

Drilled Shaft Resistance Based on Diameter, Torque and Crowd

(Drilling Resistance vs. Rock Strength)

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FDOT Geotechnical Research in Progress Report

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University of Florida

Department of Civil & Coastal Engineering

Presented August 1, 2014



Scope

- From 5 Drillings Parameters
 - Torque, T
 - Crowd, F
 - Penetration rate, u
 - Rotational speed, N
 - Bit diameter, d

} Obtain Drillability Strength, D_s
Karasawa (2002)
- Compare D_s vs. Laboratory strengths, q_u , and q_t
 - In Laboratory on Homogenous Blocks at 4 different design strengths with 2 different bit diameters (4.5" and 6")
 - In the Field D_s . Vs Cores (Laboratory q_u , and q_t)
- Field Drilling
 - Obtained drill rig monitoring equipment from Jean Lutz, N.A.
 - Sites: Little River (Quincy); Overland (Jacksonville); Kanapaha (Gainesville) – All Sites have load tests

Jean Lutz Monitoring Equipment



**DIALOG
(DAQ)**

**C16400 -
Pressure
Transducer
(Torque)**

**C16400 -
Pressure
Transducer
(Crowd)**

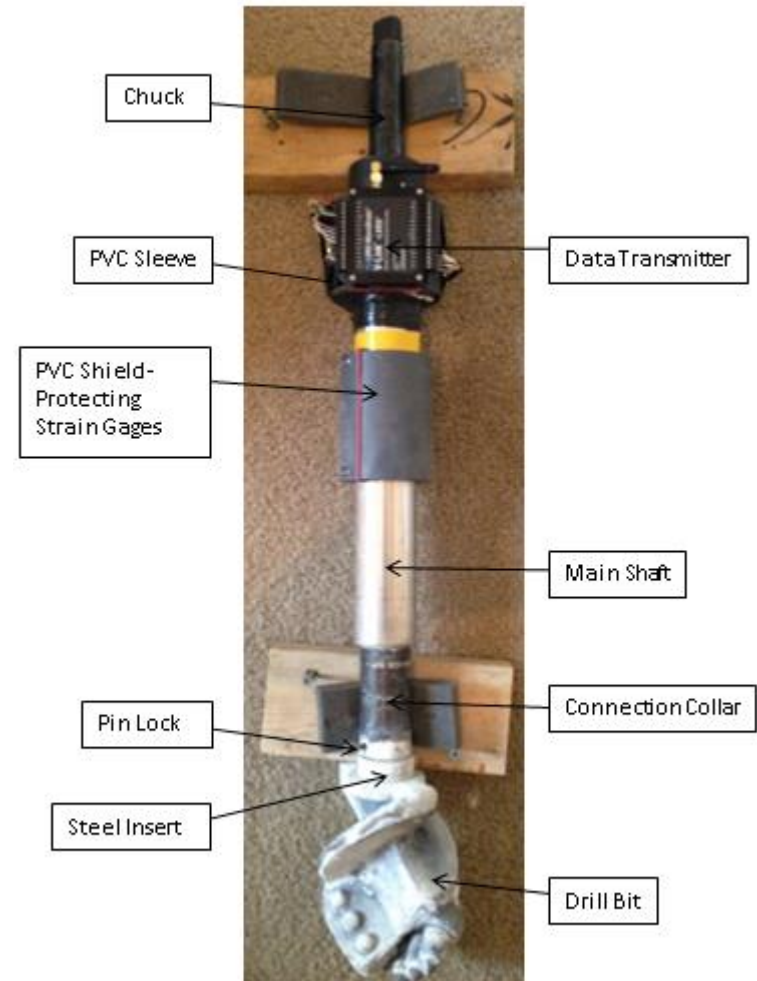
**F82 -
Rotary
Encoder
(Penetration
rate)**

**VR28 -
Proximity
Sensor
(Rotational
speed)**

**Junction
Boxes**

Laboratory Coupler to Monitor Crowd and Torque

- Main shaft constructed using Aluminum pipe
 - 2" O.D. and 1" I.D.
- 2 sets of torque rosettes and 2 sets of axial strain gages
 - Full bridge
 - Located approximately 180° apart
 - Compensates for bending and temperature effects
- Lord Microstrain V-Link LXRS for wireless data transmission



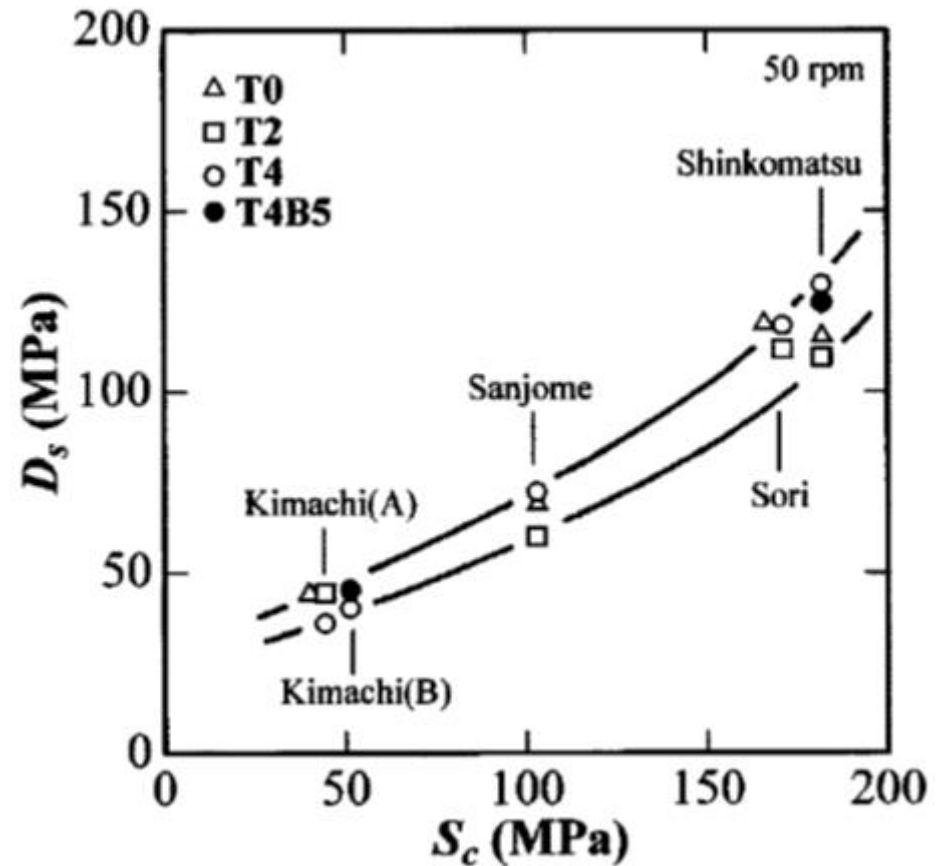
Drilling Process

- Create large synthetic limestone (Gatorock) blocks
 - (40" x 22.5" x 22.5")
- Select proper drill parameter settings
 - Rotational speed
 - Penetration rate
- Monitor applied torque and crowd (axial) forces
- Using these drilling parameters, "Drillability Strength", D_s , is found



D_s vs. q_u

- $D_s = a_F/a_T^2 = 64NT^2/Fud^3$
- Karasawa compared:
 - Drillability Strength of rock, D_s
 - Unconfined Compressive Strength, S_c or q_u
- D_s vs. q_t (split tension) plot will also be developed



* S_c (q_u – unconfined compression)

Axial Force Calibration

- During preliminary axial calibration, peak loads only reached 55 lbs
- It was noticed during drilling peak loads for some rock strengths far exceeded 55 lbs
 - Up to 500+ lbs.
- It was decided to recalibrate the system using higher axial loads
- How does the applied torque forces affect the axial loading?

Axial Force Calibration

- Used the Instron on UF's campus to provide the loading
- The drill rod was vertically leveled
- Constant loads were applied in 2 minute intervals
 - 100, 250 and 500 lbs
- Baseline readings were taken for 2 minutes before and after each loading phase
 - Does it return back to zero?
- Provides 960 readings for each loading and resting period
 - 800 readings from each period are used for the averages



Axial Force Calibration

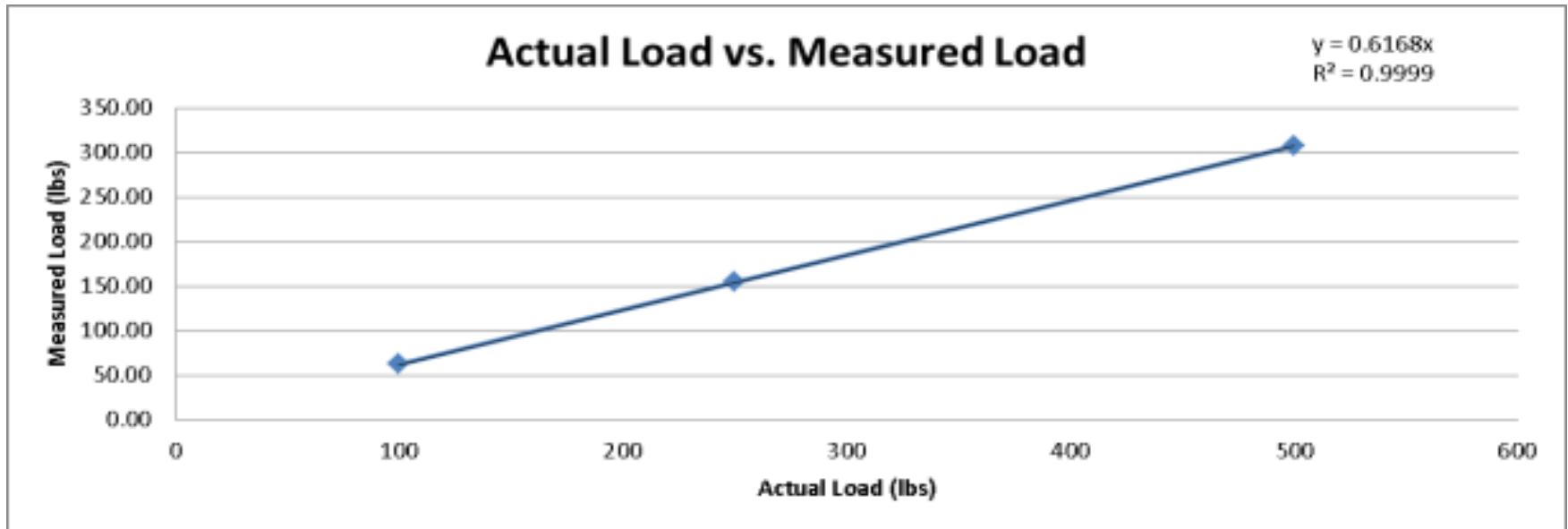
- Results displayed an approximate percent difference of 38% for each load.

Loading Phase	Channel 2 (Uncalibrated)	Channel 4 (Uncalibrated)	Channel 2 (Calibrated)	Channel 4 (Calibrated)	Measured Load (lbs)	% Difference
baseline	-9.668798065	-4.093927414				
100	-62.5090573	-77.39515653	-52.55	-73	62.77	-37.23%
baseline	-10.24806841	-4.69895825				
250	-144.6969158	-179.6609006	-134.79	-174.83	154.81	-38.08%
baseline	-9.556484249	-4.968884207				
500	-241.3569253	-389.2261041	-231.78	-383.99	307.89	-38.42%
baseline	-9.58861208	-5.496425149				

- Applied load vs. measured load plot was created
 - Should provide a linear curve
 - Allows loads to be adjusted equally providing a calibration factor

Axial Force Calibration

- Linear trend was confirmed by $R^2 = 0.9999$ with the intercept set to zero



- A calibration factor was developed between the predicted and measured loads

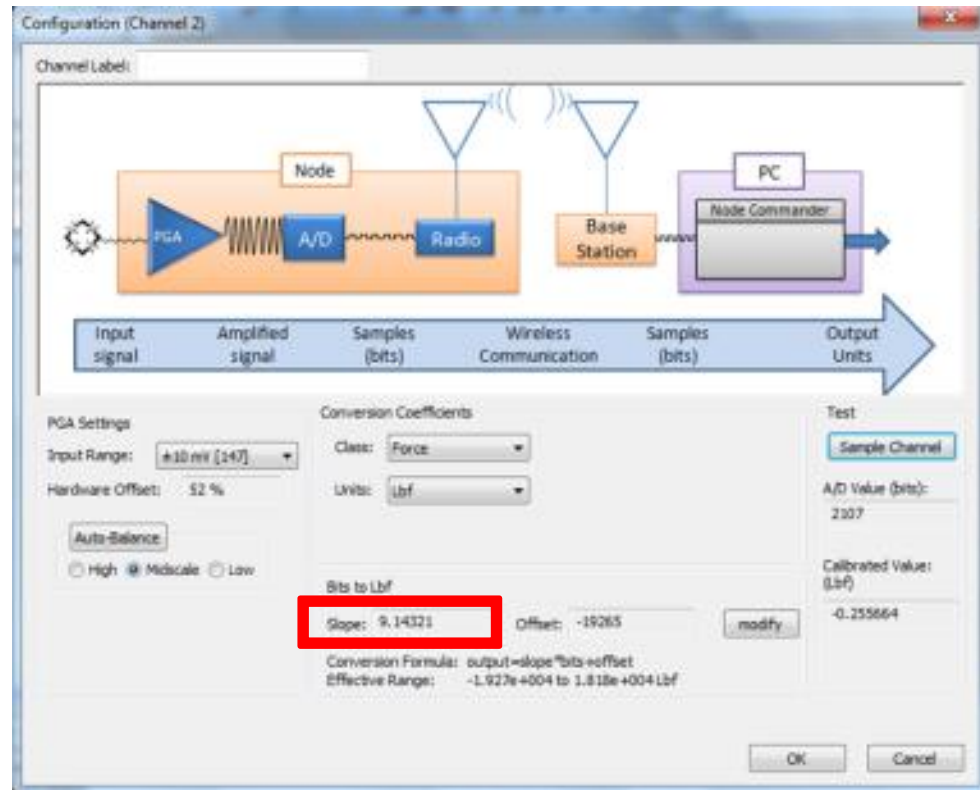
Axial Force Calibration

- Using the equation from the curve, $y = 0.6168x$
- $1 / 0.6168 = 1.621271077$
 - Calibration factor = 1.621271077
- Multiply the measured load by the Calibration factor to obtain the adjusted measured load
- Adjusted measured loads now matched the applied loads
 - Instron ± 3 lbs sensitivity

Loading Phase	Channel 2 (Uncalibrated)	Channel 4 (Uncalibrated)	Channel 2 (Calibrated)	Channel 4 (Calibrated)	Measured Load (lbs)	% Difference	Adjusted Load (lbs)	% Difference
baseline	-9.668798065	-4.093927414						
100	-62.5090573	-77.39515653	-52.55	-73	62.77	-37.23%	101.77	-2.43%
baseline	-10.24806841	-4.69895825						
250	-144.6969158	-179.6609006	-134.79	-174.83	154.81	-38.08%	250.99	-0.57%
baseline	-9.556484249	-4.968884207						
500	-241.3569253	-389.2261041	-231.78	-383.99	307.89	-38.42%	499.17	0.22%
baseline	-9.58861208	-5.496425149						

Axial Force Calibration

- Calibrate coupler system using Node Commander software
- The Calibration factor was used to adjust the software's slope
 - Software slope developed through shunt calibration
 - Slope converts bits to lbf
- This will be used for the remainder of the drillings



Torque Loading Effects on Axial Force

- Channel 2 is in compression
- Channel 4 is in tension
- Values are opposite in sign and approximately offset each other
- The system is functioning properly
 - Forces negate one another



M (in-lbs)	W (lbs)	Ch-1	Ch-2	Ch-3	Ch-4	%Diff 1-3	%Diff 2-4
140.8	8.8	-141.34	-55.20	-143.87	54.59	1.79%	1.10%
281.6	17.6	-283.02	-101.77	-283.22	99.32	0.07%	2.41%
422.4	26.4	-423.09	-145.16	-422.82	139.65	-0.06%	3.80%
563.2	35.2	-561.30	-186.70	-560.20	183.56	-0.20%	1.68%

Investigating the Drilling Procedure

Old Drilling Procedure

- Dry drill 8 inches
- Clean bit and hole
- Wet drill 9 inches
 - Adding water with a cup
 - Removing water with suspended solids using a wet vac
- Clean bit and hole
- Wet drill final 3 inches
 - 20 inches total

New Drilling Procedure

- Dry drill 8 inches
- Clean bit and hole
- Wet drill 4 inches
 - Adding water using continuous flow via controlled nozzle
 - Removing water with suspended solids using a wet vac
- Clean bit and hole
- Repeat wet drilling in 4 inch increments until 20 inch depth is reached

Comparing Drilling Procedures

Old Drilling Procedure

- CV values typically ranged from 0.2 - 0.6
- More problematic with longer drill runs
- Large amounts of debris caked on bit (bit bite)



New Drilling Procedure

- CV values consistently range from 0.1 – 0.3
- Can set the drill press to automatically stop at 4 inches, less problematic
- Less debris caked on bit



Reanalyzing Old Data

- Review old drillings
 - Length of drill runs
 - Review drill log comments for any problems during drilling
- Use only the first four inches of each good drill run
 - No problems during drilling
- Use Calibration factor to adjust the recorded axial forces
 - Used in both sets of data to the right

- Original data

Final Results - 673psi - Wet		
Description	T (in-lbs)	F (lbf)
Average	521.5	124.8
Maximum	849.2	245.9
Minimum	211.6	36.4
Std. Deviation	131.3	52.4
CV	0.252	0.420

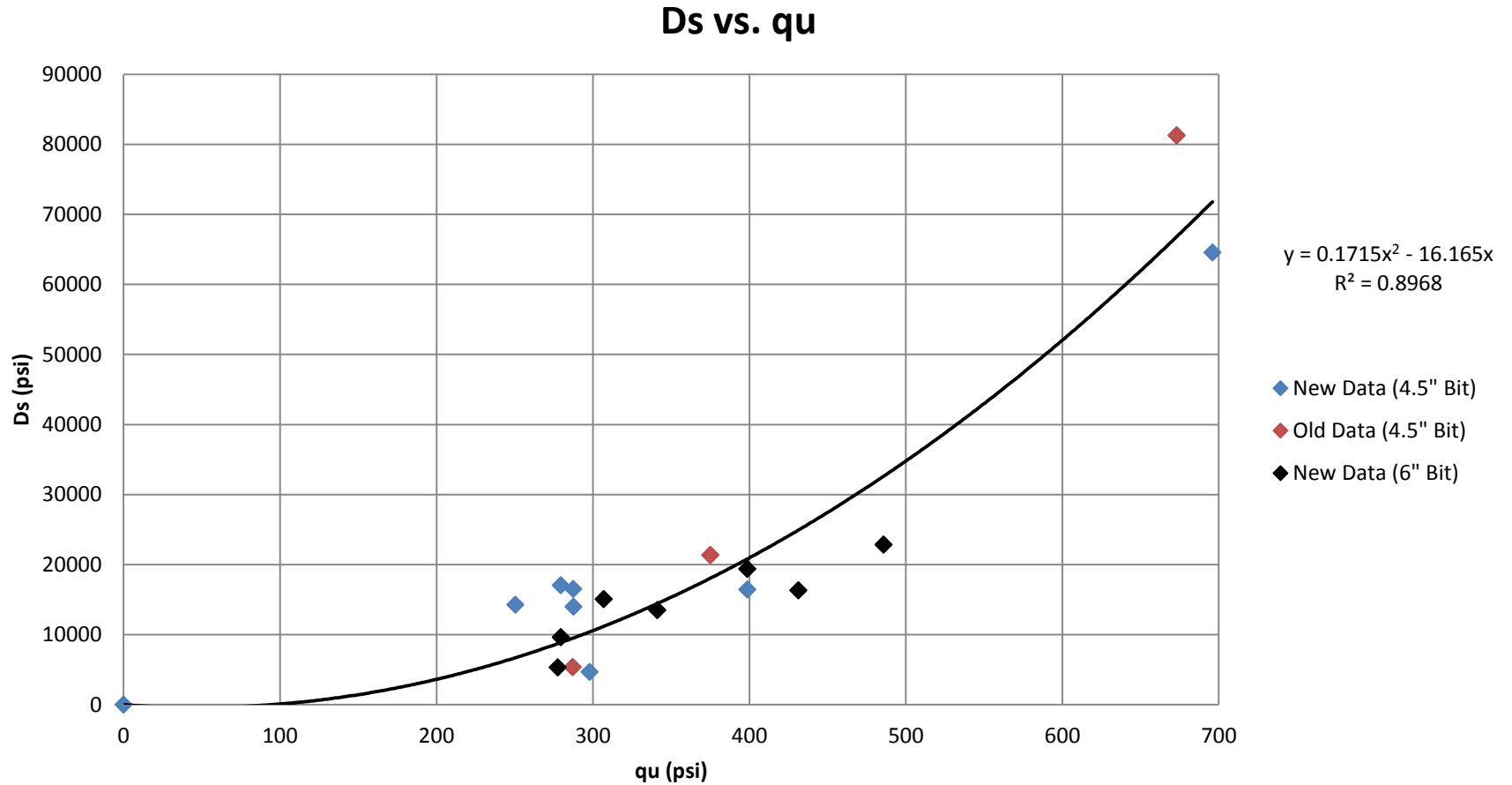
- Updated data

Final Results - 673psi - Wet		
Description	T (in-lbs)	F (lbf)
Average	421.0	109.4
Maximum	587.2	230.1
Minimum	209.0	45.7
Std. Deviation	73.5	38.4
CV	0.175	0.351

Developing the D_s vs. q_u Curve

- Final curve will consist of nearly 70 data points from laboratory drillings
- Different drilling parameters will be used
 - 3 penetration rates (0.008, 0.014, 0.02 in/rev)
 - 2 rotational speeds (20 and 40 rpms)
 - 2 bit diameters (4.5" and 6")
- Gatorock strengths will range from approximately 140 psi to 1667 psi
- Using 17 drillings a preliminary curve was developed
 - 3 old drillings (updated)
 - 14 new drillings

Preliminary D_s vs. q_u Curve



Field Monitoring

- First field monitoring trial took place November 2013 at the Little River Bridge Site (Quincy Florida)
- Case Atlantic allowed monitoring of their IMT AF 250 Drill Rig in cooperation with RS&H
- Successfully monitored a test shaft and a production shaft – Monitored Full Length of Shaft
- Test shaft was instrumented with an Osterberg load cell
 - Instrumented with Strain Gages, i.e. measured skin friction
 - Estimated Skin Friction from $D_s \rightarrow q_u, q_t \rightarrow f_s$

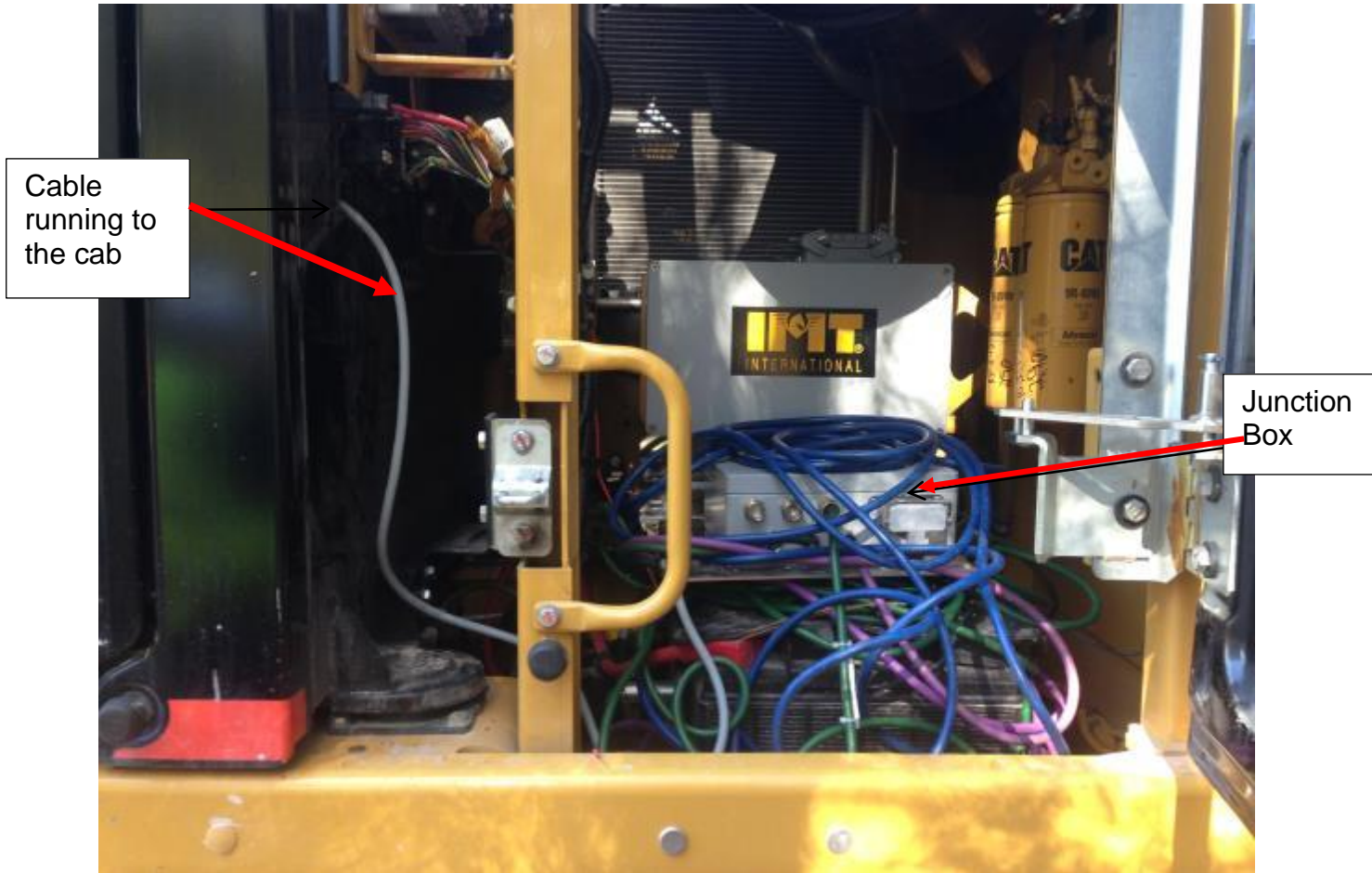
Monitoring Equipment Installation

- IMT AF 250 was a brand new drill rig
- Many of the sensors we planned to install were built in
- Jean Lutz field technician installed and calibrated the equipment
- Installed pressure transducer on the mast for crowd monitoring
- DIALOG (DAQ) was installed in the cab
- Junction box was installed in the electrical compartment
- Tapped into 3 existing sensors to monitor torque, rotational speed and penetration rate

IMT AF 250



Junction Box

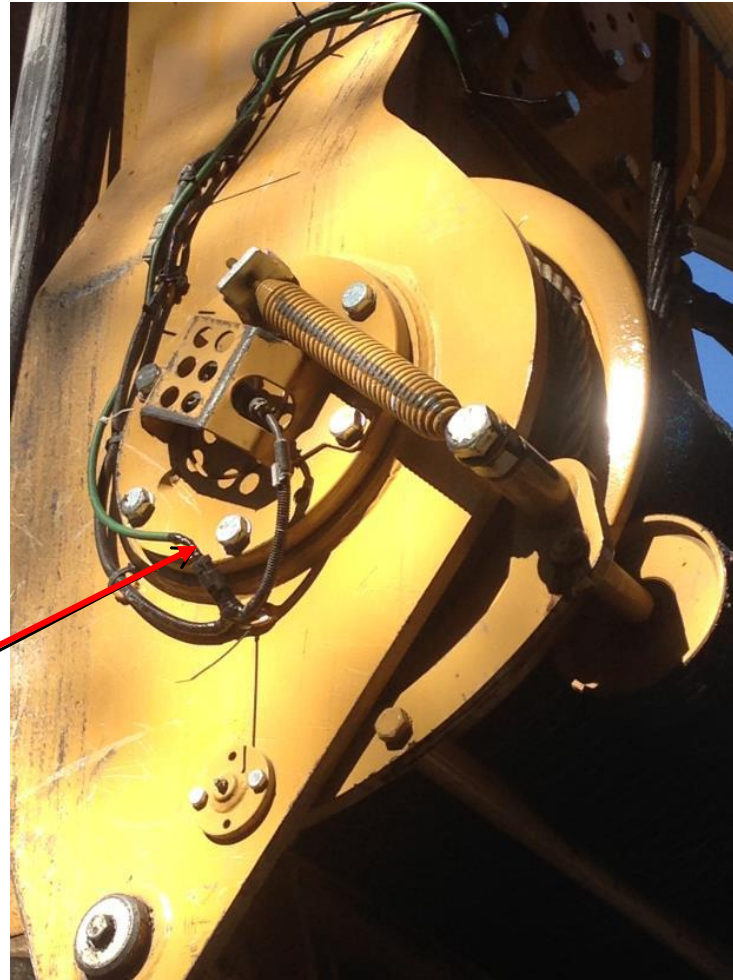


DIALOG (DAQ)



DIALOG

Depth Sensor – Penetration Rate



Tapping into the
depth sensor

Rotational Speed and Torque Sensors



Tapping into the rotational speed and torque sensors

Installing the Crowd Sensor

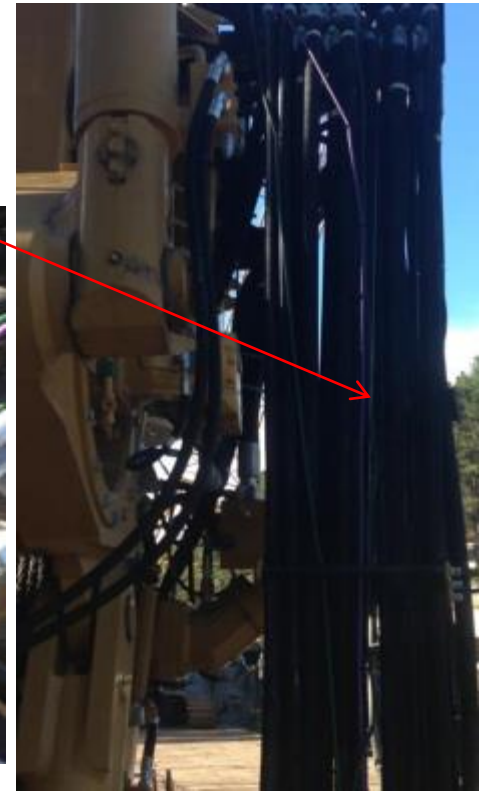
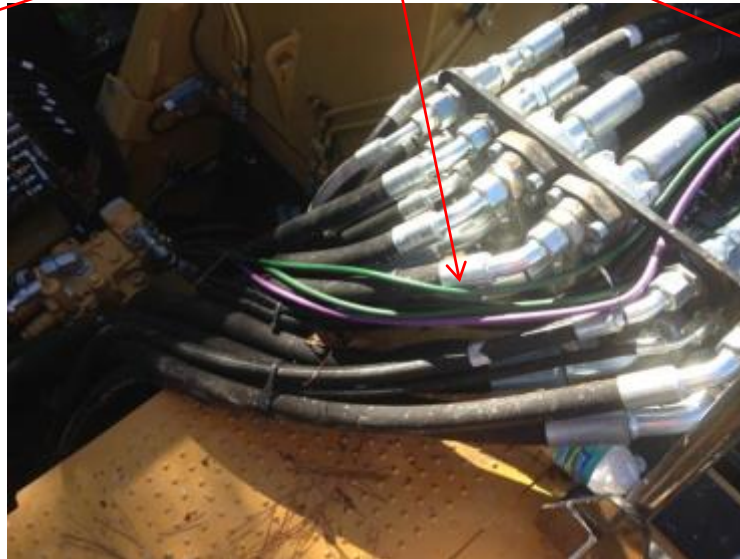


Cabling Secured to Hydraulic Lines

- Cabling is secured to the hydraulic lines using zip ties and kept out of the way
 - Does not disturb operations



Cabling secured to Hydraulic lines



Monitoring Drilling in Real Time

On the Rig



Off the Rig



Analyzing Field Data

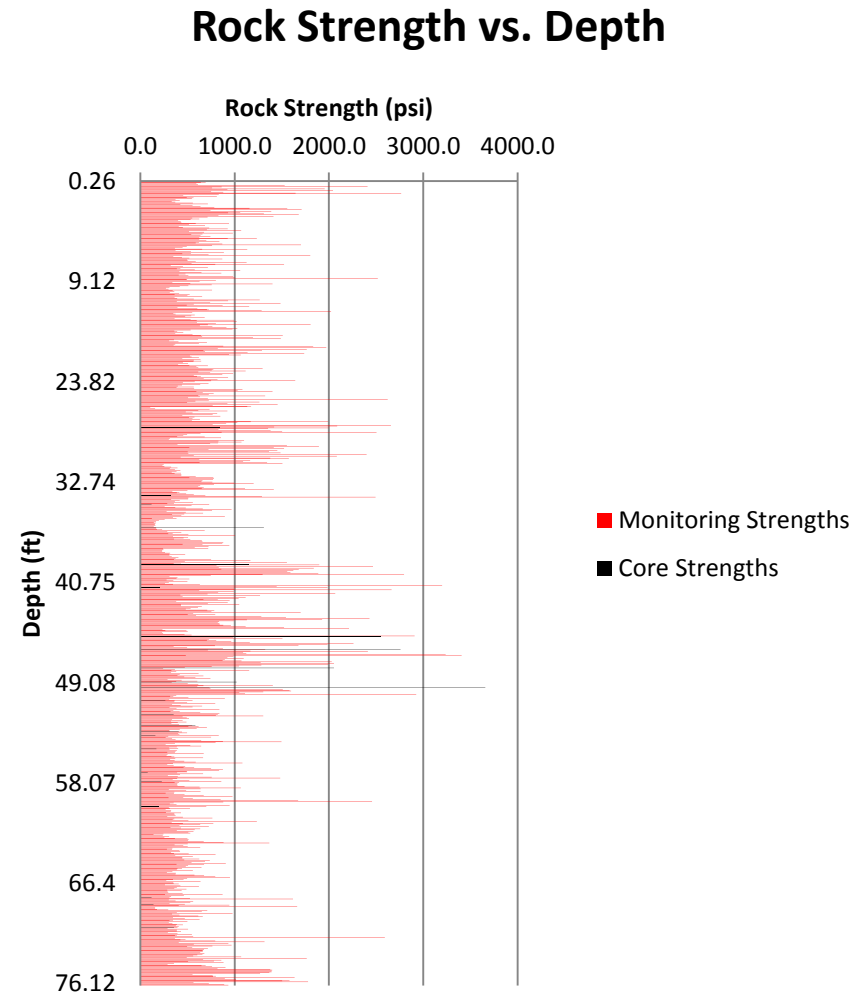
- Using the preliminary D_s vs q_u curve equation:
- $0.1715x^2 - 16.165x - y = 0$
 - $x = q_u$ (psi)
 - $y = D_s$ (psi)
- The following equation is developed using the quadratic solution:

$$q_u = \frac{16.165 + \sqrt{(-16.165)^2 - 4 * 0.1715 * (-D_s)}}{2 * (0.1715)}$$

- This provides a means to assess rock strength, q_u , from recorded field drilling parameters

Rock Strength vs. Depth (Preliminary)

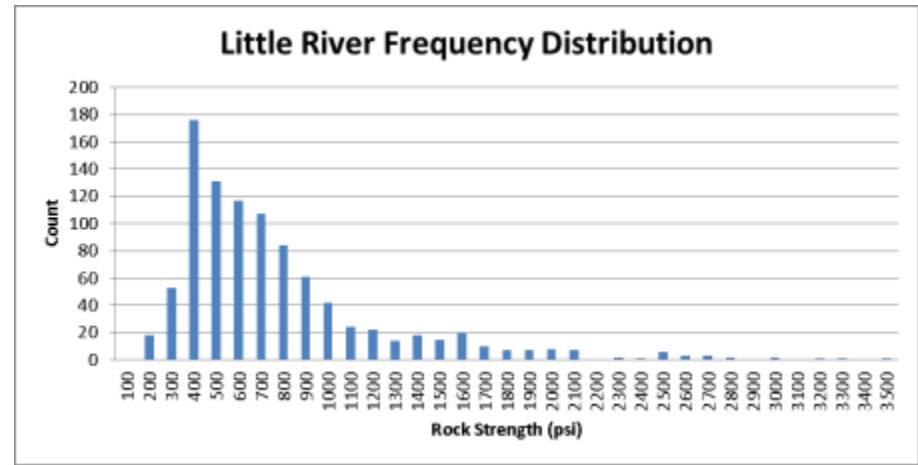
- Core data from Boring B-4 was compared to the data
 - Recovered and tested by FDOT
 - Boring B-4 is the 1 of 6 available for comparison
- Core data and monitored drilling results show similar trends and strengths at respective depths
 - Stratification is observed from both sets of data



Summary of Statistics

- 12.1% difference for the average strength
- 6.9% difference for the maximum strength
- 32.5% difference for the minimum strength
 - Less difference in actual strength than maximum
- Frequency distribution displays a log-normal distribution as expected
- Majority of strengths fell within planned Gatorock strengths for lab drilling
 - 140 – 1667 psi
- **Need more Core Strengths to Define Variability**

Description	Monitored Data	Core Data
	qu (psi)	qu (psi)
Average	727.77	827.89
Max	3406.08	3658.65
Min	103.59	78.21
Std Dev	490.92	998.21
CV	0.67	1.21



Future Plans

- Finish Laboratory Drilling
 - Develop final D_s vs. q_u and D_s vs. q_t curves
- Monitor Overland bridge site in Jacksonville
 - Beginning late August 2014
 - 4 shafts with static load testing planned will be monitored
 - Compare D_s vs Laboratory Strength and Measured Shaft Side Friction
- Continue analyzing Little River Data
 - Obtain more core data
 - Use existing and new core data to develop correlation
 - Compare D_s vs Laboratory Strength and Measured Shaft Side Friction
- Continue Site Investigation at Kanapaha
 - Designated site for the projects static load test
 - Preliminary CPT's have been taken
 - SPT's, coring and more CPT's will take place
- Finalize projects static load test setup and perform testing
 - Estimate shaft capacities from Kanapaha site investigation
 - 2 drill rigs available for shaft installation
- Draft Final Report

Citations

- Karasawa et al. “Proposed Practical Methods to Estimate Rock Strength and Tooth Wear While Drilling With Roller-Cone Bits.” The Journal of Energy Resources Technology, Vol. 128 (2002): pp. 125-132.
- Teale, R. “The Concept of Specific Energy in Rock Drilling,” International Journal of Rock Mechanics and Mining, Vol. 2 (1965): pp. 57–73.
- McVay, Michael. Niraula, Lila. “Development of P-Y Curves for Large Diameter Piles/Drilled Shafts in Limestone for FBPIER.” FDOT Final Report (2004): p. 14.
- McVay, Michael. Ellis, Ralph. “Static and Dynamic Field Testing of Drilled Shafts: Suggested Guidelines on Their Use for FDOT Structures.”, FDOT Final Report (2003).
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Questions?