Oil & Natural Gas Technology

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Quarterly Research Performance Progress Report
(Period ending 09/30/2016)

Borehole Tool for the Comprehensive Characterization of Hydrate-Bearing Sediments

Project Period (10/1/2013 to 9/30/2017)

Submitted by:
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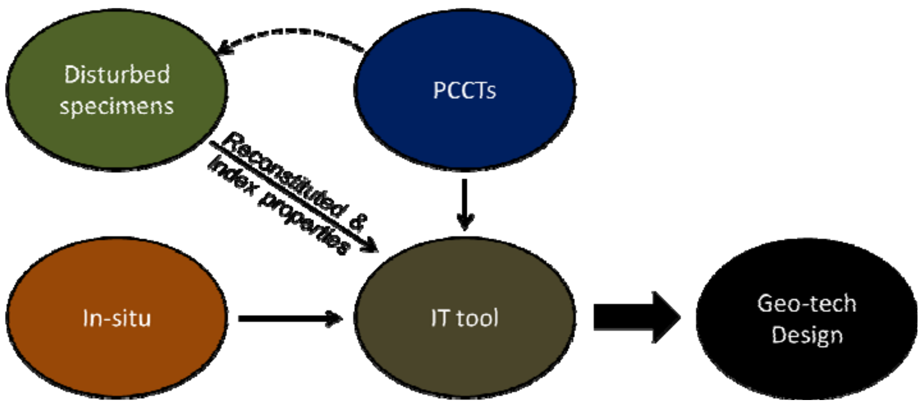
Office of Fossil Energy

DISCLAIMER:

Context – Goals.

The physical properties of hydrate bearing sediments are critical for gas production strategies, geo-hazard mitigation and its impact on gas recovery engineering. Typically, the determination of physical properties relies on correlations and experimental data recovered from conventional and pressure cores. Inherent sampling disturbance and testing difficulties add significant uncertainty. In this research, we develop a new comprehensive borehole tool for the characterization of hydrate bearing sediments, and an IT tool for the physics-bases selection of appropriate parameters.



Accomplishments

The main accomplishments for this period include:

- Tool deployment in the Red Sea:
    - Deployment procedure updates
    - Penetration resistance
    - Thermal properties
    - Hydraulic conductivity

Plan - Next reporting period

(1) modifications / updates of the tool and electronics after field deployment

(2) fundamentals of thermal properties measurement techniques

(3) preliminary design of coupling mechanism of the tool and BHA

Research in Progress

Borehole Tool – Field Test

Introduction. An offshore test has been performed on the near coast of King Abdullah University of Science and Technology (KAUST, Saudi Arabia). The location for this test is shown on the Figure 1 at about 12 km from the shore. The test site was advised by the Coastal and Marine Operations Resources of KAUST and agreed together with the Coast Guard. The water depth at this site is 20.6 meters. Figure 2 summarizes the field work.

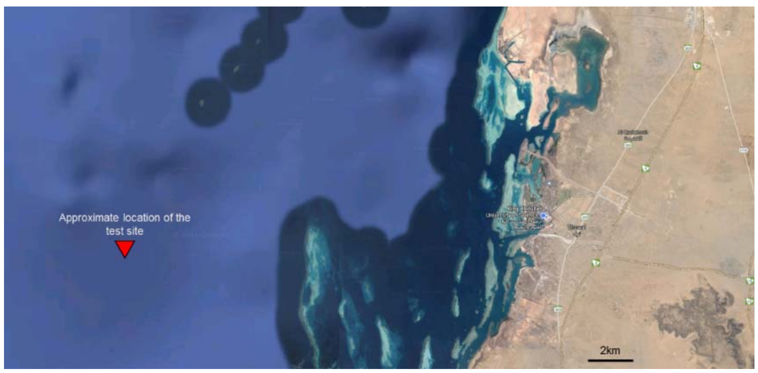


Figure 1. Test site: 12 km offshore KAUST.

Figure 2. Tool deployment. a) Research Vessel Thuwal R/V; b) Departing from KAUST; c) Tool ready to be lowered; d) Tool recovery.

As part of this field test, two deployments were accomplished. It was possible to: determine penetration resistances, water pressures, thermal properties, and obtain soil and water samples.

Tool and general procedure. For this deployment, the in-situ tool was assembled as shown in Figure 3.

Typical testing procedures are following:

- Arrival at the testing site;
- Lower the tool up to 5 meters for stabilization and final check for electronics and sensors;
- Sediment testing: cone penetration at a rate of 2 meters/minute;
- Controlled water sampling;
- Tool recovery.

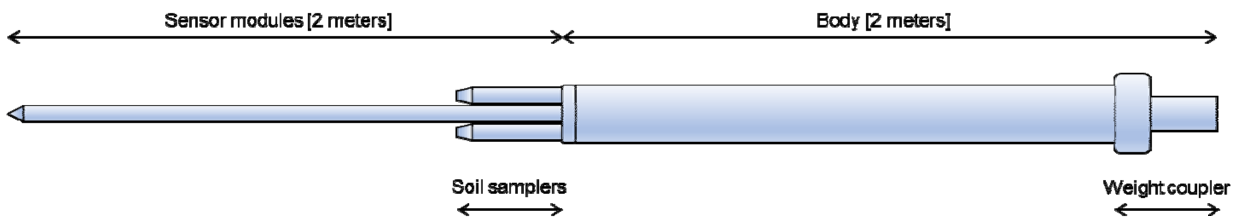


Figure 3. General schematics of the tool and the dimensions.

Figure 4 shows the measured water pressure and penetration rate recorded by a built-in accelerometer. Key sequential events (marked in Fig. 4 as well) can be summarized as:

1. Setting the tool vertical;
2. First approach up to 5 meters water depth;
3. Stabilization at 5 meters depth and general check of electronics/sensors;
4. Descent to a maximum water depth of 20 meters at a rate of 2 meters /minute;
5. First touch to the sediment, tool stabilization, and electronics final check;
6. Sediment penetration (note: slight tilting of the tool was observed, as shown by the accelerations in X and Y directions);
7. Internal valve opened for fluid sampling (note the internal water pressure drop);
8. Valve closed and tool recovery;
9. Travel through the water column;
10. Setting the tool horizontally on the deck.

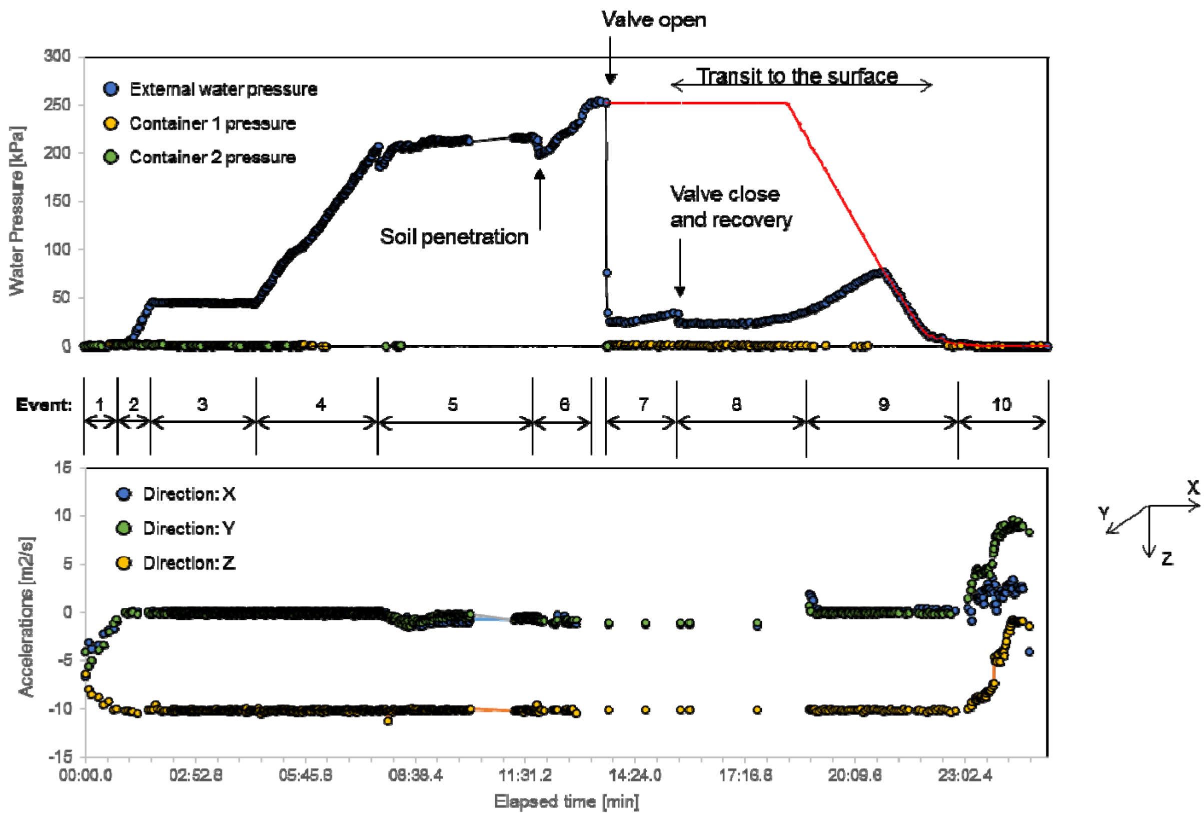


Figure 4. Detailed tool deployment data.

Results – Penetration resistance. During the deployments, it was possible to obtain the penetration resistance up to 3.5 meters in the sediment. Figure 5 shows the obtained signature for this deployment. Results show a low penetration resistance of about 150 kPa which can be expected for a non-dense material. Note that the pore water pressure decreases on the first meters but tend to increase approaching the hydrostatic water pressure. This might be due to a small layer of fine material on the first meter and a subsequent sandy material below it allowing to increase water pressure.

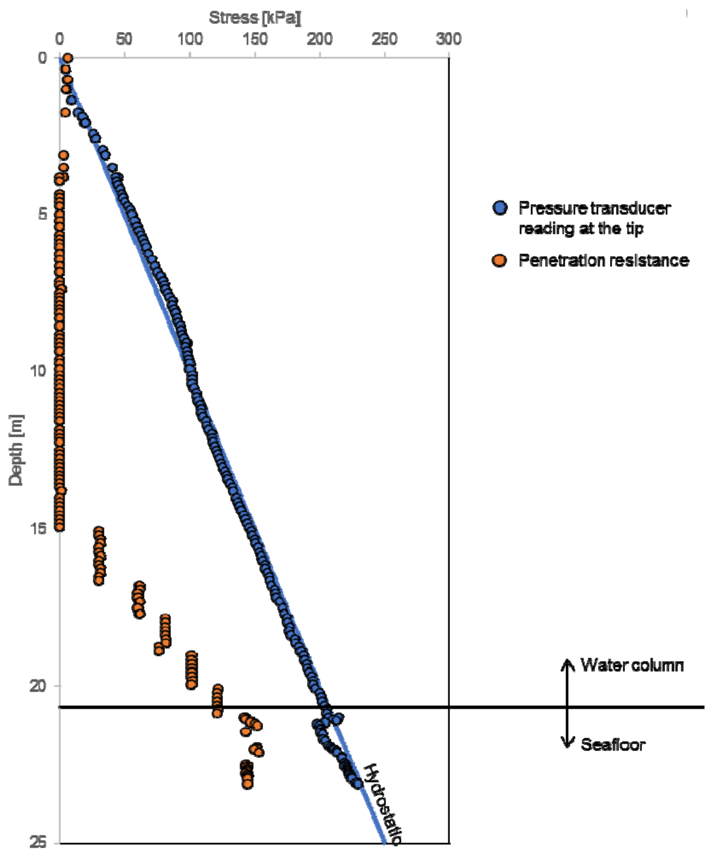


Figure 5. Penetration resistance obtained for the tool deployment.

Results - Thermal properties. On the second deployment, two thermocouples were continuously measuring temperature (located at the tip of the tool). Due to the high temperatures at the ship's deck, the tool was able to reach a constant 34 Celsius on the surface. After penetration on the sediment, the tool liberated that heat to the sediment. Because of the high complexity of this system, a numerical simulation was performed to match those computed values with the ones measured. Figure 6 shows the COMSOL transient simulation on t=0 seconds, considering the properties of the tool (stainless steel) and iterating the sediment properties to match the recorded temperature.

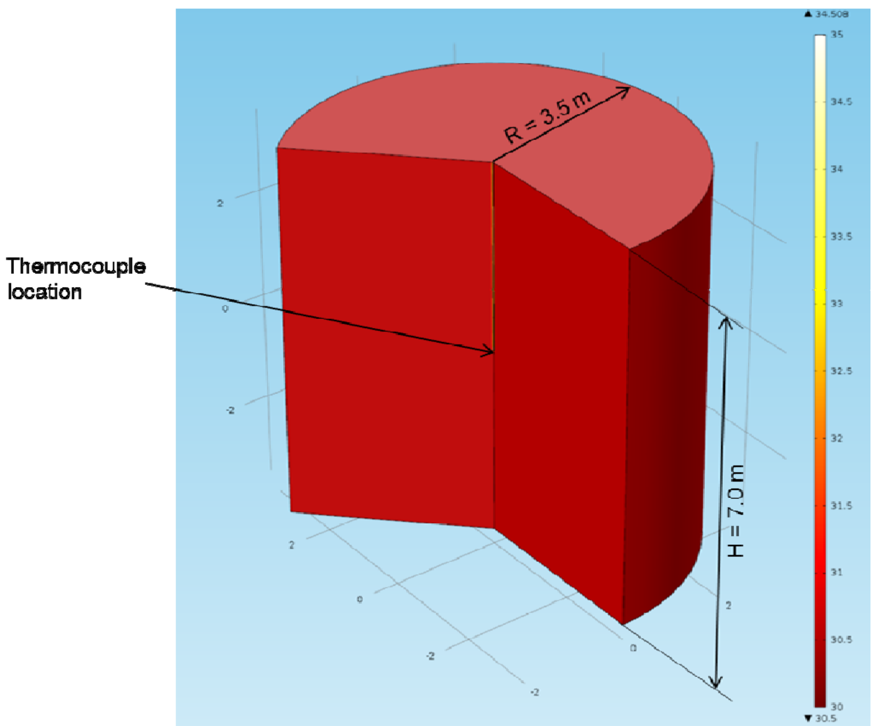


Figure 6. COMSOL numerical simulation for thermal properties determination. Dimensions of this model are shown here along with the initial conditions (tool at 33.75 Celsius and sediment temperature at 30.5 Celsius) and the thermocouple location.

The thermal properties of any material can be described by its thermal conductivity (k), specific heat capacity (c_p) and density (ρ). These parameters can be combined in the thermal diffusivity, defined as:

$$\alpha = \frac{k}{\rho c_p}\left[\frac{m^2}{s}\right]$$

Figure 7 shows the measured values from the two thermocouples and the simulation on continuous lines for different values of thermal diffusivity. Results show that the thermal diffusivity that best fits the measured data is approximately 10^{-6} m^2/s.

Assuming a saturated loose soil with density of 1500 kg/m3 and heat capacity of 1500 J/kg*K, delivers a thermal conductivity of about 2.2 W/m*K, which compares well with literature values of soils (Oke 1987).

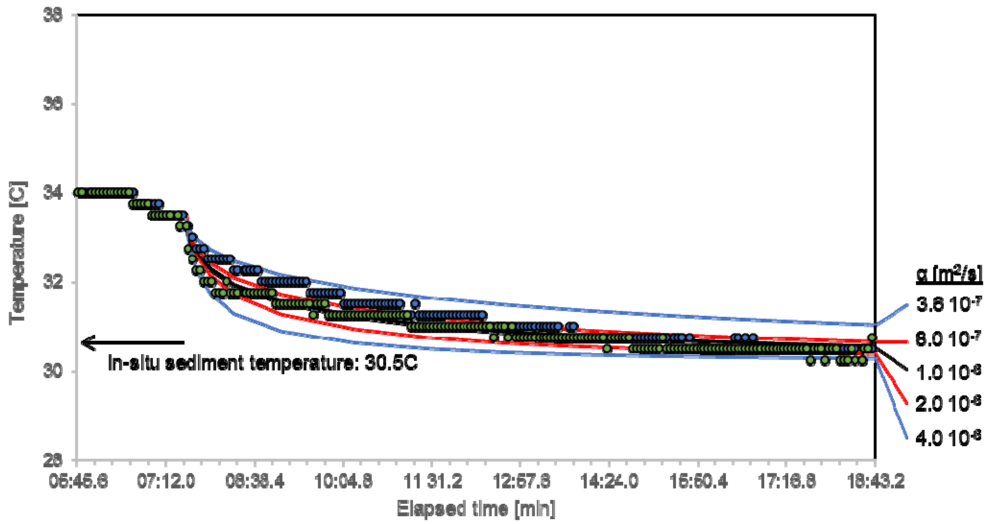


Figure 7. Thermal property of the Red Sea sediments on the selected test site. Blue and green dots represents the measured values, while the continuous lines different COMSOL simulations for this particular case.

Results – Hydraulic conductivity. While the tool was positioned on the seafloor during the second deployment, the internal valve was opened letting water inside the sediment to flow into the internal container. Measuring the internal gas pressure on time (Figure 8-a) it was possible to compute a 1.72 ml/min flow rate. Once again this system was simulated on a COMSOL model for different hydraulic conductivity conditions (Figure 8-b). Thanks to this simulation, an interpretation chart was designed. Figure 8-c shows this chart and where the test conducted plots on it. Results show the material tested behaves as a clayey sediment.

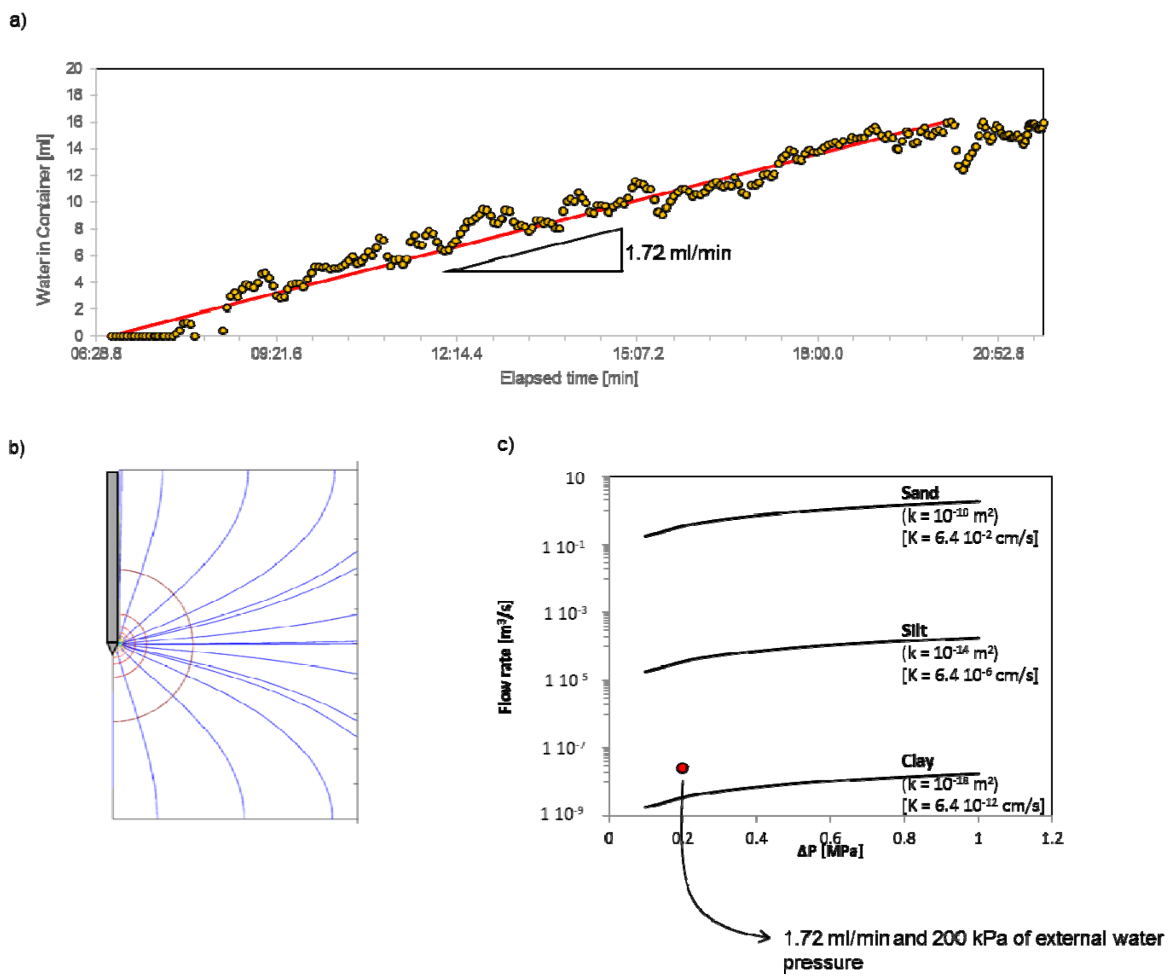


Figure 8. Hydraulic conductivity test; a) water volume in the container during sampling; b) numerical simulation on COMSOL; c) data interpretation.

MILESTONE LOG

	Milestone	Completion Date	Comments
Title Planned Date Verification method	Completion PMP November 2013 Report	11/2013	
Title Planned Date Verification method	Insertion – Tool design September 2014 Report	9/2014	
Title Planned Date Verification method	Database and IT tool September 2014 Report	9/2014	
Title Planned Date Verification method	Electronics in operation January 2015 Report	1/2015	New generation of electronics and packaging method in progress
Title Planned Date Verification method	Lab testing of prototype September 2015 Report	6/2015	Additional thermal modulus is under developing
Title Planned Date Verification method	Tool deployment Before September 2016 Report	9/2016	The next deployment is scheduled in November, 2016; The coupling of this tool with IODP BHAs is under developing.

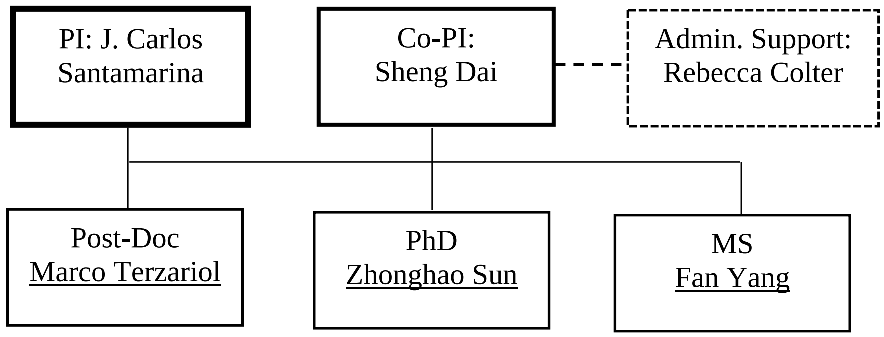
PRODUCTS

- **Publications – Presentations:** None at this point
- **Website:** Publications and key presentations are included in http://egel.kaust.edu.sa/. (for academic purposes only)
- **Technologies or techniques:** None at this point.
- **Inventions, patent applications, and/or licenses:** None at this point.
- **Other products:** None at this point.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Research Team: The current team involves:

- Marco Terzariol (Post-Doc)
- Zhonghao Sun (PhD student)
- Fan Yang (MS student)
- Sheng Dai (Assistant Professor)
- Carlos Santamarina (Professor)



IMPACT

None at this point.

CHANGES/PROBLEMS:

No-cost time extension to 9/30/2017 has been requested.

SPECIAL REPORTING REQUIREMENTS:

We are progressing towards all goals for this project.

BUDGETARY INFORMATION:

As of the end of this research period, expenditures are summarized in the following table.

Baseline Reporting Quarter DE-FE0013961	Budget Period 3							
	Q1		Q2		Q3		Q4	
	10/1/15 - 12/31/15		1/1/16 - 3/31/16		4/1/16 - 6/30/16		7/1/16 - 9/30/16	
	Q1	Cumulative Total	Q2	Cumulative Total	Q3	Cumulative Total	Q4	Cumulative Total
Baseline Cost Plan								
Federal Share	30,000	345,515	30,000	375,515	30,000	405,515	71,510	477,025
Non-Federal Share	14,693	97,103	14,692	111,795	14,693	126,488	-	126,488
Total Planned	44,693	442,618	44,692	487,310	44,693	532,003	71,510	603,513
Actual Incurred Cost								
Federal Share	6,315	250,608	28,411	279,020	51,392	330,412	56,613	387,025
Non-Federal Share	15,655	93,760	10,436	104,196	5,218	109,415	2,744	112,158
Total Incurred Costs	21,969	344,368	38,848	383,216	56,611	439,826	59,357	499,183
Variance								
Federal Share	-23,685	-94,907	-1,589	-96,495	21,392	-75,103	-14,897	-90,000
Non-Federal Share	962	-3,343	-4,256	-7,599	-9,475	-17,073	2,744	-14,330
Total Variance	-22,724	-98,250	-5,844	-104,094	11,918	-92,177	-12,153	-104,330

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