Drilled Shaft Resistance Based on Diameter, Torque and Crowd
(Drilling Resistance vs. Rock Strength)
BDV 31 977 20

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FDOT Geotechnical Research in Progress Report
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Presented August 1, 2014

Scope

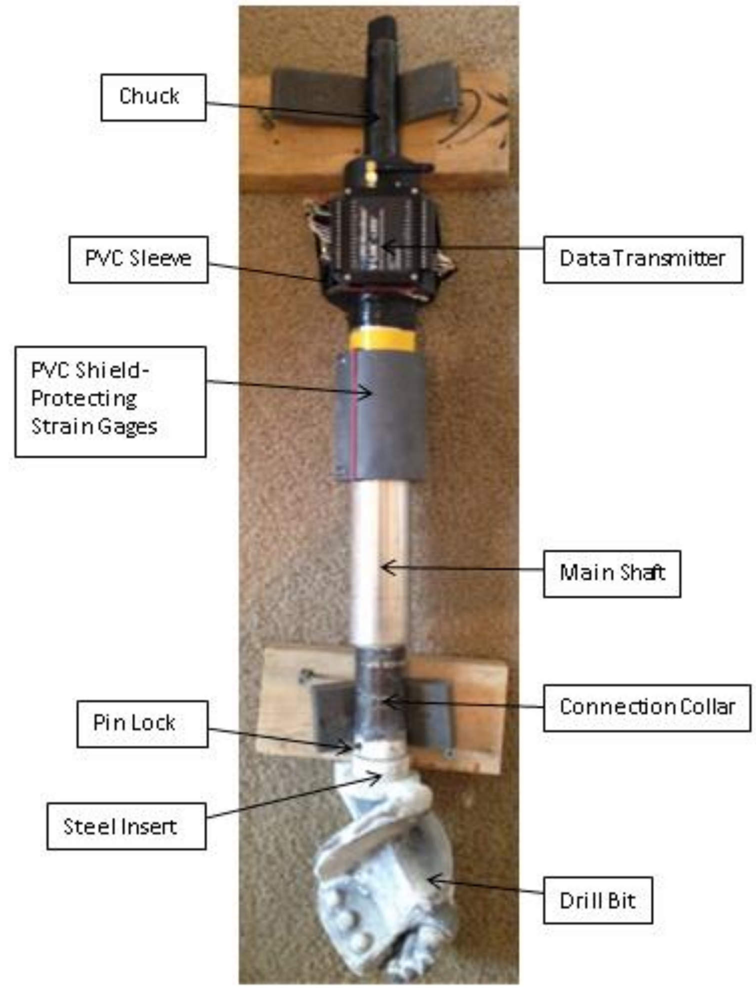
- From 5 Drillings Parameters
  - Torque, T
  - Crowd, F
  - Penetration rate, u
  - Rotational speed, N
  - Bit diameter, d

  } Obtain Drillability Strength, Ds Karasawa (2002)
- Compare Ds 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 Ds. 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

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

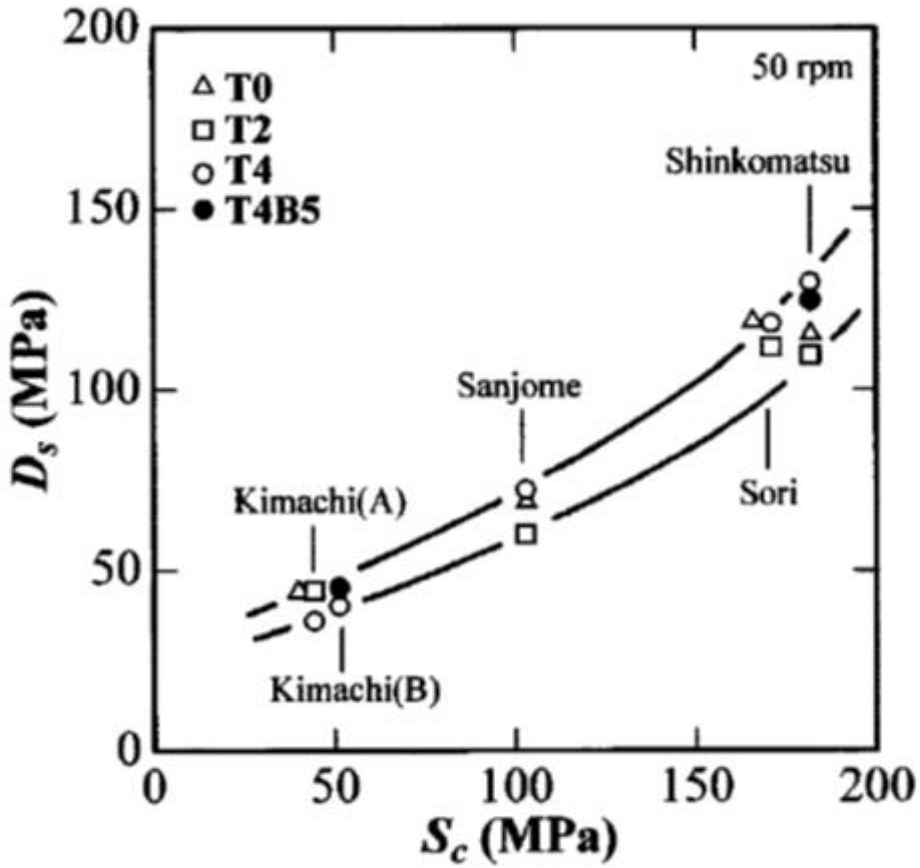


Drilling Process

- 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)**

Karasawa, 2002

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

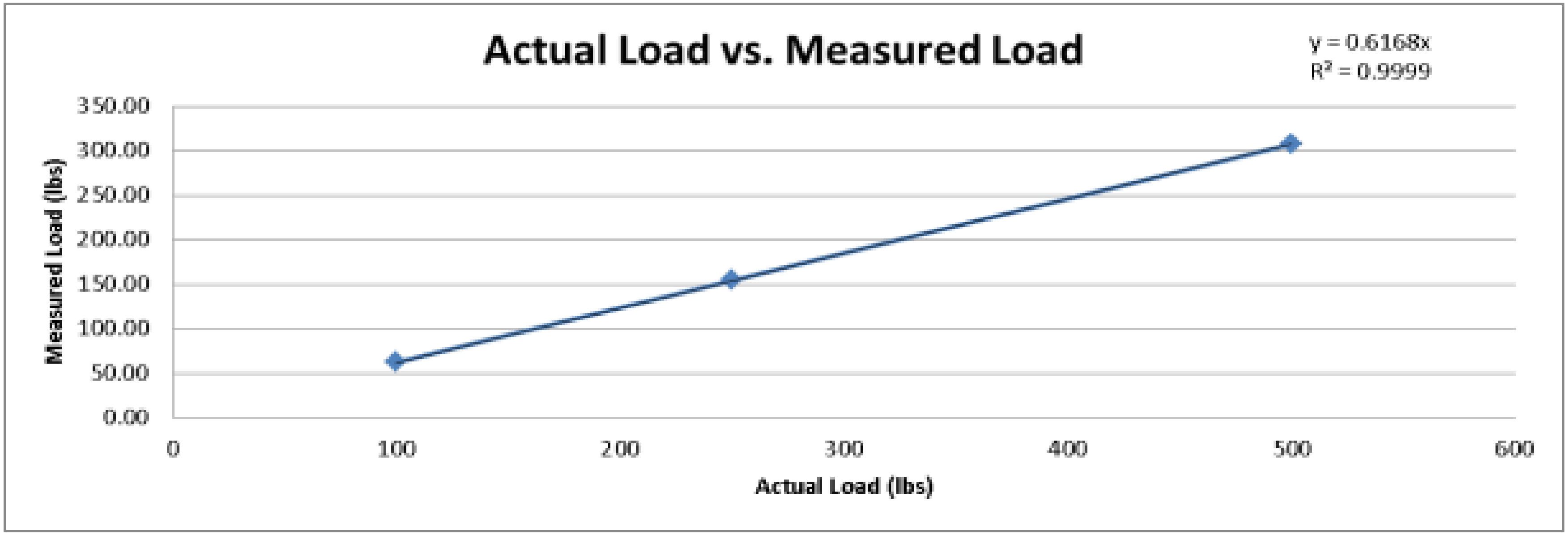
- Results displayed an approximate percent difference of 38% for each load.

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

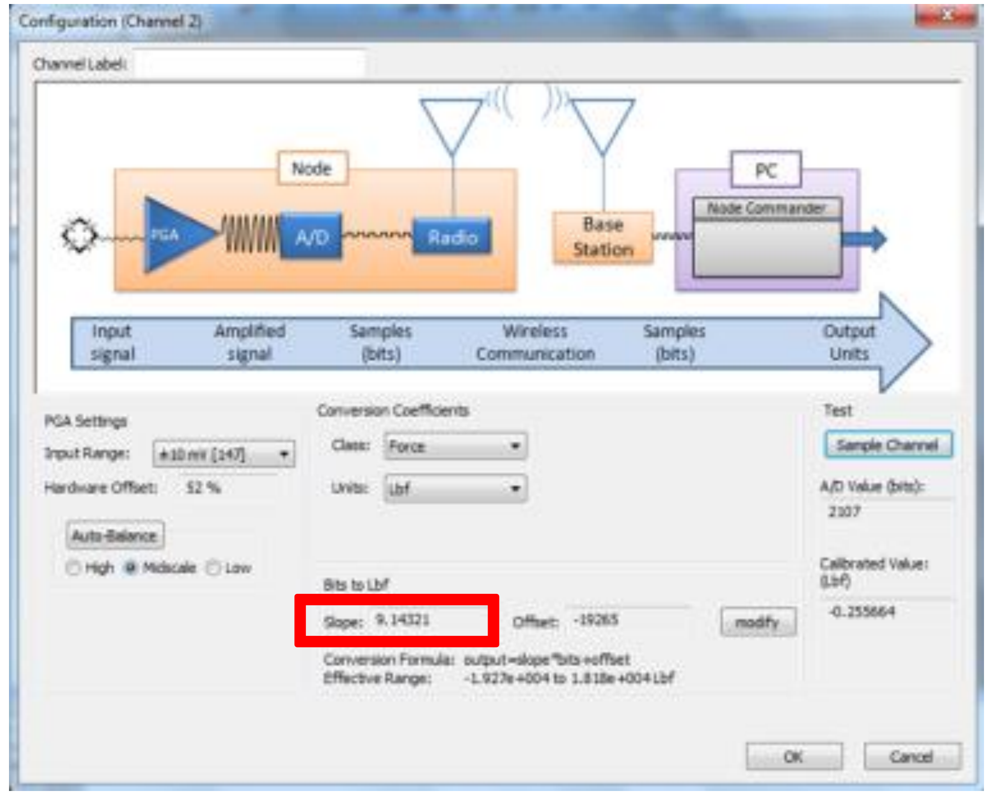
Axial Force Calibration

- 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 $\pm$ 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

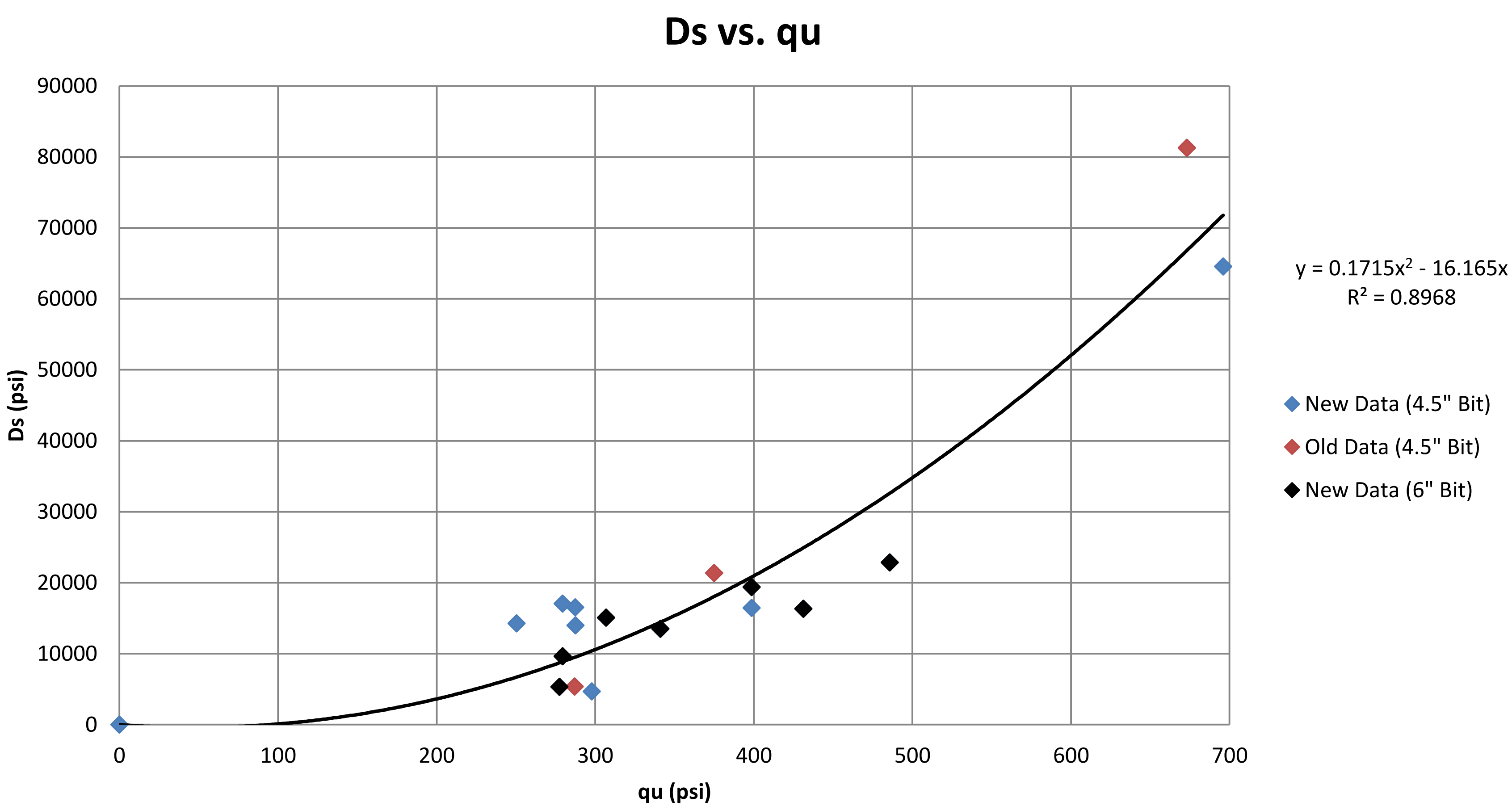
- Updated data

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

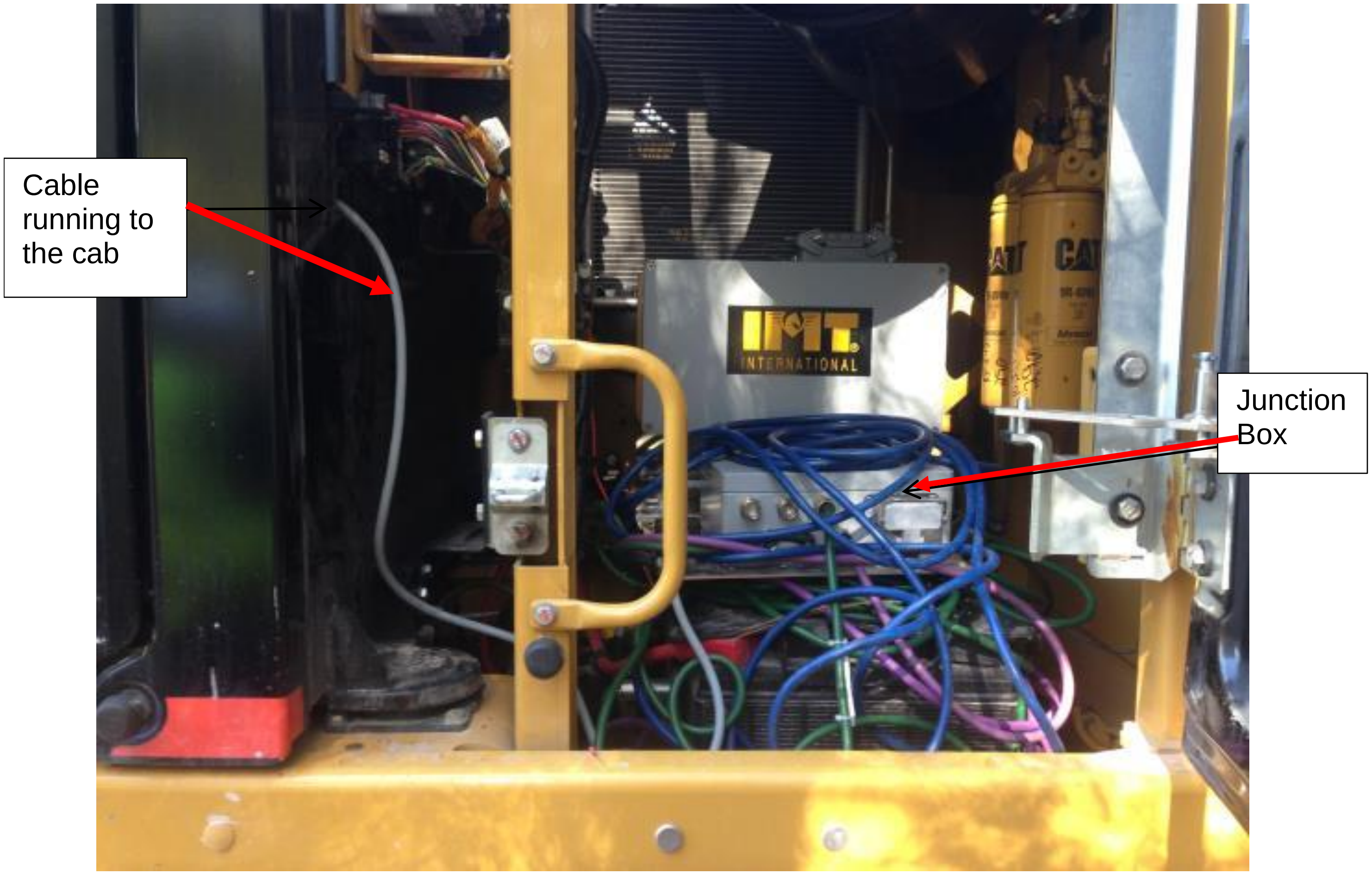
- First field monitoring trial took place November 2013 at the Little River Bridge Site (Quincy Florida)
- Case Atlantic allowed monitoring of their IMT AF 250 Drill Rig in cooperation with RS&H
- Successfully monitored a test shaft and a production shaft – Monitored Full Length of Shaft
- Test shaft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

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

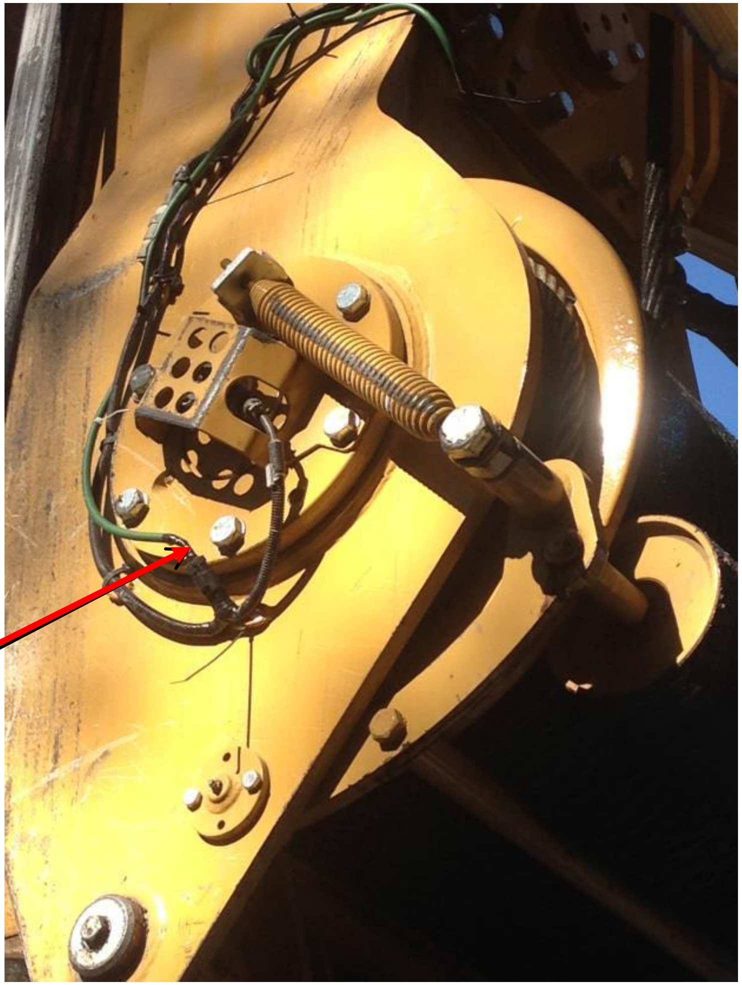
IMT AF 250

Junction Box



DIALOG (DAQ)

Depth Sensor – Penetration Rate



Tapping into the depth sensor

Rotational Speed and Torque Sensors

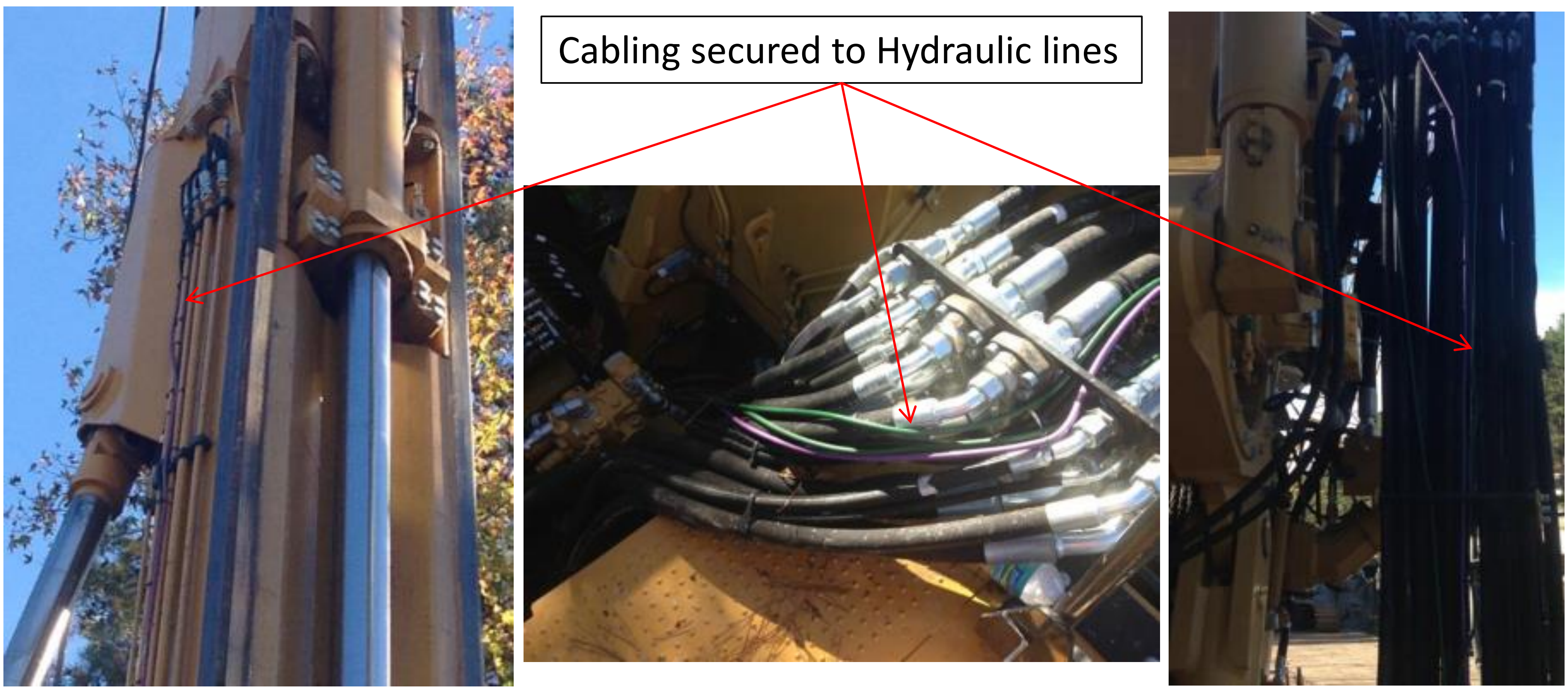
Tapping into the rotational speed and torque sensors

Installing the Crowd Sensor



Cabling Secured to Hydraulic Lines

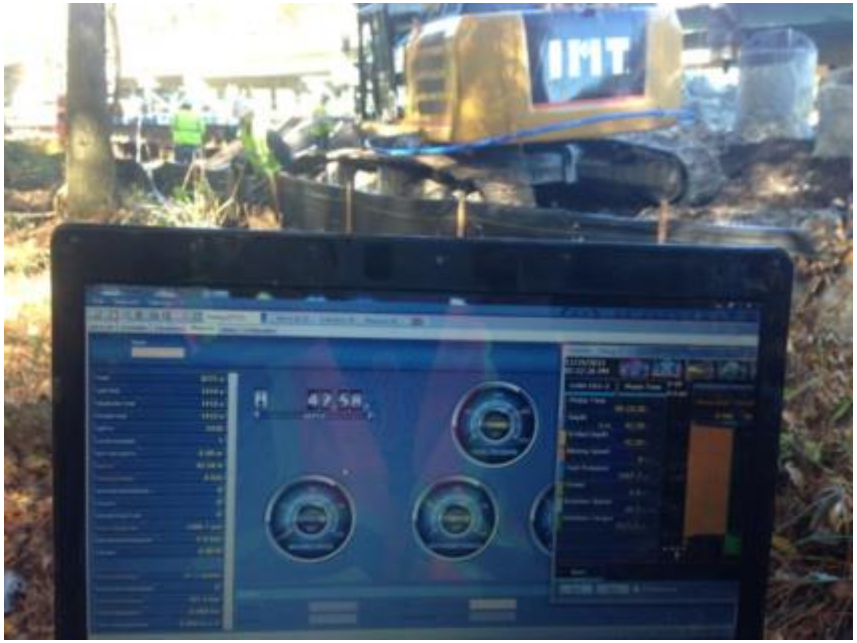
- Cabling is secured to the hydraulic lines using zip ties and kept out of the way
  - Does not disturb operations



Monitoring Drilling in Real Time

On the Rig

Off the Rig



Analyzing Field Data

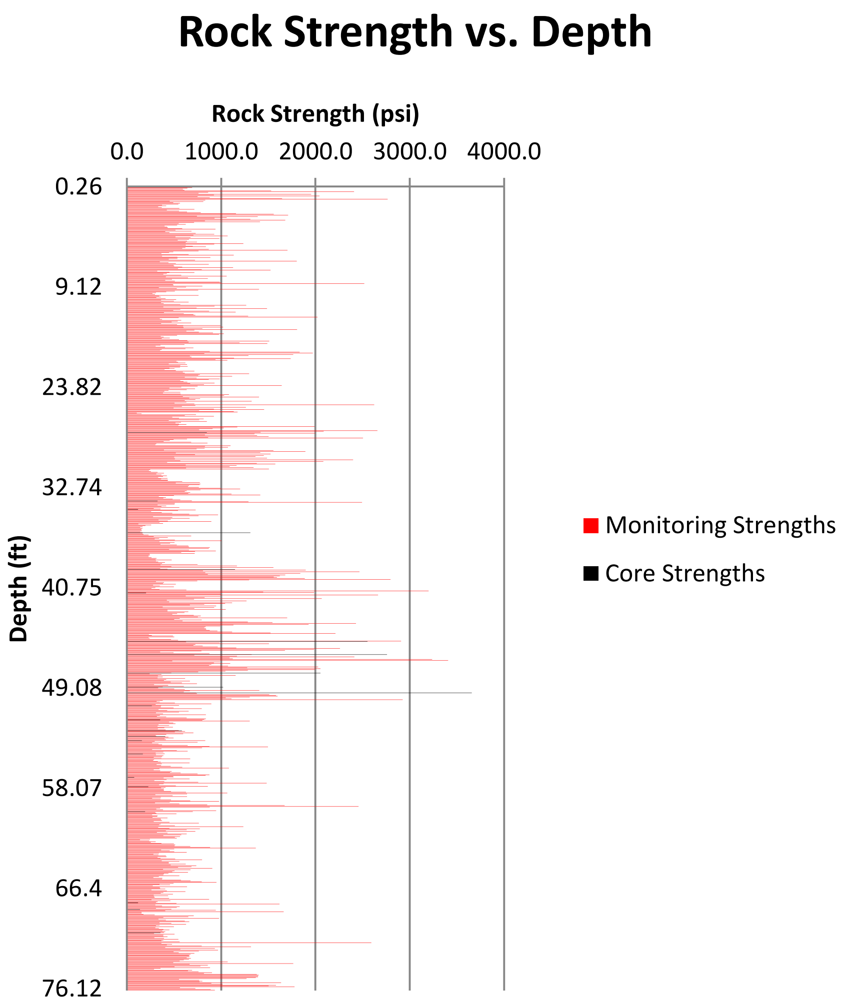
- Using the preliminary D_s vs q_u curve equation:
- $0.1715x^2 - 16.165x - y = 0$
  - $x = q_u$ (psi)
  - $y = D_s$ (psi)
- The following equation is developed using the quadratic solution:

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

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

Rock Strength vs. Depth (Preliminary)

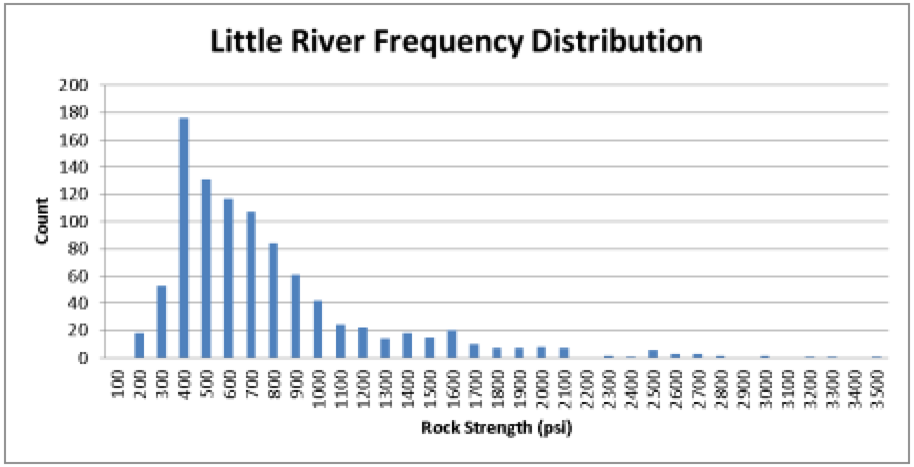
- Core data from Boring B-4 was compared to the data
  - Recovered and tested by FDOT
  - Boring B-4 is the 1 of 6 available for comparison
- Core data and monitored drilling results show similar trends and strengths at respective depths
  - Stratification is observed from both sets of data



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 statnamic load testing planned will be monitored
  - Compare Ds 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 Ds 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.
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Questions?