5
5	—	5.6 E 5
6	—	—
7	—	—
8	—	—

Unconventional Performance Testing

Shear Bond Testing

Table 12 presents results of shear bond strength tests performed with temperature and pressure cycling on Compositions 1, 3, 4, and 5. For more information on test procedures, see Appendix C.

Table 12—Shear Bond Strengths (psi)

System	Simulated Formation	Comp. 1	Comp. 3	Comp. 4	Comp. 5
Baseline	hard	1194	127/98	109/78	—
	soft	198	233	143	223
Temperature-Cycled	hard	165	299/215	191/269	—
	soft	72	7	56	149
Pressure-Cycled	hard	194/106	276/228	294/170	—
	soft	23	22*	23*	11

* Visual inspection revealed samples were cracked.

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Shrinkage Testing

Information on test procedures for shrinkage testing is provided in Appendix D.

Annular Seal Testing

Table 13 presents the results of annular seal tests performed on Compositions 1, 3, and 4. For information on test procedures for annular seal testing, see Appendix E.

Table 13—Annular Seal Tests

Condition Tested	Formation Simulated	Composition 1	Composition 3	Composition 4
Initial Flow	Hard	0 Flow	0 Flow	0 Flow
	Soft	0 Flow	0.5K (md)	0 Flow
Temperature-Cycled	Hard	0 Flow	0 Flow	0 Flow
	Soft	0 Flow	123K md / (2200 md)	43K (md)*
Pressure-Cycled	Hard	0 Flow	0 Flow	0 Flow
	Soft	27K (md)	0.19K (md)*	3K (md)

* Visual inspection revealed samples were cracked.

Pipe-in-Pipe Testing

A pipe-in-pipe test was designed to simulate the shrinkage of cement that can lead to fluid leakage when no external fluid is present outside the cement. Four models were tested:

- 6-in. flange
- 6-in. flange with 200-psi pressure
- 5-ft flange with vacuum
- 5-ft flange with 200-psi pressure

In all cases, no leaks were observed. The cement provided a tight seal to gas flow.

Mathematical Modeling

The graphs in this section represent an average of test results obtained in testing the performance of a neat cement (baseline), latex cement, and foamed cement. The compressive and tensile strengths and shear bond strength of the cements are shown in **Table 14**.

The abbreviations “PIP” and “PIS” are used in the following graphs to differentiate between test conditions that simulate hard formations (pipe-in-pipe) and those that simulate soft formations (pipe-in-soft).

Table 14—Compressive Strength

Cement	Compressive Strength After 10 Days (psi)	Tensile Strength (psi)	Shear Bond PIP	Shear Bond PIS
Composition 3	3436	578	321	147
Composition 5	3630	504	432	237
Composition 1	4035	673	519.6	203

Compressive Failure

Figures 10 and 11 show the results of tests used to predict the effect of casing pressure and confining pressure on the radial stress experienced by the inner pipe, the cement sheath, and a hard formation.

The model showed that annular cement retains its integrity at high casing pressures and at high confining pressures in a hard formation.

When casing pressure was varied (**Figure 10**), and no confining pressure was applied, virtually no variation in the radial stress was observed for the cement or the formation. All variation, rather, was limited to the internal casing.

When confining pressure was varied (**Figure 11**), and casing pressure was fixed at 5,000 psi, the greatest variation in radial stress was observed in the inner casing and outer pipe (representing the formation), with very little variation observed in the cement. This is because of the differences in the Young's modulus properties of the cement vs. the Young's modulus of the steel pipe.

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Figure 10—Compressive failure, simulated hard formation (1 of 2)

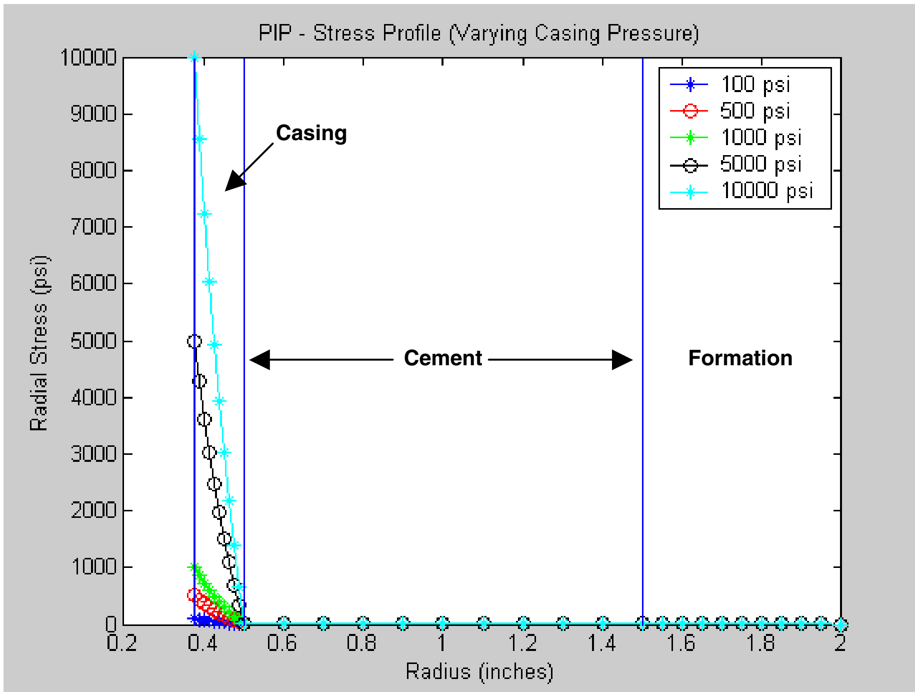
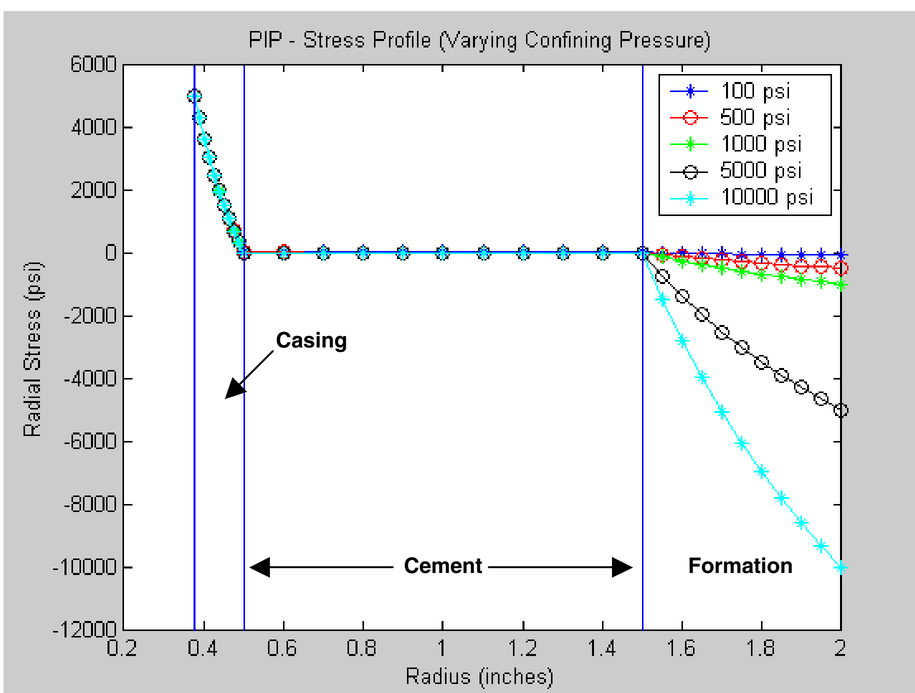


Figure 11—Compressive failure, simulated hard formation (2 of 2)



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Cements were then tested to determine the effects of varying casing pressure and confining pressure in a soft formation scenario. Without confining pressure (**Figure 12**), the cement and the formation experience no variation in radial stress as casing pressure increases. As in the test with the hard formation, the variation is limited to the inner casing.

However, when the casing pressure is fixed at 500 psi, and the confining pressure is increased from 100 psi to 10,000 psi (**Figure 13**), the radial stress in the cement layer increases accordingly, to a point beyond which the sheath can withstand. At pressures of 5,000 psi and above, the cement sheath will almost certainly fail.

The positive and negative values shown in Figure 13 are used to differentiate radial stress (positive values) from the opposite of radial stress (negative values).

Figure 12—Compressive failure, simulated soft formation (1 of 2)

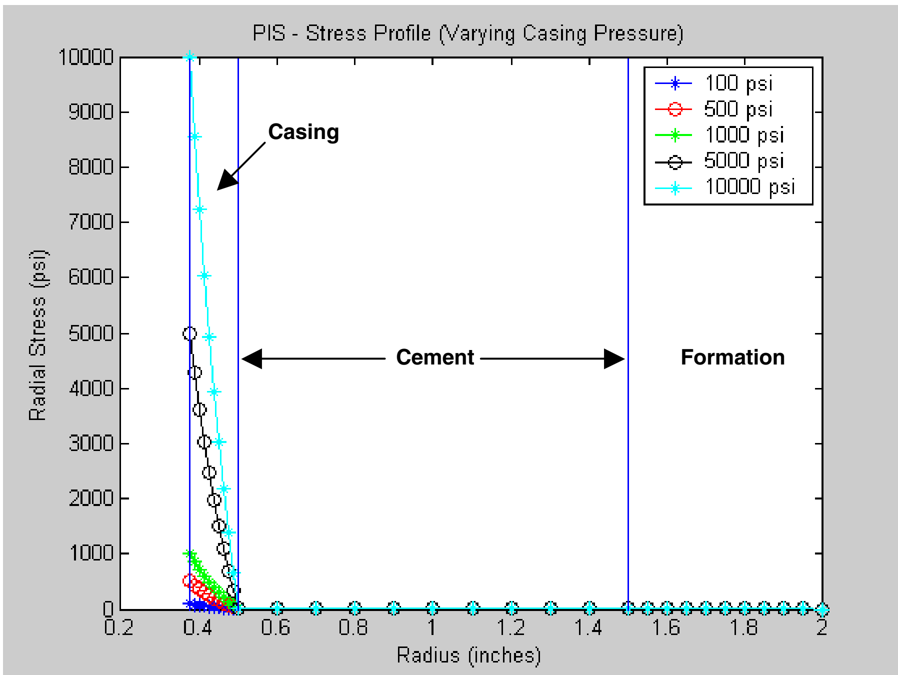

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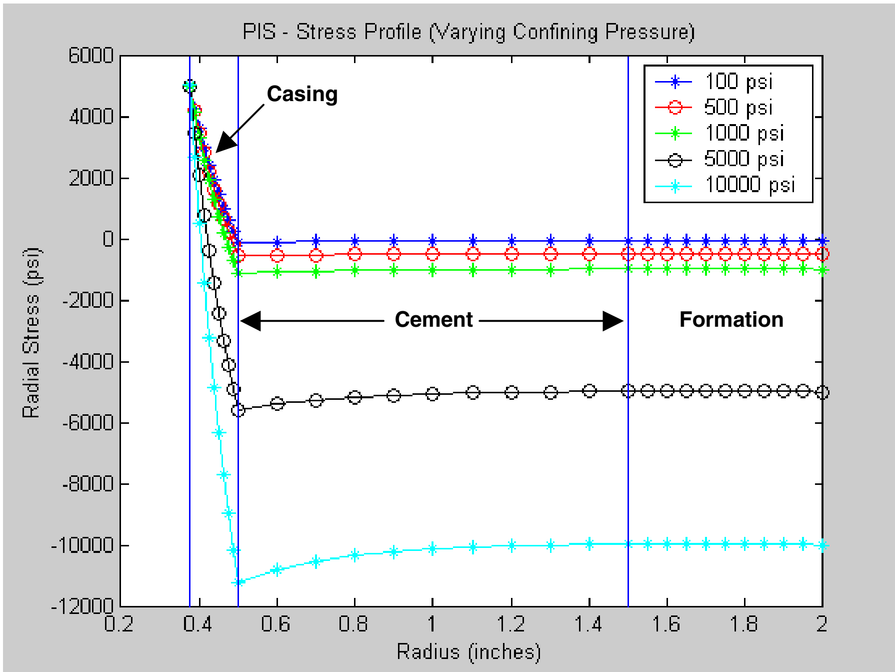
Figure 13— Compressive failure, simulated soft formation (2 of 2)



Shear Failure (Hoop Stress)

In a simulated hard formation (**Figure 14**), the variation in hoop stress at the pipe-cement interface is significantly less than that at the cement-formation interface. No significant variation in hoop stress is observed in the cement layer. Therefore, if failure occurs, it will most likely occur at the cement-formation interface.

In a simulated soft formation (**Figure 15**), there is almost no variation in the formation hoop stress, and there is slightly more variation in the hoop stress of the cement sheath. While the magnitude of variation between the pipe-cement interface and the cement-formation interface is significant, it is not as great as in the simulated hard formation shown in Figure 14. That is because the soft formation is more flexible and does not create the high stress contrast during displacement.

If failure occurs, it will most likely be at the pipe-cement interface.

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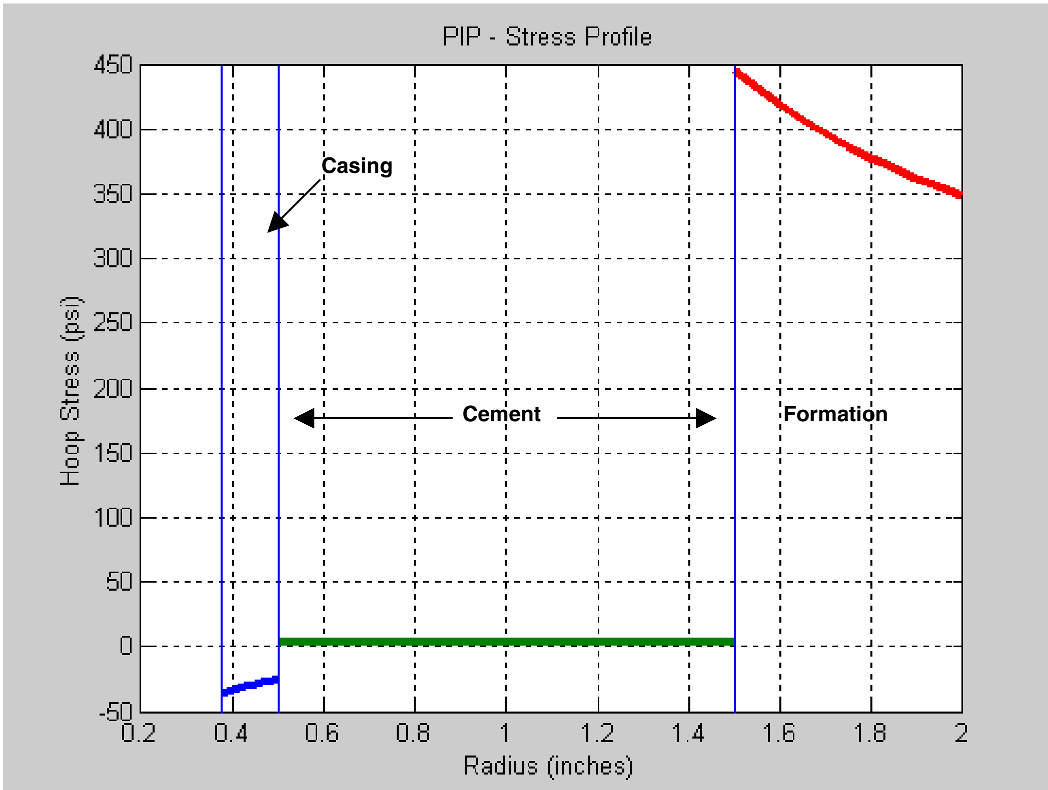
Figure 14—Shear failure, simulated hard formation (1 of 2)



Casing Pressure	15 psi
Confining Pressure	100 psi
Hoop Stress Contrast	~ 450 psi

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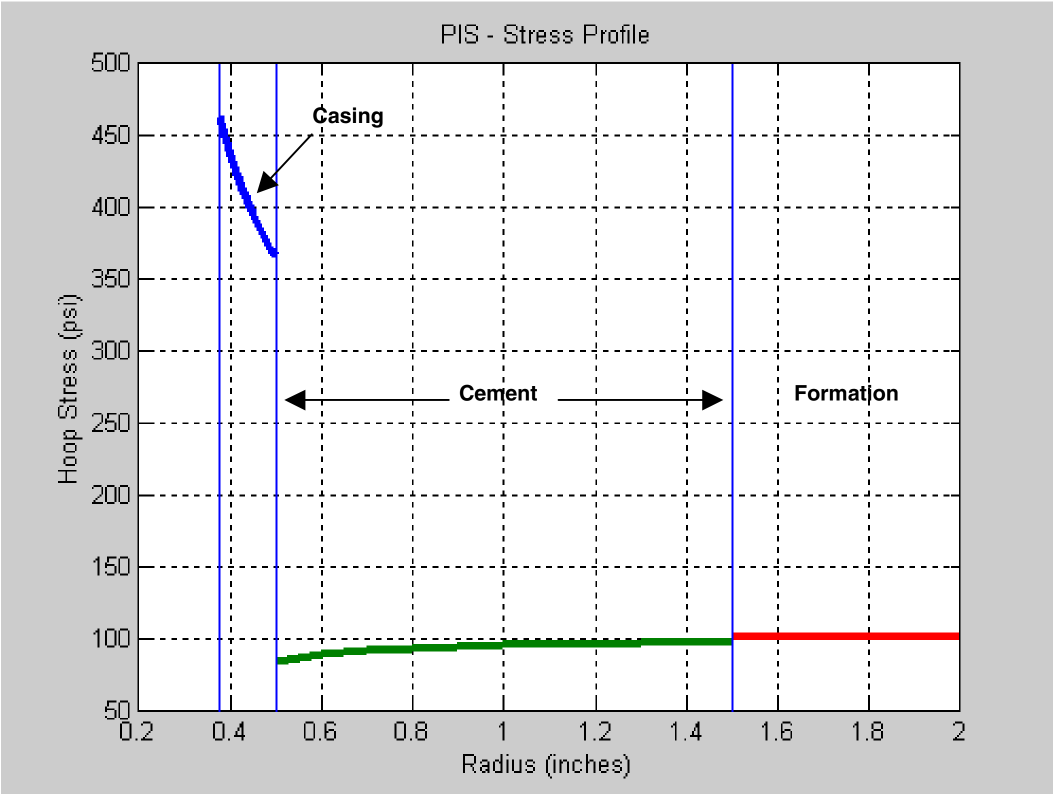
Figure 15—Shear failure, simulated soft formation (2 of 2)



Casing Pressure	15 psi
Confining Pressure	100 psi
Hoop Stress Contrast	~ 300 psi

Heat of Hydration

Cements were tested for the effect of heat of hydration on the cement integrity. First, the borehole temperature was increased from 300K to 400K, and the heat of hydration rate was held constant (**Figure 16**). As the temperature increased, the peak temperature moves closer to the pipe-cement interface. Because the steel pipes conduct heat very well, little if any variation is seen in the inner casing or outer pipe.

With a fixed borehole temperature (**Figure 17**), increasing the heat of hydration rate causes an increase in the temperature of the cement sheath. At the peak heat of hydration rate, the temperature is increased by nearly 30C, which can cause considerable stress on the cement system.

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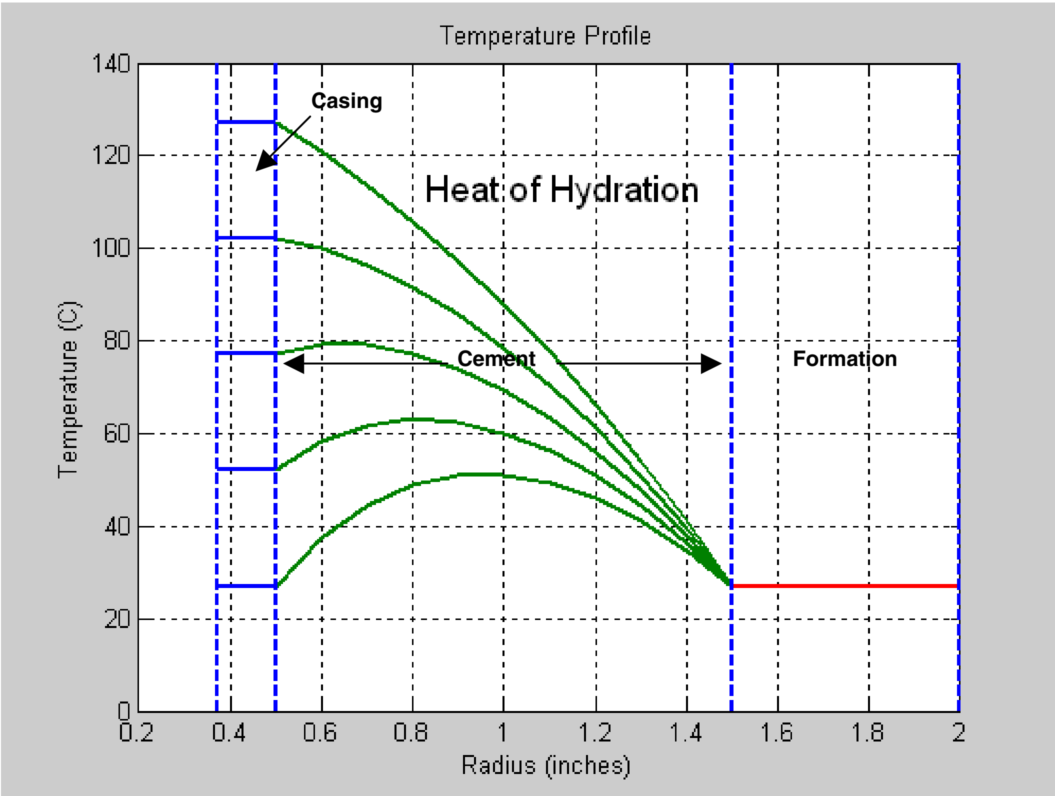
When viewed as a radial stress profile (**Figure 18**), the highest heat of hydration rate creates a radial stress of 600 psi on the cement sheath, but little variation of radial stress is observed within the cement.

Figure 16—Heat of hydration, temperature profile (1 of 2)



Borehole Temperature	300 K to 400 K
Heat of Hydration Rate	3.5 KJ/Kg.sec

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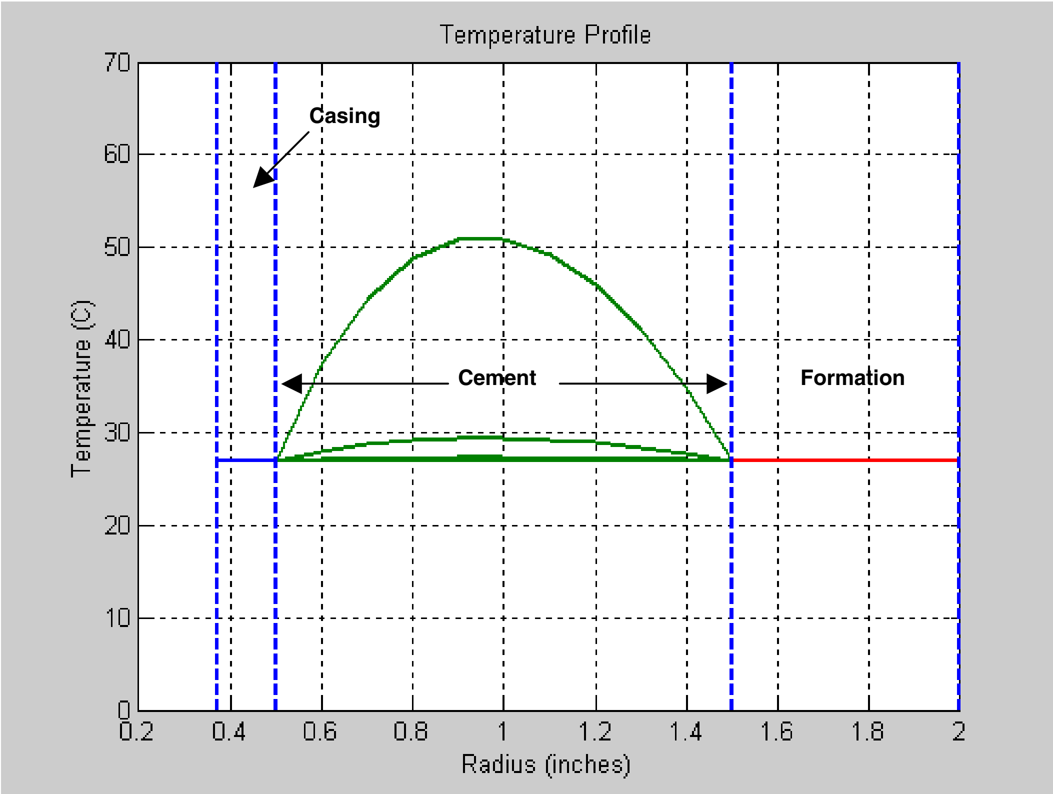
Figure 17—Heat of hydration, temperature profile (2 of 2)



Borehole Temperature	300 K
Heat of Hydration Rate	3.5 KJ/Kg.sec - 3.5 KJ/Kg.sec

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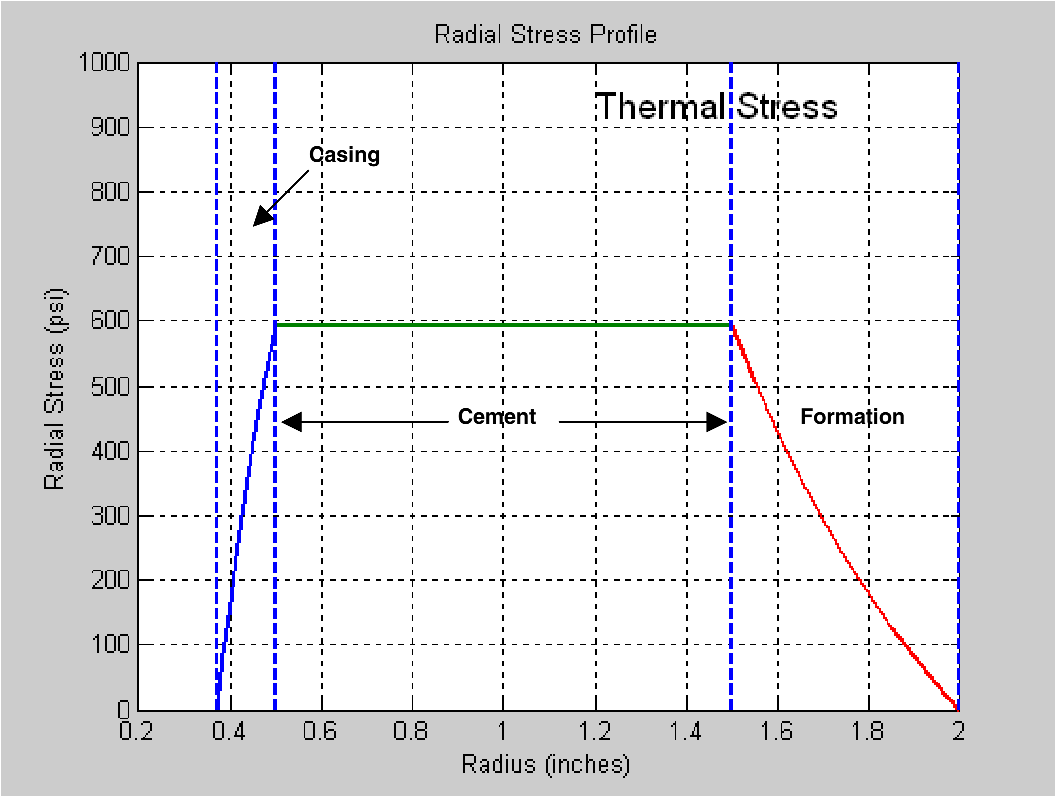
Figure 18—Heat of hydration, radial stress profile



Borehole Temperature	300 K
Reservoir Temperature	300 K

Linear Superposition with Elastic Stress

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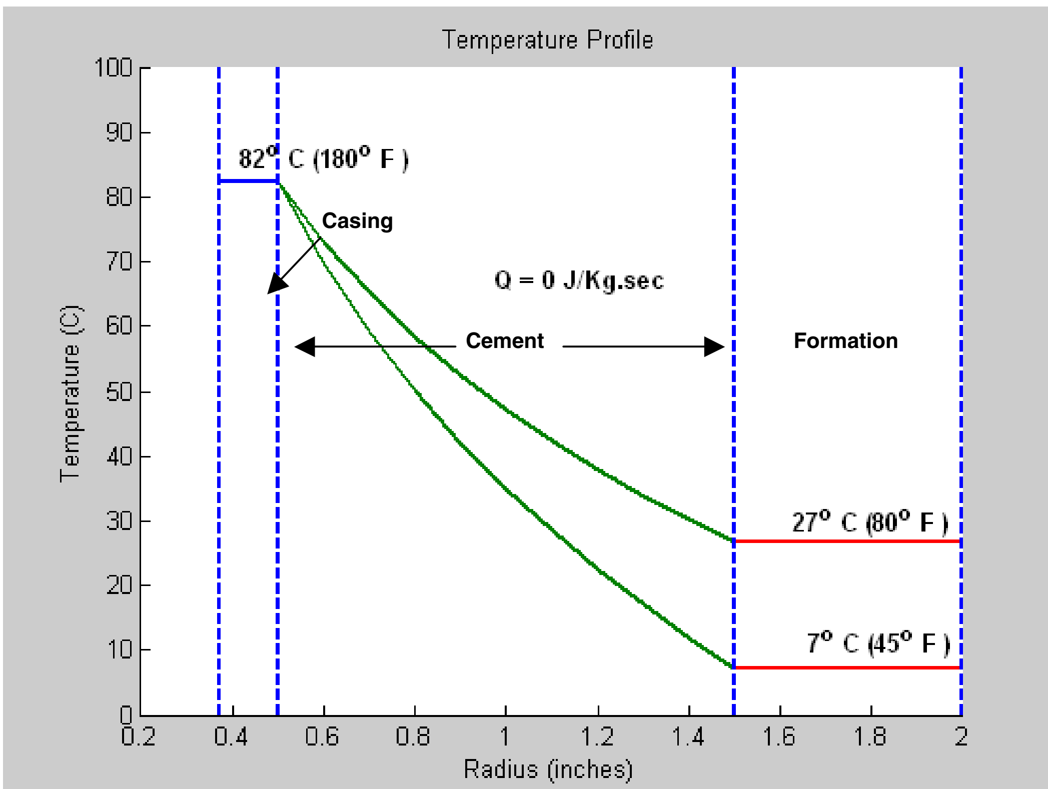
Thermal Stress

Thermal stress tests were performed to evaluate the effect of thermal stress on the cement. **Figure 19** plots the differences between the borehole temperature and two different reservoir temperatures.

The large temperature contrast between the inner casing and formation can cause significant radial stress (as much as 700 psi in **Figure 20**), which can affect the integrity of cement. However, the radial stress does not vary greatly within the cement.

Figure 19—Thermal stress, temperature profile



Borehole Temperature	180°F
Reservoir Temperature	45°F, 80°F
Heat of Hydration Rate	0 J/Kg.sec

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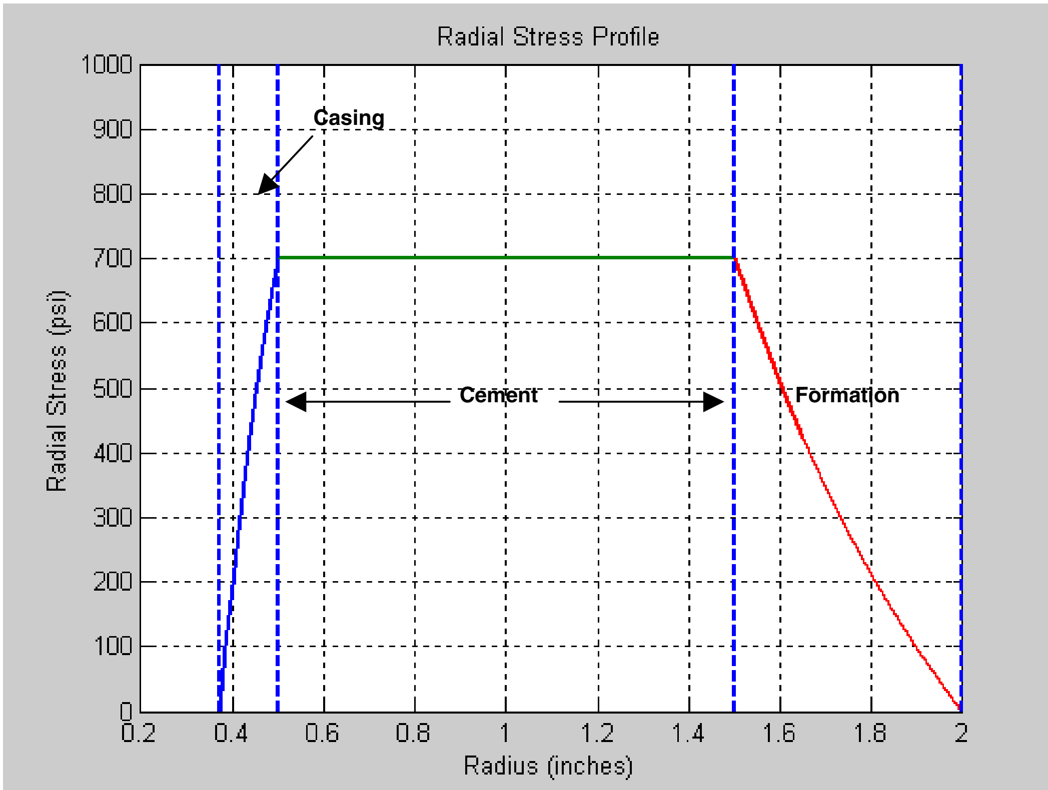
Figure 20—Thermal stress, radial stress profile



Borehole Temperature	180°F
Reservoir Temperature	45°F, 80°F
Heat of Hydration Rate	0 J/Kg.sec

- Higher thermal stress
- No significant variation within cement

Hoop Stress (Tensile) without Confining Pressure

Cements were tested to determine how hoop stress would affect the cement, given a specific casing pressure. No hoop stress variation was observed in either the cement or the outer pipe in simulated hard formations (**Figure 21**) and soft formations (**Figure 22**). The only contrast in hoop stress was apparent at the pipe-cement interface. This can be attributed to the difference in the elastic Young's modulus properties of the pipe and the cement.

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Figure 21—Hoop stress (tensile), simulated hard formation, 0-psi confining pressure

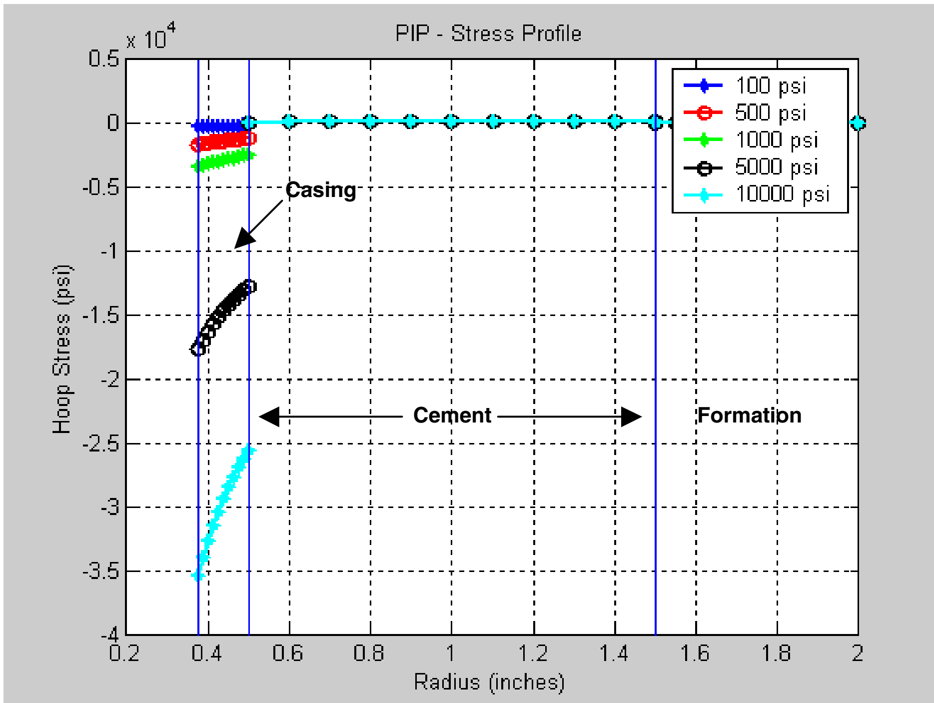
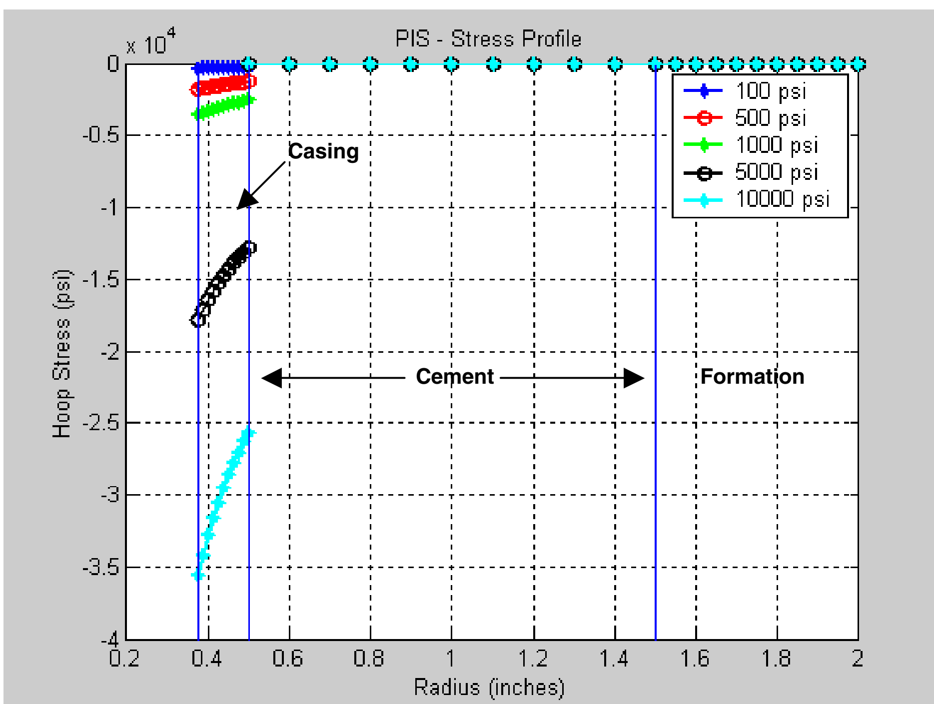


Figure 22— Hoop stress (tensile), simulated soft formation, 0-psi confining pressure



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Displacement (No Confining Pressure)

The next set of simulations was conducted to determine the effect of varying casing pressures on displacement, in both hard and soft formations with no confining pressure. In hard formation tests, a larger displacement, and incidentally, a larger variation in displacement, was observed within the cement (**Figure 23**). The displacement of the cement is significantly large to absorb the load.

In simulated soft formations (**Figure 24**), a large displacement (and variation in displacement) was observed for both the cement and the formation.

Figure 23—Displacement profile, simulated hard formation, 0-psi confining pressure

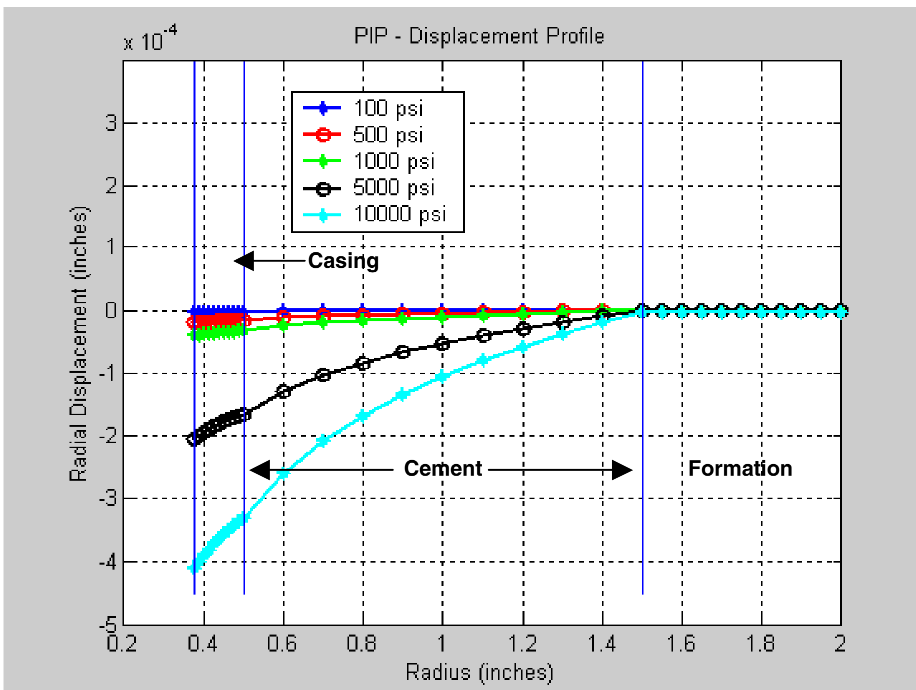
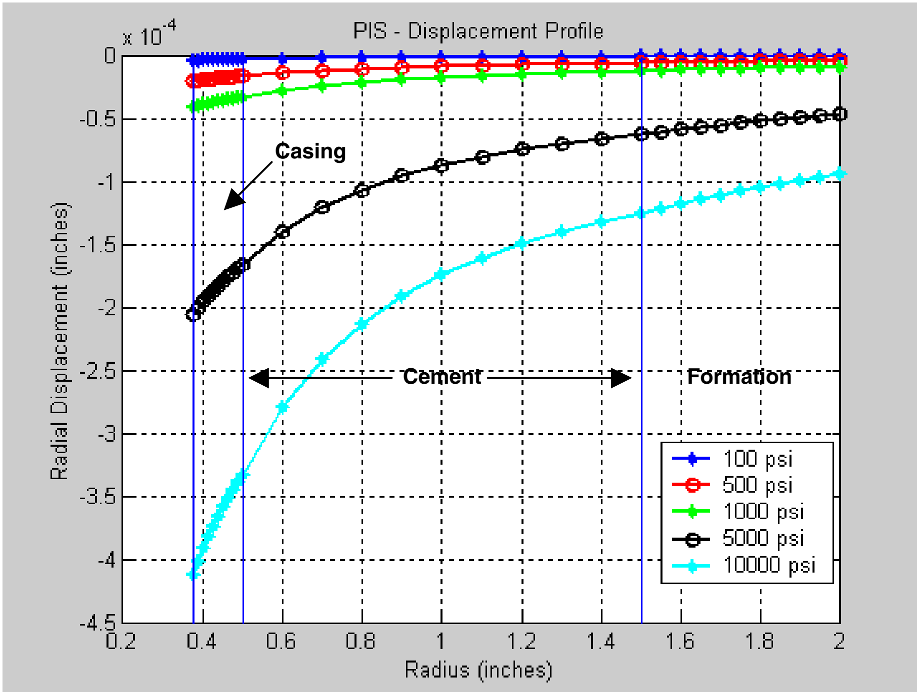


Figure 24—Displacement profile, simulated soft formation, 0-psi confining pressure



*C*ementing *S*olutions, *I*nc.

Hoop Stress (Tensile) with Confining Pressure

Tests were also performed to determine the effect of varying casing pressures on hoop stress with 500-psi confining pressure.

When applied to a simulated hard formation configuration (**Figure 25**), the test indicated that increasing casing pressures result in an increase in hoop stress at the cement-outer pipe interface; yet, the cement itself does not experience much hoop stress.

Increasing casing pressures in the simulated soft formation test (**Figure 26**) revealed a slightly higher hoop stress in the cement and the formation, but no significant contrast in hoop stress at the cement-formation interface.

Figure 25—Hoop stress (tensile), simulated hard formation, 500-psi confining pressure

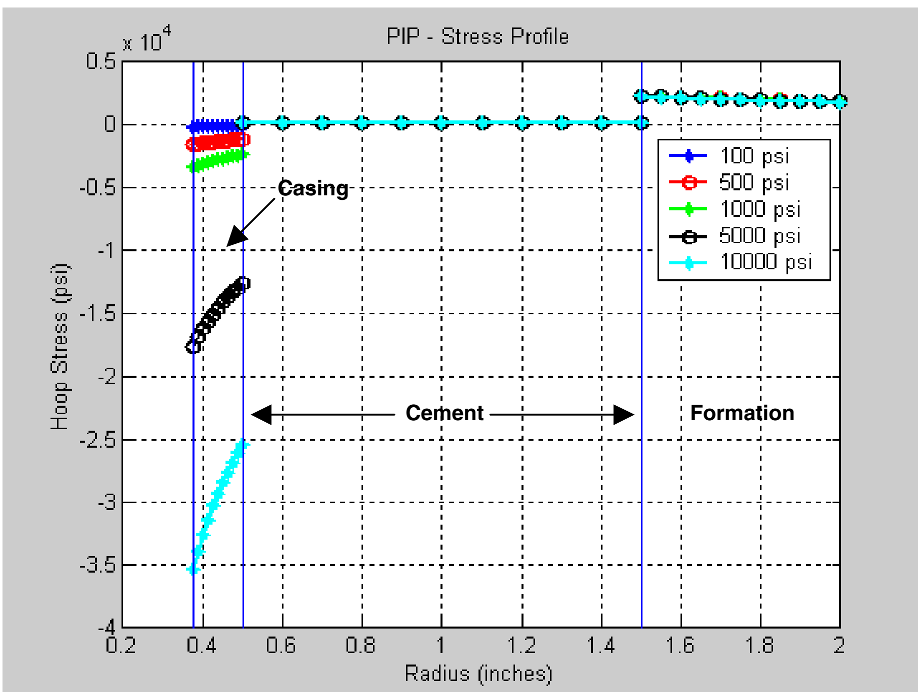


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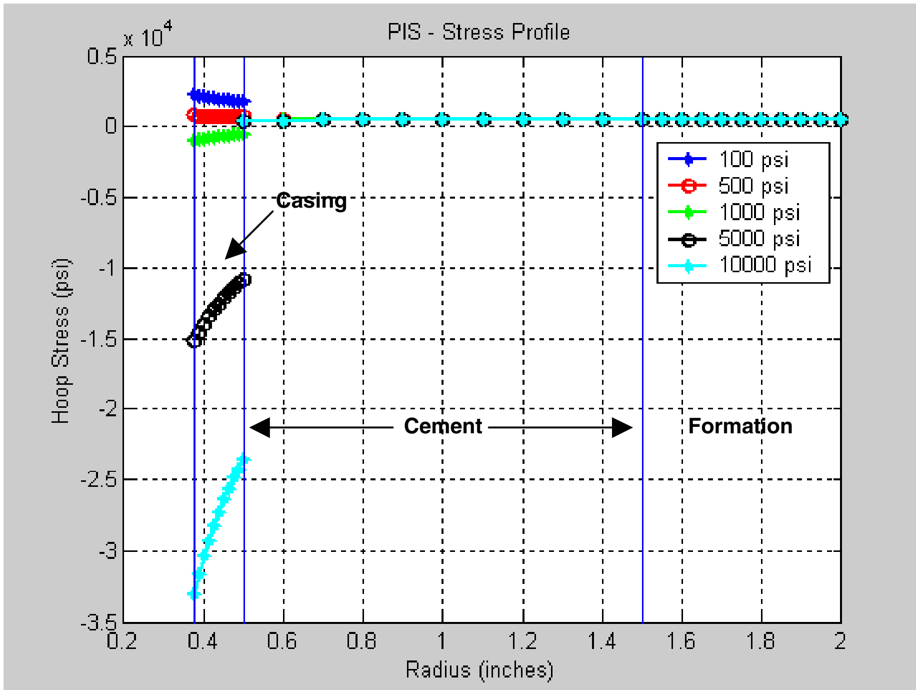
Figure 26—Hoop stress (tensile), simulated soft formation, 500-psi confining pressure



Displacement with Confining Pressure

As casing pressures vary and confining pressure is held constant in a hard formation, hoop stress increases in the formation, and stays constant in the cement. Displacement, rather, varies within the cement, and is almost constant in the formation (**Figure 27**).

As casing pressures are varied and confining pressure is held constant in a soft formation, hoop stress is slightly greater than that of the hard formation, and remains constant through the cement-formation interface. Displacement varies significantly in both the cement and the formation (**Figure 28**). This variation helps explain why no significant difference in hoop stress values is seen at the cement-formation interface in Figure 26.

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Figure 27—Displacement profile, simulated hard formation, 500-psi confining pressure

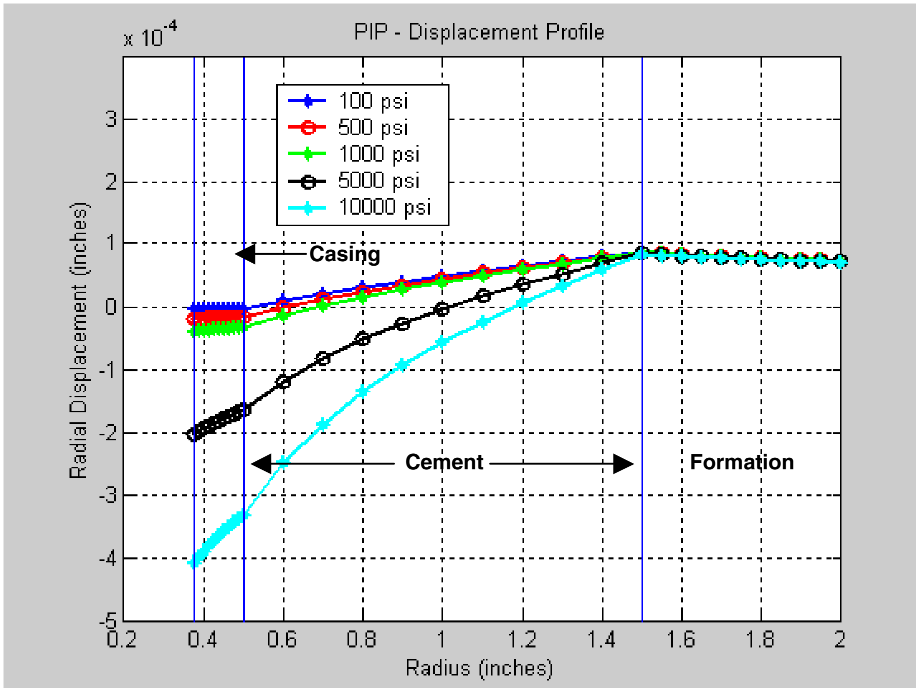
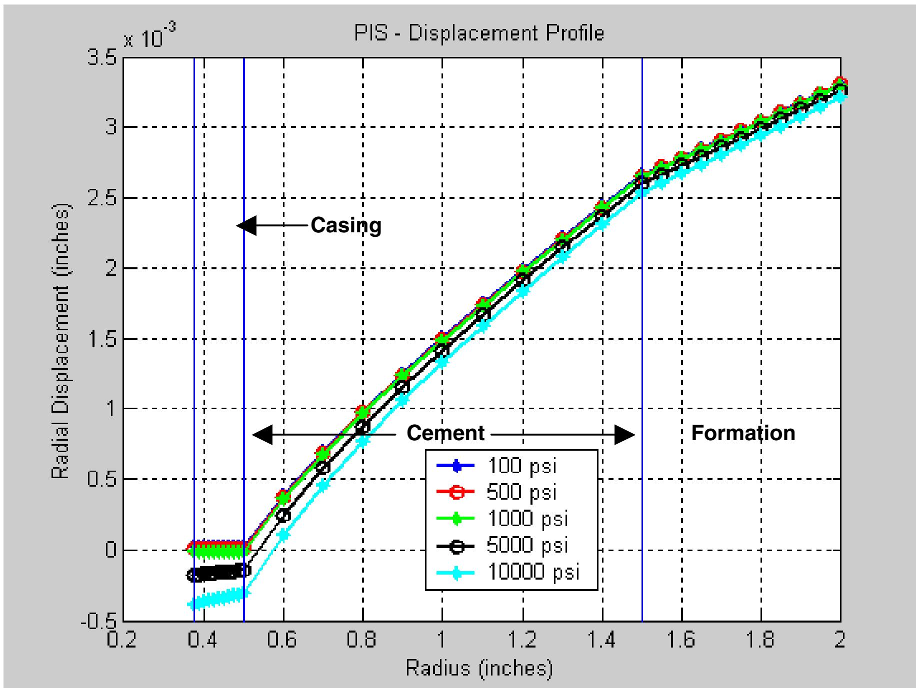


Figure 28— Displacement profile, simulated soft formation, 500-psi confining pressure



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Appendix A—Young's Modulus Testing

Traditional Young's modulus testing was performed using ASTM C469[1], Standard Test Method for Static Modulus of Elasticity (Young's Modulus) and Poisson's Ratio of Concrete in Compression.

The following procedure is used for the Young's modulus testing.

1. Each sample is inspected for cracks and defects.
2. The sample is cut to a length of 3.0 in.
3. The sample's end surfaces are then ground to get a flat, polished surface with perpendicular ends.
4. The sample's physical dimensions (length, diameter, weight) are measured.
5. The sample is placed in a Viton jacket.
6. The sample is mounted in the Young's modulus testing apparatus.
7. The sample is brought to 100-psi confining pressure and axial pressure. The sample is allowed to stand for 15 to 30 min until stress and strain are at equilibrium. (In case of an unconfined test, only axial load is applied.)
8. The axial and confining stress are then increased at a rate of 25 to 50 psi/min to bring the sample to the desired confining stress condition. The sample is allowed to stand until stress and strain reach equilibrium.
9. The sample is subjected to a constant strain rate of 2.5 mm/hr.
10. During the test, the pore-lines on the end-cups of the piston are open to atmosphere to prevent pore-pressure buildup.
11. After the sample fails, the system is brought back to the atmospheric stress condition. The sample is removed from the cell and stored.

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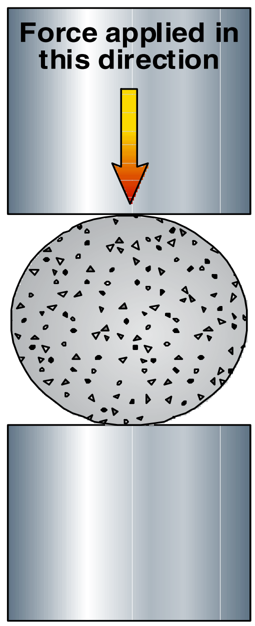
Appendix B—Tensile Strength Testing

Tensile strength was tested using ASTM C496[2] (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the specimen dimensions were 1.5 in. diameter by 1 in. long. **Figure B1** shows a general schematic of how each specimen is oriented on its side when tested. The force was applied by constant displacement of the bottom plate at a rate of 1 mm every 10 minutes. Change in the specimen diameter can be calculated from the test plate displacement. The (compressive) strength of the specimen during the test can be graphed along with the diametric strain (change in diameter/original diameter) to generate the tensile Young's modulus.

Figure B1—Sample Orientation for ASTM C496-90 Testing



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Appendix C—Shear Bond Strength Testing

Shear bond strength tests are used for investigating the effect that restraining force has on shear bond. Samples are cured in a pipe-in-pipe configuration (**Figure C1**) and in a pipe-in-soft configuration (**Figure C2**). The pipe-in-pipe configuration consists of a sandblasted internal pipe with an outer diameter (OD) of 1 $^{1}/_{16}$ in. and a sandblasted external pipe with an internal diameter (ID) of 3 in. and lengths of 6 in. A contoured base and top are used to center the internal pipe within the external pipe. The base extends into the annulus 1 in. and cement fills the annulus to a length of 4 in. The top 1 in. of annulus contains water.

For the pipe-in-soft shear bonds, plastisol is used to allow the cement to cure in a less-rigid, lower-restraint environment. Plastisol is a mixture of a resin and a plasticizer that creates a soft, flexible substance. This particular plastisol blend (PolyOne's Denflex PX-10510-A) creates a substance with a hardness of 40 duro.

The pipe-in-soft configuration contains a sandblasted external pipe with an ID of 4 in. A molded plastisol sleeve with an ID of 3.0 in. and uniform thickness of 0.5 in. fits inside this external pipe. With the aid of a contoured base and top, a sandblasted internal pipe with an OD of 1 $^{1}/_{16}$ in. is then centered within the plastisol sleeve. The pipes and sleeve are 6 in. long. The base extends into the annulus 1 in. and cement fills the annulus to a length of 4 in. between the plastisol sleeve and the inner 1 $^{1}/_{16}$ -in. pipe. The top inch of annulus is filled with water.

Figure C1—Cross-Section of Pipe-in-Pipe Configuration for Shear Bond Tests

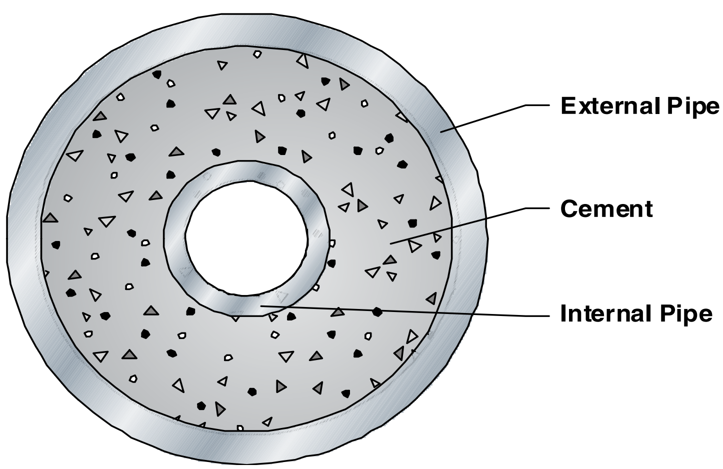
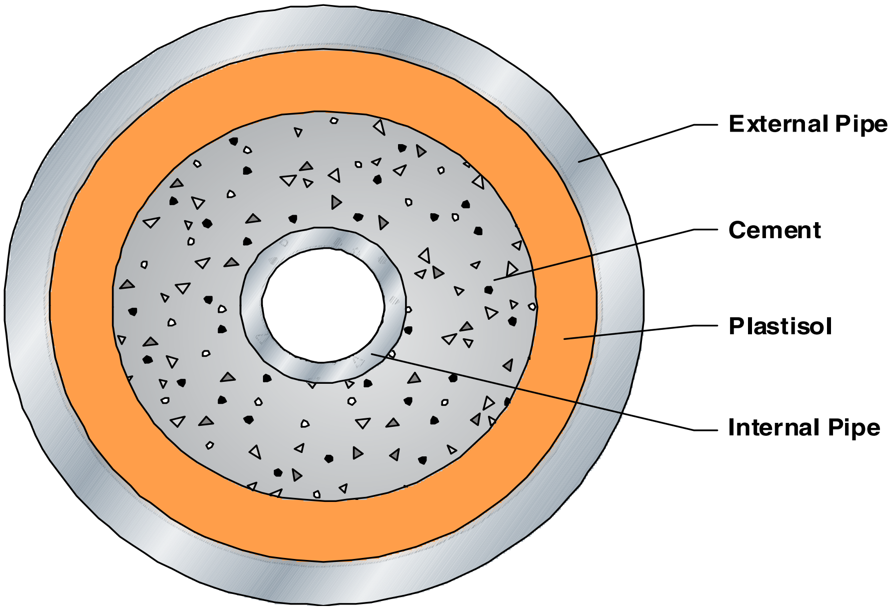
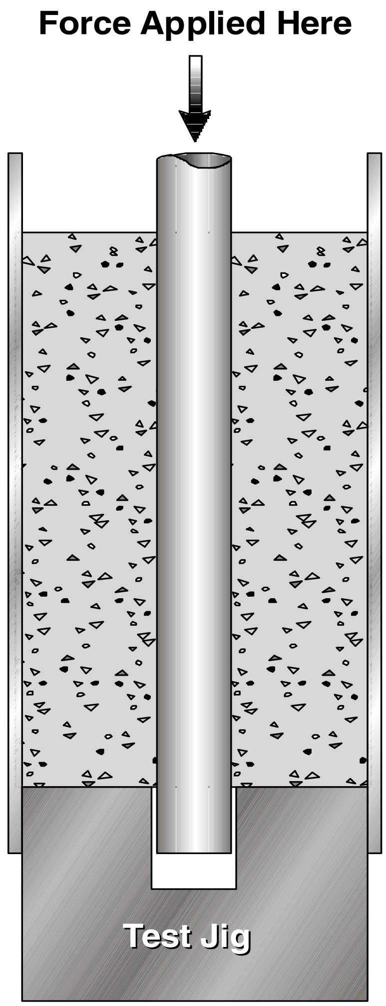


Figure C2— Cross-Section of Pipe-in-Soft Configuration for Shear Bond Tests



The shear bond measures the stress necessary to break the bond between the cement and the internal pipe. This was measured with the aid of a test jig that provides a platform for the base of the cement to rest against as force is applied to the internal pipe to press it through. (**Figure C3**) The shear bond force is the force required to move the internal pipe. The pipe is pressed only to the point that the bond is broken; the pipe is not pushed out of the cement. The shear bond strength is the force required to break the bond (move the pipe) divided by the surface area between the internal pipe and the cement.

Figure C3—Configuration for Testing Shear Bond Strength



Temperature Cycling

The effect that temperature cycling has on shear bond is tested as follows.

The temperature cycling procedure is designed to simulate temperature conditions that might be encountered during production of a well. The samples are first cured for 14 days in a 45°F water bath at atmospheric pressure. They are then subjected to five days of temperature cycling. During each of these five days of temperature cycling, the cured samples are cycled as follows.

1. Samples are removed from 45°F water bath and placed in 96°F water bath for one hour.
2. Samples are placed in 180°F water bath for four hours.
3. Samples are placed in 96°F water bath for one hour.

4. Samples are placed back in 45°F water bath.

Pressure Cycling

The effect that pressure cycling has on shear bond is tested as follows.

The pressure cycling procedure is designed to simulate pressure conditions that might be encountered during production of a well. Because these samples will be dealing with high pressures, the interior pipe of each sample was made from 1-in. diameter, 40/41 coiled tubing pipe that can withstand 10,000 psi. Each end of the pipe is threaded. One end will have a pressure-tight cap on it during pressure cycling and the other end of the pipe will be connected to the pressure source.

The samples are first cured for 14 days in a 45°F water bath at atmospheric pressure. They are then subjected to five periods of pressure cycling in which the interior pipe is pressured to 5,000 psi for 10 minutes and then allowed to rest at 0 psi for 10 minutes.

Appendix D—Shrinkage Testing

Using a modified Chandler Model 7150 Fluid Migration Analyzer, tests are performed to determine shrinkage of the neat Type I cement. The following procedures are used for performing the shrinkage testing.

1. Fill the test cell with 180 cm^3 of the cement slurry.
2. Place 40 mL of water on top of cement slurry.
3. Place the hollow hydraulic piston into the test cell and on top of the water.
4. Close off the test cell and attach the pressure lines and piston displacement analyzer.
5. Close all valves except valve on top of test cell cap. Purge air out of system.
6. Apply 1,000-psi hydrostatic piston pressure to the test cell and begin recording data (time, piston displacement, and pressure).
7. Run test and gather data for desired amount of time.

Appendix E—Annular Seal Testing

The following procedures are for the use of the Pipe-in-Soft annular seal apparatus (for simulating soft formations) and the Pipe-in-Pipe annular seal apparatus (for simulating hard formations). The Pipe-in-Soft apparatus is to be used with cores that were formed using a soft gel mold surrounding the cement slurry to form a core that was cured to set by using a semi-restricting force on the outside of the core. The Pipe-in-Pipe apparatus is to be used with cores that were made inside steel pipes, giving the cement slurry a restricting force outside of the core.

Simulated Soft Formation Test Procedure

1.) After the core is cured, place the core inside the gel mold sleeve.
2.) Place the core and sleeve inside the Pipe-in-Soft steel cell.
3.) Once inside, both ends of the core are supported with o-rings.
4.) The o-rings are then tightened to close off air-leaks that might be present.
5.) Using water, pressurize the exterior circumference of the sleeve to 25 psi. Once the pressurized water is applied to the cell, check for leaks on the ends of the cell.
6.) Using the cell’s end caps, cap off both ends of the steel cell. One end cap has a fitting that allows for N_2 gas to be applied into the cell, and the other end cap allows for the gas to exit the cell.
7.) Attach the pressure in-line to one end and then attach the pressure out-line to the other end.
8.) Apply pressure to the in-line. (Do not exceed 20 psig.) Measure the output of the out-line with flowmeters.

Simulated Hard Formation Test Procedure

1.) After the core is cured inside the steel pipe, using steel end caps, cap off each end of the pipe. Each end cap has a fitting that allows for gas to be applied into the pipe on one end, and also allows for the gas to exit the pipe on the other end.
2.) Attach the pressure in-line to one end, and then attach the pressure out-line to the other end.
3.) Apply pressure to the in-line. (Do not exceed 20 psig.) Measure the pressure output of the out-line with flowmeters.

Appendix F—Chandler Engineering Mechanical Properties Analyzer

See the attached brochure for a detailed description of the Chandler Engineering Mechanical Properties Analyzer, its applications, and its benefits.

MECHANICAL PROPERTIES ANALYZER

In recent years the oil/gas industry has begun to understand the implication of cement sheath mechanical properties on the ability of the cement to perform its zonal isolation function long term. With computer modeling capabilities, the mechanical compliance of the cement sheath relative to the deformation of the contacting rock and casing can be optimized to improve wellbore sealing. Cement formulations are being developed to address the need for flexure of the cement, rather than say the need for high compressive strength. However, the measurement of cement mechanical properties at elevated pressure and temperature has limited the implementation of cement mechanical properties as a design protocol.

With a technological breakthrough (patent applied), Chandler Engineering has developed the first high-pressure, high-temperature instrument designed specifically to measure the mechanical properties (elastic moduli and compressive strength) of oil/gas-well cements. Like the Ultrasonic Cement Analyzer (UCA), testing with the new Mechanical Properties Analyzer (Model 6265 MPro) begins with a cement slurry, which is placed into a pressure vessel. Measurements are then taken directly from this sample as it cures at elevated temperature and pressure.

The ***CHANDLER*** Model 6265 MPro has several advantages over routine mechanical properties testing. First, by providing continuous measurements, a single test with the MPro can provide more information about the cement properties than one would get from a series of routine tests. Second, samples for routine testing are typically cured in one vessel returned to room conditions, and then cored and/or cut, before testing begins in a different pressure vessel. With the MPro the sample conditions and integrity are maintained for the duration of the test (which may be days, weeks, or even months). Thus,

MODEL 6265 MPro

the MPro samples are neither subjected to damage from preparation, and handling, nor from unrealistic cooling and depressurization.

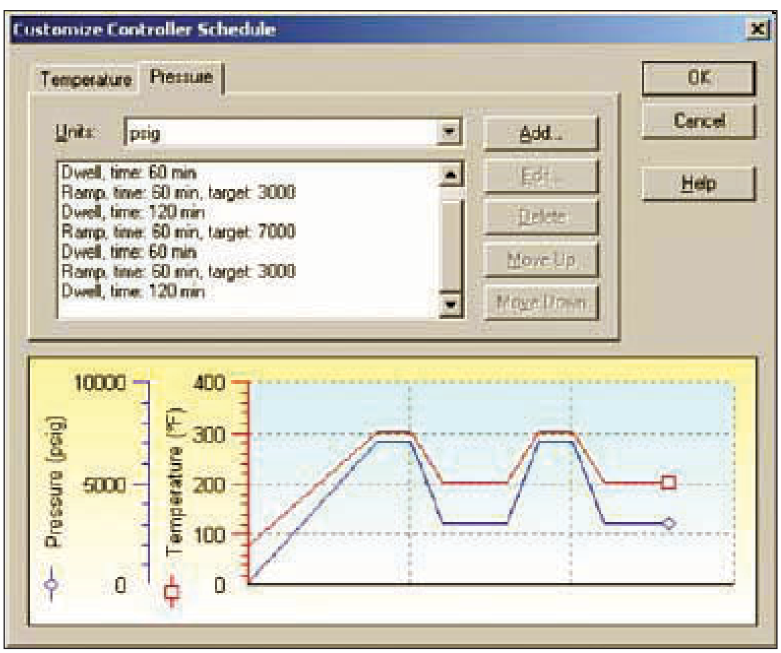
The ***CHANDLER*** Model 6265 MPro is optionally configured to perform UCA (compressive strength) Analyses in addition to the elastic mechanical properties measurements - thus providing a suite of information from a single sample and single test, and optimizing laboratory efficiency.

The new Model 6265 MPro includes programmable temperature control which provides the capability to investigate the impact of temperature variations on the cement mechanical properties. With the Chandler Model 6265P programmable pressure control module, the user can simulate realistic pressure conditions to evaluate the impact on the mechanical properties of the cement sample.

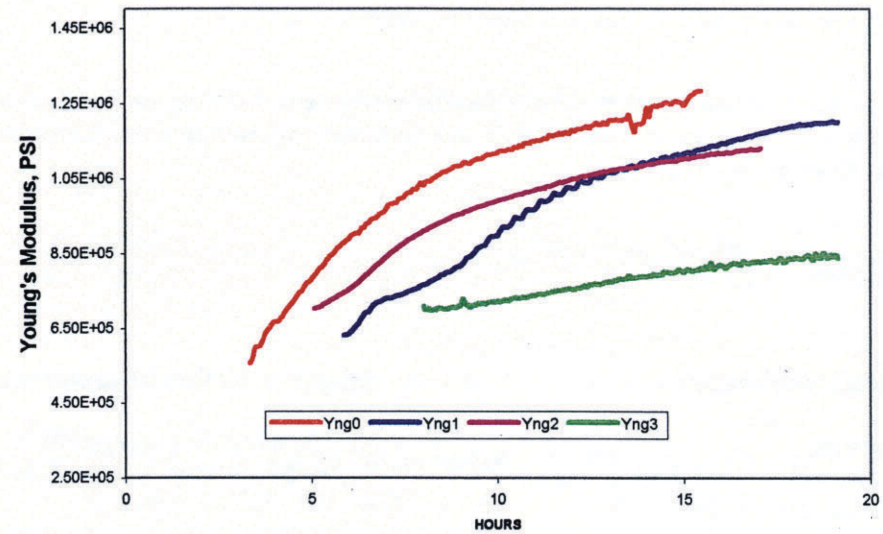
Combining the programmable pressure control module with programmable temperature control, will allow the investigator to replicate realistic pressure and temperature conditions.

Using Chandler Engineering's state-of-the-art 5270 Automation System, complex-testing protocols can be easily set up and run using a standard PC. The 5270 System can be optionally configured to control and collect/display/analyze data from several Model 6265 MPro's.

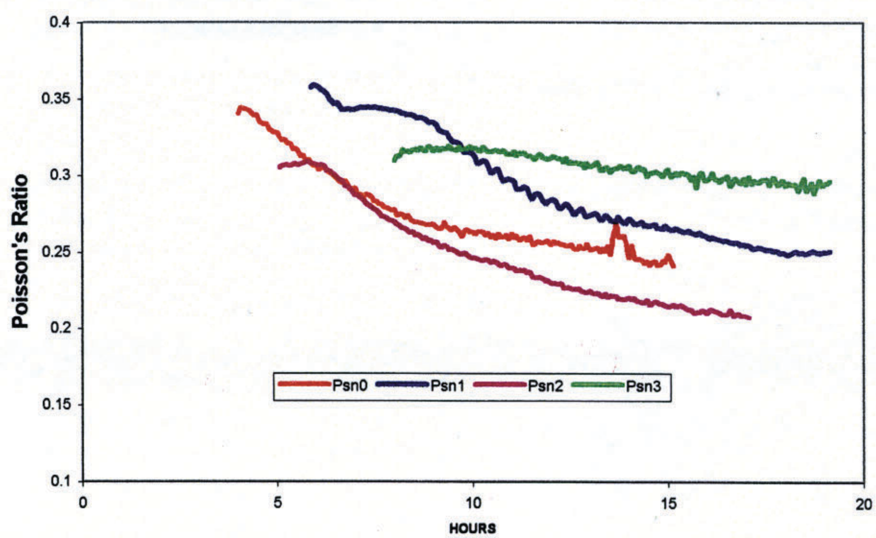
MODEL 6265P
PROGRAMMABLE PRESSURE
CONTROL MODULE



Cement Mechanical Properties Testing
Chandler Engineering Model 6265 Data
Young's Modulus vs Time



Cement Mechanical Properties Testing
Chandler Engineering Model 6265 Data
Poisson's Ratio vs Time



All Chandler Engineering products are covered by a full one-year warranty against defects in materials and workmanship. Sales terms, conditions and warranty statements are included with each quotation or confirmation of order.

More than 50 years ago, Chandler Engineering pioneered High Pressure and High Temperature Equipment. Today, Chandler Engineering is the leading manufacturer of a broad range of innovative and extremely reliable Measurement Instruments for the Energy Industry.

Chandler Engineering specializes in outfitting laboratories designed for testing cement, drilling muds and stimulation fluids. Through Research & Development, experienced manufacturing and worldwide logistic operations, Chandler Engineering provides for your complete laboratory requirements.

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- Cement Curing Chambers
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- Liquid/Slurry HPHT Rheometers
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- Ultrasonic Cement Analyzer (UCA)
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- Sample Cylinders

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Appendix 10

Quarterly Report 10

Ultra-Lightweight Cement

Tenth Quarterly Technical Progress Report

January 1 to March 31, 2003

Fred Sabins

Issued April 30, 2003

DOE Award Number
DE-FC26-00NT40919

Submitted by Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report discusses testing that was performed for analyzing the alkali-silica reactivity of ULHS in cement slurries.

Table of Contents

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required (1) to limit hydrostatic pressure on the formation, and (2) to prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, ultra-lightweight materials must be mixed into the slurry.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water. This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field-testing.

The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile strengths of 8 different cement specimens are being tested.

ASR is a potentially damaging phenomenon that occurs in cement materials exposed to caustic environments. Excess silica in the cement can react with calcium hydroxide to produce calcium silicate hydrate gel that disrupts the cement's crystalline lattice. This reaction can cause lowered strength and expansion of the cement.

Executive Summary

Laboratory testing during the tenth quarter focused on evaluation of the alkali-silica reaction of 8 different cement compositions containing ULHS. The original laboratory procedure for measuring set cement expansion resulted in test specimen erosion that was unacceptable. This procedure has been modified and testing has been re-initiated.

This report provides a progress summary of ASR testing. The testing program initiated in November produced questionable initial results so the procedure was modified slightly and the testing was reinitiated. Results thus far indicate some cements are failing mechanically in the caustic curing environment. Bead cement compositions, however, are performing well so far.

Alkali-Silica Testing

Approval was made for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oil well cements, and conduct long-term tests to verify if ASR is occurring and when and how it manifests itself. Compositions to be tested in the ASR evaluation are listed in Table 1.

The results obtained thus far are presented in Tables 2 through 4. Test specimens of several compositions are being recast via a modified procedure to ensure proper curing. Testing will continue until the project's scheduled ending.

ASR Data Summary

Table 1

	Slurry Composition	**Density** Lbs/gal	**Water Requirement** Gals/sack
1	Class H Neat	16.4	4.30
2	TXI LW Neat	13.5	6.00
3	Class H Bead	9.0	11.81
4	TXI LW Bead	9.0	12.63
5	Class H Salt	16.4	4.30
6	TXI LW Salt	13.5	6.00
7	Class H Bead Salt	9.0	11.81
8	TXI LW Bead Salt	9.0	12.63

Table 2

Compressive Strength

Slurry	24 Hour	7 Day	14 Day	1 mon	2 mon	3 mon	4 mon	5 mon	6 mon
1	1454	2117	2143	3564	X	X	X	X	X
2	741	*	1759	*	*	*	*	*	*
3	597	552	1058	816	X	X	X	X	X
4	501	633	1164	972	X	X	X	X	X
5	1670	1434	1899	3856	X	X	X	X	X
6	1109	*	625	*	*	*	*	*	*
7	607	577	1128	956	X	X	X	X	X
8	576	*	1195	*	*	*	*	*	*
Test Date	**12/11/02**	**03/10**		**03/31**	**04/28**	**05/26**	**06/23**	**07/21**	**08/18**

Note: * Test not performed pending new test method
X- In progress

Table 3

Tensile Strength

Slurry	24 Hour	7 Day	14 Day	1 mon	2 mon	3 mon	4 mon	5 mon	6 mon
1	660	459	297	462	X	X	X	X	X
2	327	*	*	*	*	*	*	*	*
3	224	131	200	145	X	X	X	X	X
4	131	133	164	158	X	X	X	X	X
5	620	364	355	361	X	X	X	X	X
6	240	*	*	*	*	*	*	*	*
7	244	166	301	155	X	X	X	X	X
8	135	*	*	*	*	*	*	*	*
Test Date	**03/03**	**03/10**	**03/17**	**03/31**	**04/28**	**05/26**	**06/23**	**07/21**	**08/18**

Note: * Test not performed pending new test method
X- In progress

Table 4

% Linear Expansion

Slurry	24 Hour	7 Day	14 Day	1 mon	2 mon	3 mon	4 mon	5 mon	6 mon
1	0	0.03	0.03	-0.06	-0.05	X	X	X	X
2	*	*	*	*	*	*	*	*	*
3	0	0.01	0.02	0.38	0.40	X	X	X	X
4	0	0.02	0.04	0.18	0.16	X	X	X	X
5	0	-0.02	-0.01	0.06	0.06	X	X	X	X
6	*	*	*	*	*	*	*	*	*
7	0	-0.05	-0.04	0.31	0.30	X	X	X	X
8	0	0.01	0.05	0.11	-0.06	X	X	X	X
Test Date	**01/13**	**01/28**	**02/04**	**02/27**	**03/28**	**04/25**	**05/23**	**06/20**	**07/18**

Note: * Test not performed pending new test method
X- In progress

ASR Test Procedure

Testing Procedures
A variation of the Length Change of Hardened Hydraulic-Cement Mortar and Concrete (ASTM C157-93) methods was used to test expansion in the slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) methods were used to determine a change in the tensile strength of specimens as a result of ASR. A tensile strength measurement is performed at 24 hours (initial reading), 7 days, 28 days, 2 months, 4 months, and 6 months. For statistical purposes, six replicates of each slurry are made.

A modified compressive strength test is performed using modified API procedures. Specimens are poured into cylinder molds and compressive strengths are measured. A compressive strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and 6 months. For statistical purposes, 3 replicates of each slurry are made.

Test Slurry Composition
As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal will be used. Ultra-light hollow sphere (ULHS) slurries with similar bead concentrations and a density of 9.0 lb/gal will also be used. Several 0.5% sodium chloride slurries will be used to evaluate accelerated ASR.

Neat Slurries (Baseline)

- Class H cement mixed with 4.3 gal of fresh water per sack to achieve a density of 16.4 lb/gal
- TXI Lightweight cement mixed with 6.0 gal of fresh water per sack to achieve a density of 13.5 lb/gal

Ultra-Light Hollow Sphere (ULHS) Slurries

- Class H cement plus 42.14% BWOC 3M 6K (6,000 psi) beads mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- TXI Lightweight cement plus 37.19% BWOC 3M 6K (6,000 psi) beads mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Salt Slurries

- Class H cement plus 0.5% BWOC NaCl mixed with 4.3 gallons of fresh water sack for a density of 16.4 lb/gal
- TXI Lightweight cement plus 0.5% BWOC NaCl mixed with 6.0 gallons of fresh water per sack for a density of 13.5 lb/gal
- Class H cement with 42.14% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 11.81 gallons of fresh water per sack for a density of 9.0 lb/gal
- TXI Lightweight cement with 37.19% BWOC 3M 6K (6,000 psi) beads plus 0.5% BWOC NaCl mixed with 12.63 gallons of fresh water per sack for a density of 9.0 lb/gal

Testing Conditions

- Curing Temperature – 174°F
- Slurries tested for a minimum of 200 days.

Mixing Procedures

Prepare a ULHS slurry as follows.

1. Weigh the appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry according to Appendix A of API RP 10B.
3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place this slurry in a Waring blender and mix at 4,000 rpm for 15 seconds.

Alkali-Silica Reactivity (ASR) Testing for Compressive Strength

Curing the Specimens

One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made. Cure each test specimen in a heated, circulating water bath at 174°F, containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
2. Mark specimens for identification or positioning as required on brass plates inscribed with slurry design.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min.
4. When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and take compressive strength readings.
5. After specimen identification, return remaining cores to lime saturated water at 174°F, to be tested at any age.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

After curing, the sample is extracted from the mold and cut into 1-in. ±1/8 in. sections in length. A ¼-in. section of the top surface of the sample is cut first. Next, the three 1-in. sections to be measured are cut. Each 1-in. ±1/8 in. section is identified as top, middle, and bottom and is measured for compressive strength in the test machine. The remaining sample pieces are discarded. The density of each sample is calculated before it is measured for compressive strength. The density is calculated by suspending the cut-core samples in water and weighing them using a Denver Instruments Lab Balance, model TR-2102.

Each sample is then placed in turn in a Carver Press (hydraulic). Force is applied in accordance with API specification **10B-7.5.6.1.** A digital pressure gauge records the specimen's failure in PSI.

Calculate the specimen compressive strength at any age as follows**:**

$$Cs = \frac{G \times 5.15}{SA}$$

Cs = compressive strength
G = digital gage reading (PSI)
SA = surface area
5.15 = constant to convert gauge reading to lbs/force

Alkali-Silica Reactivity (ASR) Testing for Expansion

Curing the Specimens
One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made. Cure each test specimen at 174°F in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
    a. Never strike or jar a specimen during removal.
    b. Never exert pressure directly against the gage studs.
    c. Make sure the gage stud holder remains attached to the stud during specimen removal.

2. Etch specimens for identification or positioning as required with a scriber, inscribed with slurry design and expansion bar number on each specimen as it applies.

3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.

4. When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water at 174°F.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Apparatus
Molds for cement specimen curing have one section and are constructed as shown in Fig. 6. Molds for test specimens used in determining the length change of cement pastes and mortars produce 1 *X* 1 *X* 11 ¼-in. prisms with a 10-in. gage length. The gage length is the nominal length between the innermost ends of the gage studs. The parts of the molds should fit tightly and firmly together when assembled, and their surfaces should be smooth and free of pits.

The molds are made of steel not readily attacked by the cement paste, mortar, or concrete. The sides of the molds should be sufficiently rigid to prevent spreading or warping. For the molds shown in Fig. 6, the tolerance on dimension A is ±0.03 in. Each end plate of the mold is equipped to hold properly in place during the setting period.

The gage studs are of American Iron and Steel Institute (AISI) 3 Type 316 stainless steel. To prevent restraint of the gage studs before the specimen is removed, the device for holding the gage studs in position is arranged such that it can be partially or completely released after the slurry hardens in the mold. The gage studs are set so their principal axes coincide with the principal axis of the test specimen. For the molds shown in Fig. D-1, gage studs extend into the specimen 0.625 ± 0.025 in. and the distance between the inner ends of the gage studs is 10.00 ± 0.10 in.. Ten inches is the gage length for calculating length change.

Test Measurement

The comparator for the molds shown in Fig. D-1 features a dial micrometer or other measuring device graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens. The terminals of the comparator are plane, polished, and heat-treated, and are fitted with collars held in place with set screws. The collars extend 0.062 ± 0.003 in. beyond the plane face of the terminal and have an inside diameter 0.02 in. greater than the average diameter of the portion of the gage studs that must fit into the collars.

The comparator must allow the checking of the measuring device against a reference bar at regular intervals. The reference bar has an overall length of 11 5/8 ±1/8 in. for the specimen in use. The bar is made of a steel alloy with a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end of the reference bar is fitted with heat-treated, hardened, and polished tips machined to the same shape as the contact end of the gage studs used in test specimens.

Reference Bar

Place the reference bar (Fig. D-2) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of immersion, blot the pins, and place the bar in the comparator, read, and record the indication.
4. Return the bar to immersion and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to immersion, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:
L = change in length at *x* age, %
Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;
Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time
G = nominal gage length, 10 in.

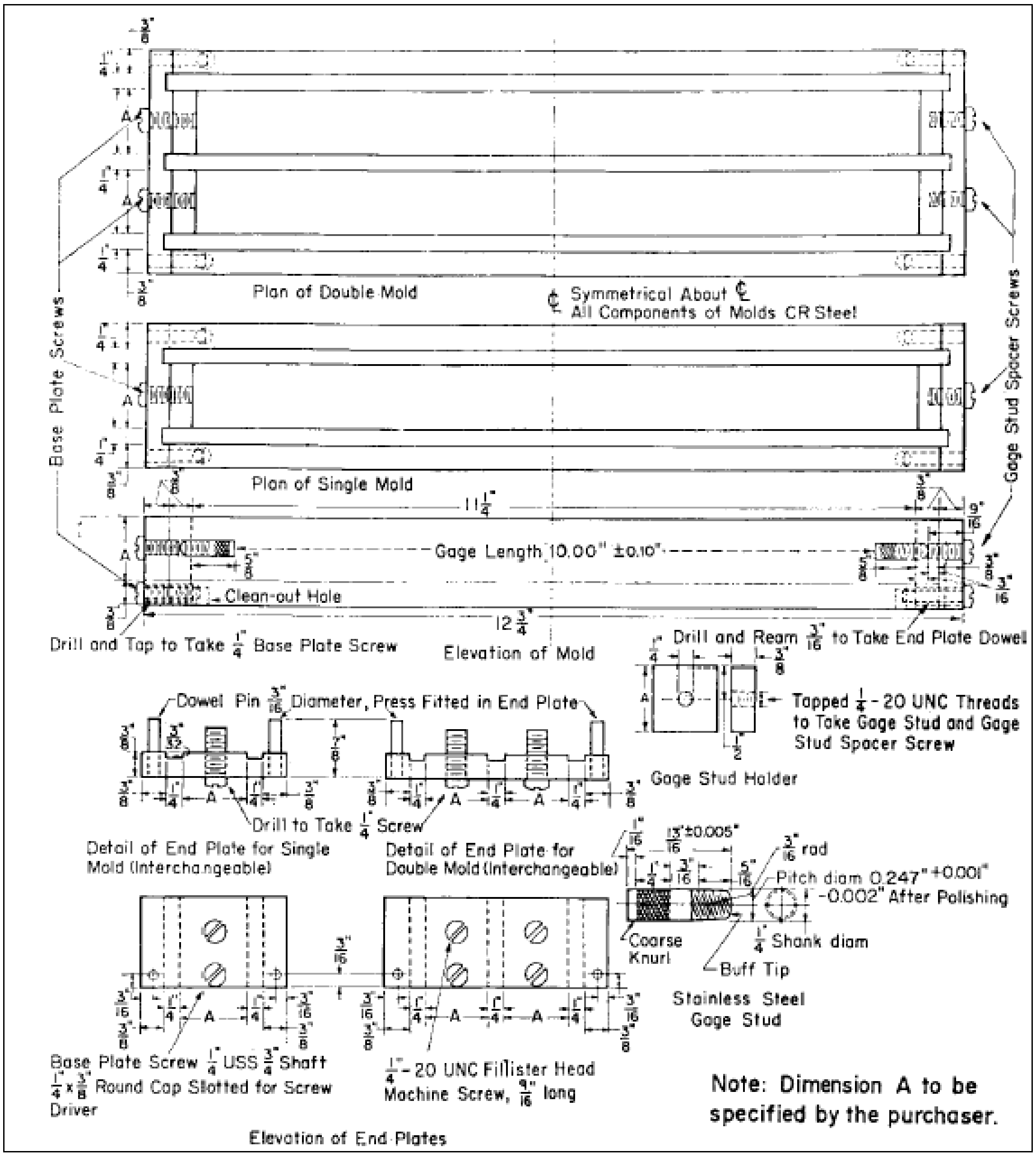
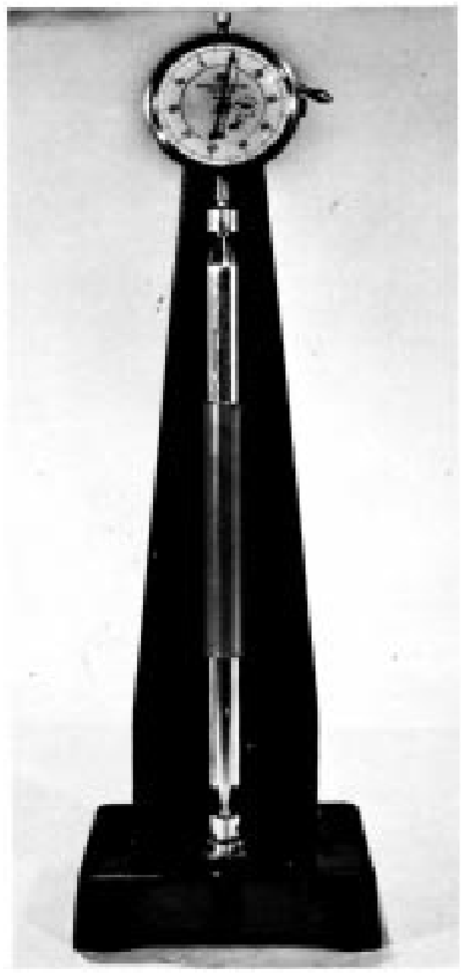


Figure 1—Test specimen mold schematics



Type of Suitable Apparatus for Measurement of Length Changes

Figure 2—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is placed in a 1.5 x 5-in. mold sealed at both ends.

Curing the Cement Specimens
One of the test slurries (containing six replicates) is prepared per day until all samples for the project have been made.

Prepare the molds as follows.

1. Place slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Stir the remaining slurry by hand and place into additional molds and repuddle it.

3. Seal the molds and place them upright in a heated, circulating water bath at 174°F.
4. Remove specimens from the molds at an age of 23 1/2 hours. Age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
5. Mark specimens for identification or positioning as required on brass plates inscribed with slurry design.
6. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min.
7. After specimen identification, return remaining cores to lime saturated water at 174°F, to be tested at any age.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement
After curing, the sample is extracted from the mold and cut into 1-in. ±1/8 in. sections in length. The density of each sample is measured before it is measured for tensile strength.

A ¼-in. section of the top surface of the sample is cut first. Next, the three 1-in.sections to be measured are cut. Each 1-in. ±1/8 in. section is identified as top, middle, and bottom and is measured for tensile strength in the test machine. The remaining sample pieces are discarded.

Tensile strengths are performed at the Westport Technology Center. The core specimen's are cured at CSI and transported to Westport after they have been cured at any age. The specimen's are delivered submerged in water, and testing is performed within 24 hours.
Tensile strength measured at Westport is performed according to ASTM standards C-496-2. The force is applied by constant displacement of the bottom plate at a rate of 1 mm every 10 minutes. Change in the specimen diameter can be calculated from the test plate displacement. The use of two pieces of plywood according to ASTM designation C496-90-4.3 is not applied to this measurement.

The maximum reading is noted and used in the following equation:

T(psi) = (2*F) / (PI*L*D)

Where
T = tensile strength (psi)
F = maximum force recorded (lbf)
PI = 3.14
L = sample length (inch)
D = sample diameter (inch)

Fig. 3 shows a general schematic of how each specimen is oriented on its side during testing.

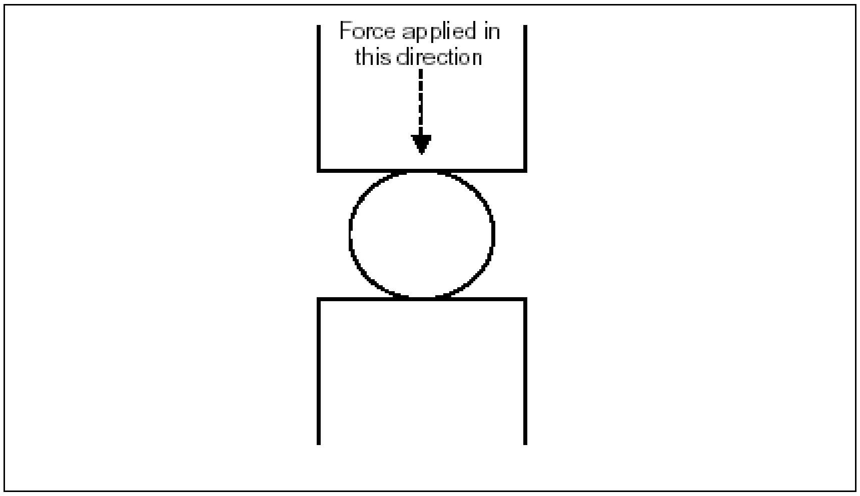


Figure 3—Tensile strength Crush Diagram

Conclusions

1. At this point in the project, usable ASR test specimens have been poured.
2. The testing regime is on schedule.
3. Compressive strength results indicate no adverse effect from curing in the caustic curing medium.
4. Tensile strengths of most specimens appear to be decreasing. Exceptions are low density cements 4 and 7.
5. Expansion is occurring in compositions containing Class H cement and salt.

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
MMS—Minerals Management Service
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. API Recommended Practice 10B: “Recommended Practices for Testing Well Cements,” 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.

Appendix 11

Quarterly Report 11

Ultra-Lightweight Cement

Eleventh Quarterly Technical Progress Report

April 1 to June 30, 2003

Fred Sabins

Issued July 31, 2003

DOE Award Number
DE-FC26-00NT40919

Submitted by
Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report discusses testing that was performed for analyzing the alkali-silica reactivity of ULHS in cement slurries.

Table of Contents

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required to limit hydrostatic pressure on the formation, and prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth's surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry's stability and set cement's strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, a portion of the mix water must be replaced with ultra-lightweight materials.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water. This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction (ASR) in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile and compressive strengths of eight different cement formulations are being tested.

ASR is a potentially damaging phenomenon that occurs in cement materials containing certain types of silica-containing materials when they are exposed to alkali in high-pH environments. The ASR reaction produces alkali-silicate gel, which swells and disrupts the cement's crystalline lattice. This reaction can cause expansion and microcracking of the cement and reduced strength.

Executive Summary

Laboratory testing during the eleventh quarter focused on evaluation of the alkali-silica reaction of eight different cement compositions, four of which contain ULHS. This report provides a progress summary of ASR testing. The original laboratory procedure for measuring set cement expansion resulted in unacceptable erosion of the test specimens. In subsequent tests, a different expansion procedure was implemented and an alternate curing method for cements formulated with TXI Lightweight cement was employed to prevent sample failure caused by thermal shock.

The results obtained with the modified procedure showed improvement over data obtained with the original procedure, but data for some compositions were still questionable. Additional modification of test procedures for compositions containing TXI Lightweight cement were implemented and testing is ongoing.

Alkali-Silica Reaction (ASR) Data Summary

Approval was granted for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oilwell cements, and conduct long-term tests to verify whether ASR is occurring and when and how it manifests itself. Compositions to be tested in the ASR evaluation are listed in Table 1.

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal is used. ULHS slurries with similar bead concentrations and a density of 9.0 lb/gal were used.

The results are presented in Tables 2 through 7. Test specimens of several compositions were recast via a modified procedure to ensure proper curing. Revised test methods are outlined in the ASR Test Protocol section of this report. Testing will continue until the project's scheduled ending.

Table 1—Compositions Tested

Slurry Composition Number	Description	Density (lb/gal)	Water Requirement (gal/sk)
1	Class H Cement	16.4	4.30
2	TXI Lightweight Cement	13.5	6.00
3	Class H Cement + 42% 3M Beads	9.0	11.69
4	TXI Lightweight Cement + 37% 3M Beads	9.0	12.63
5	Class H Cement + 0.5% Salt	16.4	4.30
6	TXI Lightweight Cement + 0.5% Salt	13.5	6.00
7	Class H Cement + 42% 3M Beads + 0.5% Salt	9.0	11.81
8	TXI Lightweight Cement + 37% 3M Beads + 0.5% Salt	9.0	12.63

Table 2—Compressive Strength, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	1.46	1.48	2.45	2.05	3.22	2.68	X	X
3	1.00	0.93	1.78	1.37	1.60	1.19	1.23	X	X
5	1.00	0.86	1.14	2.30	1.91	3.00	2.46	X	X
7	1.00	0.95	1.86	1.57	1.40	1.55	1.22	X	X

X – Test in progress

Table 3—Compressive Strength, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1	1.23	1.13	X	X	X	X	X	X
4	1.00	0.83	0.74	X	X	X	X	X	X
6	1.00	1.28	1.00	X	X	X	X	X	X
8	1.00	0.81	0.93	X	X	X	X	X	X

X – Test in progress

Compressive strength testing was performed on cylinder molds rather than 2-in. cubes. Therefore, these compressive strength data are normalized to the initial 24-hour reading for each slurry.

Table 4—Tensile Strength, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	0.70	0.45	0.70	0.72	0.75	0.68	X	X
3	1.00	0.58	0.89	0.64	0.68	0.82	0.75	X	X
5	1.00	0.59	0.57	0.58	.60	0.88	0.70	X	X
7	1.00	0.68	1.23	0.83	0.66	0.54	0.63	X	X

X – Test in progress

Table 5—Tensile Strength, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1.00	0.77	0.74	X	X	X	X	X	X
4	1.00	0.79	0.99	X	X	X	X	X	X
6	1.00	0.67	0.68	X	X	X	X	X	X
8	1.00	0.70	1.24	X	X	X	X	X	X

X – Test in progress

Table 6—Percentage of Linear Expansion

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	0	0.03	0.03	-0.06	-0.05	-0.06	-0.05	-0.04	X
3	0	0.01	0.02	0.38	0.40	0.39	0.38	0.60	X
5	0	-0.02	-0.01	0.06	0.06	0.02	0.06	0.07	X
7	0	-0.05	-0.04	0.31	0.30	0.30	0.30	0.35	X

X – Test in progress

Table 7—Percentage of Linear Expansion

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	-0.35	-0.31	-0.31	X	X	X	X	X	X
4	0.04	0.06	0.06	X	X	X	X	X	X
6	0.02	0.22	0.22	X	X	X	X	X	X
8	0.02	0.04	0.04	X	X	X	X	X	X

X – Test in progress

Conclusions

1. Usable ASR test specimens have been poured using the modified curing procedure with TXI Lightweight cements.
2. The testing regime is on schedule.
3. Compressive strength results indicate no major adverse effect from curing in the caustic curing medium.
4. Tensile strengths of most specimens appear to be decreasing.
5. Expansion is occurring in all compositions except in normal-density cements without salt or beads (Compositions 1 and 2).

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Testing Procedures

A variation of Test Methods for Determination of Shrinkage and Expansion of Oilfield Cement Formulations (ISO-WD-10426-5) was used to test ***expansion in TXI Lightweight slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, two replicates of each slurry are made.

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test ***expansion in Class H slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) was used to determine a change in the ***tensile strength*** of the specimens to determine if ASR may occur in cement containing ULHS. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A ***compressive strength*** test was performed using modified API procedures. Specimens were poured into cylindrical molds and compressive strengths were measured. A compressive strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, three replicates of each slurry are made.

Testing Conditions

- Slurries were tested for a minimum of 200 days.
- Curing temperature was 174°F.**

***NOTE: To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, TXI lightweight specimens are ramped from room temperature to 174°F in a freshwater bath prior to being placed in a lime-saturated bath.*

Mixing Procedures

Prepare slurry designs that do not contain ULHS according to Appendix A of API RP 10B.

Prepare slurries containing ULHS as follows.

1. Weigh appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry containing all additives except ULHS according to Appendix A of API RP 10B.

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place the slurry in a Waring blender and mix at 4,000 rpm for 15 seconds.

Alkali-Silica Reactivity (ASR) Testing for Expansion of TXI Lightweight Slurries

The testing method used for measuring expansion of TXI Lightweight specimens is similar to that described in ISO/WD 10426-5, Test Methods for Determination of Shrinkage and Expansion of Oilwell Cement Formulations. For this testing, the slurry is placed in annular ring molds.

Test Apparatus

The annular expansion ring mold is a device suitable for measuring expansion properties of a cement formulation. It consists of five separate parts (Figures A-1 and A-2):

- base
- top lid
- internal ring
- external expandable ring with gage studs
- set bolt (holds the mold together)

The outside diameter of the inner ring is 50.8mm (2 in.), and the inside diameter of the outer expansion ring is 88.9mm (3.5 in.).

Preparation of Mold and Specimens

The mold is prepared according to ISO/WD 10426-5.3.1. The specimen is prepared according to ISO/WD 10426-5.3.2.

Curing Procedures

To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, all TXI lightweight specimens are cured using a temperature ramp method. All samples are placed in a freshwater bath at room temperature (approximately 80°F). Then, a bath heater is turned on and temperature is ramped to 174°F at a rate of 2°F /min. After the bath has reached 174°F, samples are placed in a lime-saturated bath at 174°F.

Test Measurement

Immediately after the mold is filled with slurry and before the specimen is cured in a lime-saturated bath, an initial measurement is taken. A micrometer with a precision of 0.01 in. is used to measure the distance between the two steel gage studs.

After the specimen is cured, a second measurement is taken in the same manner as the initial measurement. This measurement must be performed immediately after the specimen is removed from the 174ºF bath to prevent erroneous measurement due to excessive cooling.

Calculate the expansion as follows:

$\%_{dc} = (d_f - d_i) \times 9.095$

Where

$\%_{dc}$ = dimensional change of the cement sample (expressed as a percentage)
d_f = final distance measured after curing (expressed in inches)
d_i = initial distance measured before curing (expressed in inches)

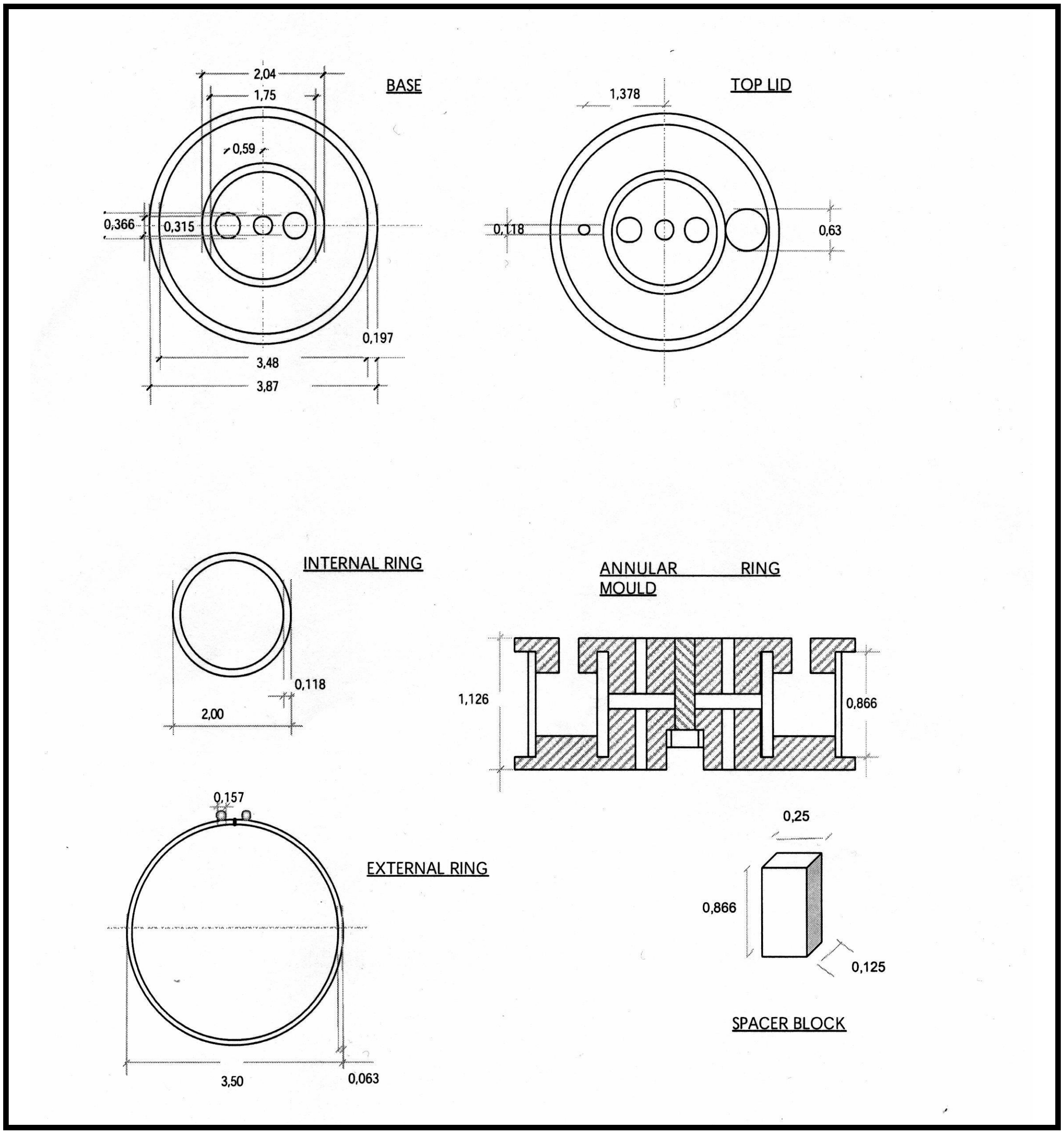


Figure A-1—Test specimen mold schematic

 (a)  (b)

Figure A-2—Annular ring mold

Alkali-Silica Reactivity (ASR) Testing for Expansion of Class H Slurries

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test expansion in Class H slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project.

Test Apparatus

Molds for test specimens used in determining the length change of cement pastes and mortars produce 1×1×11 ¼-in. prisms with a 10-in. gage length (see Figure A-3). The gage length is the nominal length between the innermost ends of the gage studs.

Curing Procedures

Cure each test specimen at 174°F in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 ½ hours. The age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
2. Etch specimens for identification or positioning as required with a scriber, inscribed with slurry design and expansion bar number on each specimen as it applies.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water at 174°F.

The comparator shown in Figure A-4 features a dial micrometer graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens.

Reference Bar

Place the reference bar (Figure A-4) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.
To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of curing bath, blot the pins, and place the bar in the comparator, read, and record the indication.
4. Return the bar to curing bath and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to curing bath, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:

L = change in length at *x* age, %
Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;
Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time
G = nominal gage length, 10 in.

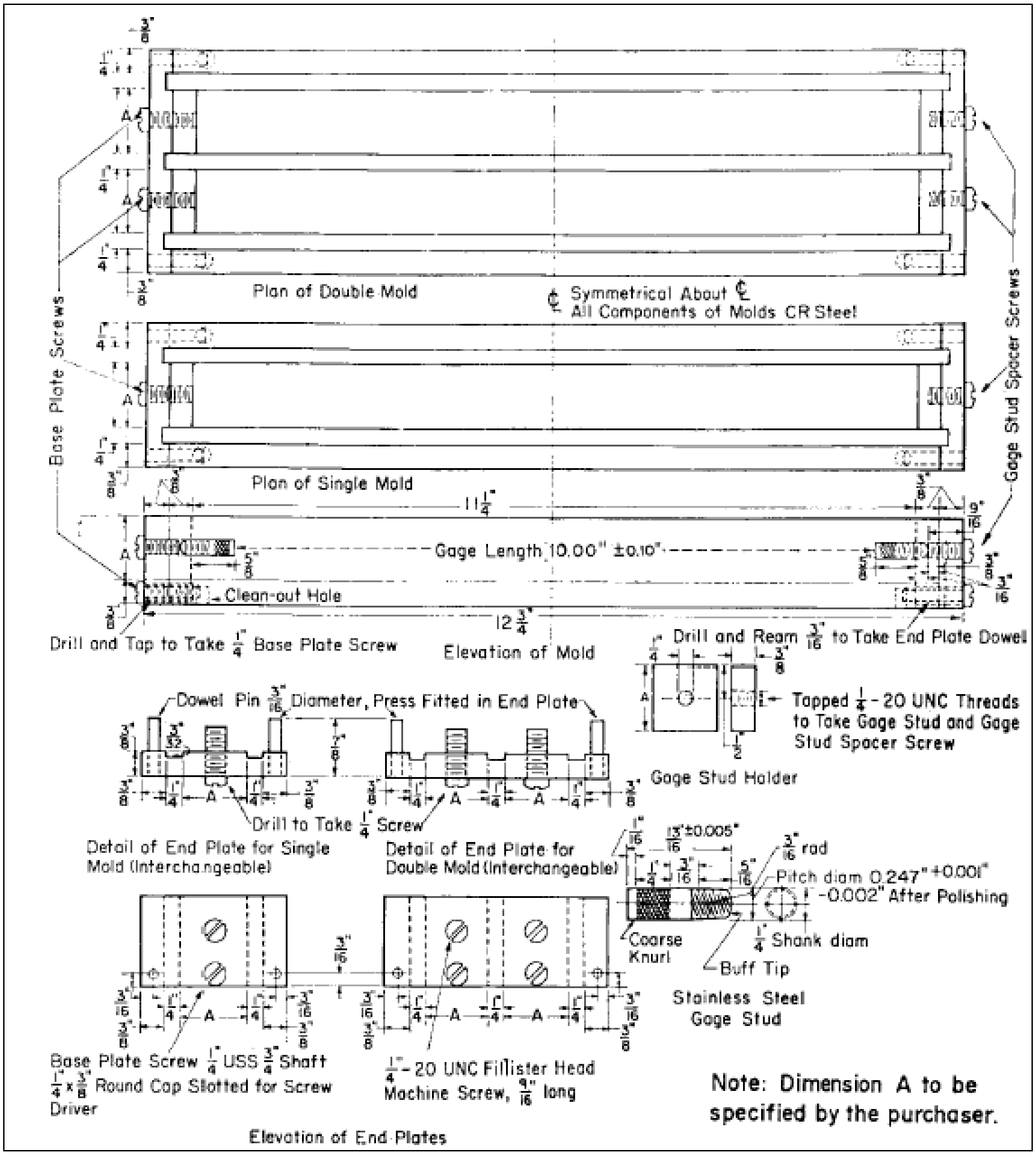
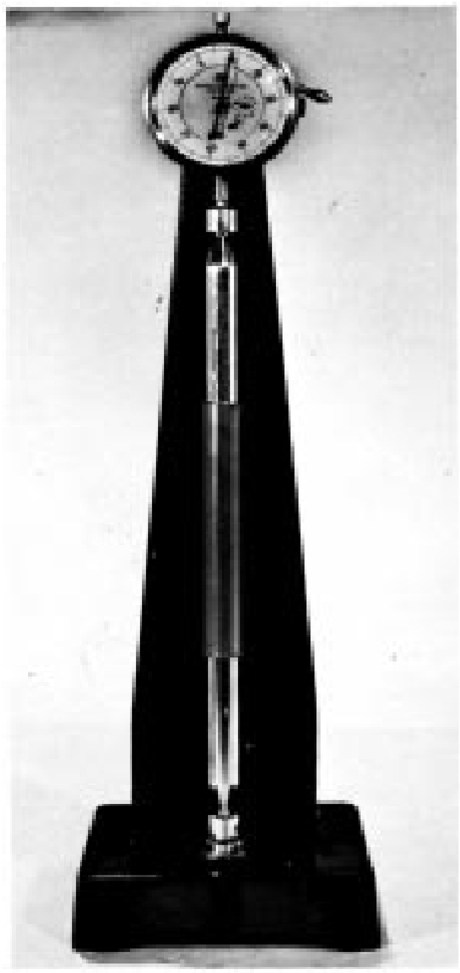


Figure A-3—Expansion test specimen mold schematics



Type of Suitable Apparatus for Measurement of Length Changes

Figure A-4—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is cured in a 1.5 x 5-in. plastic mold to make three 1 x 1.5 inch specimens.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.

3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

Tensile strengths are determined at the Westport Technology Center. The cylindrical specimens are cured at CSI. Following curing, a ¼-in. section is cut from each end of the specimen and discarded. Three 1-in.sections are cut and identified as top, middle, and bottom. The sections are then submerged in water for transport to Westport.

Testing is performed within 24 hours once the specimens are received at Westport.

Before a sample is measured for tensile strength, its density is calculated by suspending each 1-in. specimen in water and weighing it. The density is calculated according to Archimedes Principle, as follows:

$$D = (M_{air} / M_{water}) * 8.34$$

Where

D	= density (lbm/gal)
M_{air}	= mass of specimen in air
M_{water}	= mass of specimen in water
8.34	= weight of fresh water (lb/gal)

Tensile strength measurements are performed at Westport according to ASTM standard C-496-2. Force is applied by constant displacement of the bottom plate at a rate of 1 mm every 10 minutes. The change in the specimen diameter can be calculated from the test plate displacement. The use of two pieces of plywood as described in ASTM designation C496-90-4.3 is not applied to this measurement.

The maximum reading is noted and used in the following equation:

$$T(psi) = (2*F) / (PI*L*D)$$

Where

T	= tensile strength (psi)
F	= maximum force recorded (lbf)
PI	= 3.14
L	= sample length (in.)
D	= sample diameter (in.)

Fig. A-5 shows a general schematic of how each specimen is oriented on its side during testing.

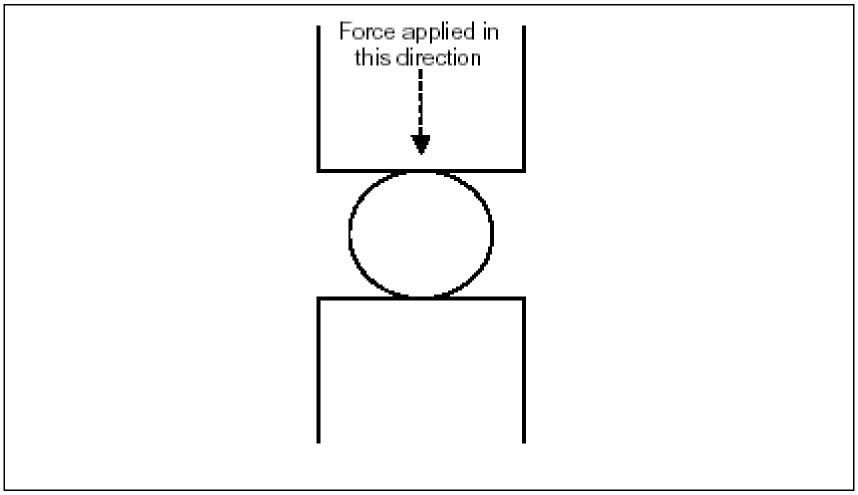


Figure A-5—Tensile strength crush diagram

Alkali-Silica Reactivity (ASR) Testing for Compressive Strength

Compressive strength testing is performed using modified API procedures. For this testing, the slurry is placed in a 1.5 x 5-in. plastic, cylindrical mold.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.
3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

After curing, three 1-in. by 1.5-in. diameter cylinders are cut from each specimen. A ¼-in. section is cut from the ends of each specimen and discarded. Each section is identified as top, middle, and bottom.

Before a sample is measured for compressive strength, its density is calculated by suspending each 1-in. specimen in water and weighing it. The density is calculated according to Archimedes Principle, as follows:

$$D = (M_{air} / M_{water}) * 8.34$$

Where

D = density (lbm/gal)
M_{air} = mass of specimen in air
M_{water} = mass of specimen in water
8.34 = weight of fresh water (lb/gal)

Each sample is then placed in turn in a Carver press (hydraulic). Force is applied in accordance with API Recommended Practice 10B Section 7.5.6.1**.** A digital pressure gauge records the specimen's failure in pounds per square inch (psi).

Calculate the compressive strength as follows:

$$Cs = F / SA$$

Where

Cs = compressive strength
F = force
SA = surface area

Fig.A-6 shows a general schematic of orientation of specimens during testing.

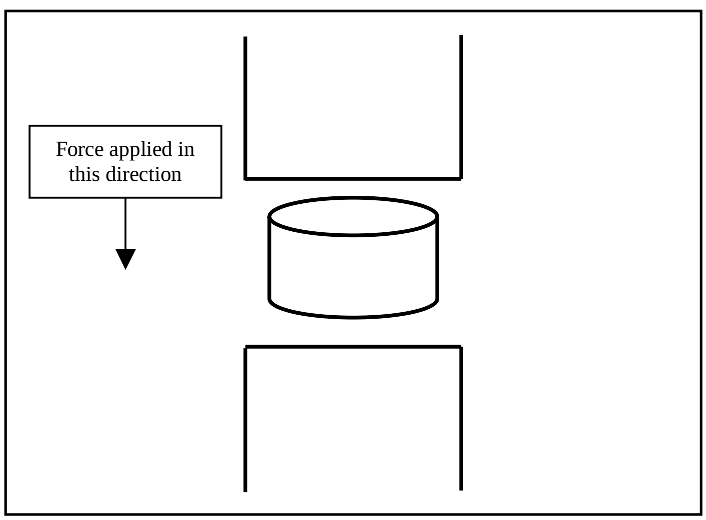


Figure A-6—Compressive strength crush diagram

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
MMS—Minerals Management Service
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. "Recommended Practices for Testing Well Cements," API Recommended Practice 10B, 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.
2. ISO 10426-1:2000, Petroleum and natural gas industries—Cements and materials for well cementing—Part 1: Specification.
3. "Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, and Concrete," ASTM C157/C157M-99, Annual book of ASTM Standards Vol. 04.02.
4. "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM C496-96, Annual Book of ASTM Standards Vol. 04.02.

Appendix 12

Quarterly Report 12

Ultra-Lightweight Cement

Twelfth Quarterly Technical Progress Report

July 1 to September 30, 2003

Fred Sabins

Issued October 31, 2003

DOE Award Number
DE-FC26-00NT40919

Submitted by
Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report discusses testing that was performed for analyzing the alkali-silica reactivity of ULHS in cement slurries.

Table of Contents

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required to limit hydrostatic pressure on the formation, and prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth’s surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry’s stability and set cement’s strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, a portion of the mix water must be replaced with ultra-lightweight materials.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water. This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction (ASR) in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile and compressive strengths of eight different cement formulations are being tested.

ASR is a potentially damaging phenomenon that occurs in cement materials containing certain types of silica-containing materials when they are exposed to alkali in high-pH environments. The ASR reaction produces alkali-silicate gel, which swells and disrupts the cement’s crystalline lattice. This reaction can cause expansion and microcracking of the cement and reduced strength.

Executive Summary

Laboratory testing during the twelfth quarter focused on evaluation of the alkali-silica reaction of eight different cement compositions, four of which contain ULHS. This report provides a progress summary of ASR testing. The original laboratory procedure for measuring set cement expansion resulted in unacceptable erosion of the test specimens. In subsequent tests, a different expansion procedure was implemented and an alternate curing method for cements formulated with TXI Lightweight cement was employed to prevent sample failure caused by thermal shock.

The results obtained with the modified procedure showed improvement over data obtained with the original procedure, but data for some compositions were still questionable. Additional modification of test procedures for compositions containing TXI Lightweight cement were implemented and testing is ongoing.

Alkali-Silica Reaction (ASR) Data Summary

Approval was granted for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oilwell cements, and conduct long-term tests to verify whether ASR is occurring and when and how it manifests itself. Compositions to be tested in the ASR evaluation are listed in Table 1.

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal is used. ULHS slurries with similar bead concentrations and a density of 9.0 lb/gal were used.

The results are presented in Tables 2 through 7. Test specimens of several compositions were recast via a modified procedure to ensure proper curing. Revised test methods are outlined in the ASR Test Protocol section of this report. Testing will continue until the project's scheduled ending.

Table 1—Compositions Tested

Slurry Composition Number	Description	Density (lb/gal)	Water Requirement (gal/sk)
1	Class H Cement	16.4	4.30
2	TXI Lightweight Cement	13.5	6.00
3	Class H Cement + 42% 3M Beads	9.0	11.69
4	TXI Lightweight Cement + 37% 3M Beads	9.0	12.63
5	Class H Cement + 0.5% Salt	16.4	4.30
6	TXI Lightweight Cement + 0.5% Salt	13.5	6.00
7	Class H Cement + 42% 3M Beads + 0.5% Salt	9.0	11.81
8	TXI Lightweight Cement + 37% 3M Beads + 0.5% Salt	9.0	12.63

*All additives are % BWOC

Table 2—Compressive Strength at 174°F, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	1.46	1.48	2.45	2.05	3.22	2.68	4.37	4.08
3	1.00	0.93	1.78	1.37	1.60	1.19	1.23	2.43	2.13
5	1.00	0.86	1.14	2.30	1.91	3.00	2.46	2.48	2.95
7	1.00	0.95	1.86	1.57	1.40	1.55	1.22	2.09	2.34

*Average of three replicates

Table 3—Compressive Strength at 174°F, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1	1.23	1.13	0.79	1.18	1.62	X	X	X
4	1.00	0.83	0.74	0.88	1.02	1.28	X	X	X
6	1.00	1.28	1.00	1.35	1.27	1.07	X	X	X
8	1.00	0.81	0.93	0.93	0.92	1.34	X	X	X

X – Test in progress
* Average of three replicates

Compressive strength testing was performed on cylinder molds rather than 2-in. cubes. Therefore, these compressive strength data are normalized to the initial 24-hour reading for each slurry.

Table 4—Tensile Strength at 174°F, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	0.70	0.45	0.70	0.72	0.75	0.68	1.12	0.84
3	1.00	0.58	0.89	0.64	0.68	0.82	0.75	1.01	0.84
5	1.00	0.59	0.57	0.58	.60	0.88	0.70	0.87	0.99
7	1.00	0.68	1.23	0.83	0.66	0.54	0.63	0.65	1.03

*Average of six replicates

Table 5—Tensile Strength at 174°F, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1.00	0.77	0.74	0.92	0.66	0.72	X	X	X
4	1.00	0.79	0.99	1.25	1.15	1.21	X	X	X
6	1.00	0.67	0.68	0.79	0.65	0.60	X	X	X
8	1.00	0.70	1.24	1.55	0.81	0.92	X	X	X

X – Test in progress
*Average of six replicates

Table 6—Linear Expansion (%) at 174°F, Class H Slurries

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	0	0.03	0.03	-0.06	-0.05	-0.06	-0.05	-0.04	-0.04
3	0	0.01	0.02	0.38	0.40	0.39	0.38	0.60	0.61
5	0	-0.02	-0.01	0.06	0.06	0.02	0.06	0.07	0.07
7	0	-0.05	-0.04	0.31	0.30	0.30	0.30	0.35	0.33

*Average of six replicates

Table 7—Linear Expansion (%) at 174°F, TXI Lightweight Slurries

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	0.15	0.19	0.19	0.2	0.31	0.34	X	X	X
4	0.04	0.06	0.06	0.04	0.1	0.12	X	X	X
6	0.14	0.17	0.17	0.17	0.24	0.26	X	X	X
8	0.02	0.04	0.04	0.04	0.06	0.08	X	X	X

X – Test in progress
*Average of two replicates

Conclusions

1. Usable ASR test specimens have been poured using the modified curing procedure with TXI Lightweight cements.
2. The testing regime is on schedule.
3. Compressive strength results indicate no major adverse effect from curing in the caustic curing medium.
4. Tensile strengths of most specimens appear to be decreasing.
5. Expansion occurs in all compositions except in Class H cement without salt or beads (Composition 1).

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Testing Procedures

A variation of Test Methods for Determination of Shrinkage and Expansion of Oilfield Cement Formulations (ISO-WD-10426-5) was used to test ***expansion in TXI Lightweight slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, two replicates of each slurry are made.

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test ***expansion in Class H slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) was used to determine a change in the ***tensile strength*** of the specimens to determine if ASR may occur in cement containing ULHS. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A ***compressive strength*** test was performed using modified API procedures. Specimens were poured into cylindrical molds and compressive strengths were measured. A compressive strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, three replicates of each slurry are made.

Testing Conditions

- Slurries were tested for a minimum of 200 days.
- Curing temperature was 174°F.**

***NOTE: To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, TXI lightweight specimens are ramped from room temperature to 174°F in a freshwater bath prior to being placed in a lime-saturated bath.*

Mixing Procedures

Prepare slurry designs that do not contain ULHS according to Appendix A of API RP 10B.

Prepare slurries containing ULHS as follows.

1. Weigh appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry containing all additives except ULHS according to Appendix A of API RP 10B.

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place the slurry in a 1000 ml Waring blender and mix at 4,000 rpm for 15 seconds.

Alkali-Silica Reactivity (ASR) Testing for Expansion of TXI Lightweight Slurries

The testing method used for measuring expansion of TXI Lightweight specimens is similar to that described in ISO/WD 10426-5, Test Methods for Determination of Shrinkage and Expansion of Oilwell Cement Formulations. For this testing, the slurry is placed in annular ring molds.

Test Apparatus

The annular expansion ring mold is a device suitable for measuring expansion properties of a cement formulation. It consists of five separate parts (Figures A-1 and A-2):

- base
- top lid
- internal ring
- external expandable ring with gage studs
- set bolt (holds the mold together)

The outside diameter of the inner ring is 50.8mm (2 in.), and the inside diameter of the outer expansion ring is 88.9mm (3.5 in.).

Preparation of Mold and Specimens

The mold is prepared according to ISO/WD 10426-5.3.1. The specimen is prepared according to ISO/WD 10426-5.3.2.

Curing Procedures

To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, all TXI lightweight specimens are cured using a temperature ramp method. All samples are placed in a freshwater bath at room temperature (approximately 80°F). Then, a bath heater is turned on and temperature is ramped to 174°F at a rate of 2°F /min. After the bath has reached 174°F, samples are placed in a lime-saturated bath at 174°F.

Test Measurement

Immediately after the mold is filled with slurry and before the specimen is cured in a lime-saturated bath and heated to 174°F, an initial measurement is taken. A micrometer with a precision of 0.01 in. is used to measure the distance between the two steel gage studs.

After the specimen is cured, a second measurement is taken in the same manner as the initial measurement. This measurement must be performed immediately after the specimen is removed from the 174ºF bath to prevent erroneous measurement due to excessive cooling.

Calculate the expansion as follows:

$\%_{dc} = (d_f - d_i) \times 9.095$

Where

$\%_{dc}$ = dimensional change of the cement sample (expressed as a percentage)
d_f = final distance measured after curing (expressed in inches)
d_i = initial distance measured before curing (expressed in inches)

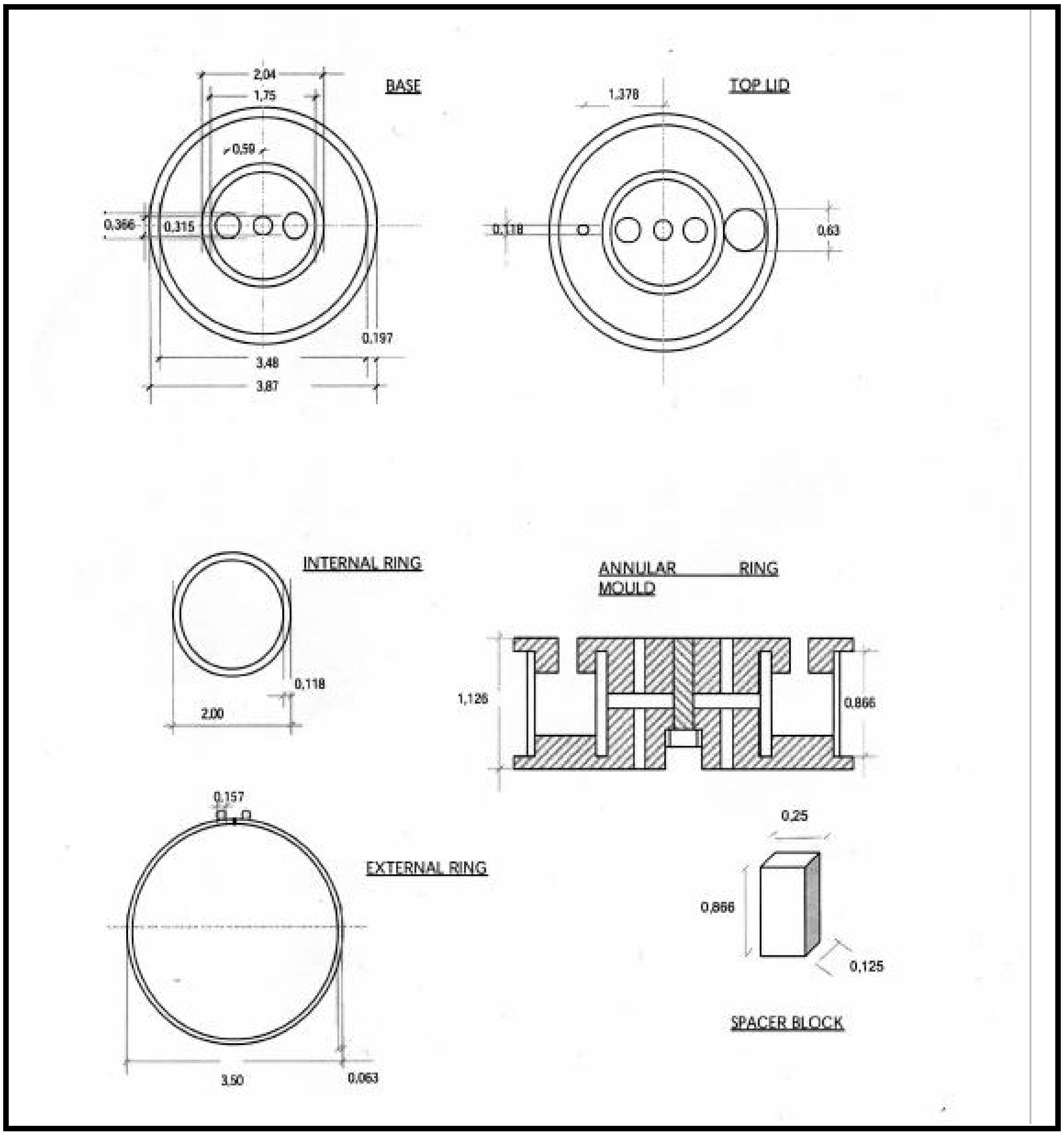


Figure A-1—Test specimen mold schematic

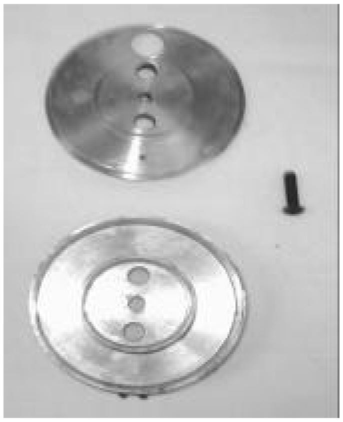
 (a)  (b)

Figure A-2—Annular ring mold

Alkali-Silica Reactivity (ASR) Testing for Expansion of Class H Slurries

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test expansion in Class H slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project.

Test Apparatus

Molds for test specimens used in determining the length change of cement pastes and mortars produce 1×1×11 ¼-in. prisms with a 10-in. gage length (see Figure A-3). The gage length is the nominal length between the innermost ends of the gage studs.

Curing Procedures

Cure each test specimen at 174°F in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 ½ hours. The age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
2. Etch specimens for identification or positioning as required with a scriber, inscribed with slurry design and expansion bar number on each specimen as it applies.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water at 174°F.

The comparator shown in Figure A-4 features a dial micrometer graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens.

Reference Bar

Place the reference bar (Figure A-4) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of curing bath, blot the pins, and place the bar in the comparator, read, and record the length.
4. Return the bar to curing bath and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to curing bath, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar length. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:

L = change in length at *x* age, %
Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;
Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time
G = nominal gage length, 10 in.

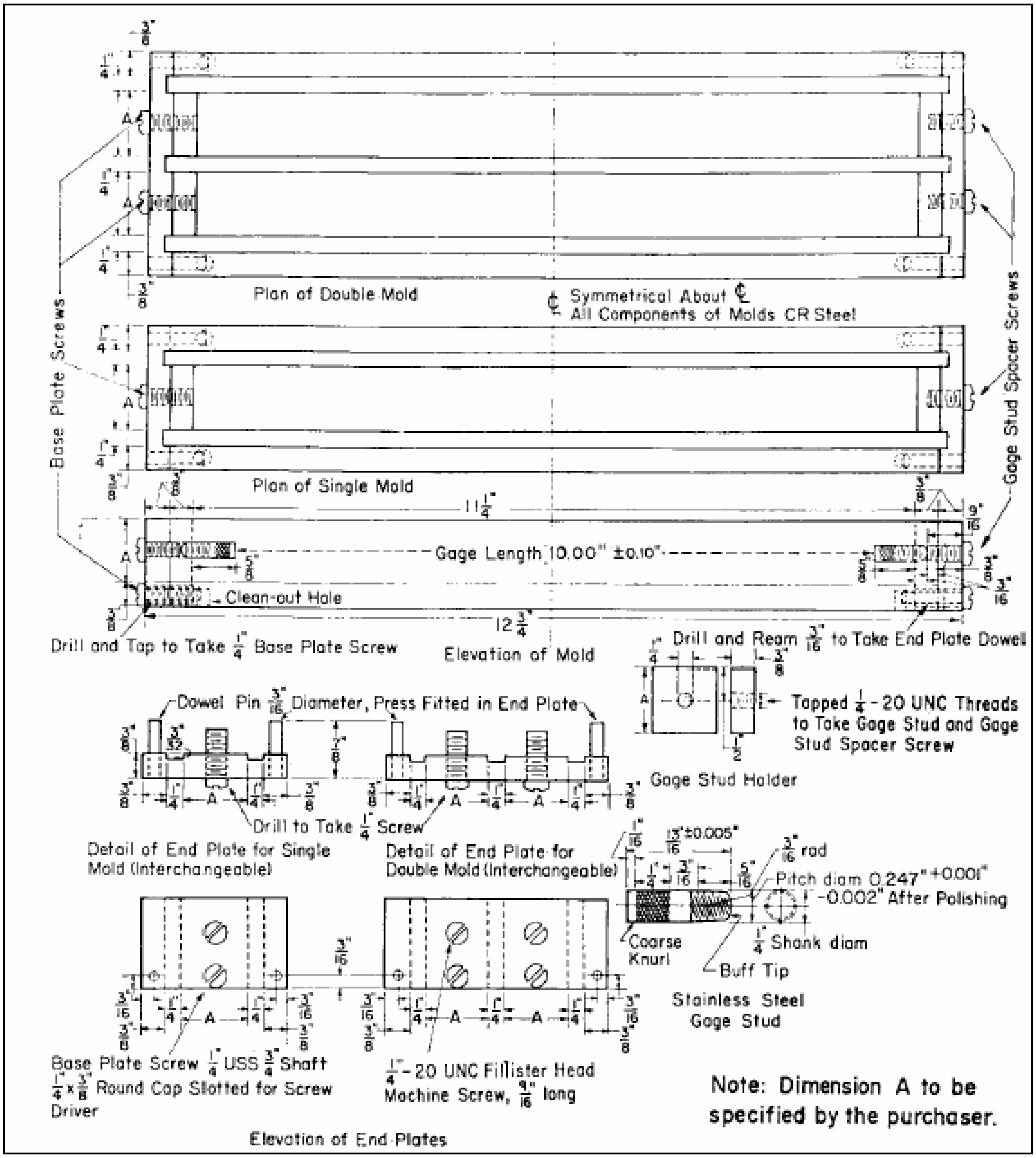
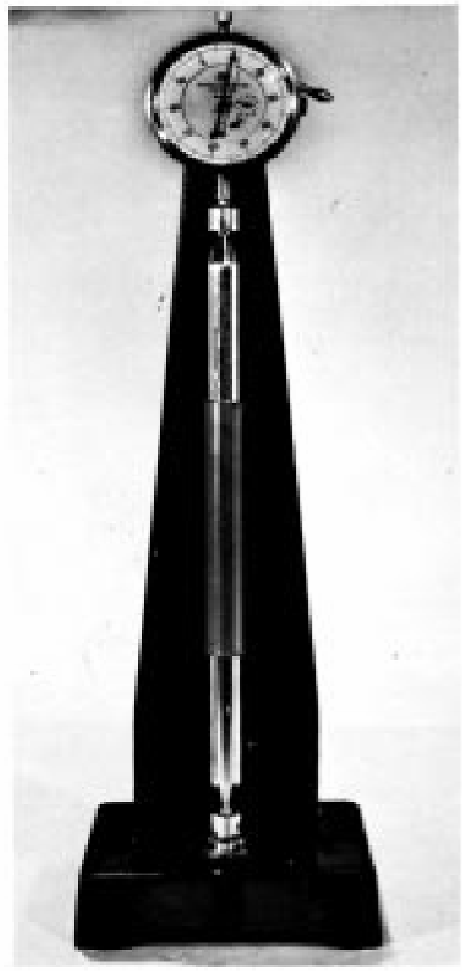


Figure A-3—Expansion test specimen mold schematics



Type of Suitable Apparatus for Measurement of Length Changes

Figure A-4—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is cured in a 1.5 x 5-in. plastic mold to make three 1 x 1.5 inch specimens.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.

3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

Tensile strengths are determined at the Westport Technology Center. The cylindrical specimens are cured at Cementing Solutions, Inc. Following curing, a ¼-in. section is cut from each end of the specimen and discarded. Three 1-in.sections are cut and identified as top, middle, and bottom. The sections are then submerged in water for transport to Westport.

Testing is performed within 24 hours once the specimens are received at Westport.

Before a sample is measured for tensile strength, its density is calculated by suspending each 1-in. specimen in water and weighing it. The density is calculated according to Archimedes Principle, as follows:

$$D = (M_{air} / M_{water}) * 8.34$$

Where

D	= density (lbm/gal)
M_{air}	= mass of specimen in air
M_{water}	= mass of specimen in water
8.34	= weight of fresh water (lb/gal)

Tensile strength measurements are performed at Westport according to ASTM standard C-496-2. Force is applied by constant displacement of the bottom plate at a rate of 1 mm every 10 minutes. The change in the specimen diameter can be calculated from the test plate displacement. The use of two pieces of plywood as described in ASTM designation C496-90-4.3 is not applied to this measurement.

The maximum reading is noted and used in the following equation:

$$T(psi) = (2*F) / (PI*L*D)$$

Where

T	= tensile strength (psi)
F	= maximum force recorded (lbf)
PI	= 3.14
L	= sample length (in.)
D	= sample diameter (in.)

Fig. A-5 shows a general schematic of how each specimen is oriented on its side during testing.

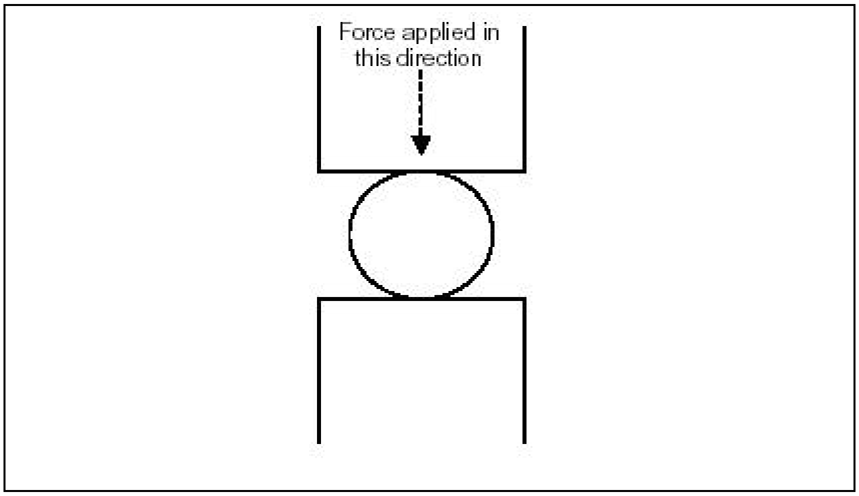


Figure A-5—Tensile strength crush diagram

Alkali-Silica Reactivity (ASR) Testing for Compressive Strength

Compressive strength testing is performed using modified API procedures. For this testing, the slurry is placed in a 1.5 x 5-in. plastic, cylindrical mold.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.
3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

After curing, three 1-in. by 1.5-in. diameter cylinders are cut from each specimen. A ¼-in. section is cut from the ends of each specimen and discarded. Each section is identified as top, middle, and bottom.

Before a sample is measured for compressive strength, its density is calculated by suspending each 1-in. specimen in water and weighing it. The density is calculated according to Archimedes Principle, as follows:

$$D = (M_{air} / M_{water}) * 8.34$$

Where

D = density (lbm/gal)
M_{air} = mass of specimen in air
M_{water} = mass of specimen in water
8.34 = weight of fresh water (lb/gal)

Each sample is then placed in turn in a Carver press (hydraulic). Force is applied in accordance with API Recommended Practice 10B Section 7.5.6.1**.** A digital pressure gauge records the specimen's failure in pounds per square inch (psi).

Calculate the compressive strength as follows:

$$Cs = F / SA$$

Where

Cs = compressive strength
F = force
SA = surface area

Fig.A-6 shows a general schematic of orientation of specimens during testing.

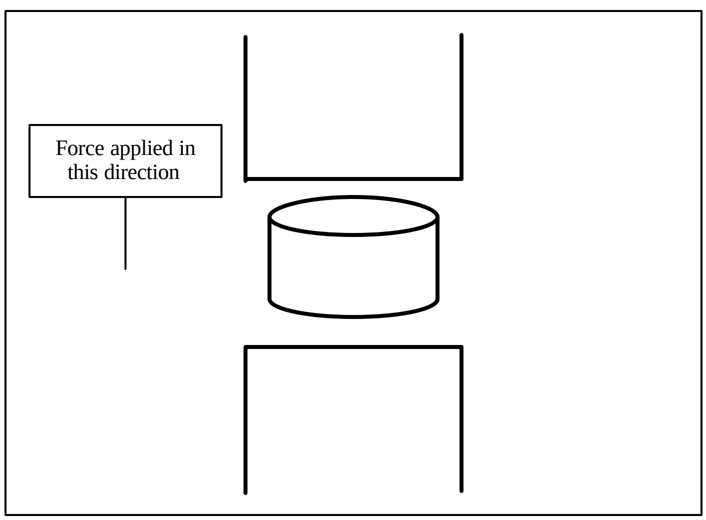


Figure A-6—Compressive strength crush diagram

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
MMS—Minerals Management Service
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. "Recommended Practices for Testing Well Cements," API Recommended Practice 10B, 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.
2. ISO 10426-1:2000, Petroleum and natural gas industries—Cements and materials for well cementing—Part 1: Specification.
3. "Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, and Concrete," ASTM C157/C157M-99, Annual book of ASTM Standards Vol. 04.02.
4. "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM C496-96, Annual Book of ASTM Standards Vol. 04.02.

Appendix 13

Quarterly Report 13

Ultra-Lightweight Cement

Thirteenth Quarterly Technical Progress Report

October 1 to December 31, 2003

Fred Sabins

Issued January 30, 2004

DOE Award Number
DE-FC26-00NT40919

Submitted by
Cementing Solutions, Inc.
4613 Brookwoods Drive
Houston, TX 77092

Disclaimer

Abstract

The objective of this project is to develop an improved ultra-lightweight cement using ultra-lightweight hollow glass spheres (ULHS). This report discusses testing that was performed for analyzing the alkali-silica reactivity of ULHS in cement slurries.

Table of Contents

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Introduction

Oilwell cementing involves placing a pumpable slurry of Portland cement, additives, and water into a wellbore. The slurry is pumped into the annular space between the borehole and a steel pipe (called a casing) that acts as a conduit from the reservoir to the surface. The setting of cement in place serves three important functions: (1) it supports the casing in the hole, (2) it isolates various formations from one another, and (3) it controls fluid movement within the well.

Typically, cement fluid density is anywhere from 12 to 17 lb/gal. Certain conditions that require the application of low-density cements can be encountered during the well construction process. Lower density is required to limit hydrostatic pressure on the formation, and prevent the formation from fracturing and imbibing the well fluid. This phenomenon, known as lost circulation, increases drilling and completion times and increases construction cost because of the need for expensive remedial treatments. Lost circulation most commonly occurs in the upper sections of the well, where surface and intermediate casings are installed. Because formations covered by these casings are relatively close to the Earth’s surface, application temperatures for these low-density cements are low.

The minimum density achievable with conventional cements and additives is approximately 11 lb/gal. At this density, the slurry’s stability and set cement’s strength and permeability are only marginally acceptable. Adding water to reduce the density of these conventional cements is impractical because additional water dilutes the cement, causing low strength and high permeability. Low temperatures, such as those in the upper well sections, delay strength development. To obtain a lower cement density or greater cement strength, a portion of the mix water must be replaced with ultra-lightweight materials.

Ultra-lightweight hollow spheres (ULHS) are excellent candidate materials for producing ultra-lightweight cements. These small hollow glass beads effectively trap air in the slurry, thereby lowering the slurry density without the addition of water. This project is designed to develop cementing systems using ULHS through a carefully designed program of modeling, design, laboratory testing, and field testing.

The goals of this portion of the project are to study the long-term effects of the alkali-silica reaction (ASR) in cements and to conduct a comprehensive evaluation of the ULHS from 3M and the potential for this product to be susceptible to ASR. The expansion and tensile and compressive strengths of eight different cement formulations are being tested.

ASR is a potentially damaging phenomenon that occurs in cement materials containing certain types of silica-containing materials when they are exposed to alkali in high-pH environments. The ASR reaction produces alkali-silicate gel, which swells and disrupts the cement’s crystalline lattice. This reaction can cause expansion and microcracking of the cement and reduced strength.

Executive Summary

Laboratory testing during the thirteenth quarter focused on evaluation of the alkali-silica reaction of eight different cement compositions, four of which contain ULHS. This report provides a progress summary of ASR testing. The original laboratory procedure for measuring set cement expansion resulted in unacceptable erosion of the test specimens. In subsequent tests, a different expansion procedure was implemented and an alternate curing method for cements formulated with TXI Lightweight cement was employed to prevent sample failure caused by thermal shock.

The results obtained with the modified procedure showed improvement over data obtained with the original procedure, but data for some compositions were still questionable. Additional modifications of test procedures for compositions containing TXI Lightweight cement were implemented.

Alkali-Silica Reaction (ASR) Data Summary

Approval was granted for a continuation of the current cooperative agreement with DOE. This agreement consisted of a new task to study the long-term effects of the Alkali-Silica Reaction (ASR) in ULHS cements. The goal of this task is to determine procedures and methods from the construction industry that are applicable to oilwell cements, and conduct long-term tests to verify whether ASR is occurring and when and how it manifests itself. Compositions to be tested in the ASR evaluation are listed in Table 1.

As a baseline for testing, neat Class H cement with a density of 16.4 lb/gal and TXI Lightweight cement with a density of 13.5 lb/gal is used. ULHS slurries with similar bead concentrations and a density of 9.0 lb/gal were used.

The results are presented in Tables 2 through 7. Test specimens of several compositions were recast via a modified procedure to ensure proper curing. Revised test methods are outlined in the ASR Test Protocol section of this report.

Table 1—Compositions Tested

Slurry Composition Number	Description	Density (lb/gal)	Water Requirement (gal/sk)
1	Class H Cement	16.4	4.30
2	TXI Lightweight Cement	13.5	6.00
3	Class H Cement + 42% 3M Beads	9.0	11.69
4	TXI Lightweight Cement + 37% 3M Beads	9.0	12.63
5	Class H Cement + 0.5% Salt	16.4	4.30
6	TXI Lightweight Cement + 0.5% Salt	13.5	6.00
7	Class H Cement + 42% 3M Beads + 0.5% Salt	9.0	11.81
8	TXI Lightweight Cement + 37% 3M Beads + 0.5% Salt	9.0	12.63

*All additives are %BWOC

Table 2—Compressive Strength at 174°F, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	1.46	1.48	2.45	2.05	3.22	2.68	4.37	4.08
3	1.00	0.93	1.78	1.37	1.60	1.19	1.23	2.43	2.13
5	1.00	0.86	1.14	2.30	1.91	3.00	2.46	2.48	2.95
7	1.00	0.95	1.86	1.57	1.40	1.55	1.22	2.09	2.34

*Average of three replicates

Table 3—Compressive Strength at 174°F, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1	1.23	1.13	0.79	1.18	1.62	1.74	1.78	1.73
4	1.00	0.83	0.74	0.88	1.02	1.28	1.51	1.40	1.40
6	1.00	1.28	1.00	1.35	1.27	1.07	1.67	1.38	1.33
8	1.00	0.81	0.93	0.93	0.92	1.34	1.70	1.57	1.76

*Average of three replicates

Compressive strength testing was performed on cylinder molds rather than 2-in. cubes. Therefore, these compressive strength data are normalized to the initial 24-hour reading for each slurry.

Table 4—Tensile Strength at 174°F, Class H Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	1.00	0.70	0.45	0.70	0.72	0.75	0.68	1.12	0.84
3	1.00	0.58	0.89	0.64	0.68	0.82	0.75	1.01	0.84
5	1.00	0.59	0.57	0.58	.60	0.88	0.70	0.87	0.99
7	1.00	0.68	1.23	0.83	0.66	0.54	0.63	0.65	1.03

*Average of six replicates

Table 5—Tensile Strength at 174°F, TXI Lightweight Slurries Normalized to 24-Hour Values

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	1.00	0.77	0.74	0.92	0.66	0.72	0.42	0.34	0.34
4	1.00	0.79	0.99	1.25	1.15	1.21	1.05	1.07	1.19
6	1.00	0.67	0.68	0.79	0.65	0.60	0.27	0.35	0.21
8	1.00	0.70	1.24	1.55	0.81	0.92	1.62	0.74	0.69

*Average of six replicates

Table 6—Percentage of Linear Expansion at 174°F, Class H Slurries

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
1	0	0.03	0.03	-0.06	-0.05	-0.06	-0.05	-0.04	-0.04
3	0	0.01	0.02	0.38	0.40	0.39	0.38	0.60	0.61
5	0	-0.02	-0.01	0.06	0.06	0.02	0.06	0.07	0.07
7	0	-0.05	-0.04	0.31	0.30	0.30	0.30	0.35	0.33

*Average of six replicates

Table 7—Percentage of Linear Expansion at 174°F, TXI Lightweight Slurries

Slurry	24 hr	7 days	14 days	1 mo.	2 mo.	3 mo.	4 mo.	5 mo.	6 mo.
2	0.15	0.19	0.19	0.2	0.31	0.34	0.37	0.40	0.41
4	0.04	0.06	0.06	0.04	0.1	0.12	0.13	0.12	0.14
6	0.14	0.17	0.17	0.17	0.24	0.26	0.32	0.36	0.42
8	0.02	0.04	0.04	0.04	0.06	0.08	0.06	0.07	0.10

*Average of two replicates

Conclusions

1. The testing regime is complete.
2. Compressive strength results indicate no major adverse effect from curing in the caustic curing medium.
3. Tensile strengths of slurry composition numbers 1, 2, 3, 6 and 8 show a decrease over time. Slurry composition numbers 5 and 7 decrease early on but increase back to a baseline value by the end of the testing period. Slurry composition number 4 had an increase in tensile strength over time.
4. Expansion occurs in all compositions except in slurry composition number 1.

Appendix A—Alkali-Silica Reactivity (ASR) Lightweight Testing

Testing Procedures

A ***compressive strength*** test was performed using modified API procedures. Specimens were poured into cylindrical molds and compressive strengths were measured. A compressive strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, three replicates of each slurry are made.

A variation of Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496-90) was used to determine a change in the ***tensile strength*** of the specimens to determine if ASR may occur in cement containing ULHS. A tensile strength measurement is performed at 24 hours, 7 days, 28 days, 2 months, 4 months, and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test ***expansion in Class H slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, six replicates of each slurry are made.

A variation of Test Methods for Determination of Shrinkage and Expansion of Oilfield Cement Formulations (ISO-WD-10426-5) was used to test ***expansion in TXI Lightweight slurries***. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project. For statistical purposes, two replicates of each slurry are made.

Testing Conditions

- Slurries were tested for a minimum of 200 days.
- Curing temperature was 174°F.**

***NOTE: To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, TXI lightweight specimens are ramped from room temperature to 174°F in a freshwater bath prior to being placed in a lime-saturated bath.*

Mixing Procedures

Prepare slurry designs that do not contain ULHS according to Appendix A of API RP 10B.

Prepare slurries containing ULHS as follows.

1. Weigh appropriate amounts of the cement sample, additives, water, and ULHS into separate containers.
2. Mix the cement slurry containing all additives except ULHS according to Appendix A of API RP 10B.

3. Pour the slurry into a metal mixing bowl and slowly add ULHS while continuously mixing by hand with a spatula. Mix thoroughly.
4. Place the slurry in a 1000 ml Waring blender and mix at 4,000 rpm for 15 seconds.

Alkali-Silica Reactivity (ASR) Testing for Expansion of TXI Lightweight Slurries

The testing method used for measuring expansion of TXI Lightweight specimens is similar to that described in ISO/WD 10426-5, Test Methods for Determination of Shrinkage and Expansion of Oilwell Cement Formulations. For this testing, the slurry is placed in annular ring molds.

Test Apparatus

The annular expansion ring mold is a device suitable for measuring expansion properties of a cement formulation. It consists of five separate parts (Figures A-1 and A-2):

- base
- top lid
- internal ring
- external expandable ring with gage studs
- set bolt (holds the mold together)

The outside diameter of the inner ring is 50.8mm (2 in.), and the inside diameter of the outer expansion ring is 88.9mm (3.5 in.).

Preparation of Mold and Specimens

The mold is prepared according to ISO/WD 10426-5.3.1. The specimen is prepared according to ISO/WD 10426-5.3.2.

Curing Procedures

To help prevent thermal shock of the lightweight cement, which can cause a variance in test data, all TXI lightweight specimens are cured using a temperature ramp method. All samples are placed in a freshwater bath at room temperature (approximately 80°F). Then, a bath heater is turned on and temperature is ramped to 174°F at a rate of 2°F /min. After the bath has reached 174°F, samples are placed in a lime-saturated bath at 174°F.

Test Measurement

Immediately after the mold is filled with slurry and before the specimen is cured in a lime-saturated bath, an initial measurement is taken. A micrometer with a precision of 0.01 in. is used to measure the distance between the two steel gage studs.

After the specimen is cured, a second measurement is taken in the same manner as the initial measurement. This measurement must be performed immediately after the specimen is removed from the 174ºF bath to prevent erroneous measurement due to excessive cooling.

Calculate the expansion as follows:

$\%_{dc} = (d_f - d_i) \times 9.095$

Where

$\%_{dc}$ = dimensional change of the cement sample (expressed as a percentage)
d_f = final distance measured after curing (expressed in inches)
d_i = initial distance measured before curing (expressed in inches)

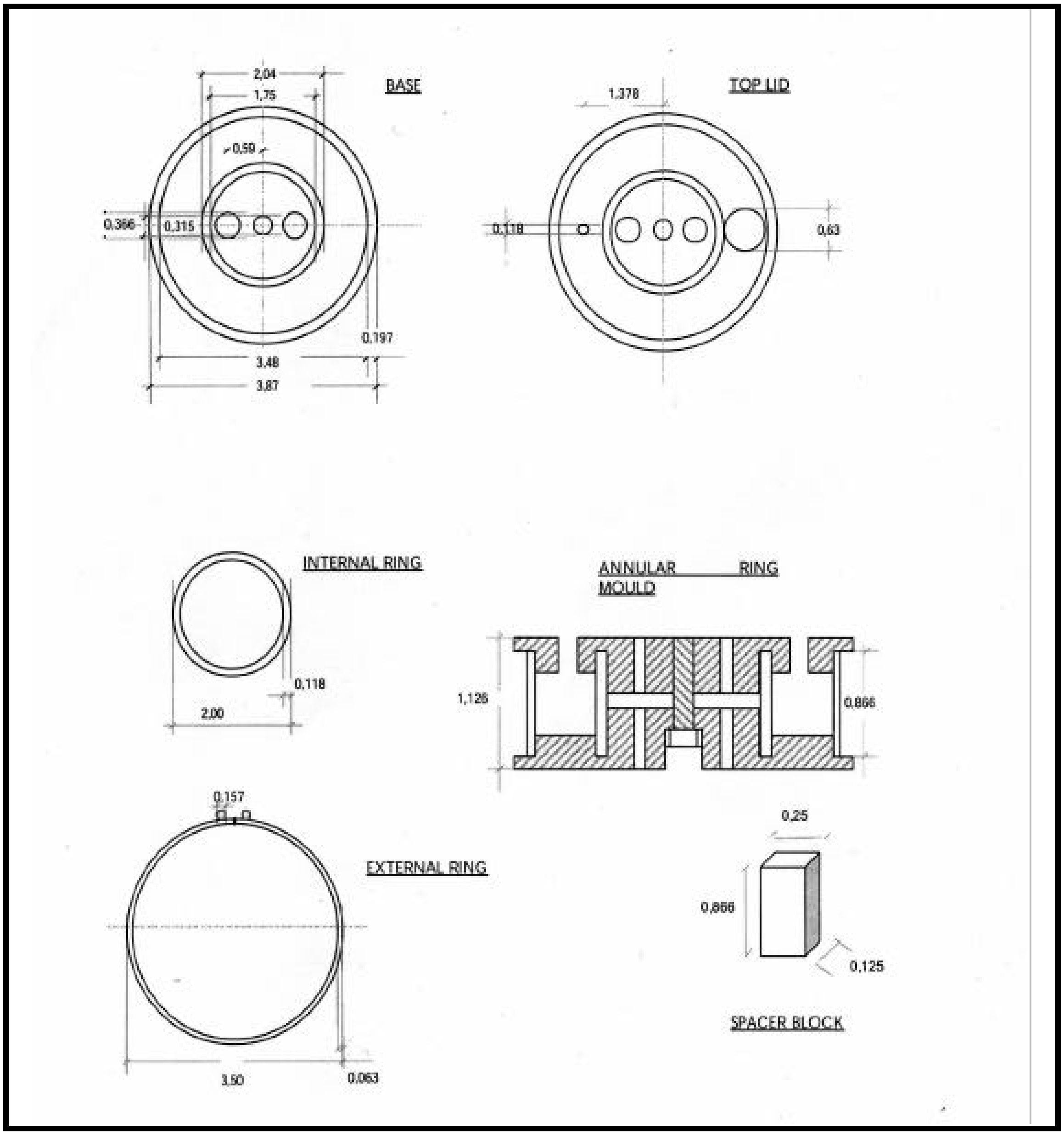


Figure A-1—Test specimen mold schematic

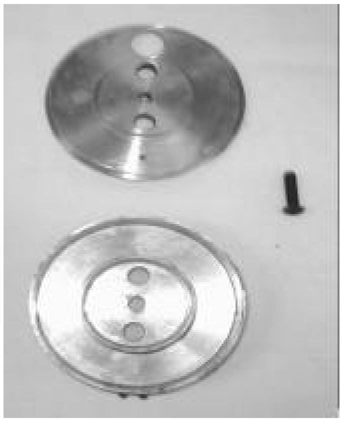
 (a)  (b)

Figure A-2—Annular ring mold

Alkali-Silica Reactivity (ASR) Testing for Expansion of Class H Slurries

A variation of the Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, (ASTM C157/C157M-99) was used to test expansion in Class H slurries. An expansion measurement is taken at 24 hours, 7 days, 14 days, 28 days and every consecutive month for the duration of the project.

Test Apparatus

Molds for test specimens used in determining the length change of cement pastes and mortars produce 1×1×11 ¼-in. prisms with a 10-in. gage length (see Figure A-3). The gage length is the nominal length between the innermost ends of the gage studs.

Curing Procedures

Cure each test specimen at 174°F in a heated, circulating water bath containing saturated-lime curing water, as described in the procedure below.

1. Remove specimens from the molds at an age of 23 ½ hours. The age of each specimen is measured from the moment when water is added to the cement during the mixing operation.
2. Etch specimens for identification or positioning as required with a scriber, inscribed with slurry design and expansion bar number on each specimen as it applies.
3. Place the specimens in lime-saturated water maintained at 73.4 ±°F (23.0 ± 0.5°C) for a minimum of 15 min. This helps minimize variation in length measurements due to variation in temperature of the specimens.

Important—Monitor the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

When the specimens are 24 ± ½ hours in age, remove them from water storage one at a time, wipe with a damp cloth, and immediately take a comparator reading. Then, return each specimen in lime-saturated water at 174°F.

The comparator shown in Figure A-4 features a dial micrometer graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of specimens.

Reference Bar

Place the reference bar (Figure A-4) in the instrument in the same position each time a comparator reading is taken. Check the dial gage setting of the measuring device by taking a comparator reading of the reference bar at least at the beginning and end of a series of specimen readings to span no more than a half-day, provided the apparatus is kept in a room maintained at constant temperature.

To obtain a comparator reading, perform the following steps.

1. Clean the hole in the base of the comparator into which the gage stud on the lower end of the bar fits.
2. Read and record the comparator indication of the length of the reference bar.
3. Take one bar out of curing bath, blot the pins, and place the bar in the comparator, read, and record the length.
4. Return the bar to curing bath and clean the hole in the base of the comparator.
5. Repeat the procedure with second and subsequent bars until all bars have been read, returned to curing bath, and the readings recorded.
6. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar length. Blot only around the pins.

Calculate the specimen length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100$$

Where:

L = change in length at *x* age, %

Lx = comparator reading of specimen at *x* age minus comparator reading of reference bar at *x* age;

Li = initial comparator reading of specimen minus comparator reading of reference bar at that same time

G = nominal gage length, 10 in.

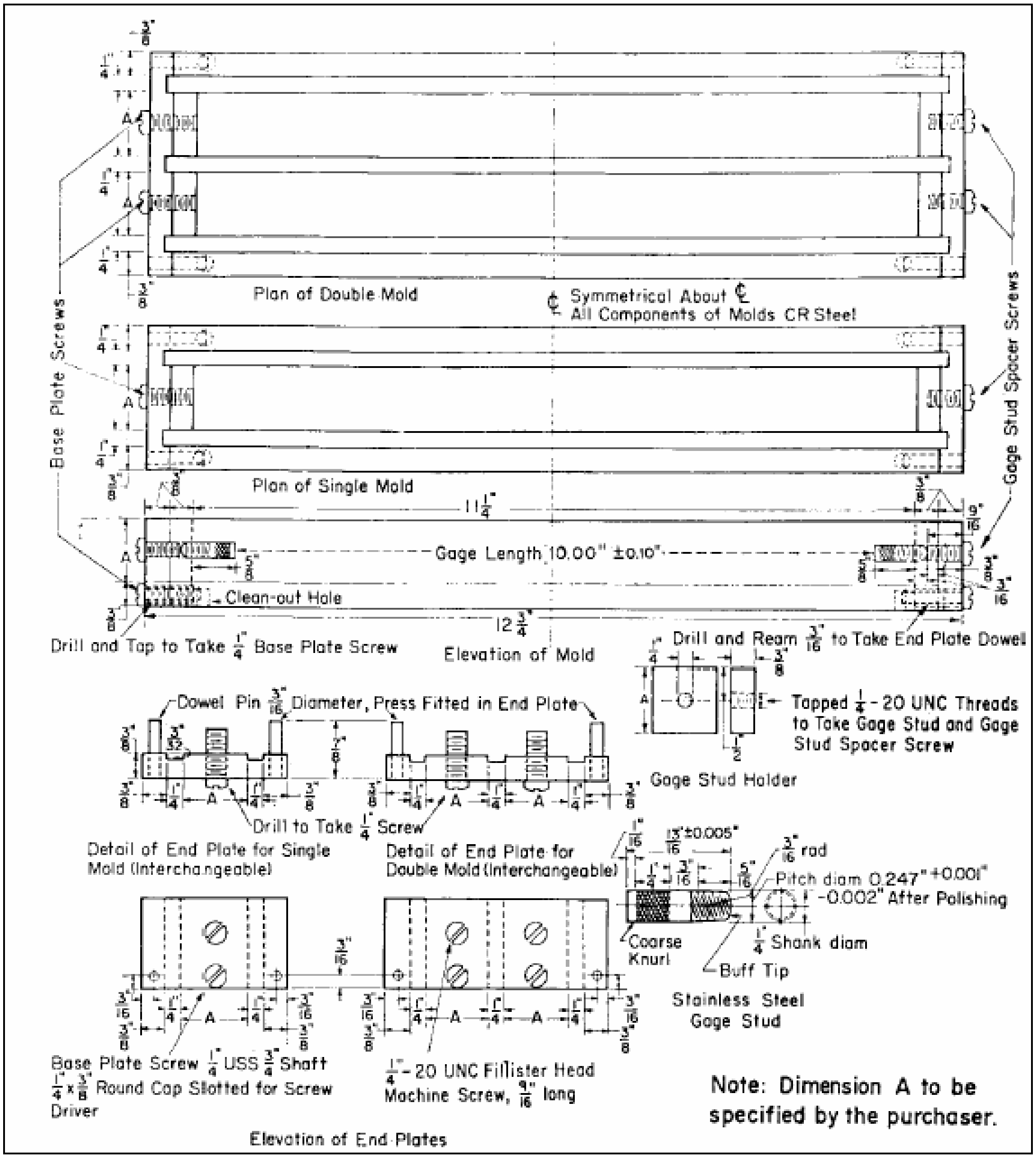
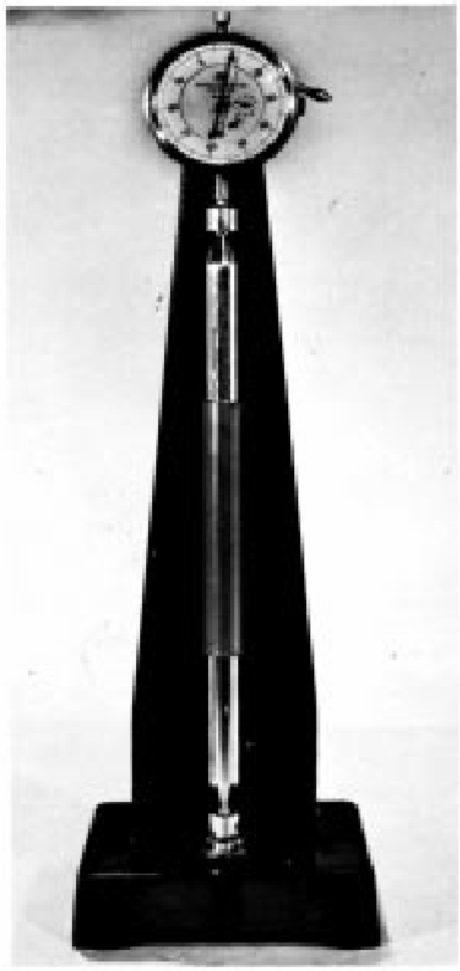


Figure A-3—Expansion test specimen mold schematics



Type of Suitable Apparatus for Measurement of Length Changes

Figure A-4—Reference bar

Alkali-Silica Reactivity (ASR) Testing for Tensile Strength

The testing method used is similar to that described in ASTM C496-90 (Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). For this testing, the slurry is cured in a 1.5 x 5-in. plastic mold to make three 1 x 1.5 inch specimens.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.

3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

Tensile strengths are determined at the Westport Technology Center. The cylindrical specimens are cured at Cementing Solutions, Inc. Following curing, a ¼-in. section is cut from each end of the specimen and discarded. Three 1-in.sections are cut and identified as top, middle, and bottom. The sections are then submerged in water for transport to Westport.

Testing is performed within 24 hours once the specimens are received at Westport.

Tensile strength measurements are performed at Westport according to ASTM standard C-496-2. Force is applied by constant displacement of the bottom plate at a rate of 1 mm every 10 minutes. The change in the specimen diameter can be calculated from the test plate displacement. The use of two pieces of plywood as described in ASTM designation C496-90-4.3 is not applied to this measurement.

The maximum reading is noted and used in the following equation:

$$T(psi) = (2*F) / (PI*L*D)$$

Where

T	= tensile strength (psi)
F	= maximum force recorded (lbf)
PI	= 3.14
L	= sample length (in.)
D	= sample diameter (in.)

Fig. A-5 shows a general schematic of how each specimen is oriented on its side during testing.

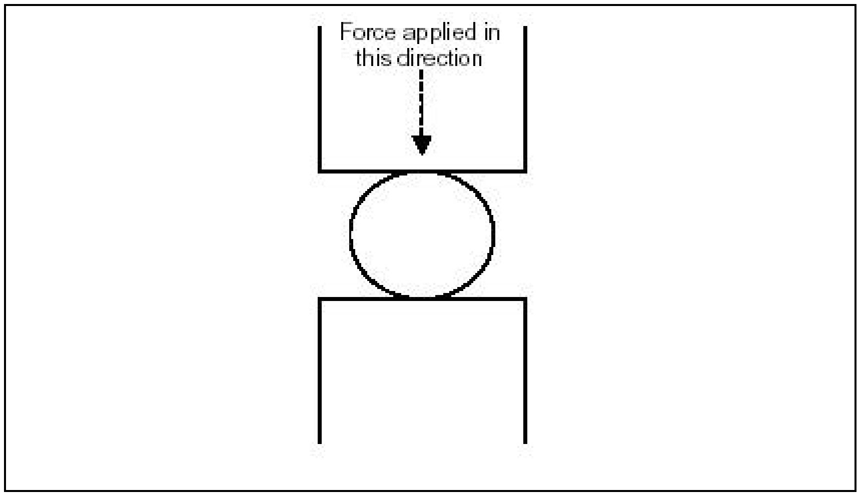


Figure A-5—Tensile strength crush diagram

Alkali-Silica Reactivity (ASR) Testing for Compressive Strength

Compressive strength testing is performed using modified API procedures. For this testing, the slurry is placed in a 1.5 x 5-in. plastic, cylindrical mold.

Curing Procedures

Cure each test specimen in a 174°F circulating water bath containing lime-saturated curing water, as described in the procedure below. Specimens remain confined in plastic molds until they are cut for strength determination.

1. Place the slurry in a mold, filling to approximately one-half of the mold depth, and puddle it.
2. Pour the slurry to the top of mold and puddle it.
3. Mark specimen molds for identification or positioning as required on brass plates inscribed with the slurry design.

Important—Monitor and adjust the curing water weekly to ensure that the lime concentration of the saturated aqueous solution is at 1,600 mg/L, +/- 300 mg/L.

Test Measurement

After curing, three 1-in. by 1.5-in. diameter cylinders are cut from each specimen. A ¼-in. section is cut from the ends of each specimen and discarded. Each section is identified as top, middle, and bottom.

Each sample is then placed in turn in a Carver press (hydraulic) for compressive strength measurements. Force is applied in accordance with API Recommended Practice 10B Section 7.5.6.1**.** A digital pressure gauge records the specimen's failure in pounds per square inch (psi).

Calculate the compressive strength as follows:

$$Cs = F / SA$$

Where

Cs	= compressive strength
F	= force
SA	= surface area

Fig.A-6 shows a general schematic of orientation of specimens during testing.

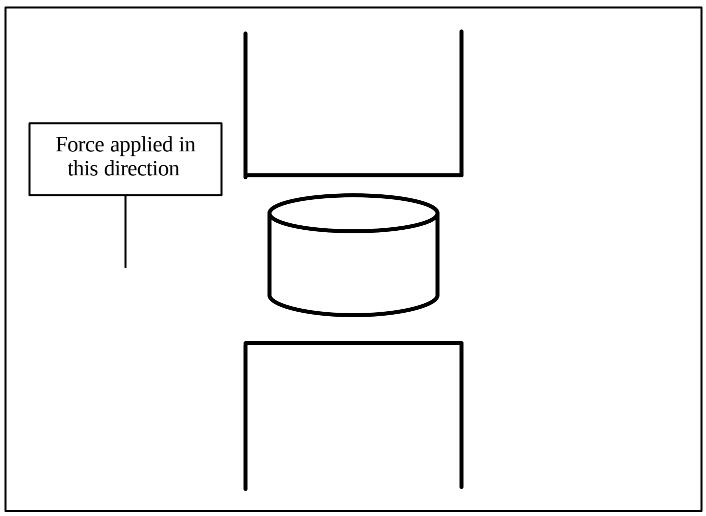


Figure A-6—Compressive strength crush diagram

List of Acronyms and Abbreviations

API—American Petroleum Institute
ASR—alkali-silica reactivity
ASTM—American Society for Testing and Materials
Bc—Bearden units of consistency
BHCT—bottomhole circulating temperature
BHST—bottomhole static temperature
BWOC—by weight of cement
$CaCl_2$—chemical formula for calcium chloride
cp—centipoise
gal—gallon
H_2O—chemical formula for water
hr—hour
ID—inner diameter
in.—inch
J—Joule
lb—pound
md—millidarcy
min—minute
MMS—Minerals Management Service
OD—outer diameter
psi—pound per square inch
rev—revolution
rpm—revolutions per minute
s—second
sk—sack of cement
QC—quality control
TXI—Texas Industries
TXI LW—manufactured lightweight cement available from TXI
ULHS—ultra-lightweight hollow (glass) spheres
3K—3,000-psi designation
6K—6,000-psi designation

References

1. "Recommended Practices for Testing Well Cements," API Recommended Practice 10B, 22nd Edition, American Petroleum Institute, Washington, D.C., December 1997.
2. ISO 10426-1:2000, Petroleum and natural gas industries—Cements and materials for well cementing—Part 1: Specification.
3. "Standard Test Method for Length Change of Hardened Hydraulic-Cement, Mortar, and Concrete," ASTM C157/C157M-99, Annual book of ASTM Standards Vol. 04.02.

4. "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM C496-96, Annual Book of ASTM Standards Vol. 04.02.
5. ISO 10426-5, Cements and materials for well cementing - Part 5: Test methods for determination of shrinkage and expansion of well cement formulations at atmospheric pressure.

Appendix 14

SmartCement User's Guide

SmartCement is a decision support system designed to pick the best lightweight cement additive based on the well parameters: cement type, slurry density, water, and well requirements. These cement conditions and well requirements are entered into the program; SmartCement then ranks mechanical properties of the cement and selects a recommended additive for the well conditions entered.

Installing SmartCement

To install SmartCement,

1. Insert the CD.
2. Unzip the **SmartCement1.CAB** file.
3. Click the **Setup.exe** file.
4. Launch SmartCement by clicking the **SmartCement1.exe** file.

Entering Cement Conditions

The SmartCement system consists of two main tabs in the **Data** pane as well as an **Analysis** pane. The two tabs are **Cement Conditions** and **Well Requirements**. The following figure shows the opening screen.

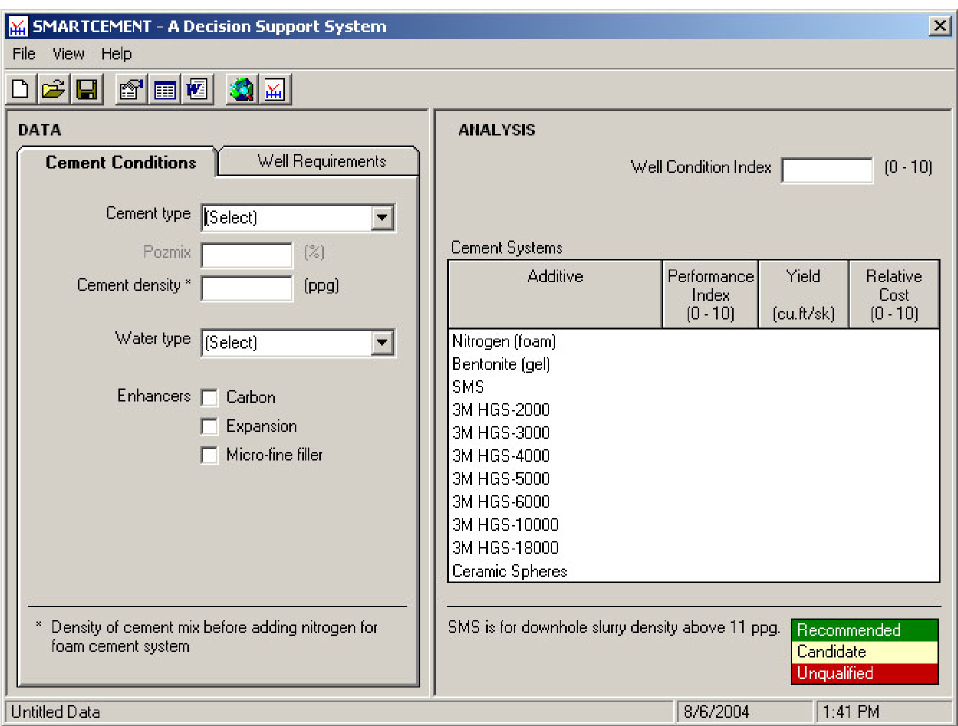


Figure 1.—SmartCement Opening Screen

To enter the cement conditions,

1. Click the **Cement Conditions** tab.
2. In the **Cement Type** pull down menu, select one of the following options:
   - Regular Type I/Class H – regular Portland-based cement
   - TXI lightweight – special lightweight cement
3. Enter a percentage of Pozmix/regular cement in the **Pozmix** field.

   Pozmix can only be used if regular Type I/Class H was selected as the cement type. If TXI lightweight was chosen as the cement type, this field will not be accessible.
4. Enter a cement density (mixed density). This is a required field for foam.
5. Select fresh water or salt water from the **Water Type** pull down menu.
6. Select enhancers (mechanical property enhancers) if desired. This is not a required field. The options are the following:
   - Carbon – carbon fillers
   - Expansion – expansion additive
   - Micro-fine filler

Entering Well Requirements

The following figure shows the **Well Requirements** tab.

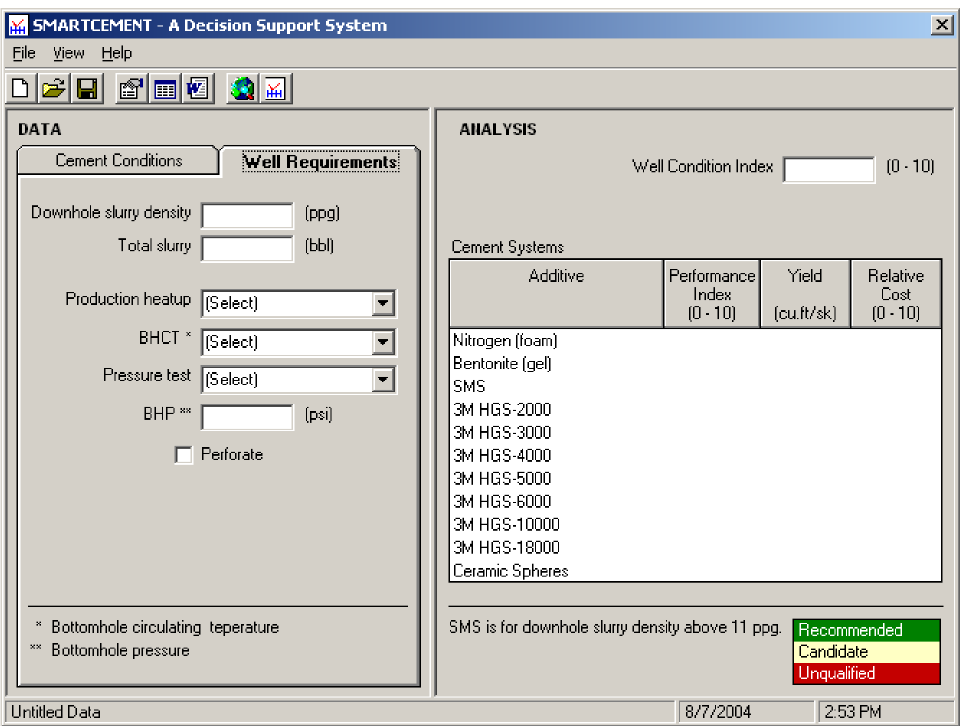


Figure 2.—Well Requirements Tab

To enter the well requirements,

1. Type the downhole slurry density. The number can have a decimal.
2. Enter the total slurry volume in bbl.
3. Select the production heat-up from the following categories. This is how fast it will be heated to BHCT.
   - High (>175ºF)
   - Medium (75ºF-175ºF)
   - Low (<75ºF)
4. Select the bottomhole circulating temperature (BHCT) from the following three categories:
   - High (>200ºF)
   - Medium (125ºF-200ºF)
   - Low (<125ºF)
5. In the **Pressure Test** pull down menu, select one of the following choices: None, Shoe Test, and Liner Top.
6. Enter the bottomhole pressure (BHP) in psi.
7. Click the **Perforate** box if you are going to do so.

Analyzing the Data Output

After all data is entered, SmartCement calculates and recommends the best additive for the information entered. Recommended additives are highlighted in green; suitable candidates are highlighted yellow; and unqualified candidates are highlighted red. The following figure shows an example of an analysis.

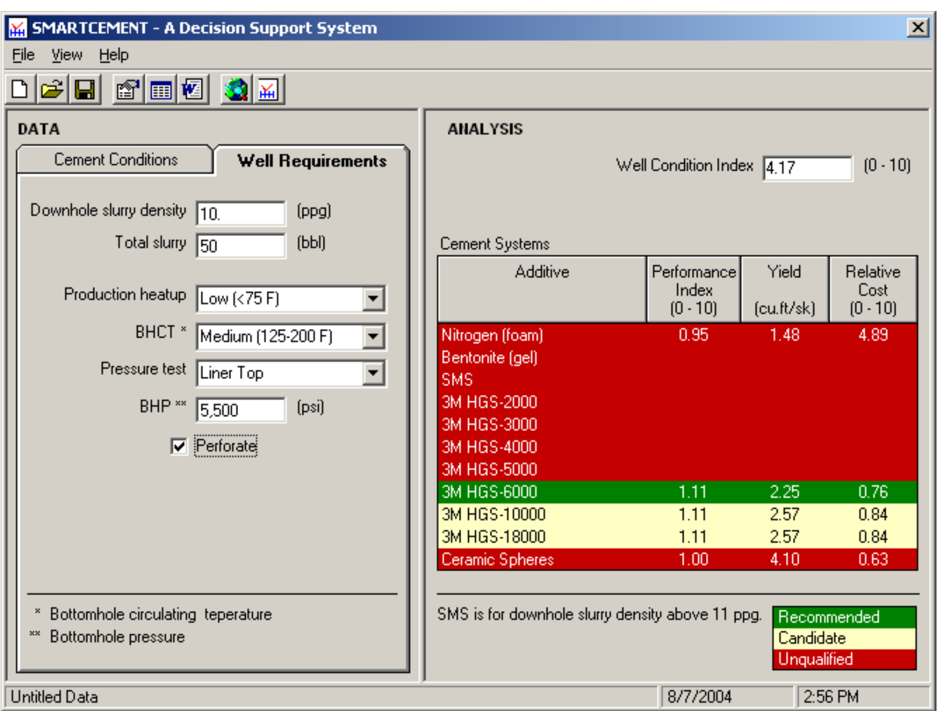


Figure 3.—Analysis Screen

Arriving at the Recommendation

The SmartCement program contains tabulated data for three mechanical properties for each additive, tensile strength, anelastic strain, and compressive strength.

The application indexes the mechanical property data and well requirements data. The mechanical properties index is divided by the well conditions index, and the result is the performance index. If the performance index is greater than one, the additive is a candidate. If the performance index is less than one, the additive is unqualified. The Recommended additive is based on the lowest relative cost of all the candidates.

Using the SmartCement Toolbar

The **SmartCement** toolbar can be used to create new files, open existing files, or save current files. It can also be used for generating reports or linking to CSI's website. The following figure shows all the icons on the toolbar.

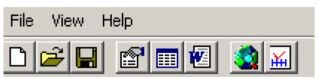


Figure 4.—Menu and Toolbar

—Creates a new file.

—Opens an existing file.

—Saves the current file.

—Opens the **Project Information** dialog box shown below. Enter the appropriate information for the project in the provided fields.

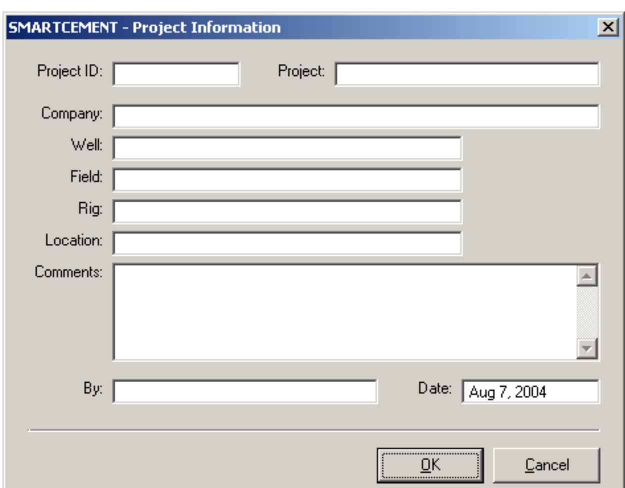
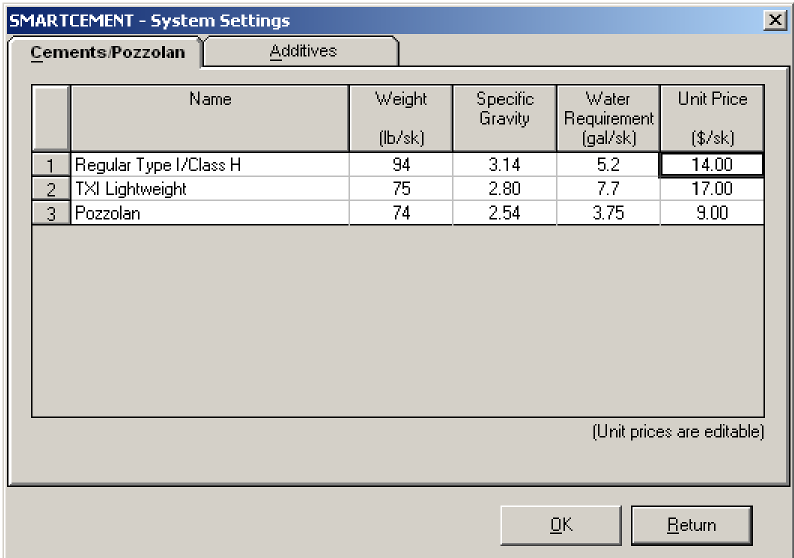


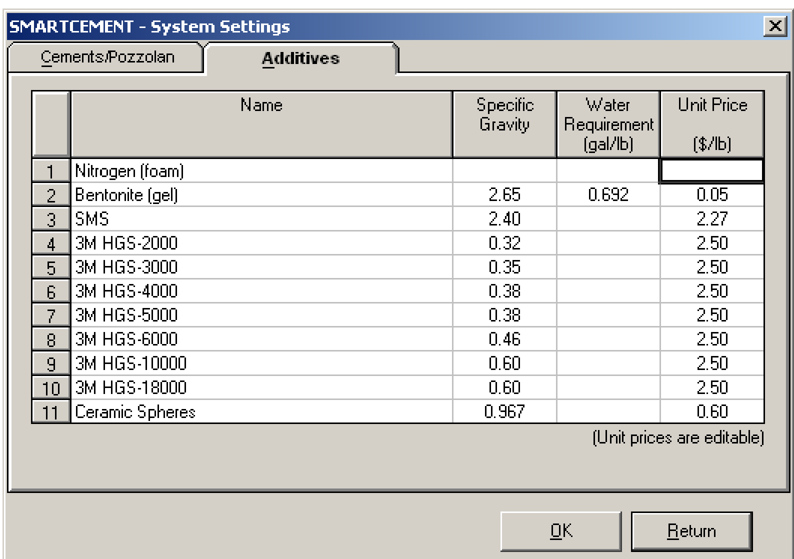
Figure 5.—Project Information Pop Up Window

—Shows the system settings for calculations and allows the user to change the unit prices. No other system settings can be changed. The **System Settings** window has two tabs, the **Cement/Pozzolan** tab and the **Additives** tab as shown in the following figures.



	Name	Weight (lb/sk)	Specific Gravity	Water Requirement (gal/sk)	Unit Price ($/sk)
1	Regular Type I/Class H	94	3.14	5.2	14.00
2	TXI Lightweight	75	2.80	7.7	17.00
3	Pozzolan	74	2.54	3.75	9.00

Figure 6.—Cements/Pozzolan Tab



	Name	Specific Gravity	Water Requirement (gal/lb)	Unit Price ($/lb)
1	Nitrogen (foam)			
2	Bentonite (gel)	2.65	0.692	0.05
3	SMS	2.40		2.27
4	3M HGS-2000	0.32		2.50
5	3M HGS-3000	0.35		2.50
6	3M HGS-4000	0.38		2.50
7	3M HGS-5000	0.38		2.50
8	3M HGS-6000	0.46		2.50
9	3M HGS-10000	0.60		2.50
10	3M HGS-18000	0.60		2.50
11	Ceramic Spheres	0.967		0.60

Figure 7.—Additives Tab

—Produces a Microsoft Word report based on the information entered and analysis produced. The following figure shows a sample report.

SMARTCEMENT - A Decision Support System
Project Report

Project Information

Project ID:
Project:
Company:
Well:
Field:
Rig:
Location:
Comments:
By:
Date:

Input Data

Cement Type:	Regular Type I/Class H
Pozmix:	50. (%)
Cement:	50. (%)
Cement Mix:	16.4 (ppg)
Water Type:	Fresh Water
Enhancers:	Micro-fine filler
Downhole Slurry:	10. (ppg)
Total Slurry:	50 (bbl)
Production Heatup:	Low (<75 F)
BHCT:	Medium (125-200 F)
Pressure Test:	Liner Top
BHP:	5,500.0 (psi)
Perforate:	Yes

System Evaluations

Candidate 1: ($/cu.ft)	Regular Type I/Class H + Pozzolan + 3M HGS-6000	76.32
Candidate 2: ($/cu.ft)	Regular Type I/Class H + Pozzolan + 3M HGS-10000	83.56
Candidate 3: ($/cu.ft)	Regular Type I/Class H + Pozzolan + 3M HGS-18000	83.56
Recommended: ($/cu.ft)	**Regular Type I/Class H + Pozzolan + 3M HGS-6000**	**76.32**

Figure 8.—Sample Report

—Links to the CSI website.

—Shows the version information for the SmartCement software.