Field Testing of Jet-Grouted Piles and Drilled Shafts

BDK-75-977-41

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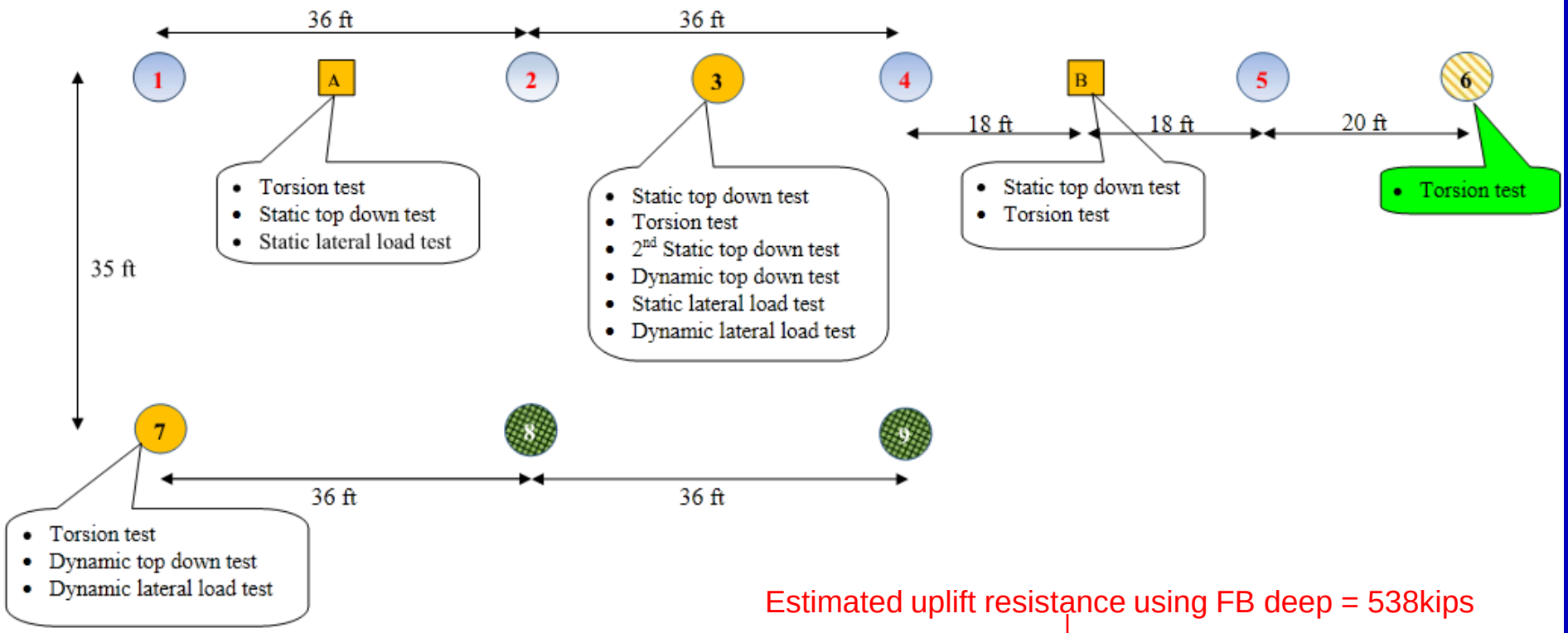
Scope of work

- Validate the design and constructability of jet-grouted piles in typical Florida soil
- Load testing of jet-grouted piles and drilled shafts:
  - Top down testing
  - Combined torsion and lateral load testing
  - Lateral load testing
- Comparison of axial, torsional and lateral behavior of jet-grouted pile vs drilled shaft
- Validate the revised FDOT design approach for drilled shaft supporting Mast Arms
- Cost comparison of jet-grouted piles vs drilled shafts

Test site: *FDOT borrow pit, Kingsley, Keystone Heights*

Test Layout



Estimated uplift resistance using FB deep = 538kips

Two, 4ft diameter x 18ft long **Test** drilled shaft

One , 4ft diameter x 12ft long **Test** drilled shaft

Two, 28 in square, 20 ft long **jet grouted pile**

Four, 4ft diameter x 40ft long **Reaction** drilled shaft

Two, 4ft diameter x 55ft long **Reaction** drilled shaft

Estimated uplift resistance using FB deep = 873 kips

Construction of Reaction and Test Drilled shafts

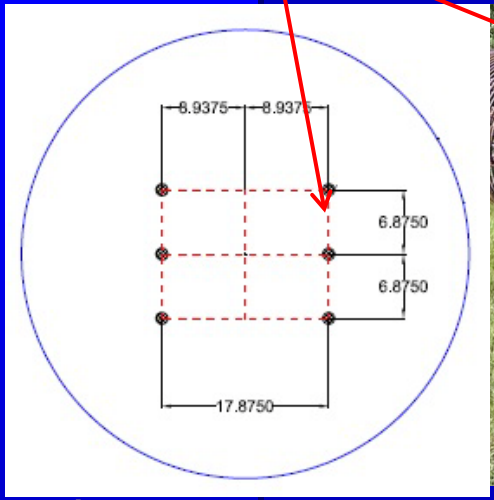
- Construction was carried out by the third party vendor: Reliable Constructors Inc., Mount Dora, FL
- Drilled shaft inspectors from FDOT district 2 was present at the site:
  - ✓ To monitor all the construction activities
  - ✓ For logging excavation & concrete placement
  - ✓ Quality control
- Wet construction method using bentonite slurry was employed

Reaction shafts

- ➢ Temporary surface casing was used for reaction shafts construction
- ➢ Sister-bar strain gages were placed in pairs at 4 different levels along length in one of the 40 ft long reaction shafts (#2), which will provide reaction during static lateral load tests.
- ➢ Concrete used was *class IV drilled shaft concrete(4000 psi)*

Reaction shafts construction

Dywidag bars attached to Reinforcing cage to transfer reaction load from beam girders during axial load test



Shaft excavation using drill rig

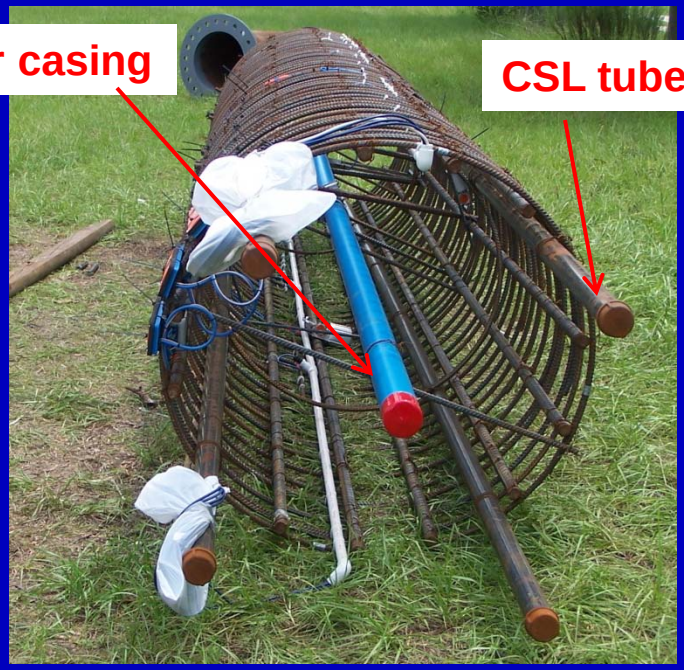
Rebar cage placement

Concrete placement

After hydration

28th day mean compressive strength: 5068 psi
Coefficient of variation = 0.133 ;

Test shaft construction



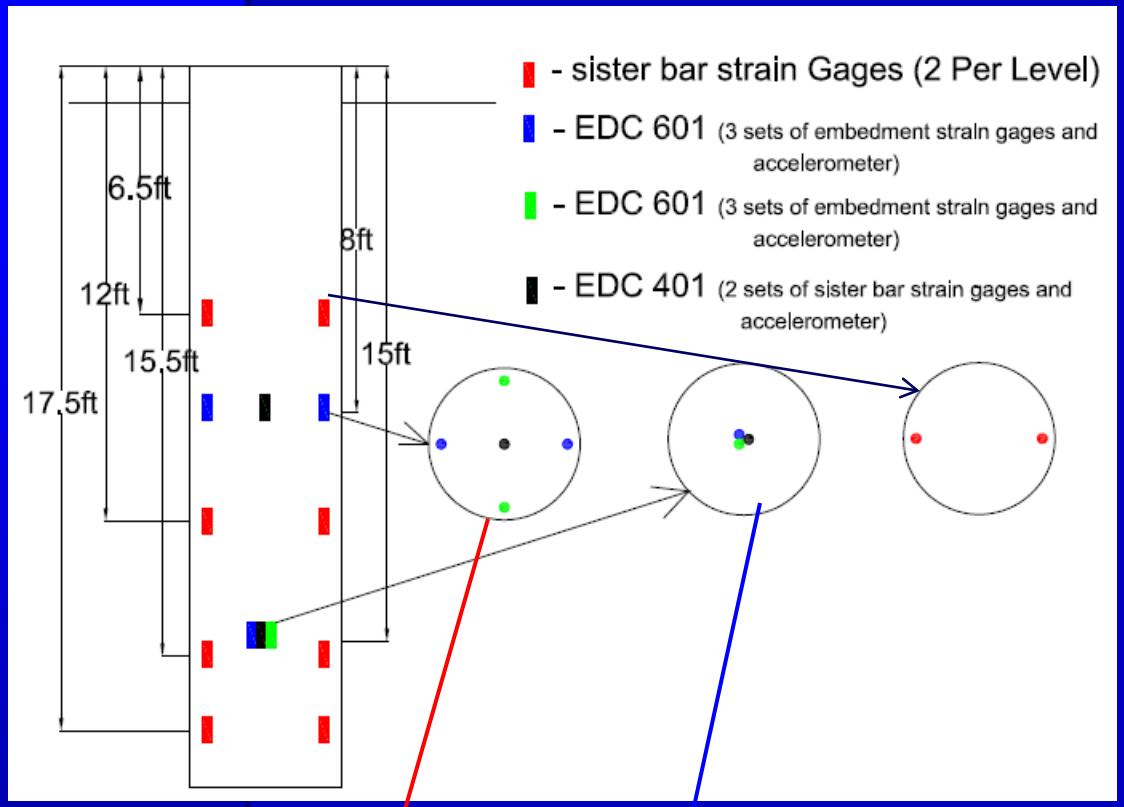
Instrumentation/monitoring tubes:

- ❑4 CSL tubes @ 90^0 apart

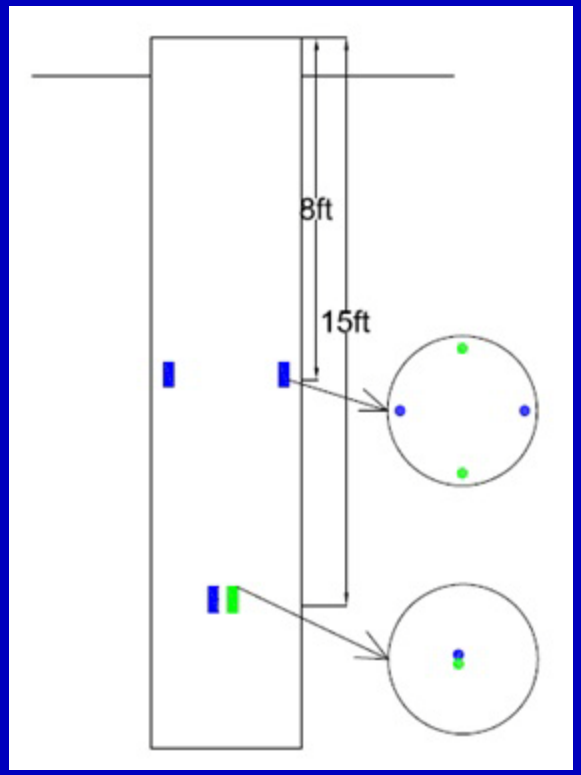
- ❑Inclinometer casing in 18ft long test shafts to set accelerometer strings for monitoring lateral deflection, bending moment, shear force and soil reaction force (static and dynamic lateral load test)

- ❑Sister-bar strain gages in pairs at 4 different levels (lateral P-y curve) along length in one of the18 ft long test shafts (#3) which will be subjected to both static axial & lateral load test
- ❑EDC 601 and EDC 401 for Dynamic axial load test (to distinguish skin and tip resistance; instrumented by Applied Foundation Testing Inc.)

Shaft # 3: two EDC 601 & one EDC 401



Shaft # 7: two EDC 601



EDC 8ft below shaft top

EDC 4ft above shaft bottom

Construction of test shafts

- ❖Dry excavation up to 6ft depth (no water)
- ❖Then, bentonite slurry was pumped and continued drilling (below water table)
- ❖ New concrete mix with smaller aggregate was used to avoid segregation and meet FDOT requirements, as the space available between the rebar cage and embedded system was 3.87in only.

Lowering reinforcing cage

Properties of concrete mix

Mix number	HC62JD
Comp. Strength 28 days (psi)	4000
Slump (in)	8+/- 1”
Air Content (%)	1.5%
Plastic Unit Weight (lbs/cf)	143.4 +/- 1.5
Cement	70%
Slag	30%
Coarse aggregate	#89 aggregate

Lowering pipe and flange connector for combined torsion and lateral load testing of the shaft

Placing dywidag bar cage (4 bars) within the embedded pipe (for future lateral load testing)

After completion

28 days comp. strength of new mix

- Mean strength = 6717 psi
- Coefficient of variation = 0.048
- Minimum strength = 6290 psi;
- Maximum strength = 7194 psi

Test site with reaction and test shafts

CSL Tests on test shafts – *performed by SMO, Gainesville*

- Tests were conducted in accordance with ASTM D 6760 using SMO's Cross Hole Analyzer
- The CSL results for all the shafts were nearly identical

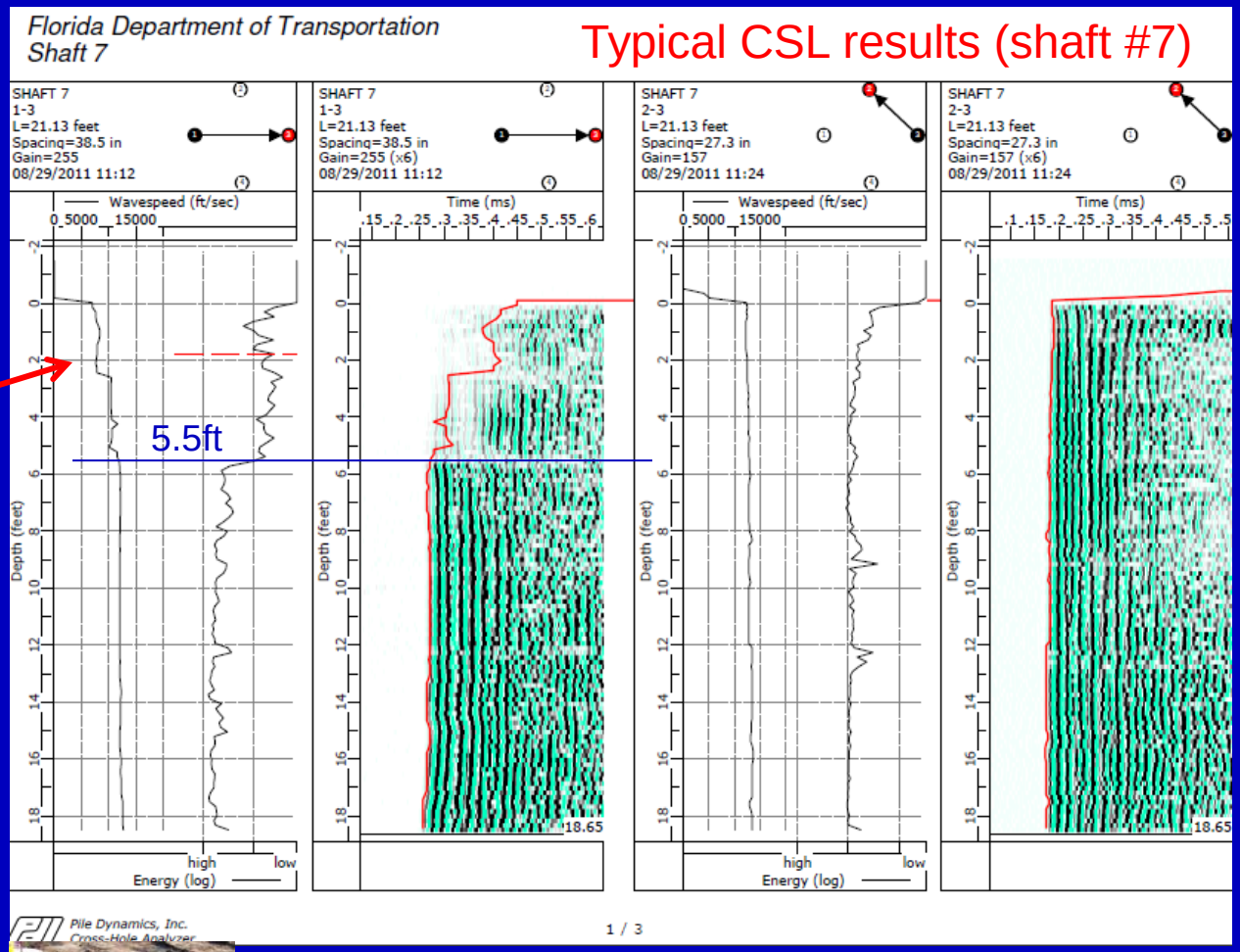
❖Adjacent tube pairs:

Uniform first arrival time (FAT) and energy throughout the depth, indicating good quality and integrity of shafts.

❖Diagonal tube pairs

Identical reduction in wave speed (increase in FAT) and energy strength over the top 5.5 ft of shaft - the zone where the pipe and flange section was embedded.

❖This reduction may be due to the difference in impedance of steel and concrete.



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Mast arm-Pole assembly :for combined torsion and lateral load tests

- Designed using the FDOT's MathCAD spread sheet: Mastarm v4.3 (modified to incorporate point lateral load on arm instead of wind load;)
- Designed to ensure pile/shaft - soil failure during the tests (no structural failure)
- Fabricated at Coastal Engineering lab, UF
- Pole base plate has two sets of holes: Inner hole for connecting with drilled shafts; Outer holes for connecting with jet-grouted piles;

Dimensions

	Length (ft)	Diameter (in)	Thickness (in)	Taper angle (deg)
Arm	40	20	0.625	0
Pole	22	24	0.625	0

First drilled shaft test (4ft Ø x 12-ft long shaft)

Combined torsion and lateral load test

The test was carried out in two phases:

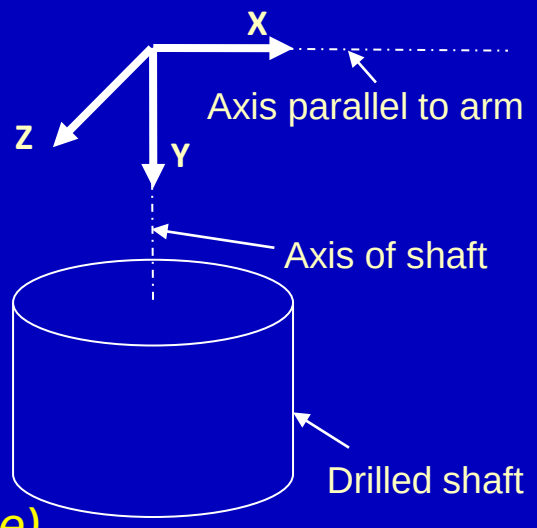
(1) Mast arm assembly on the top of shaft

--axial load, F_y = 10.7 kips Self weight

--bending moment, M_z = 118 kip-ft

(2) Lateral load on Mast arm at a standoff distance of 35 ft. (simulate wind loading; e.g., hurricane)

--combination of loads and moments (V_x, F_y, M_z, M_x, Torque).



Phase 1: Mast arm assembly on top of shaft

Bolting pole flange to embedded pipe and flange connector

Load carried by crane = 8.1 kips

Load transferred to shaft = 2.6 kips (10.7-8.1)

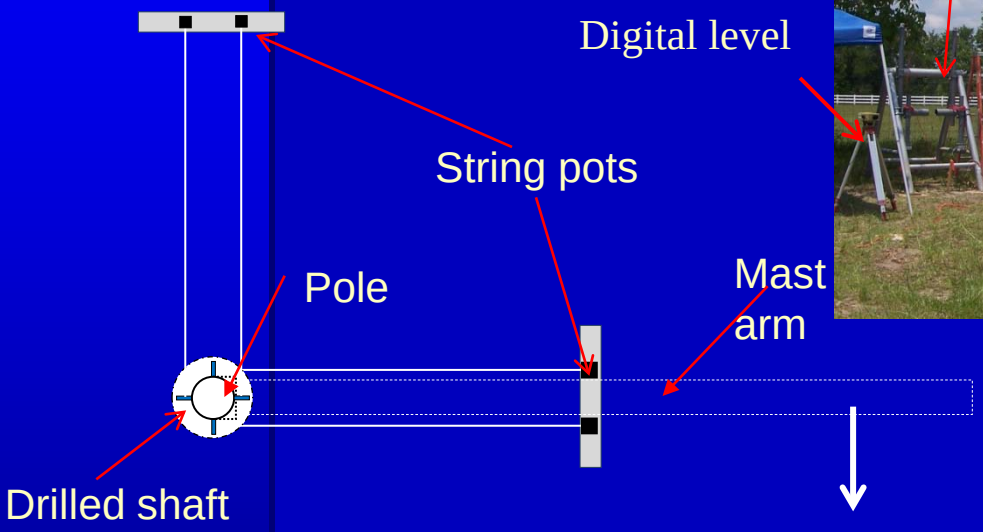
75 ton crane

Instrumentation

- 2 sets of string pots (4 pots in each set) to monitor rotation, translation & overturning:

  ---1st set → 0.5ft above the bottom flange

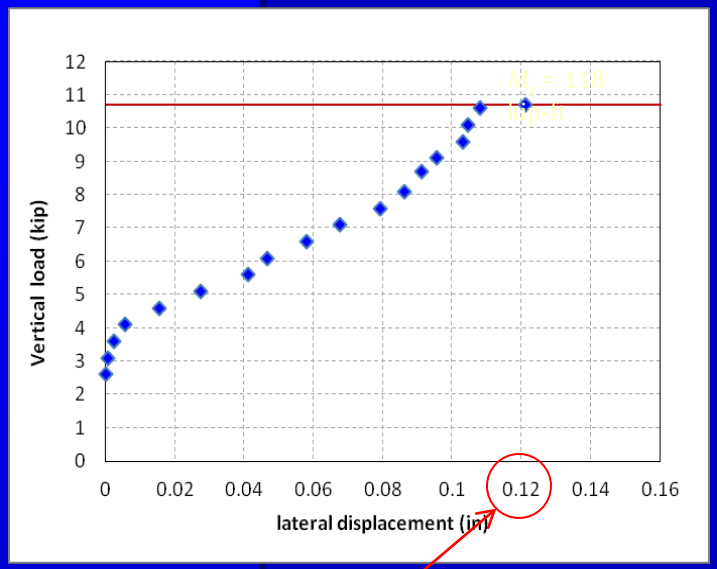
  ---2nd set → 5ft above the 1st set.



- Digital levels and invar staff (120^0 apart) for vertical displacement measurement

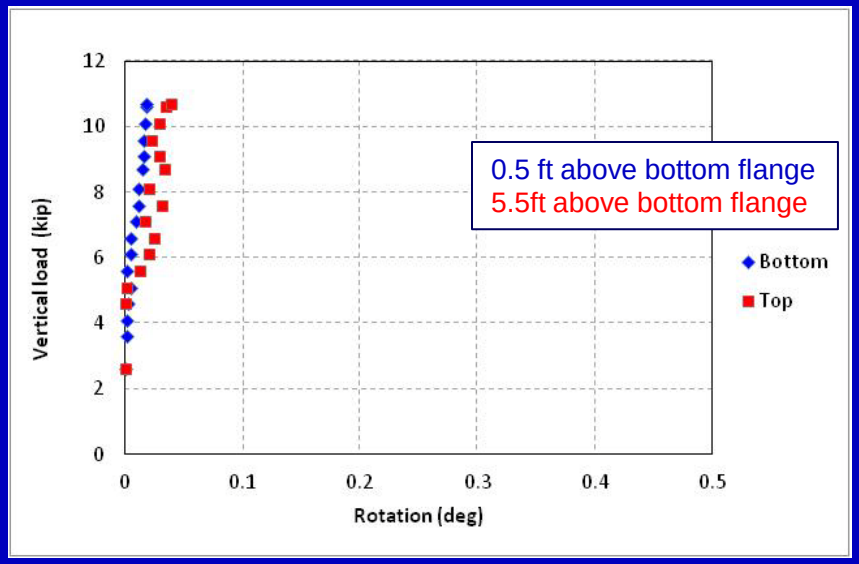
After setting the instrumentation, Mast arm assembly was gradually released from crane at an increment of about 500 lb (i.e., transferred assembly weight to shaft).

Vertical load vs lateral displacement (at bottom)



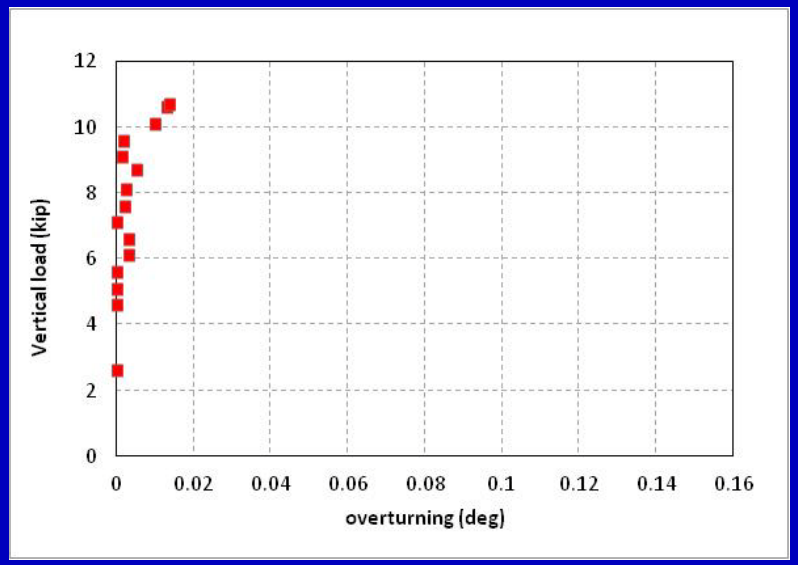
Max. lateral displacement = 0.12-in

Vertical load vs rotation



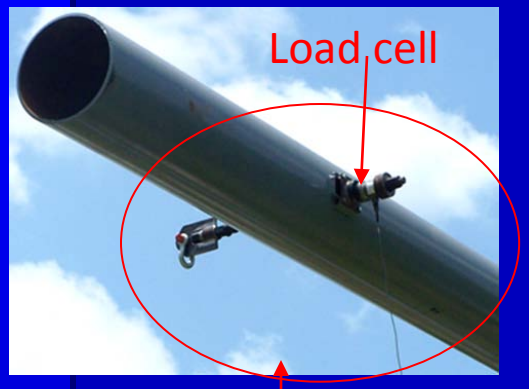
Max. rotation = 0.018-0.032^0 (clockwise)

Vertical load vs overturning



Max. over turning = 0.013^0

Phase 2: lateral load on Mast arm at a standoff distance of 35-ft

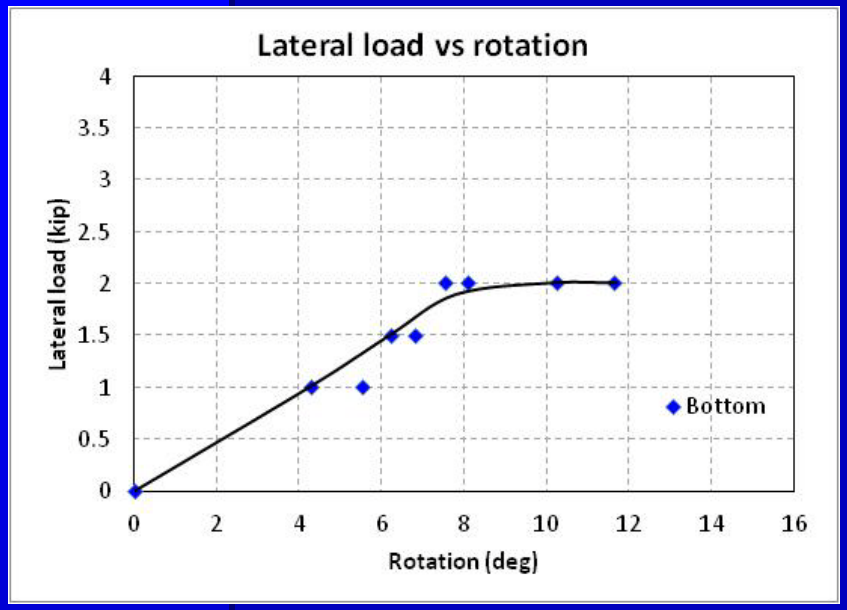


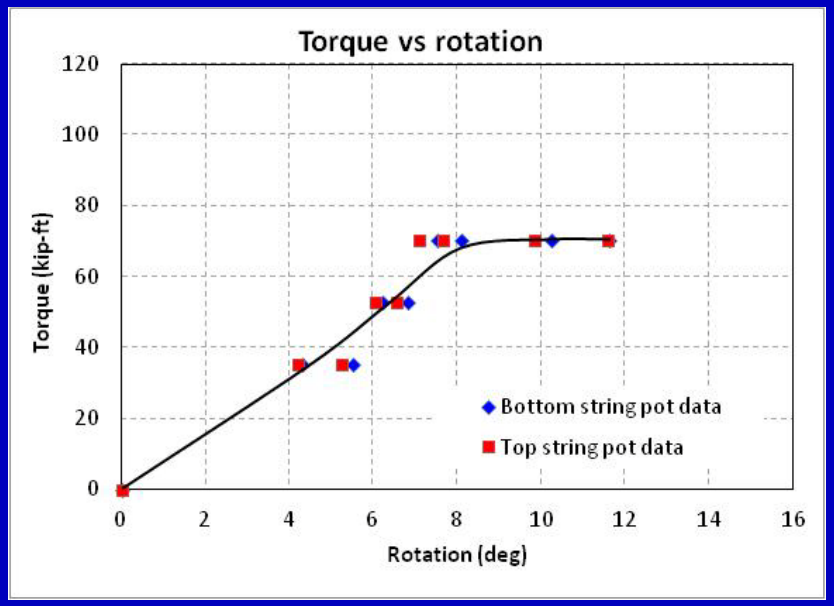
Load transfer arrangement

- The sustained load (> 1 sec) was used for estimating the ultimate torsional resistance of shaft.

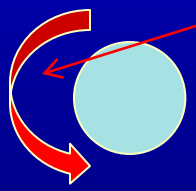
Forces and moments on shaft

Force/moment	magnitude	remarks
F_y (kips)	10.7	Due to self-weight of Mast arm assembly
M_z (kip-ft)	118	
V_z (kips), lateral load	**2**	Due to the application of lateral load
M_x (kip-ft)	43	
Torsion (kip-ft)	**70**	



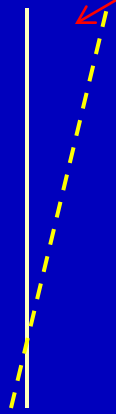


Rotation = 11.6^0
Lateral translation ≈ 4in (at ground level)
Overturning ≈ 1.4^0



Rotation

Torsional cracks

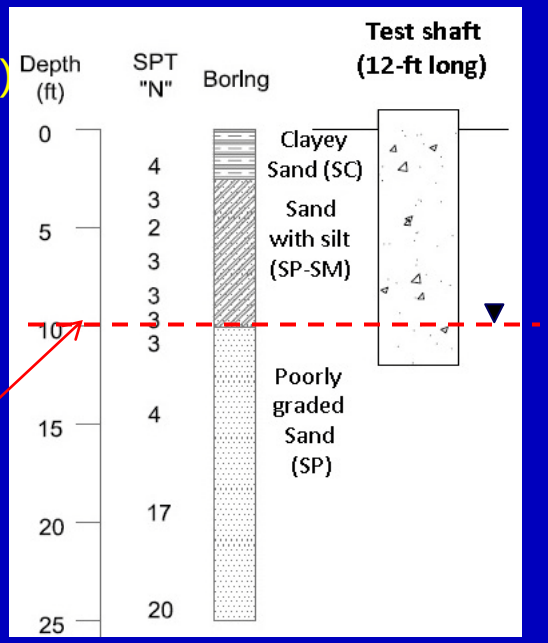


Overturning

Gap

Soil properties and boring log at shaft location (SMO, Gainesville)

Properties	value
Bulk unit weight, γ_{moist}	105 pcf
Saturated unit weight, γ_{sat}	116 pcf
Angle of internal friction, φ	27^0
Moisture content (above water table)	8.5-12%



Water table= 10-ft

Predicted torsional resistance

Method	Skin contribution	Tip contribution	Remarks
FDOT's modified design method (ω method)*	281 kips	16.6 kip-ft	FDOT Structures Manual, vol.9, 2011
Depth dependent β method (Reese and O'Neil method) **	70 kip-ft	***	FHWA 1999, 2010
Beta method with separate evaluation of K and δ (Rational method)**	98 kip-ft	***	FHWA 2010
Measured	70 kips		

*Using FDOT Mathcad program: DrilledShaft v2.0

** Using the hammer efficiency corrected SPT value (N_{60}=5)

*** No tip contribution is considered (Hu et al. 2006)

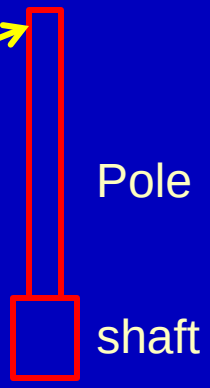
K- coefficient of lateral earth pressure; δ - interface friction angle

Lateral resistance

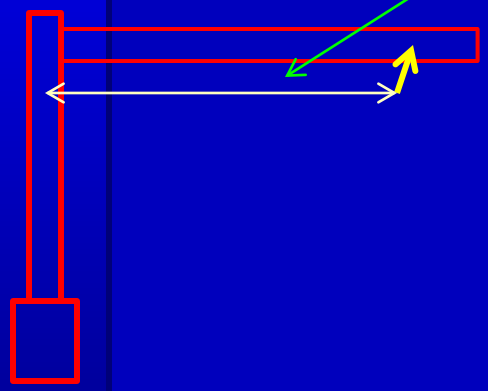
Using the force and moment equilibrium approach (Hu et al. 2006):

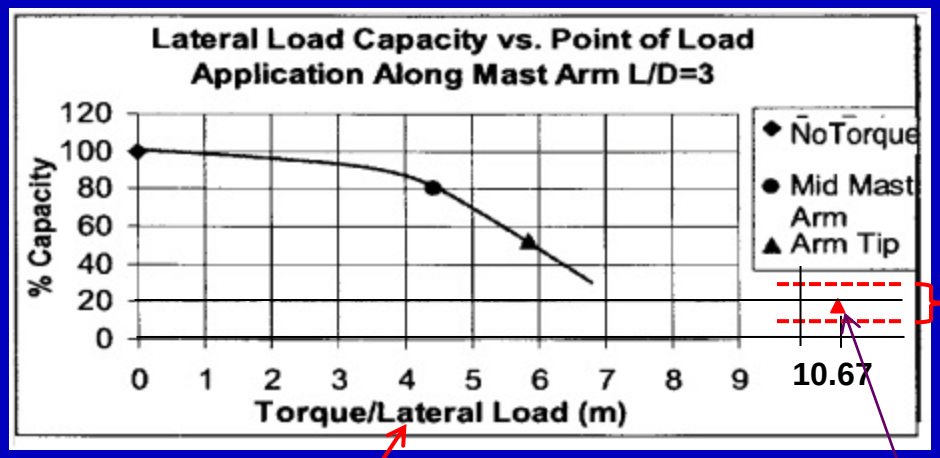
Ultimate lateral resistance due to overturning (no torsion) = 14.5 kips

(for γ_{moist} = 105 pcf, $\varphi = 27^0$, and coefficient of earth pressure at rest, K_0 = 0.4)



According to Hu et al. (2006) lateral overturning resistance is significantly reduced by torsion. (function of lateral load eccentricity)





Lateral load eccentricity

(2/14.5)x100% = 13.8%

Construction of two jet-grouted piles

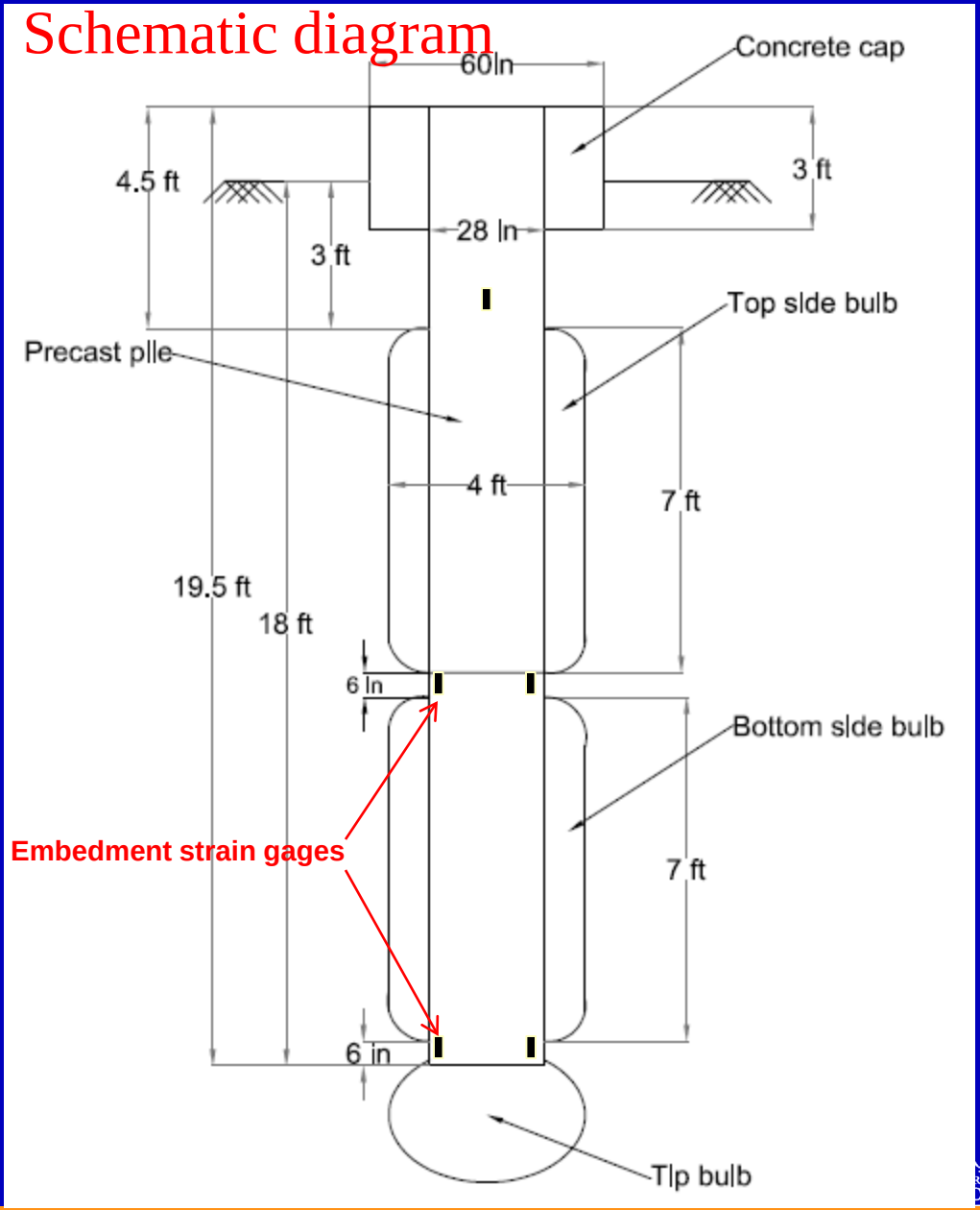
Stages:

a) Construction of precast piles

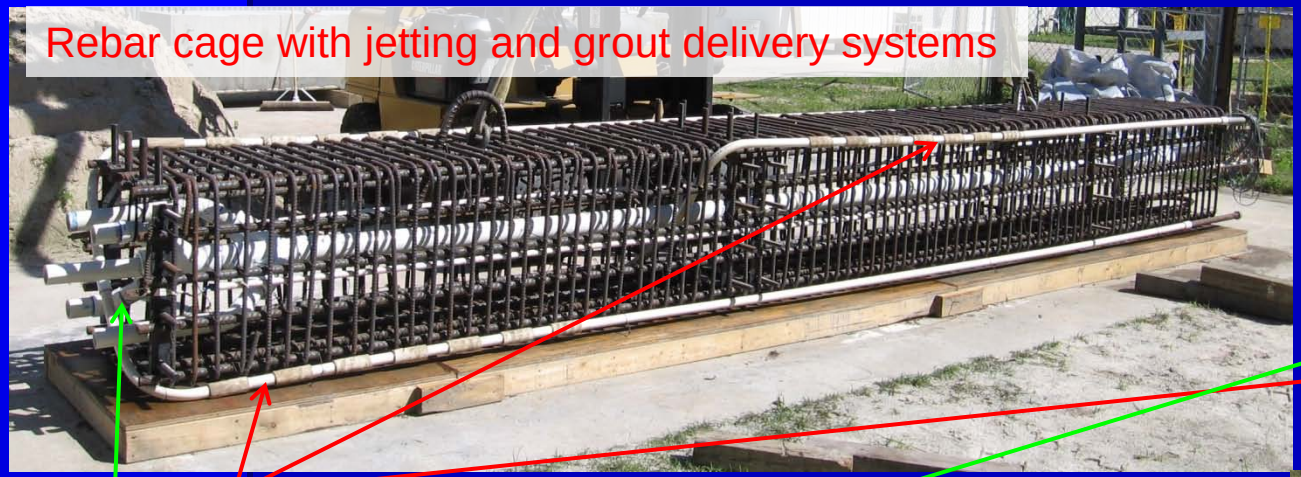
b) Preparation of precast piles for jetting

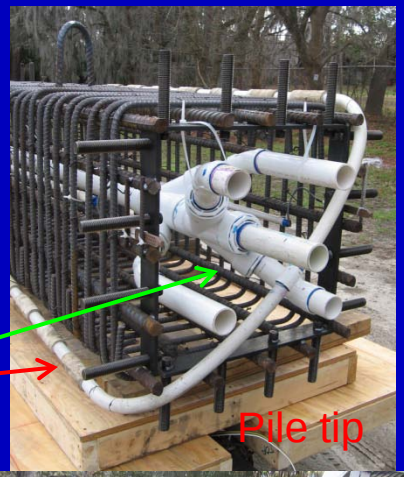
c) Jetting of piles

d) Side and tip grouting
(to be performed)



a) Construction of Pre-cast piles (28 in square and 19.5 ft long)





Side grout delivery system (1-in PVC)

- 7 pairs of holes @ 3" center to center spacing covered with gum rubber

Jetting/ tip grout delivery system:

- 3-in central pipe branched off into five 2-in diameter pipes at bottom of pile for uniform distribution of water/grout at tip

Concrete mix properties

Coarse aggregate	#89 stones
Slump	4.625 - 5.25 in
Air content	3.3%
28th day comp. strength	8092 psi

b) Preparation of pre-cast piles for jetting

i) Flushing each grout delivery system

- A pressure of about 7 psi was needed for water to exit through the ports

ii) Attaching side grout membranes (polypropylene Geomembrane)

iii) Attaching nozzles

iv) Testing of nozzles to check water distribution pattern

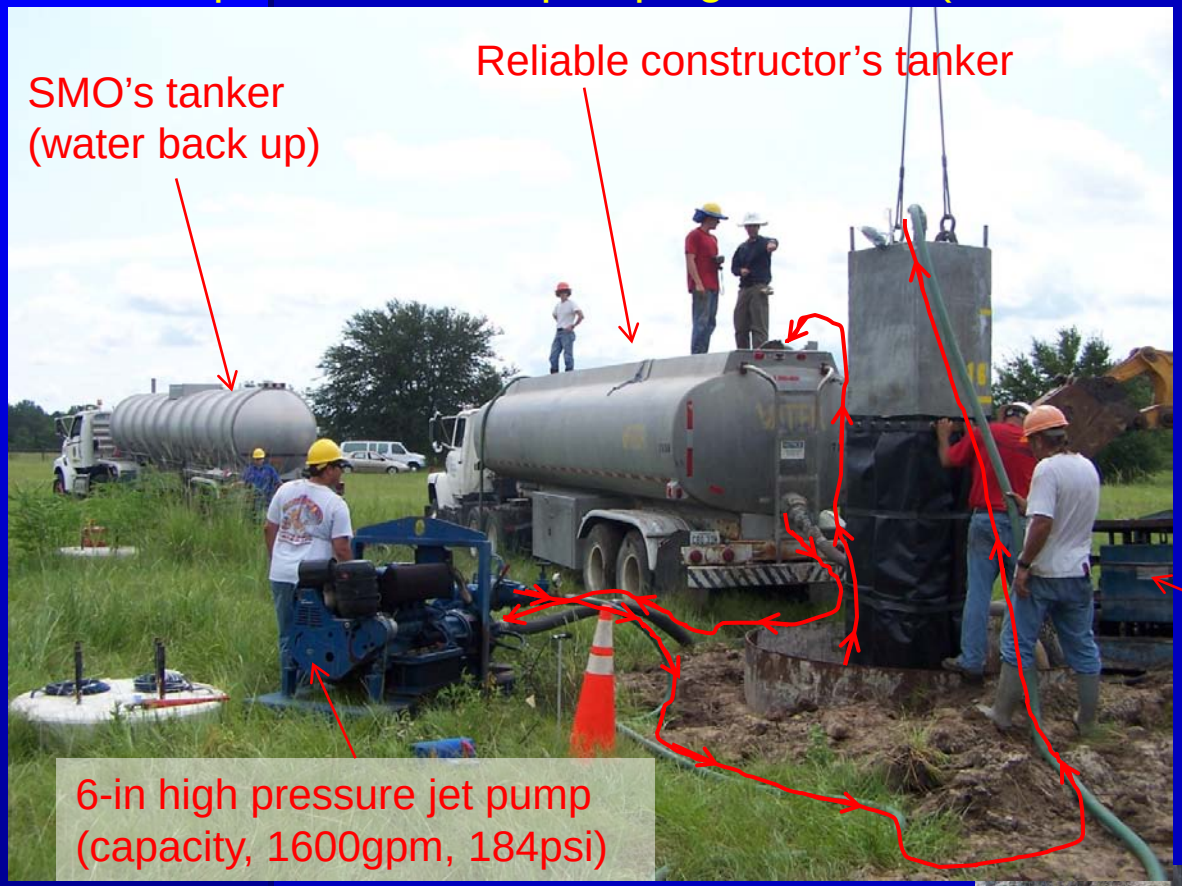
- Spray pattern under a water pressure < 5psi

Jetting of piles: Performed with the help of Reliable constructors inc. and SMO, Gainesville

1st attempt: stopped due to no water recirculation(Depth of penetration = 12.5ft)

2nd attempt - continuous pumping of water (re-circulating water)

Flow rate = 400 gal/min
Pressure = 130-135psi



Pile	Time taken
Pile 1	16 min
Pile 2	55 min

Less time due to pre-jetting

More time due to sand locking of jet pump

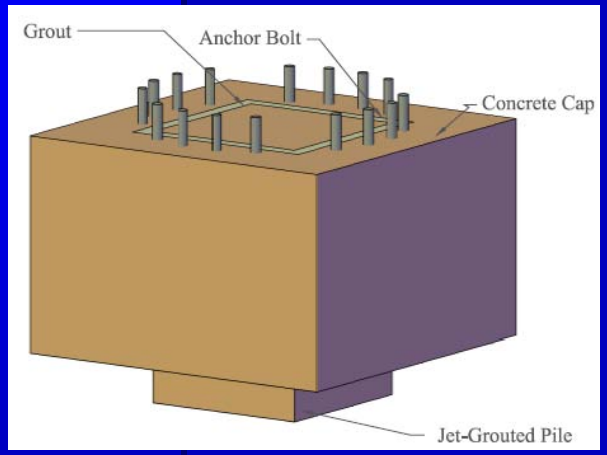
Water recirculation

After removal of casing and back filling

Total water loss (2 piles) = about 1000 gal

Concrete cap for jet grouted piles

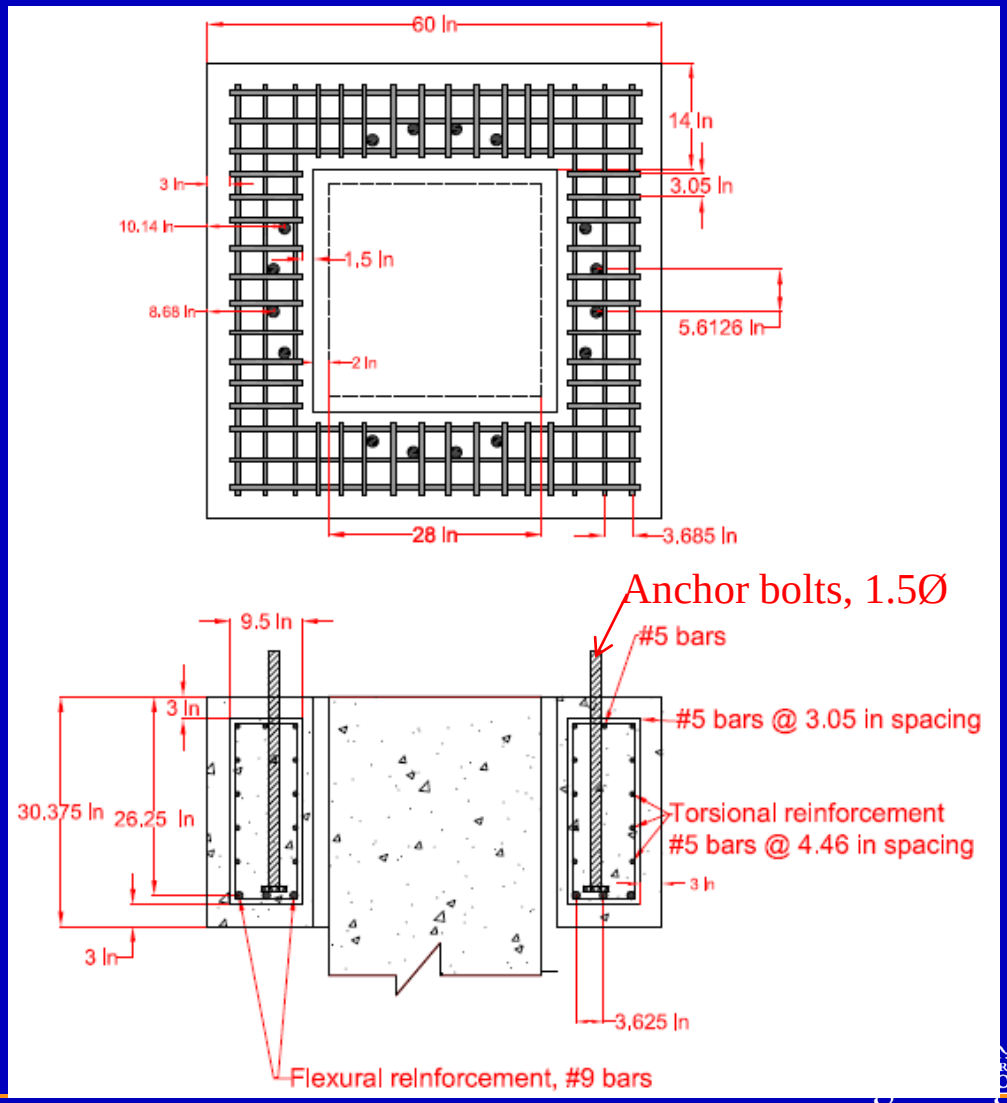
- To transfer forces and moments from Mastarm assembly to jet-grouted piles during combined torsion and lateral load test
- One precast concrete cap and the other cast-in place



Schematic of pile-cap connection

Designed according to ACI 318 - 08, AASHTO LRFD, AISC 360-05.

Reinforcement details



Precast cap construction: concrete mix was same as that for piles

Rebar cage

Ready for casting

Concrete placement

After curing

After grouting

Setting precast cap around pile

Grouting the 2" gap between pile and cap

Grout: vibropruf #11

(FDOT approved; QPL)

Consistency : fluid state

After grouting

Cast-in place cap construction:

Setting rebar cage

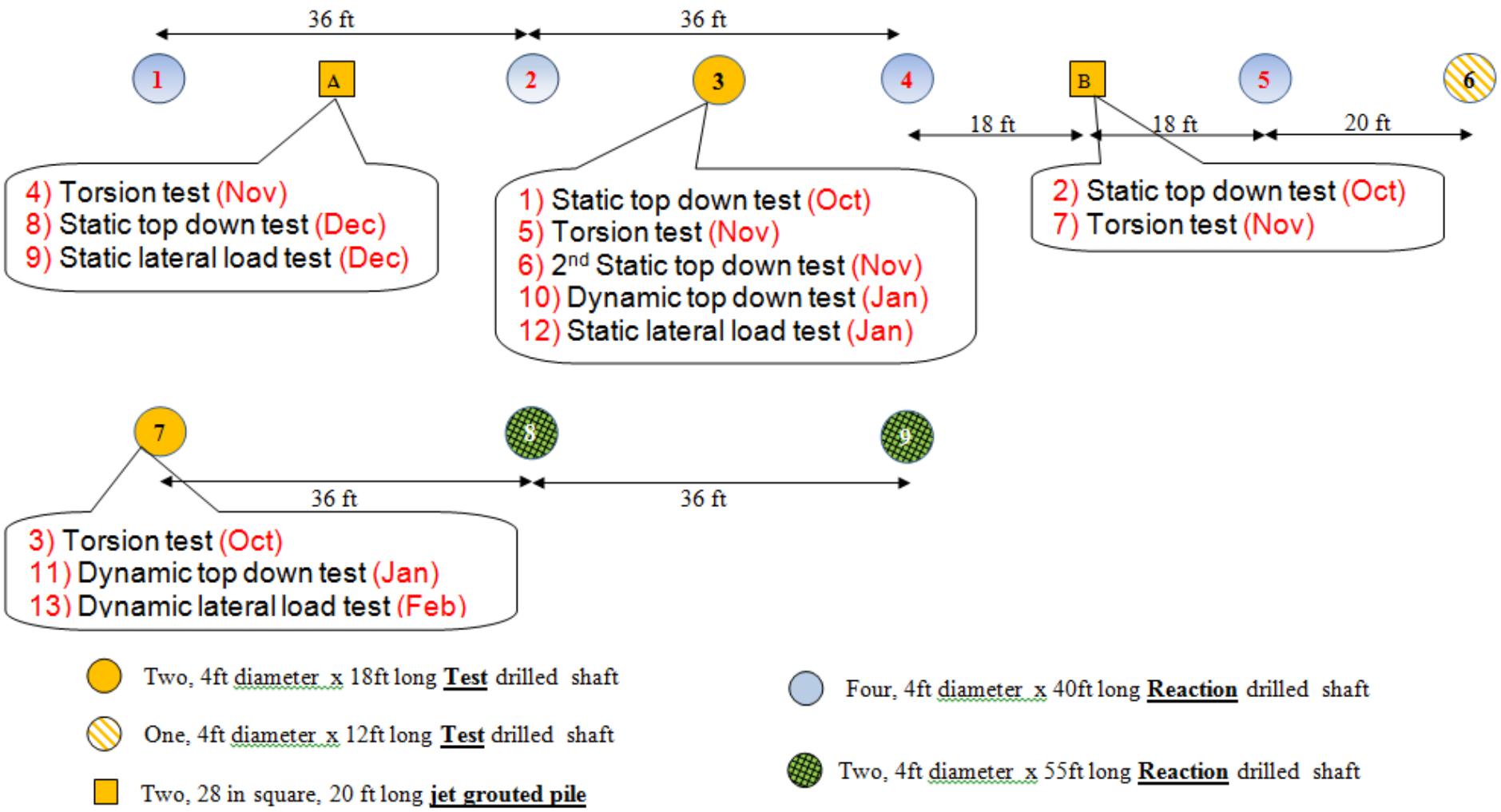
Ready for casting

Concrete placement

After concrete placement

Future works:

- Pile side and tip grouting (Sep)
- Load tests:



References

1. AASHTO, LRFD Bridge design specifications, 4th edition, 2007
2. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary
3. AISC, “Steel Construction Manual” American institute of Steel Construction
4. FDOT Mathcad Program: Mastarm v4.3
5. FDOT specification 455, “Structures Foundations – C. Drilled Shafts”,
6. FDOT Structures Design Guidelines for Load and Resistance Factor Design
7. FDOT Structures Manual, Vol. 9, 2011
8. NCHRP report 494: Structural supports for High signs, Luminaires and Traffic signals
9. Hu, Z., McVay, M., Bloomquist, D.,; Herrera, R., Peter Lai, P., (2005) “Influence of Torque on Lateral Capacity of Drilled Shafts in Sands”, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 132, No. 4, p.456-464.

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Thank you….