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

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FDOT Geotechnical Research in Progress Report
Presented by: Michael Rodgers, E.I.

University of Florida
Department of Civil & Coastal Engineering
Presented August 8, 2013

Last Year

- 5 Drillings Parameters
  – Torque, T
  – Crowd, F
  – Penetration rate, u
  – Rotational speed, N
  – Bit diameter, d
- Field Drilling
  – Survey results from District Geotechs and Contractors
    - Displayed what's being monitored and how
- Laboratory Drilling
  – Small scale drilling to develop drillability strengths for respective rock strengths
  – Results used to determine "real time" rock strength in the field

Topics Covered

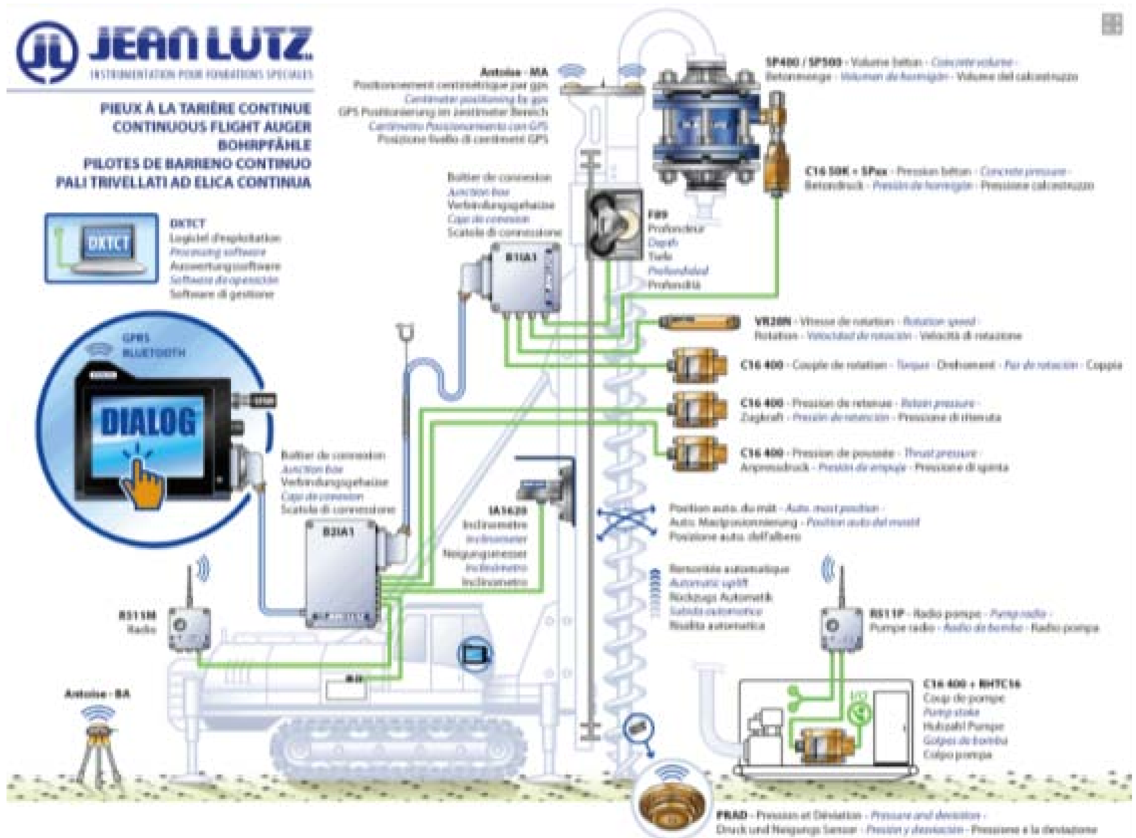
- Field Monitoring Equipment
  - UF monitoring system
  - Jean Lutz monitoring system
- Gatorock Mix Design
  - Design strengths
  - Mixing, curing and transport
- Laboratory Drilling
  - Drill press modifications
  - Laboratory coupler monitoring system
  - Drilling process
- Preliminary Laboratory Drilling Results

Components of Monitoring System

- Rotational Speed
  - Proximity Sensor
- Penetration Rate
  - Rotary Encoder
- Torque
  - Pressure Transducer
- Crowd
  - Pressure Transducer
- DAQ module
  - LabView System

Jean Lutz Monitoring System

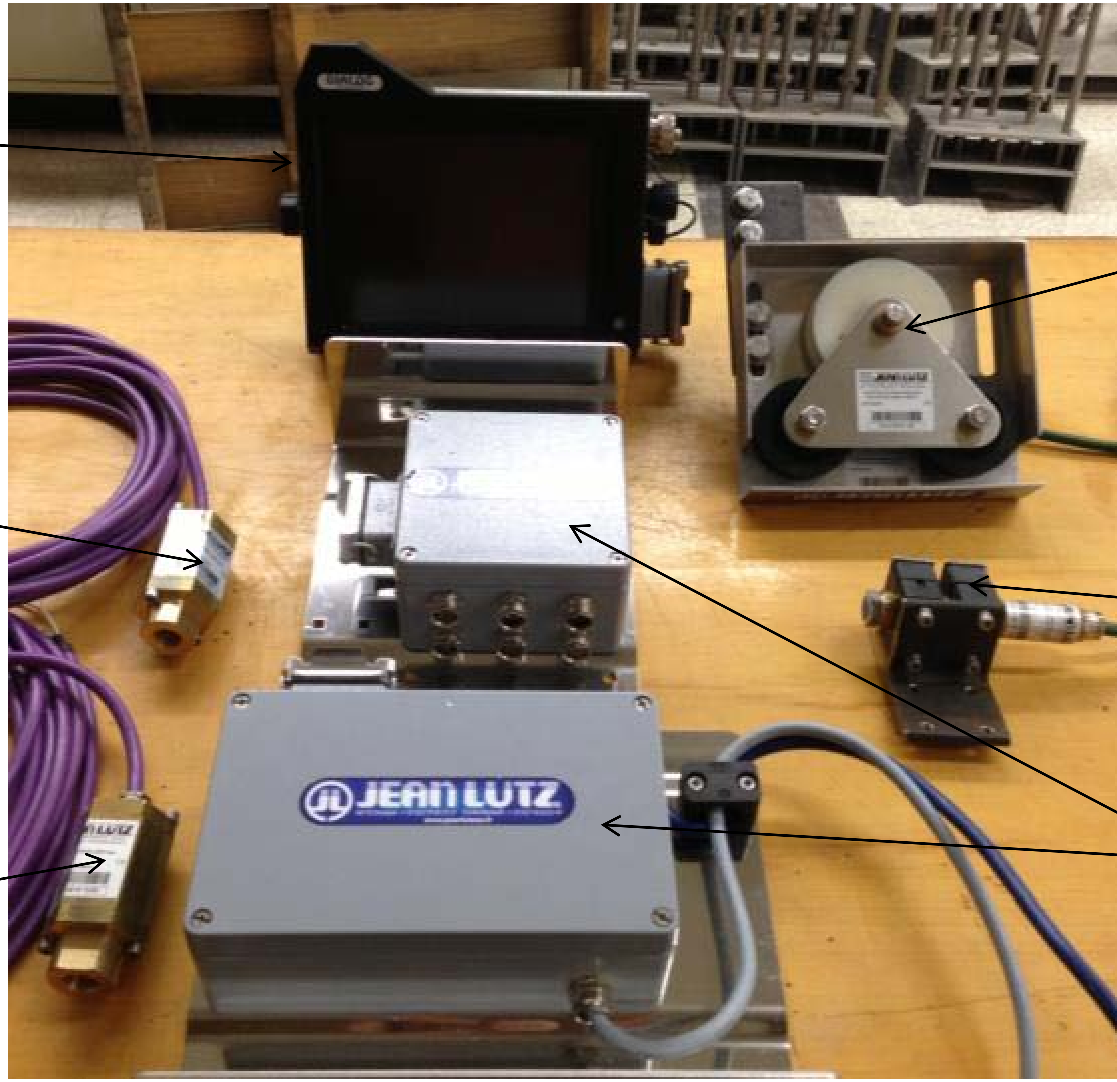
- Rotational Speed
  - VR28
- Penetration Rate
  - F82
- Torque
  - C16400
- Crowd
  - C16400
- DAQ
  - DIALOG



System Comparison

- IP Ratings
  - Jean Lutz – IP66
  - Proximity sensor and rotary encoder – IP50
- Mounting Equipment
  - Jean Lutz – Built in
- Compatibility
  - Jean Lutz – All sensors built to work together
- Durability
  - Jean Lutz – Designed to use in drilling environment

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

Synthetic Gatorock Mix

- Unconfined compressive design strengths
  - 5, 10 and 20 tsf
  - 70, 140 and 280 psi
- Limestone Screenings
  - FDOT Code 22
- Portland Cement
  - Florida Type I
- Stored at Coastal Engineering lab
  - Protected from environment

Product Quality Summary Report

Monthly QC Fine Aggregate Report

Period 10/02/2012 – 11/01/2012

Plant **1328-FEC Quarry-FDOT 87-090**

Product	1037191 M/Asphalt Scrns FDOT Code 21	1037202 Concrete Scrns SFBC	1037230 C/Asph Scrns FDOT Code 22	1037235 Concrete Scrns FDOT Code 03	1037311 Fine Asphalt Scrns FDOT Code 20	1037335 919.2 Scrns FDOT Code 23
Specification	M/Asphalt FDOT 21	Comm. Conc. Scrns.	Coarse Asph Scrns FDOT 22	FDOT Concrete Screenings	Fine Asphalt Scrns FDOT 20	919.2 Scrns FDOT 23
3/8" (9.5mm)	100.0	100.0	100.0	100.0	100.0	100.0
#4 (4.75mm)	100.0	100.0	100.0	100.0	100.0	90.7
#8 (2.36mm)	93.6	93.6	91.6	91.6	95.4	66.4
#10 (2mm)	87.5	87.6	83.9	83.9	90.9	61.5
#16 (1.18mm)	69.0	69.1	62.1	62.1	77.2	49.7
#30 (0.6mm)	48.7	48.9	40.0	40.0	61.3	36.7
#40 (0.425mm)	40.0	40.2	31.0	31.1	53.4	30.4
#50 (0.3mm)	31.2	31.4	22.8	22.8	43.8	24.0
#80 (0.18mm)	13.5	13.7	9.3	9.3	22.7	12.6
#100 (0.15mm)	8.0	8.1	5.1	5.1	14.4	7.8
#200 (75um)	1.55	1.60	1.09	1.10	2.76	2.15
Pan	0.00	0.00	0.00	0.00	0.00	0.00
FM	2.50	2.49	2.79	2.78	2.08	3.25
Total Moisture	8.01	8.01	7.16	7.16	8.49	8.56
Cu	5.42	5.41	5.86	5.87	4.44	11.52
Absorption	2.2		2.3		2.2	2.4
SPGR (Dry Gsb)	2.454		2.481		2.495	2.482
SPGR (SSD)	2.509		2.538		2.550	2.542
-#200 (75um)	1.53	1.53	1.03	1.05	2.68	2.06

Gatorock Mix Design

TRIAL BATCH -- DATA AND CALCULATIONS

(Saturated, Surface-dry Aggregates)

Specification

Cement Content:	218.553363 lbs			Date:	June 13, 2013
W/CM (lbs/lbs):	2.1			Project:	UF# 98039
				Batch:	280 psi
Air Content (%):	,-	to	,-	Mixing By:	Mike Rodgers
Slump Range (in):	,-	to	,-	Design By:	Mike Rodgers
Aggregate. SSD:	2.54	Lab =	2.58	Witness By:	Caitlin Tibbetts
Batch Size (ft^3):	14.00	C.Y. =	0.5185	C/A% (lbs/lbs):	7.99
				W/A% (lbs/lbs):	17

MATERIAL	SOURCE	WT. PER YD^3 (LB)	SPECIFIC GRAVITY	VOL. PER YD^3 (CF)	WT. PER BATCH (LB)	ADJ. WT. PER BATCH (LB)	REMARKS
CEMENT	Florida Rock	219	3.15	1.11	113.3	**113.3**	
WATER	Local	466	1.00	7.47	241.7	**241.1**	
Aggregate	Limestone	2734	2.48	17.67	1417.8	**1418.3**	
AIR		0.0 oz		0.75		0.39	
TOTAL		3419		27.00			126.6258

Gatorock Mix Design

Mix	Target Strength (psi)	Actual Strength (psi)	Target Strength (tsf)	Actual Strength (tsf)	W/C	C/A (%)	W/A (%)	Cement Content (lbs)	Mix Description
1	280	77.3	20	6	5	15.38	78.8	205.3	Too Soupy
2	280	163.1	20	12	2.5	15.38	40.1	298.9	Too Soupy
3	280	1005.9	20	72	1	15.38	17	411.5	Good
4	140	142.2	10	10	1	8.12	9.64	257.5	Dry
5	70	122.3	5	9	1	4.58	6.2	159.7	Dry
6	140	291.6	10	21	1.9	8.12	17	225.6	Good
7	70	93.7	5	7	3.4	4.58	17	129.7	Good

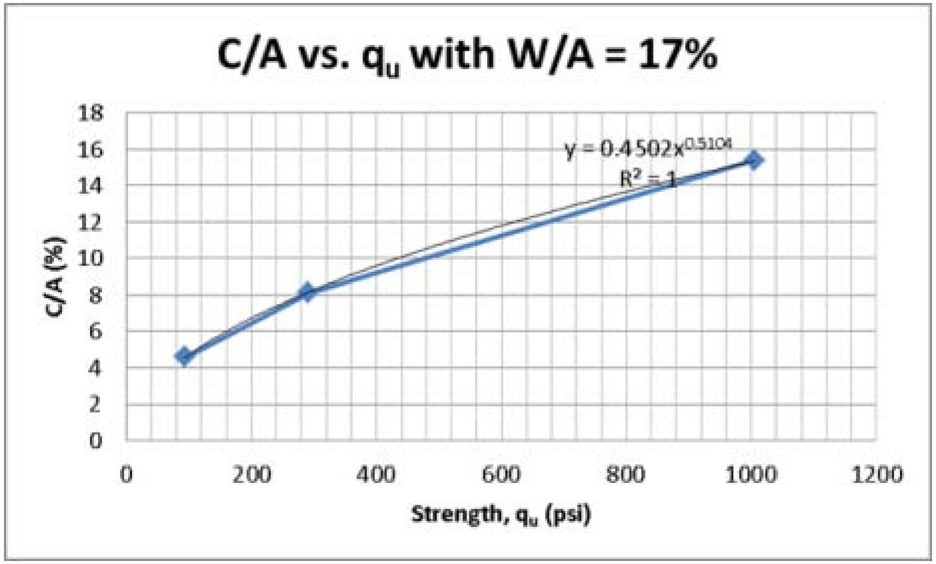
- Preliminary mix designs indicated W/A = 17% produced the best final product
- New mix designs based on W/A = 17% and varying C/A ratios from developed curve projections

Sample 4 (left) and Sample 6 (right)

Gatorock Mix Design

- Develop equation for C/A using previous results with measured strengths
- Use equation to predict new design strengths

Measured Strength (psi)	C/A %
1005.9	15.38
291.6	8.12
93.7	4.58
Predicted Strength (psi)	C/A %
280	7.99
140	5.61
70	3.94



Mix 1 - 280 psi			
μ	σ	CV	samples
283.08	16.12850364	0.05697435	1,2,3,4,5,6
277.55	9.774012035	0.035215281	1,2,3,4,5
Mix 2 - 140 psi			
μ	σ	CV	samples
154.66	8.906670954	0.057589158	1,2,3,4,5,6
151.31	3.46197672	0.022880237	1,3,4,5,6
Mix 3 - 70 psi			
μ	σ	CV	samples
70.41	8.853758157	0.125745486	1,2,3,4,6
76.24	4.666660681	0.061213975	1,2,3

Mixing Process

- Weigh out projected material (screenings and cement)
- Transport to SMO the day before mixing
- Take water content reading for mix day adjustments
- Use 1 cu-yd mixer at SMO for mixing

Mixing Process

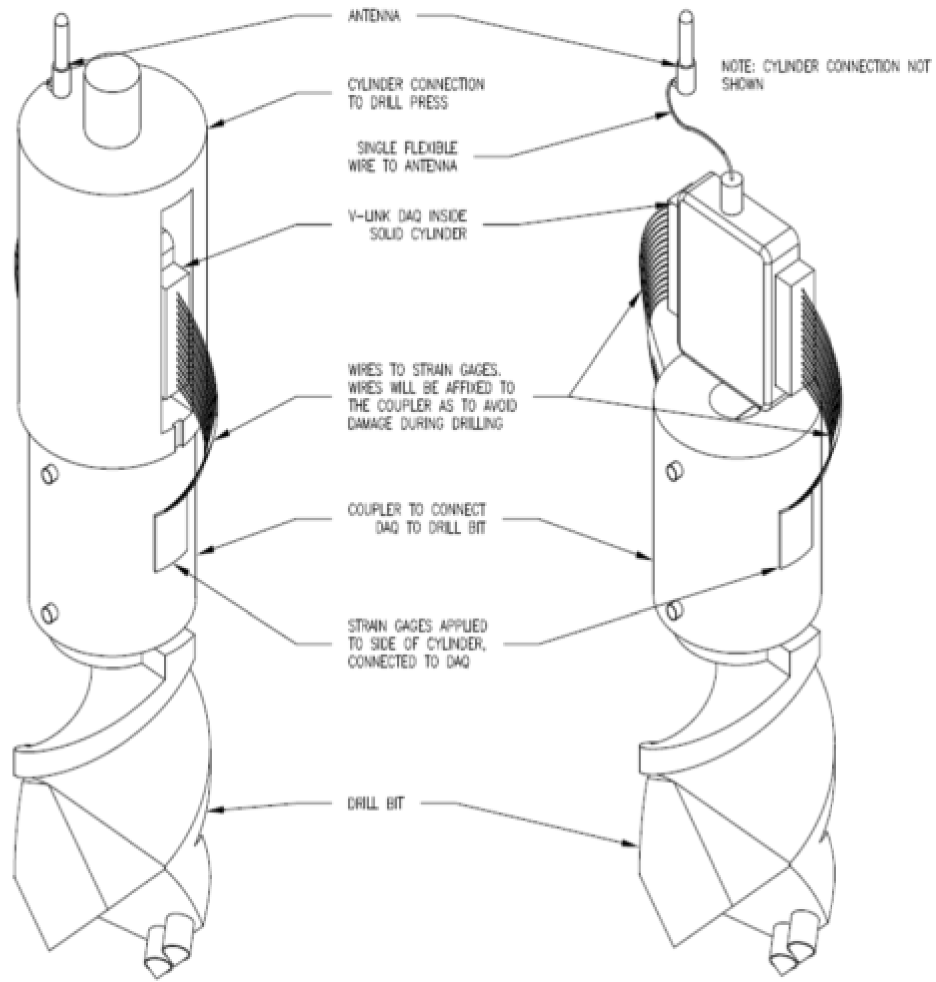
- Material placed in forms at 7-8 inch lifts
- Mix is then vibrated several minutes for each lift
- Final layer is screeded off and covered with visqueen
- Test cylinders are casted to determine 14-day strength
- After 7 days the mix is transported to the Coastal Lab to cure for the final 7 days

Drill Press

- Cincinnati Bickford Radial Arm Drill Press
  - 5 Hp motor
- 9 rotational speed settings
  - 75 – 1500 rpms
- 4 penetration rate settings
  - .004, .008, .014 and .02 in/rev
- 55 inches of clearance to the ground
  - 9 inches to build coupler system

Drill Press Problems

- Desired rotational speeds cannot be used
  - Drilling needs to be done at 20 and 40 rpms to be comparable with the field
- Insufficient ground clearance to build coupler system
  - 55 inches of total clearance
  - 40 inch tall blocks
  - 6 inch drill bit
  - Only 9 inches to design coupler
    - Complicated design
    - Possible edge effects

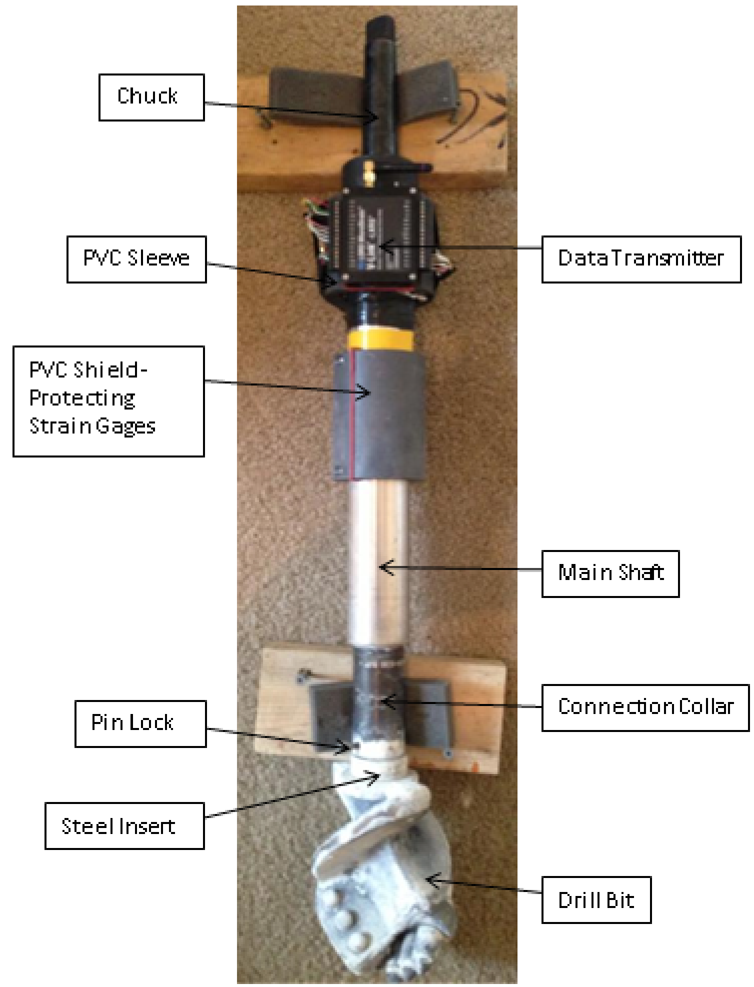


Dress Press Modifications

- Raised the elevation by 12 inches using steel reinforced concrete slab with anchors
  - 21 inches for coupler design
- Replaced magnetic switch with Variable Frequency Drive
  - Provides needed rotational speeds (20 and 40 rpms)

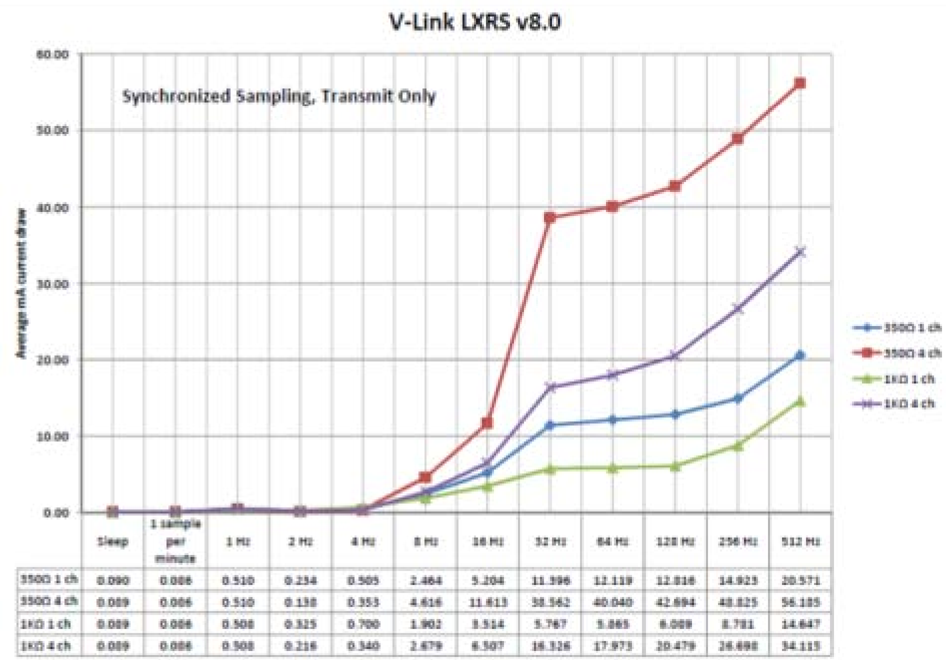
Laboratory Coupler to Monitor Crowd and Torque

- 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^{o} apart
  - Compensates for bending and temperature effects
- Lord Microstrain V-Link LXRS for wireless data transmission



V-Link LXRS

- Used with WSDA Base -101
  - Provides analog or USB interface
  - Compatible with computer or Jean Lutz DAQ
- Using an analog base station
  - Converts microstrain to custom output
  - Output signal is torque or force per bit (ie. 10 lbf / bit)
- 600 mA-hr available
  - Estimate 120 hrs of battery life
    - Sampling rate, # of channels and strain gages used
- 4 available channels
  - 2 Torque
    - Full bridge torque rosettes
  - 2 Crowd
    - Full bridge T-element strain gages



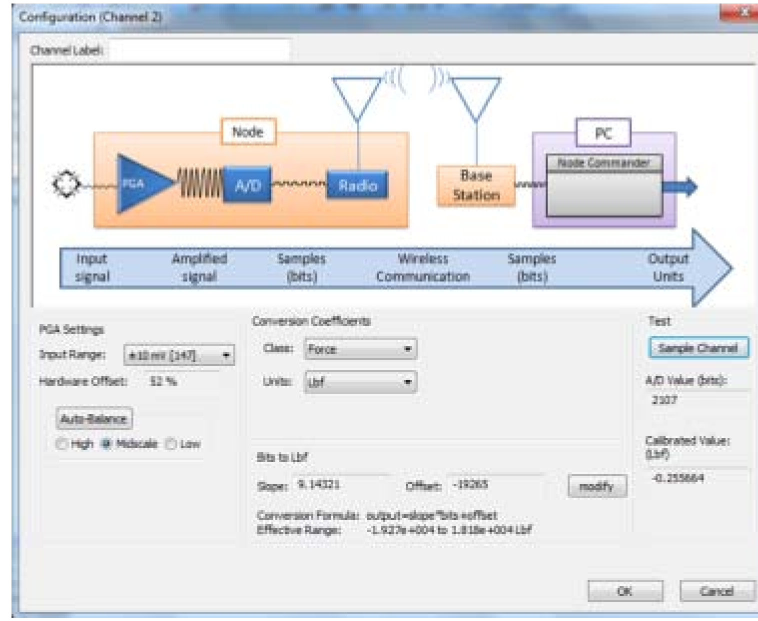
	Sleep	1 sample per minute	1 Hz	2 Hz	4 Hz	8 Hz	16 Hz	32 Hz	64 Hz	128 Hz	256 Hz	512 Hz
350Ω 1 ch	0.090	0.006	0.510	0.234	0.505	2.464	5.204	11.396	12.119	12.816	14.923	20.571
350Ω 4 ch	0.089	0.006	0.510	0.138	0.353	4.616	11.613	38.562	40.040	42.694	48.825	56.185
1KΩ 1 ch	0.089	0.006	0.508	0.325	0.700	1.902	3.514	5.767	5.865	6.009	8.781	14.647
1KΩ 4 ch	0.089	0.006	0.508	0.216	0.340	2.679	6.507	16.326	17.973	20.479	26.698	34.115

Drilling Process

- Place the Gatorock block in position next to drill
  - Ensure stability (wobbling)
- Mark center point with chalk lines
- Position drill bit to center point 1 inch above block
- Select proper drill parameter settings
  - Rotational speed
  - Penetration rate
- Lock drill into place
- Disengage arm

Drilling Process

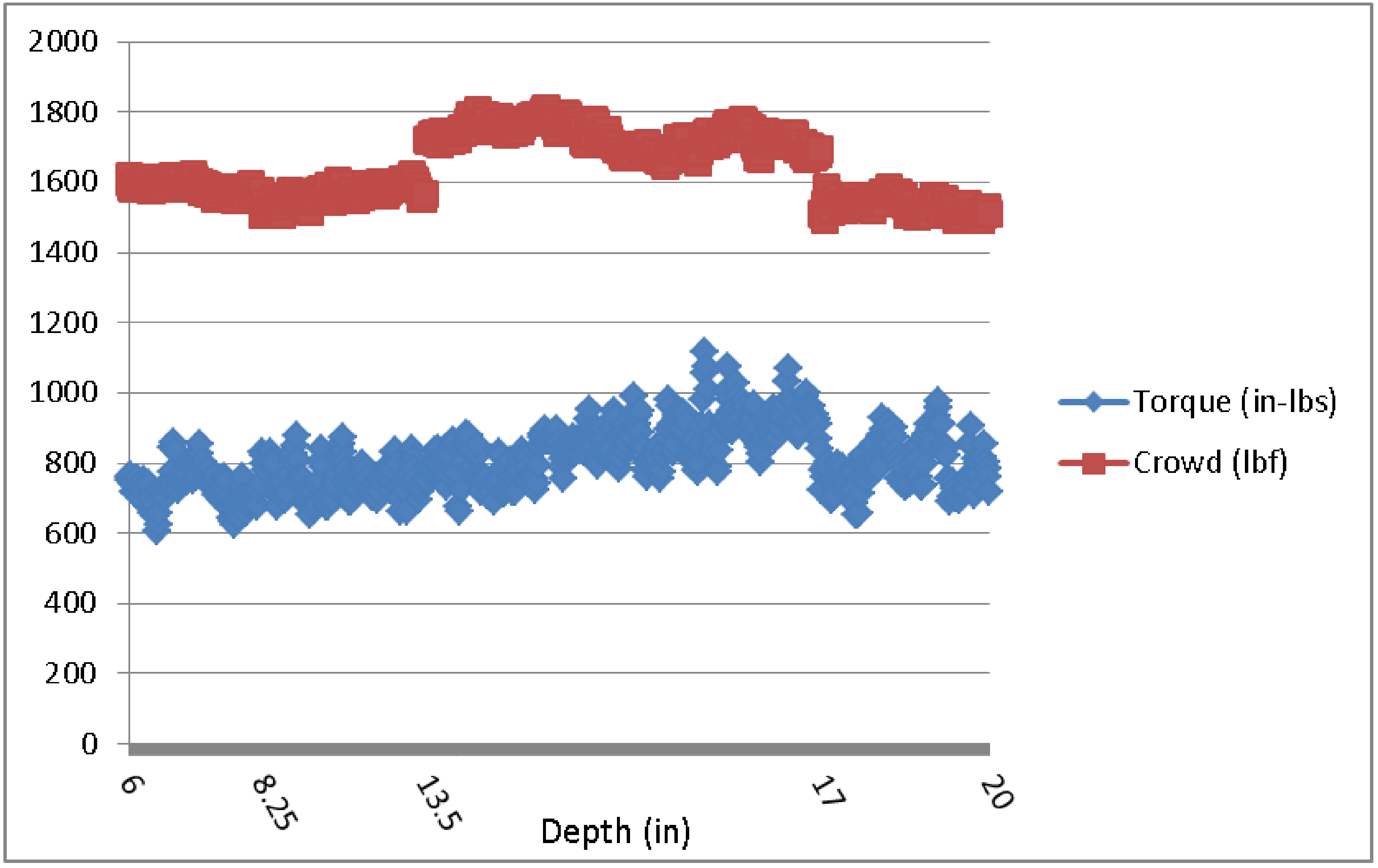
- Calibrate coupler system using Node Commander software
- Start data recording (8 Hz) and external stop watch
- Use drill logs to record drilling process and measure depths
- Reposition arm when full length of spindle is reached
- Continue drilling until 20 inch depth is reached



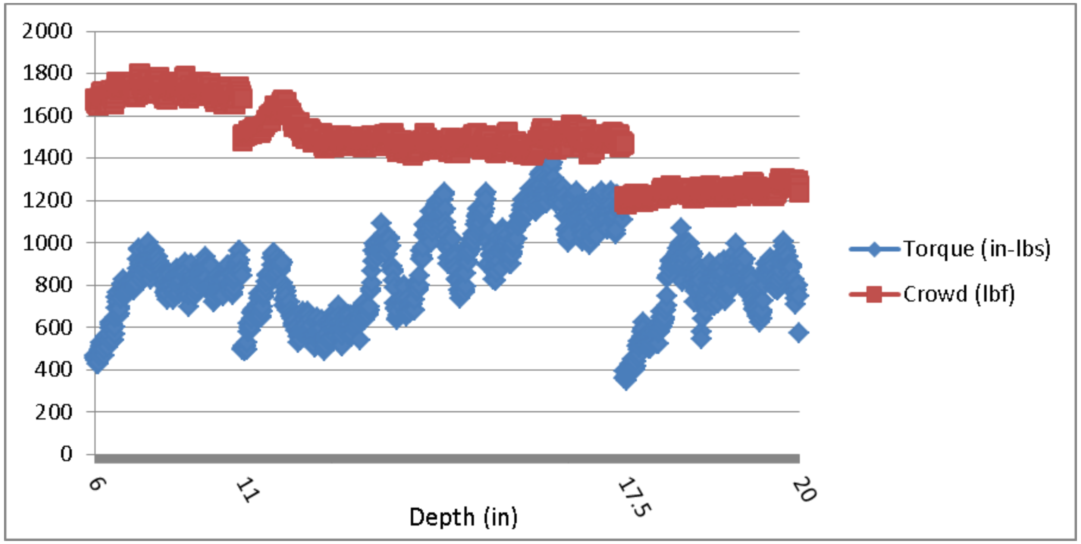
Compiling the Data

- 10,000 – 40,000 raw data points
- Drill logs are used to determine baseline readings and usable data (using time as a reference)
- Results from each respective channel are combined and averaged
  - 2 torque channels combined
  - 2 crowd channels combined
- An average for each full rotation is then taken
  - 8 Hz sampling rate at 40 rpms -> 12 readings/revolution
- These results are then averaged for the entire drilling process to determine the average torque and crowd for each drilling

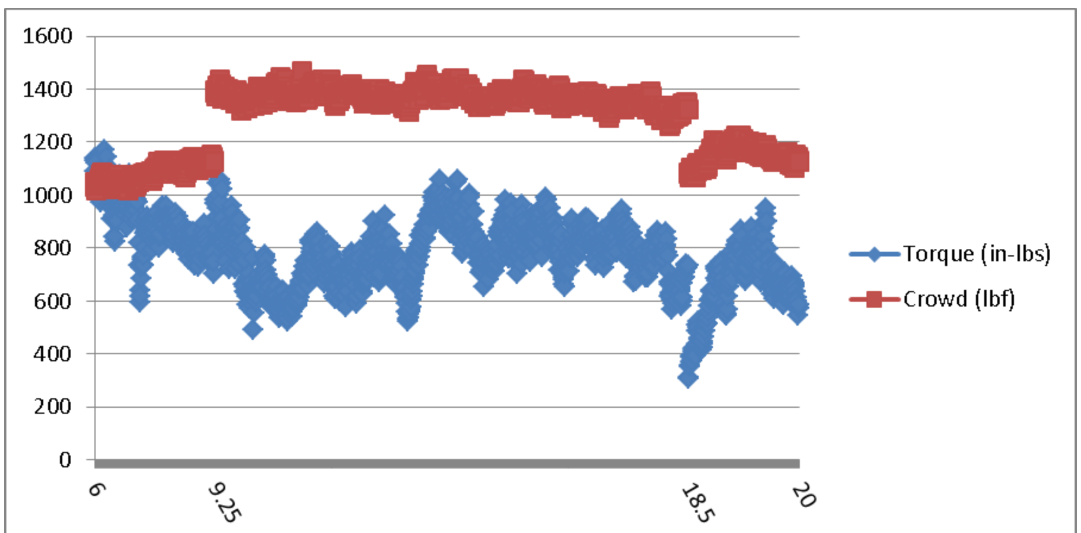
Torque and Axial Force vs. Depth



Top vs. Bottom Drilling



Final Results - Side 1 (TOP)		
Description	T (in-lbs)	F (lbf)
Average	847.5611442	1326.999603
Maximum	1410.286347	1802.537645
Minimum	351.2036013	1179.469308
Std. Deviation	210.9005275	166.064064
CV	0.248832228	0.125142512



Final Results - Side 2 (BOTTOM)		
Description	T (in-lbs)	F (lbf)
Average	778.440086	1287.421662
Maximum	1168.976437	1469.494367
Minimum	308.3559894	1016.261329
Std. Deviation	131.28193	125.1670544
CV	0.168647443	0.097223045

Preliminary Drilling Results

- Results from 3 drillings with similar rock strengths
- All blocks drilled using a rotational speed of 40 rpms
- 3 different penetration rates were used
  - 0.004, 0.008 and 0.014 in/rev
- Results are plotted as Karasawa did in 2002 and 2004

Final Results - 40rpm-4u-300psi		
Description	T (in-lbs)	F (lbf)
Average	547.66	1351.64
Maximum	962.64	1554.58
Minimum	222.93	1049.35
Std. Deviation	128.49	118.50
CV	0.23	0.09

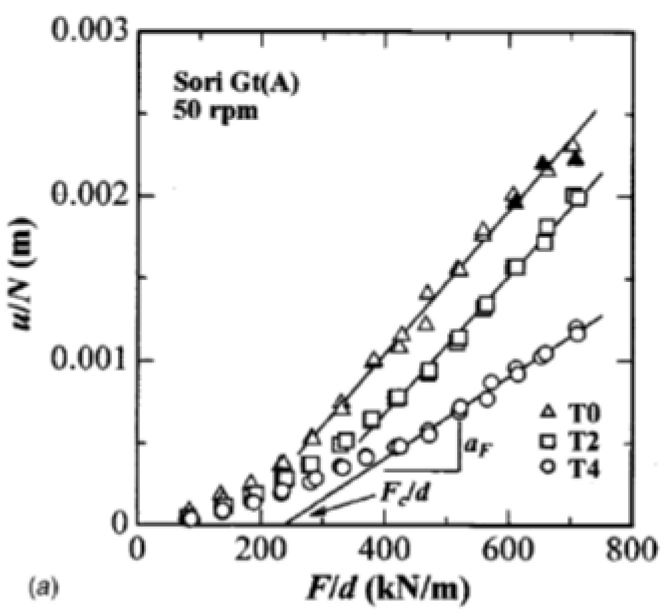
Final Results - 40rpm-8u-300psi		
Description	T (in-lbs)	F (lbf)
Average	630.97	1422.69
Maximum	1130.99	1550.44
Minimum	311.07	1283.15
Std. Deviation	165.20	49.69
CV	0.26	0.03

Final Results - 40rpm-14u-318psi		
Description	T (in-lbs)	F (lbf)
Average	803.51	1637.39
Maximum	1118.41	1812.08
Minimum	607.21	1491.28
Std. Deviation	85.76	90.95
CV	0.11	0.06

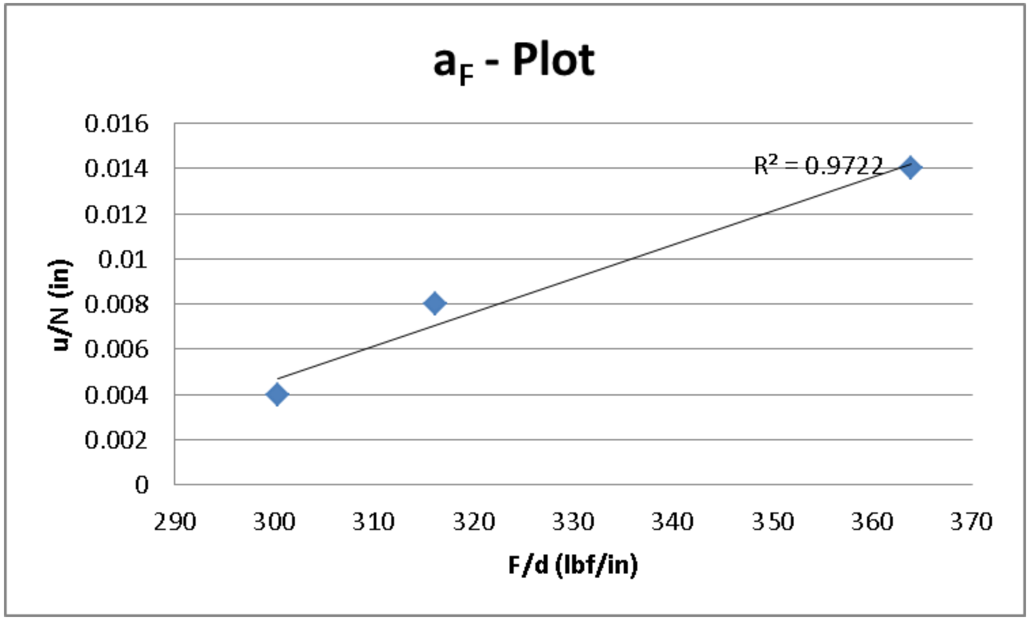
u/N vs. F/d

(penetration rate/rotation speed) vs. (axial force/bit diameter)

- Karasawa compared u/N vs. F/d to determine a slope for the force referred to as the a_F slope.
- The a_F slope should display an increasing linear trend



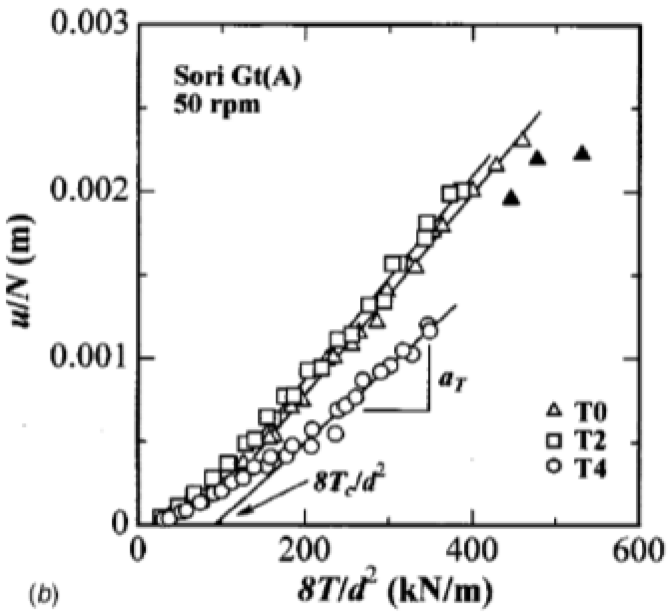
Karasawa, 2002



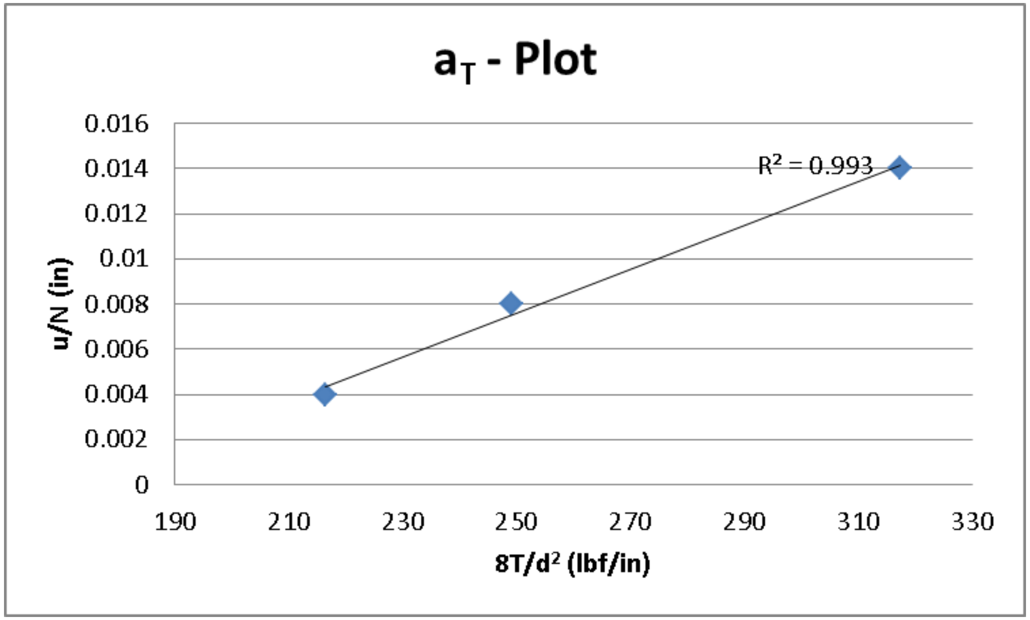
u/N vs. $8T/d^2$

(penetration rate/rotation speed) vs. (8*Torque/bit diameter^2)

- Karasawa also compared u/N vs. $8T/d^2$ to determine a slope for the torque referred to as the a_T slope.
- The a_T slope should display an increasing linear trend

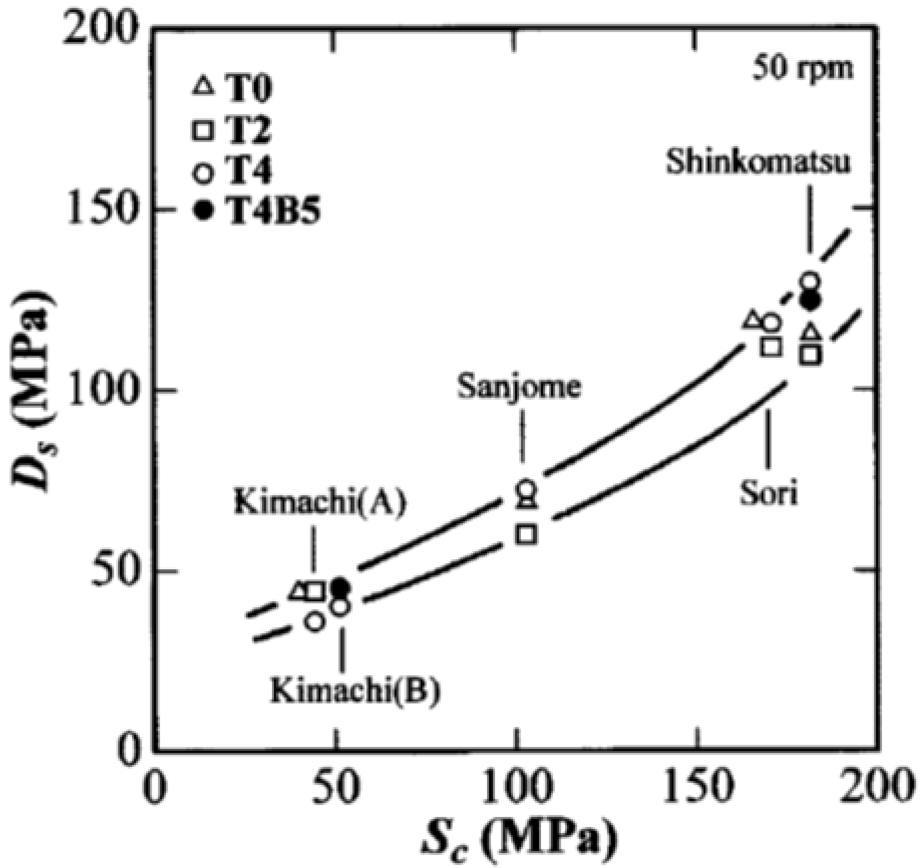


Karasawa, 2002



D_s vs. q_u

- Karasawa compared:
  - Drillability Strength of rock, D_s
  - Unconfined Compressive Strength, S_c or q_u
- $D_s = a_F/a_T^2 = 64NT^2/Fud^3$
- Plot will be developed using lab results when more strengths have been tested



$^*S_c$ (q_u – unconfined compression)

Karasawa, 2002

Future Plans

- Perform wet drilling
  - Comparing wet vs. dry
- Drilling side by side
  - Investigating disturbance and reducing block size
- Drill using different bit size
  - 3.5” or 6” bit
- Developing new mix design strengths
  - 40 and 120 tsf
- Drilling with different strengths
  - 10, 40 and 120 tsf

Changes in Design Strength

- Results from FDOT project No. 99052794 (2003) indicated higher strengths
- Eliminate 5 tsf design strength
- Add 40 and 120 tsf design strengths
- Create new mix design using previous results and methods

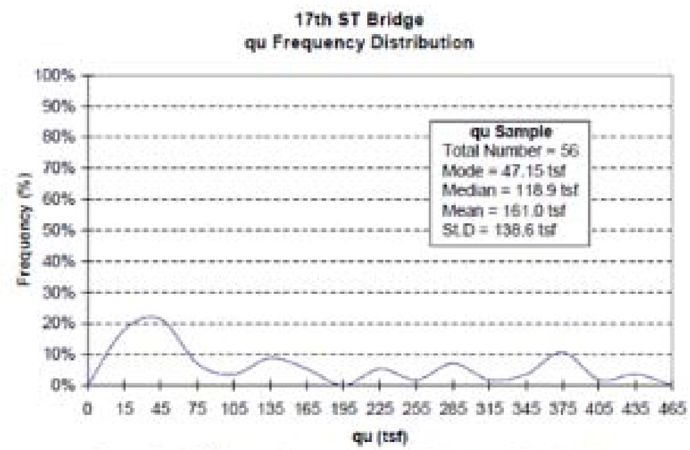


Figure 7.1 17[th] Street Causeway Site – qu Frequency Distribution

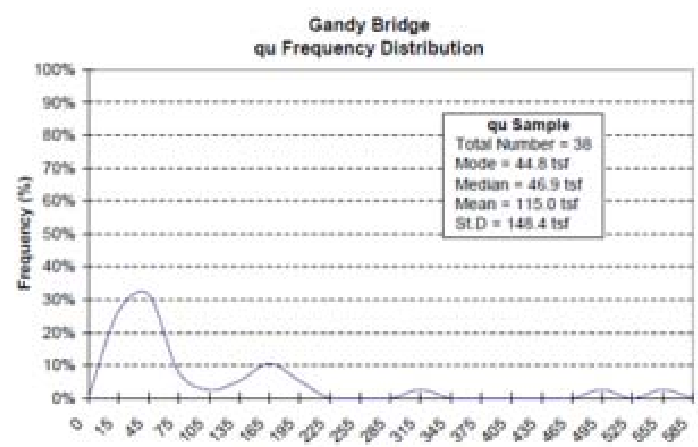


Figure 7.16 Gandy Bridge Site – qu Frequency Distribution

Future Plans

- Obtain recorded drillings from Coastal Caisson
  - B-Tronic monitors u, N, T and F
- Build field coupler monitoring system
  - Using field data from Coastal Caisson
- Develop D_s vs. q_u plot for “real time” drilling
  - Develop equation for Jean Lutz software
- Field drilling with Jean Lutz equipment
- Compare field drilling results with load test results
- Write 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 onTheir Use for FDOT Structures.”, FDOT Final Report (2003).
- Brown et al. “Drilled Shafts: Construction Procedures and LRFD Design Methods”, FHWA NHI-10-016, NHI Course No. 132014, Geotechnical Engineering Circular No. 10, May 2010

Questions?