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Composite Drill Pipe for Extended-Reach and Deep Water Applications

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ABSTRACT

Extended Reach and Deep Water Drilling are constrained by the weight of the steel drill pipe. Transfer of data between the bottom hole assembly and the well head is currently cumbersome, slow, and provides less real-time data than desired. Recognizing these limitations, the U.S. Department of Energy, National Energy Technology Laboratory, has funded a three-year program to develop and qualify a cost-effective composite drill pipe (CDP). This pipe will provide enabling capability in all three of these areas. The program was started on September 30, 1999 and had the goal of having composite drill pipe approved and commercially available by September 30, 2002. Three and three eights inch CDP, qualified for short radius drilling, was made available for use in the spring of 2002. Availability of a nominal 5 ½" size CDP is projected for early spring of 2003.

INTRODUCTION

The projected future demand for natural gas is a major driving force for offshore exploration to move to even deeper water and to extend the reach obtainable from drilling platforms.

In recent years, constrained by lower than desired return on investment (ROI) the petroleum industry has had to take a cautious approach in managing risks. Because research and development (R&D) is often one of the most risky, capital- intensive ventures a company has to deal with, it has been significantly reduced in recent times and even "outsourced". This environment in large part, explains why R&D expenditures by major producers have fallen by more than 50% since 1992. This trend seems contraindicative to successful resource development considering the major technological challenges facing industry with regard to the ultra-deepwater Gulf of Mexico and deep, unconventional reservoir environments associated with onshore gas resource development.

The focus of the Strategic Center for Natural Gas, in the Department of Energy's National Energy Technology Laboratory (NETL), is to work with industry to reduce risk through cost sharing in the development of technologies NETL considers essential for future development of domestic gas resources. As a driver for this interest, note in Figure 1 that gas demand is expected to increase significantly beyond the available supply of conventional and unconventional domestic resources by 2020. This trend results in concern for development of those technologies, which would enhance gas resource development and, thus, mitigate such national energy security issues.

One of those key technologies is composite structures, more specifically composite drill pipe. Because the composite drill pipe has the potential to be lighter (1/2 the weight of steel) and maintain required performance properties, it is considered one of the technologies potentially essential for ultra-deepwater resource development. Onshore, it will allow the existing fleet of drill rigs to drill to much greater depths. And, as a third benefit, it has significant potential to enable high speed communications (for smart drilling) up the drill pipe because of the ease of placing cables and/or fiber optic leads within the body of the drill pipe. While use of composites has increased dramatically in recent years, the cost and performance of these structures has kept them from being used more widely. With the advance of carbon fiber technology, composite structures are beginning to have the performance capabilities to compete with steel. In addition, now that carbon fibers are getting cheaper and pipe designs more sophisticated, the opportunity exists to develop a pipe, which can be cost competitive with steel. Hence, DOE is interested in attempting to accelerate development of this much-needed capability as part of its overall drilling technology portfolio to meet tomorrow's gas resource development challenges.

During the first two years of this NETL/DOE supported program, specifications for both nominal 5 ½ inch and 3 3/8 inch composite drill pipe have been finalized, materials for the composite tubing, adhesives, and abrasion coatings have been selected based on laboratory testing, and a composite tube/metal tool joint interfacial connection has been successfully tested (the tool joints in CDP are metal). See SPE 67764[1] and SPE 14266[2].

Existing facilities are being modified to allow pilot plant production of 30-foot sections of CDP at ACPT, Inc., in Huntington Beach, CA. Samples of 3 3/8 inch CDP for use in a short radius well drilling operations were provided early in C.Y. 2002. It is anticipated that commercial CDP will be available in the near future at 3 to 5 times the cost of comparable steel pipe. The nominal 5-½ inch composite drill pipe will be ready for initial drilling operations by spring of 2003.

Application of Composite Drill Pipe

Initially, the impetus to develop "cost effective" composite drill pipe was only the potential for weight savings: estimated to be less than 50% of comparable steel pipe. Further examination of the literature and discussions with knowledgeable drilling experts has better defined the potential advantages of composite drill pipe.

Smith, Chandler and Boster, SPE 67722[3], presented an excellent analysis of the problems associated with extended reach (ER), ultra deep (UD), and deep directional drilling (DDD). They pointed out the current limits are controlled by the strength to weight ratio of steel drill pipe (SDP). Materials with higher specific strength ratios will increase these limits in all three zones (See Figure 2). The strength to weight ratio of the nominal 5 ½ CDP will be 625,000 in 30 foot sections and 1,011,000 in 45 foot sections, compared to 480,000 for 135 steel and 750,000 for titanium. A 62.4%or 101% improvement over steel D.P. and –9.3 or +34.8 over titanium.

Calculations by Omsco for drill pipe in 10# /gal. mud provides the following comparison: for 6 5/8, 27.70 Grade S steel drill pipe the ultra depth allowable would be 32,000 feet, for titanium 50,000 feet, and for CDP at least 50,000 feet and possibly to over 70,000 feet (depending upon the grade) of carbon fiber used.

As shown above, offshore drilling can be divided into three regions. While increased strength to weight ratio is always advantageous each region places somewhat different requirements on the drill pipe. In E.R. (where Reach/TVD is 0.75), the limits are associated with both high angle (fatigue) and frictional effects resulting from the combinations of high angle, curve and/or total weight. It is noted and confirmed by SPE 37646[4] that CDP can be designed for flexibility such that the radius of curvatures of the hole as small as 40 feet (140 degrees per 100 feet) are within its fatigue limits. SPE 22548[5] shows a case wherein the possible horizontal reach is 3 times that of SDP for a medium radius horizontal well. This reach increase was attributed to a lowered frictional loading (light weight CDP).

It is here worthy to note that unlike any metal DP, the CDP can easily be designed, ordered, and produced to meet specific requirements for specific applications. To increase tension and compression strength more longitudinal fibers are used, similarly more hoop fibers will increase pressure capability and more fibers at a nominal 45º will improve torque capacity. In like manner, fibers with different properties are available and can be used to increase properties (at higher cost) or provide more economical CDP if the highest properties are not necessary.

Current CDP designs (presented here-in) were designed for specific load conditions. Where different loading conditions are to be encountered, the CDP can be designed for the particular application (well or portion of a string). The mechanical properties are well established and are strictly a function of the resins and fibers used and the orientation and amount of fiber in the CDP tube. This will allow any section (s) of the CDP to be optimized for the given requirements. The new design (s) can then be fed into the computer controlled tube-winding machine and specific CDP sections will be produced for specific applications.

As an example of the ability to tailor the design of composites, consider the 3 3/8" CDP shown in Table 1. It was designed for a torque load of 2000 foot lbs. As designed, a 30-foot section (including steel pin and box ends) will weigh 76.4 lbs. (31# for the joints), a 45-foot section, 100 lbs. The tensile strength of this pipe is 65,500 lbs. The resultant strength to weight ratios is 700,000 and 780,000 respectively. If this design had been for a 1000 lb. torque load, and tensile strength of 135,000 lbs., it would provide strength to weight ratios of 1,430,000 and 1,610,000 respectively for 30 or 45-foot sections.

Cost issues must also be considered. In production, the designs shown in this paper, will cost on the order of 3 to 5 times "standard" S-135 steel drill pipe. Several items need to be addressed in this regard. First, the CDP represents an enabling technology, its use will allow deeper and longer reach drilling than is possible with metal drill pipe. In addition, the drilling limit is often not the DP; rather it is the lifting or torque applying capability of the rig. Another rig limitation can be the deck loads on a floating offshore vessel. Lighter DP can extend both.

Second, when SDP is at its limits, special (expensive) precautions have to be taken. That is, the SDP has more stringent manufacturing requirements and more stringent and frequent field inspections. It is not as robust a design when near the technical limits.

Thus, even where SDP may be used (near the technical limit), CDP will lower the loads and operate at a smaller percentage of its limits… therefore be more robust. It is also noteworthy for these applications, that the CDP will have much higher fatigue properties than the steel counter part.

Third, with CDP we can easily "tailor or customize" the mechanical properties for its application and/or location in the drill string. For example, in an extended reach well, steel drill pipe would likely be used in the large vertical hole sections, while CDP would be used in the curve and high hole angle sections of the well. This allows optimization not possible when only SDP is used. Thus, even though CDP will always be more expensive than SDP on a joint per joint basis, the cost/performance of the total drill pipe string can be optimized.

Fourth and very importantly, with the weight of the drill pipe at 40% to 50% of steel, the loads to be transported and the weight supported by the drilling platform are significantly reduced. These reductions can provide very substantial cost savings.

Fifth, when the capability to reliably transfer real time signal (and power) across the metal tool joints is reduced to practice, the cost of drilling can be drastically reduced. This reduction will be effective in all drilling operations not just extended reach or deeper drilling.

Mechanical Strength Specifications for Composite Drill Pipe.

Initial work on this project concentrated on specifying the requirements for a "typical" drill pipe as a target for the CDP. These requirements have been refined during this program and will be upgraded as experience in the manufacture and use of CDP is obtained. Initially, industry partners supplied mechanical requirements identical to those of 5 7/8 inch high strength steel drill pipe (Column 1, Table 1). These were reviewed and modified through open forum industry discussions. Revised mechanical requirements were then converted to conform to the mechanical/weight characteristics possible with low cost graphite/epoxy materials. More recently, the required mechanical specifications have been exhaustively analyzed through joint efforts with Omsco. These results have been applied and are reflected in the nominal 5 ½" CDP specifications shown in Table 1.

Further consultation, with industry contacts defined an immediate need for 3 3/8 inch drill pipe to be used in short radius applications. Initial 1/3-scale testing demonstrated that the ACPT designs can meet the requirements for this size pipe. The final specifications, arrived at through discussions and analysis with a drilling contractor, are also shown in Table 1 (Column 4). Short and full length sections designed to these specifications have been manufactured and supplied for actual drilling operations.

Program Development and Current CDP Status

The testing portion of this project includes initial material screening through final in-ground evaluation of market-ready CDP. The material screening and material properties verification portions are complete. Laboratory testing included verification of mechanical, thermal and environmental properties of resins, fibers, and adhesives, and measurement of erosion and mechanical abrasion characteristics of interior and exterior coatings for CDP is complete.

Materials Testing and Selection. Temperature capability and environmental resistance were evaluated through short beam shear (SBS) and in-plane shear tests. SBS testing provides an excellent screening tool for evaluating the mechanical relationship between the resin and the fiber in composite structures. Short beam shear tests were run on the selected materials after exposure to wet and dry temperature environments ranging from ambient to 350ºF, and the results were presented in SPE paper 67764(4). SBS tests were also performed after temperature and pressure exposure to water base and oil base drilling muds at a similar range of temperatures and simulated downhole pressures for 10 days.

These tests proved that, as anticipated, the graphite fiber/epoxy matrix experienced a reduction in high temperature shear strength after exposure to moisture. It was postulated that the strength degradation was caused by hydrolysis of the resin. However, this does not constitute a fatal flaw. Resin softening is a diffusion-controlled phenomenon and the very small (¼ inch x ¼ inch x 1 inch) SBS specimens present the absolute worst-case exposure conditions. Actual CDP will be a continuous tube with walls approximately ½ inch thick and with environmental protection on both the inside and outside surfaces. In addition, drill pipe does not experience long term continuous exposure at the most extreme environmental conditions. Therefore, a second set of 100 hour boiling water exposure tests were run with in-plane shear specimens and with 1/3 scale pipe. The results of these environmental exposure tests showed that the current composite matrix can be used in downhole conditions up to 350ºF. The approved materials, as selected in this program are as presented in SPE 67764(1).

It is noted here that use at more elevated temperatures can be accommodated with higher temperature capable resin systems. Such systems are available; their use at this time would increase the cost of producing CDP. Incorporation of higher temperature systems will be considered at a later date.

As composites are much more susceptible to wear and abrasion than steel, it was recognized at the beginning of this program that CDP would have to be protected from mechanical wear. A dual approach was planned for protecting the exterior of CDP from abrasion: a highly wear resistant coating plus centralizers.

ACPT screened more than 20 potential coating systems for external abrasion protection and evaluated five selected systems through Slurry Abrasion Resistivity (SAR) testing. SAR is a standard wear test used to measure wear resistance within slurry pumps and is accepted by the oil industry. Results showed that at least one coating system (numbered 2201 in Figure 3) compares favorably with 4130 steel. ACPT has also evaluated "off-the-shelf" centralizers and determined that in addition to the abrasion resistant coating, field replaceable high durometer electrometric centralizer units will need to be utilized with CDP.

Testing of Pipe Sections. The major difficulty in producing a commercially useful composite drill pipe has always been recognized as the interface between the composite tube (pipe) and the steel joints. In order to reduce developmental costs ACPT broke the CDP development and testing into two distinct areas: subscale design and testing and full-scale design and testing. One-third size (diameter) was chosen for the small-scale effort and the full-scale work was broken into full diameter pipe in 10-foot sections and full diameter pipe at the full length of 31.5 feet (shoulder-to-shoulder) of the metal joints. To date, the 1/3 scale testing is complete; 10-foot sections of full diameter CDP have been fabricated and tested; and tooling, fabrication equipment, and procedures are being prepared for building the 31.5-foot test units. The 1/3-scale test specimens are 1.417 inch ID and have 12 inches of composite tube between the steel joints.

Twenty six (26) different 1/3-scale tension tests were completed. The results of these tests are summarized in Figure 4. Fifteen different combinations of composite/metal joint interface and composite wall configuration were evaluated. After testing showed that a successful composite/metal interface design had been achieved, full size, 10-foot sections of CDP were fabricated and tested. Figures 5 and 6 show 10-foot sections of full size CDP undergoing tension and torsion testing.

More recently, based upon the final 1/3 scale work and in order to qualify for short radius drilling, 3 3/8 inch sections have been tested. The results of these tests proved that the full-scale requirements will be met. Fabrication of specimens for "proof-prior-to-drilling" testing of the CDP is underway. This will include laboratory testing of full size nominal 5 ½" and 3 3/8" CDP, and field-testing of 3 3/8" CDP in drilling short radius wells. Figure 7 shows ACPT's source control drawing for the 3 3/8" CDP. The source control drawing for the nominal 5 ½" CDP is shown in Figure 8. An alternate Range 3 design with a tube bore larger than the tool joint bore is under development. The dual bore diameter will further reduce circulation pressure losses.

Transfer of Real Time Signals or Power through CDP

Transfer of Electrical Signal or Power Across Joints. A significant feature of CDP is that it can be designed to carry electrical power and/or real time communication lines embedded in the composite walls. The problem to be solved is reliably transmitting signal or power through the metal joints connecting individual CDP sections. Several approaches to solving this problem are currently being examined.

Direct Connect. This has been tried unsuccessfully numerous times. Several revised concepts are being investigated for ACPT by a competent engineering firm.

Acoustic Transmission. This concept is being explored with DOE funding by another contractor.

Inductive Transmission. This approach shows positive potential. Sandia National Laboratory is continuing to investigate inductive transmission. Inductive coupling has been considered and will be further investigated if the conceptual demonstrations show sufficient merit.

In anticipation of the development of a successful method for transmitting signals across metallic joints, Sandia National Laboratory has evaluated signal loss/transmission characteristics in CDP with wires incorporated into the walls of the pipe. The results proved conclusively that signal transmission can be accomplished.

Composite Drill Pipe Manufacturing

Composite drill pipe consists of a composite material tube with steel box and pin connections. The tube is manufactured by winding a composite material consisting of graphite fibers and an epoxy resin around a metal mandrel and the metal box and pin connections. This length is then cured before the mandrel is removed and recycled. The cured pipe section is finish machined and coated for abrasion resistance. As final preparation, normally done in the field, standard electrometric "centralizers" are added where required. It is noted that both the centralizers and the abrasive resistant coating can be field repaired. More extensive wear, should it occur and not be too severe, can be repaired by recycling the CDP back through the factory. Steel drill pipe protectors (rotating or non rotating) can also be incorporated into the design.

Manufacturing of Full Scale CDP

Existing equipment is being modified to allow "pilot plant" production of 30-foot sections of CDP. Additional capacity will require the incorporation of automation and continuous operation to the winding, curing, and machining functions. ACPT is working closely with Omsco, a unit of ShawCor Ltd., to establish marketing levels and schedules. These results will determine the schedule and extent of pilot plant upgrade or the necessity to build a full scale, continuous operation CDP production unit. At a future time, a full scale manufacturing plant will be installed to expand production rates and to allow production of Range 3 CDP. Range 3 CDP will have even higher strength to weight ratios.

Disclaimer

References

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2. Leslie, Dr. J.C., Williamson, S., Long, R., Jean, J., Truong, L., Neubert, H. Leslie, J. II : OTC Conference, Houston, Texas, May 9, 2002.

3. Smith, Chandler, and Boster: "Titanium Drill Pipe for Ultra-Deep and Deep Directional Drilling", paper 67722, presented at SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, February 27 – March 1, 2001.

4. Hareland, Lyons, Baldwin, Briggs, and Bratli: "Extended Reach in Composite Materials for Drill Pipe", paper SPE 37646(2), presented at SPE/IADC Drilling Conference held in Amsterdam, The Netherlands, March 4-6, 1997.

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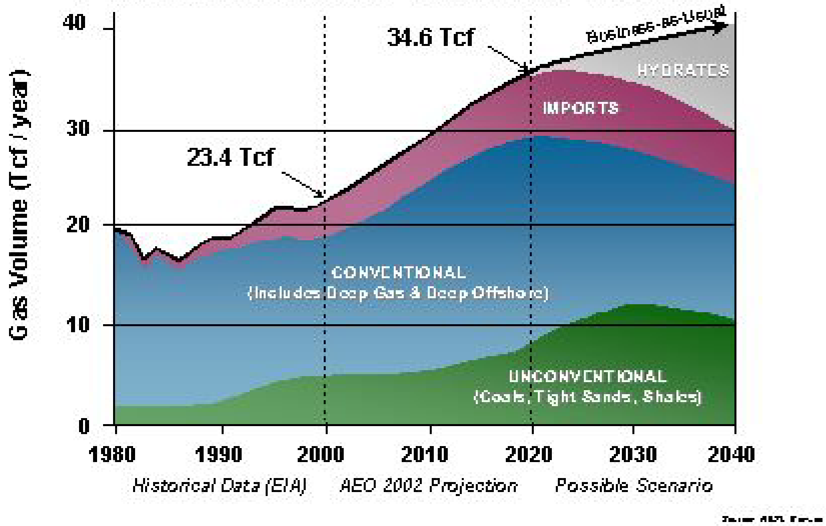
Table 1 : CDP Specifications

Case	Specifications Initial Requirements 5 7/8”	Revised CDP 5 7/8”	Revised CDP Nominal 5 ½”	CDP 3 3/8”
Tension (1000 lb. load)	20,000 TVD plus 133 Applied 199.5 Test 399 Ultimate	20,000 TVD plus 133	20,000 TVD plus 133	25 (OP) 75 (ULT)
Compression (1000 lb. load)	30 Applied 45 Test 90 Ultimate	30	30	50 (OP)
Torsion (1000 lb. load)	30 Applied 45 Test 90 Ultimate	56.25	37.5	2 (OP) 6 (ULT)
Internal Pressure (psi)	3,500 Applied 5,000 Test 10,500 Ultimate	11,875	11,000	1,000 (OP) 2,000 (ULT)
External Pressure Differential (psi)	4,500 Applied 6,750 Test 13,500 Ultimate	4,500	6,500	1,000 (OP) 2,000 (ULT)
Temperature (°F)	-67 to 250 Applied -67 to 250 Test -67 to 350 Ultimate	350	350	350

Figure 1
Gas Needed to Meet Demand



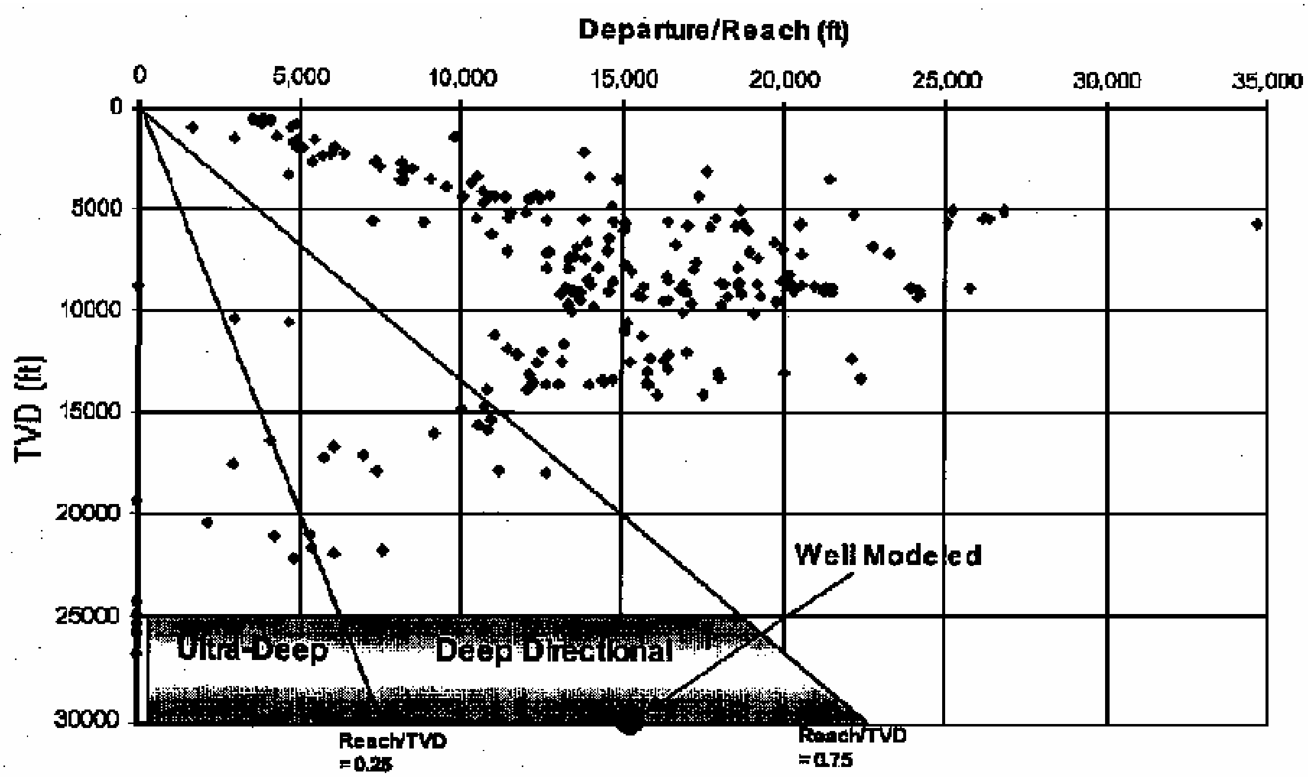


Figure 2: Industry ER, UD and DDD Activity

(reproduced from SPE paper 67722)

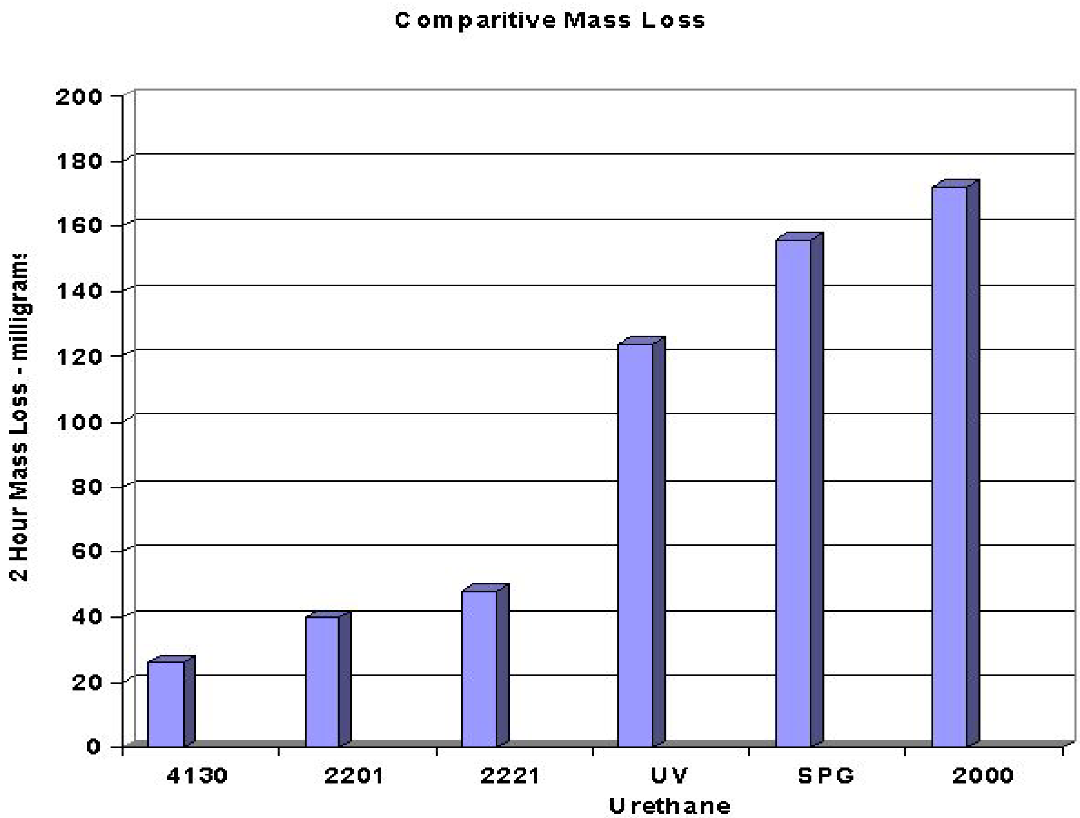


Figure 3: Results of Abrasion Testing of Various Coatings

Figure 4: One Third Scale Tension Test Summary

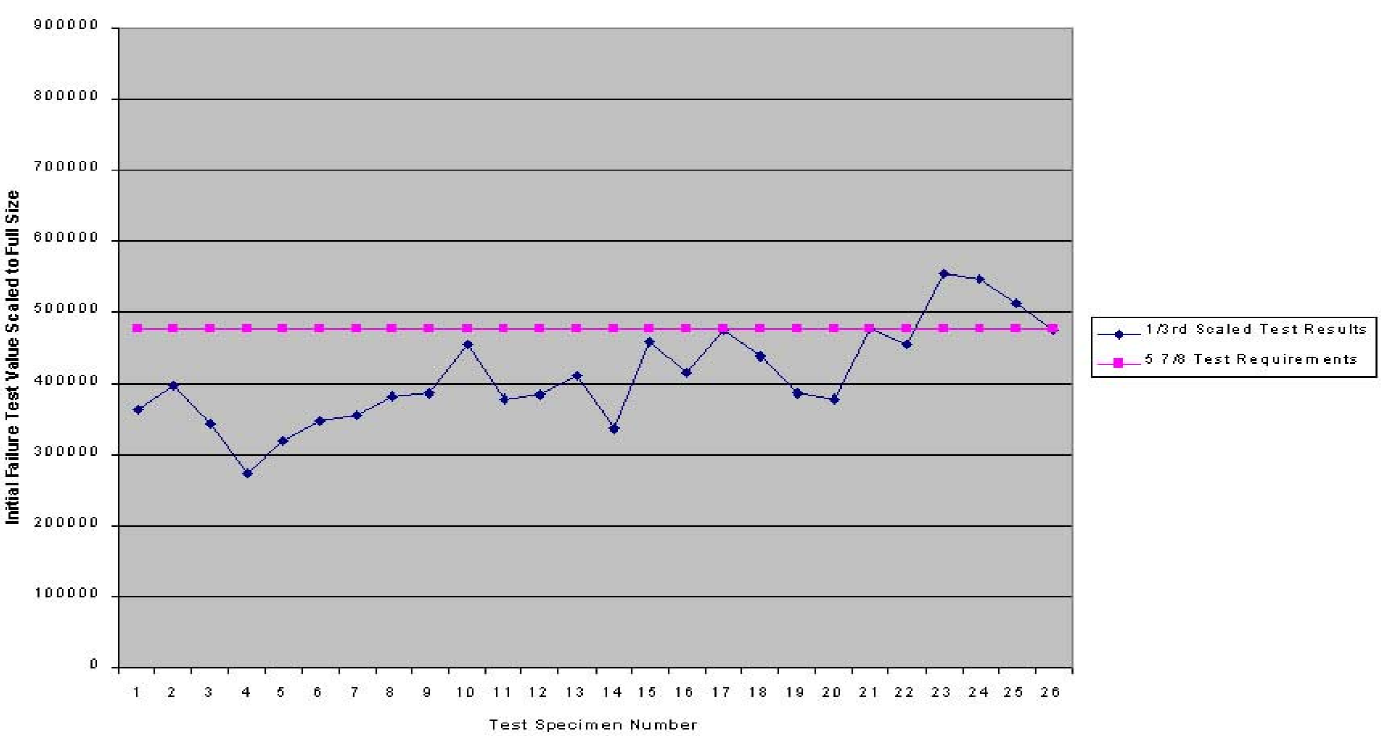


Figure 5 : 10-Ft Full Diameter Torsion Test

Figure 6: 10-Ft Full Diameter Tension Test

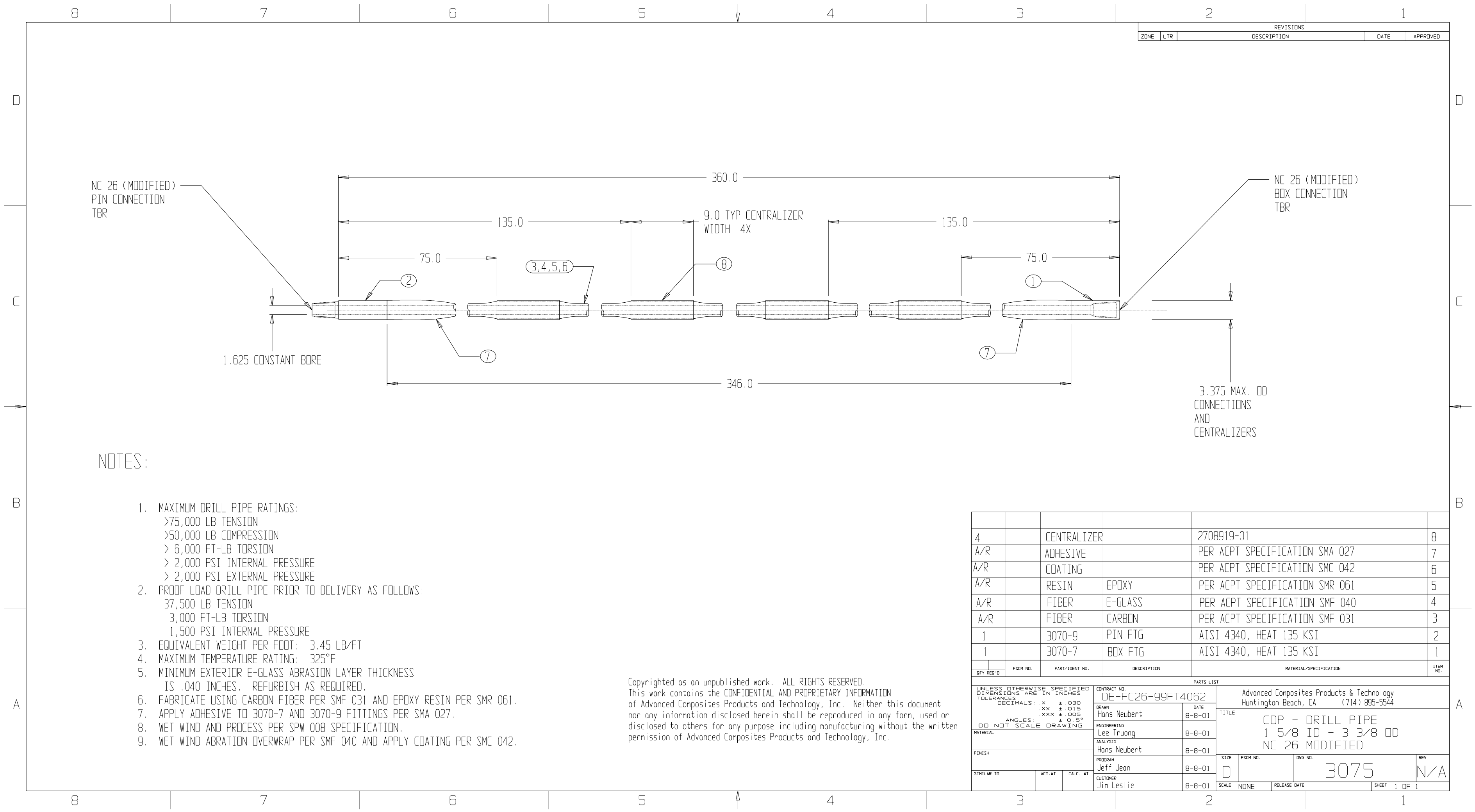


Figure 7: Source Control Drawing for 3-3/8" CDP

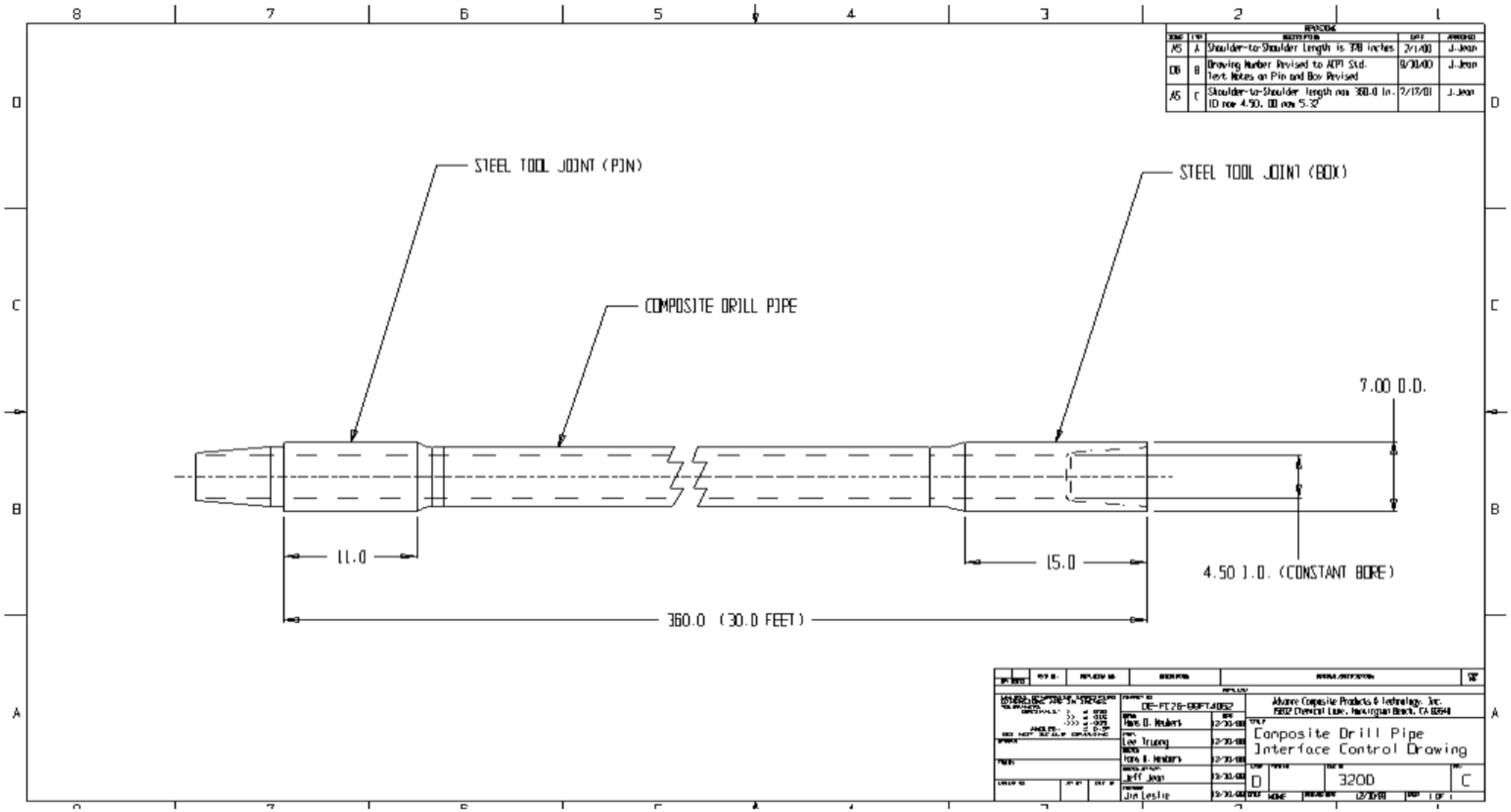


Figure 8: Source Control Drawing for Nominal 5-1/2” CDP