GRIP MEETING 2020, Progress Report

Project: Prediction model of vibration-induced settlement due to pile driving (BDV24 977-33)

Project Manager: Larry Jones

PRESENTED BY

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FDOT

Outline

- Brief project overview
  - Benefits
  - Objectives
  - Scope
- Technical background
- Survey
- Testing plan
- Numerical analyses
- Timeline

Review of benefits and objectives

Qualitative:

- Better estimation of infrastructure damage as a result of excessive pile-driving induced settlements.
- Understanding pile driving induced settlement mechanisms can improve design practices in Florida.
- Avoid unnecessary countermeasures in FDOT projects. Infrastructure damage will be minimized as a result of pile driving.

Quantitative:

- Produce pile driving induced settlement chart (or correlation or equation) relating PPV, D_r, distance from source, and input energy to be used in FDOT projects.

Objectives:

- To <u>understand</u> mechanisms of near-field and far-field settlement and determine influence zones.
- To <u>measure</u> field vibration-induced settlements in predetermined locations in Florida.
- To <u>develop</u> numerical models of dynamic settlements due to pile driving.
- To <u>develop</u> pile driving induced settlement prediction model(s) (e.g., closed formula or chart).

Scope of work

Task 1 – Technical review of case studies

Task 2 – Survey to practitioners

Task 3 – Field testing in pile installation sites

Task 4 – Numerical modeling of pile driving induced settlement

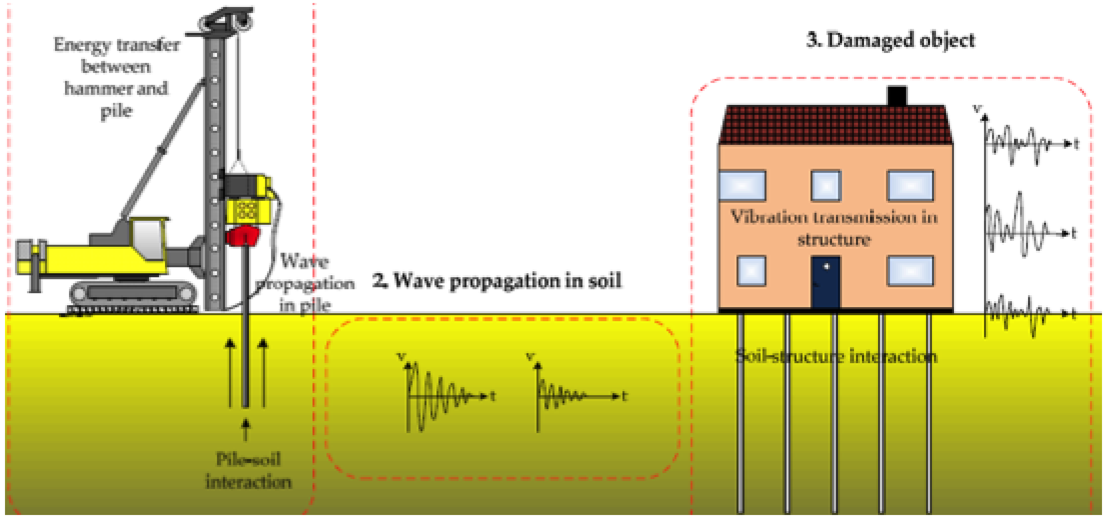
Task 5 – Empirical prediction formula or chart for dynamic settlement

Task 6 – Guidelines and recommendations

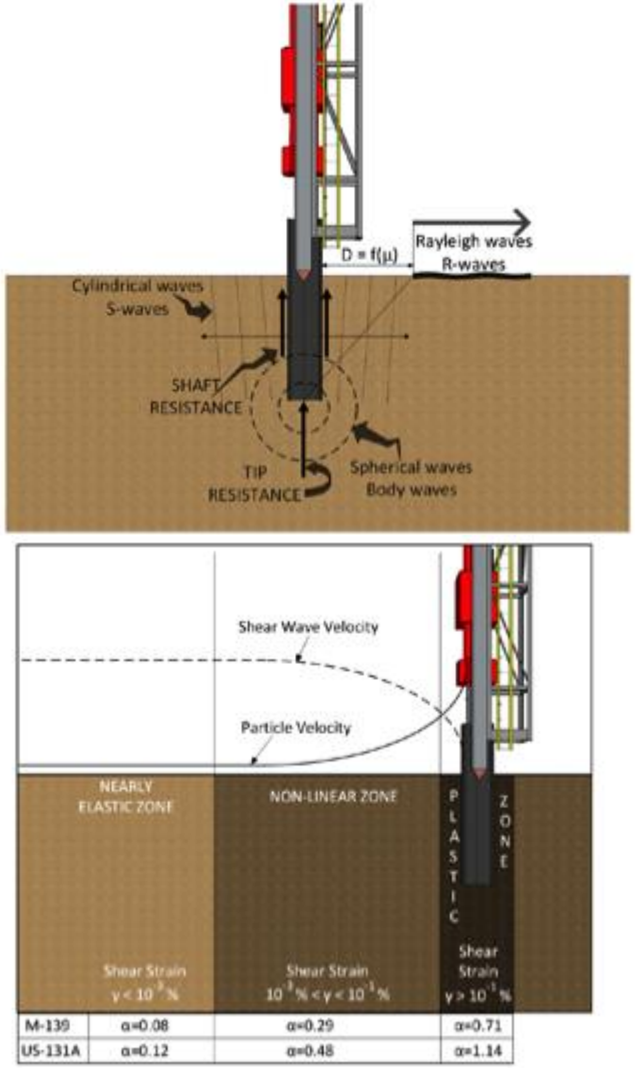
Technical background: variables involved in the problem

76 case histories and 55 papers revised to study variables involved:

- Vibration characteristics and input energy: vibration type, amplitude, frequency, and duration of the source
- Soil characteristics: soil gradation and type, relative density, and moisture content
- Attenuation characteristics: geometric and material damping



Pile-driving induced vibration in urban environments (Hintze et al. 1997 and Deckner 2013)



Energy transfer from pile to soil (top)
Hypothetical soil behavior zones in terms of shear strains and attenuation coefficients (bottom)

Methods for pile driving induced settlements (Drabkin et al. 1996)

Multifactor polynomial model. Steps:

- Estimate/measure PPV.
- Compute x_i only if within the tested ranges.
- Calculate settlement.
- Compute Δ for a sand layer of thickness H_t using Y for a 5.9 in-tall specimen.

$$\Delta = \frac{Y * 0.001}{5.9} H_t$$

Factor	Factor Code	Tested Ranges	Coding of Factors
Peak Particle Velocity (PPV)	x_1	0.1-0.7 in/sec	$x_1 = -1 + \frac{PPV - 0.1}{0.3}$
Deviatoric Stress (s)	x_2	2-15 psi	$x_2 = -1 + \frac{s - 2}{6.5}$
Confining Pressure (p)	x_3	10-30 psi	$x_3 = -1 + \frac{p - 10}{10}$
Sand Mixture	x_4	Coarse, Medium or Fine	x_4 ranges from -1 for coarse sand to 1 for fine sand
Number of vibration cycles (N)	x_5	60-500,000 cycles	$x_5 = -1 + \frac{N - 60}{26{,}997}$
Moisture content	x_6	Dry, Saturated	x_6 ranges from -1 for dry sand to 2 for saturated sand
Initial relative density	x_7	Loose, Medium Dense	x_7 ranges from -1 for loose sand to 2 for medium dense sand

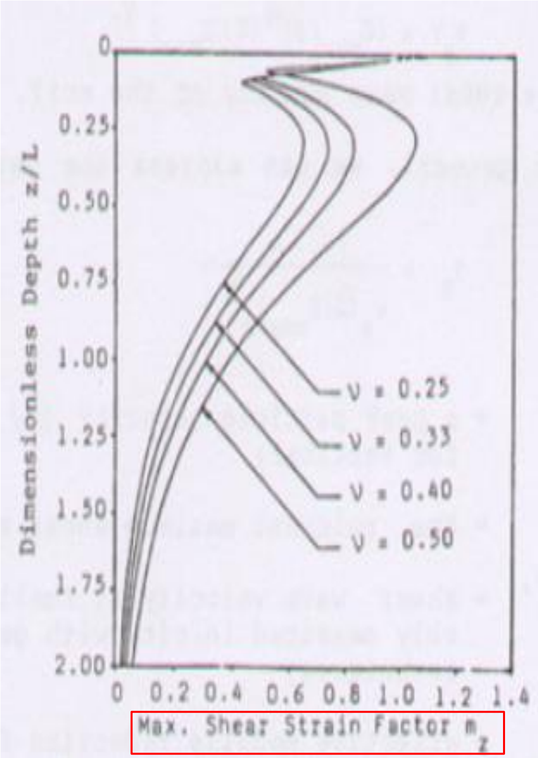
$$\ln Y = 2.27 + 1.19x_1 - 0.71{x_1}^2 + 0.49x_2 - 0.68{x_2}^2 - 0.8x_3 + 1.09{x_3}^2 - 0.46x_4 + 0.06{x_4}^2 + 0.45x_5 - 0.38{x_5}^2 - 0.19x_6 - 0.1x_7$$

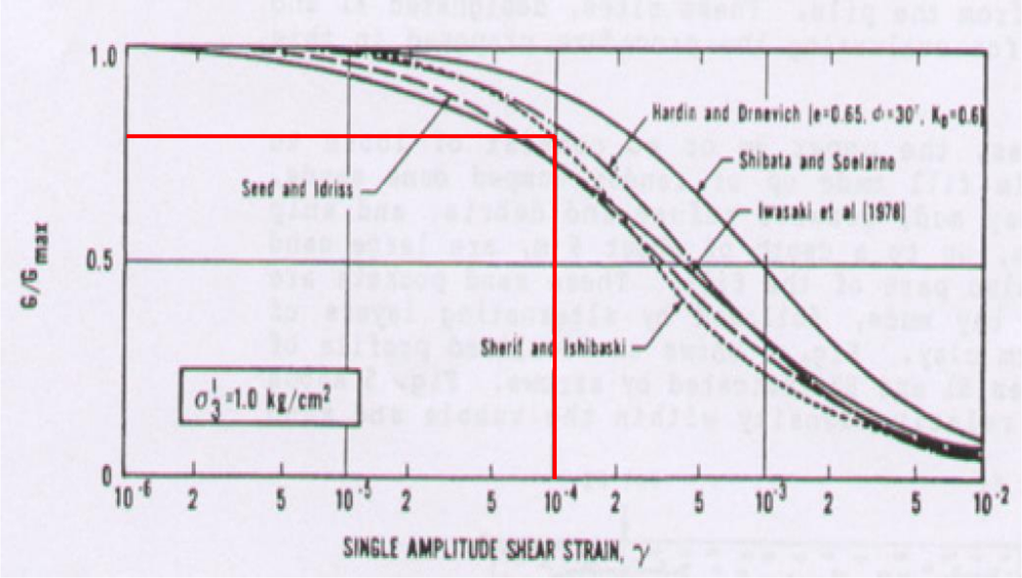
Settlement for a 5.9 in. tall specimen

Methods for pile driving induced settlements (Mohamad and Dobry, 1987)

- Similar to soil liquefaction hazard assessments.
- It is used to determine threshold PPV_t and settlement *susceptibility* in sands.
- *Susceptibility* defined in terms of shear strain (γ_t), typically 0.01%.
- The model does not calculate specific settlements. It provides susceptibility to excessive settlements.

Determine m_z → Determine G/G_{max}* and V_s → Calculate PPV_t





*Based on shear modulus degradation curves for the site at a shear strain of 0.01%.

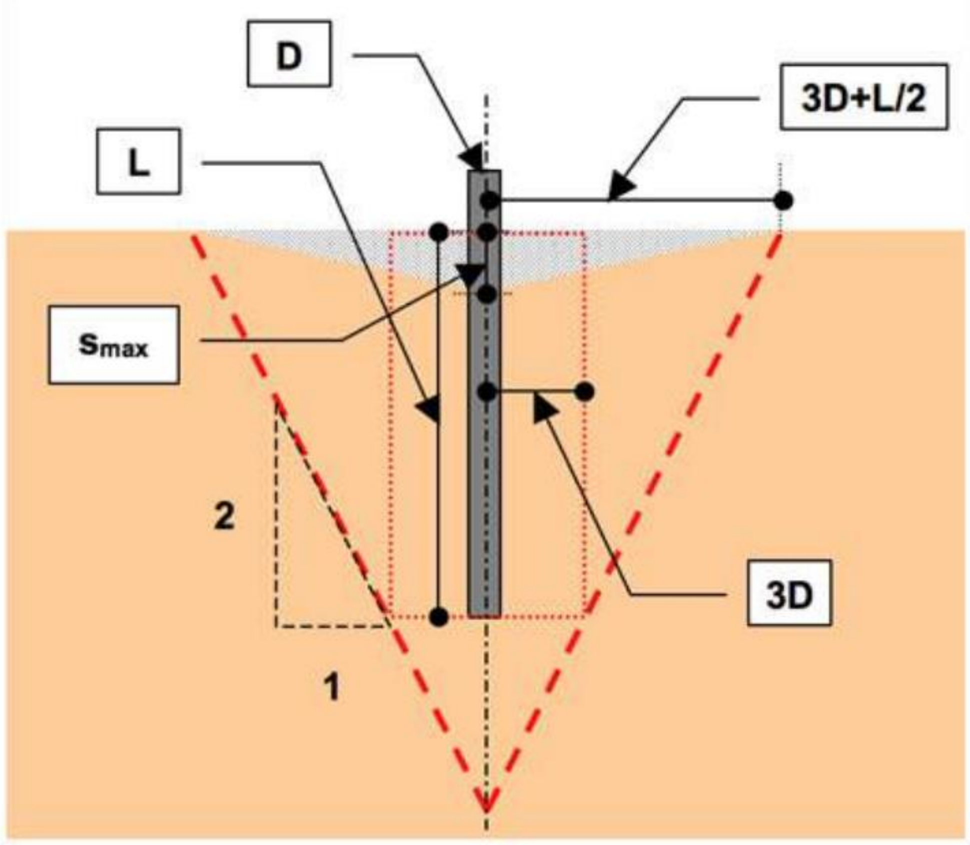
Calculate the threshold PPV_t and compare with measured or computed PPV attenuation curves to determine susceptible zones (i.e., distances from the pile).

$$PPV_t = \gamma_t \frac{V_S \left(\frac{G}{G_{max}}\right)^{1/2}}{m_z}$$

Methods for pile driving induced settlements (Massarsch 2004)

- Settlements depend on soil type and stratification, groundwater conditions (degree of saturation), pile type, and method of pile installation (driving energy).

- Densification due to pile driving occurs within a zone of three pile diameters around the pile.



Settlements adjacent to a single pile in homogeneous sand

$$S_{max} = \alpha(L + 6D)$$

$$S_{avg} = \alpha \frac{(L + 3D)}{3}$$

Compression factor, α, for sand based on relative density and level of driving energy (depends on PPV)

Ground Vibrations:	Low	Medium	High
Soil Density	- - - - - Compression factor, α - - - - -		
Very loose	0.02	0.03	0.04
Loose	0.01	0.02	0.03
Medium	0.005	0.01	0.02
Dense	0.00	0.005	0.01
Very dense	0.00	0.00	0.005

Case histories: pile driving database

Database of Case Histories: Pile Driving Induced Settlements

Reference	Location	Type of Pile	Pile Group	Number of Piles	Distance between Piles (m)	Pile Specifications	Pile Length (m)	Type of Hammer	Type of soil	Water Table (m)	Depth of penetration (m)
Grizi et.al,2016	Niles, Michigan	H-Pile	No	-	-	360x109 mm*kg/m	16.8	Pileco D30-32 Diesel Hammer	Loose to medium-dense sand	-	16.2
	Constantine, Michigan	H-Pile	No	-	-	360x109 mm*kg/m	16.8	Delmag D30-32 Diesel Hammer	Surficial Loose to medium-dense sand and hard sandy clay	-	13.1
Wersäll and Massarsch, 2013	Gothenburg, Sweden	Driven Concrete Pile	Yes		1.3	275 mm	52.0		Soft Clay	-	52.0
Hwang et.al, 2001	Chiayi-Taipo, Taiwan	Driven Hollow Concrete Pile	Yes	13	2.4	Outer Diameter 800 mm; Inner Diameter 560 mm	34.0	Delmag D100 Diesel Hammer	Surficial soft clay and medium-dense sand	1.0	34.0
Bozozuk et.al, 1978	Contrecoeur, Quebec	Driven Concrete Pile	Yes	116	1.5	300 mm	26.0	-	Marine Clay		26
Wong and Chua, 1999	Singapur Island, Singapur	Driven Concrete Pile	No	-	-	350 x 350 mm		-			
Brunning and Joshi, 1989	Calgary, Alberta	H-Pile	Yes	6	2	300 x 300 mm	11	D-22 Diesel Hammer	Dense Gravel		11
	North Yorkshire, England		Yes	7	-	-	-	Delmag 30.02 Diesel Hammer			

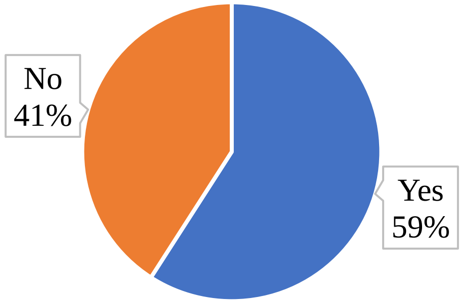
Vibration Measurements		Atenuation Parameters				Ground Movement		
Distance from Pile (m)	PPV (mm/s)	Geophone Depth (r	n	α (1/m)	k	Type of Displacemer	Distance from Pile (m)	Measurement (mm)
		0	0.5	0.13	-	-		
		0	0.5	0.13	-	-		
		-				Heave	25	12
		-				Heave	2.4	39
						Heave	3	110
2.1	22	0						

Variables summarized in database:

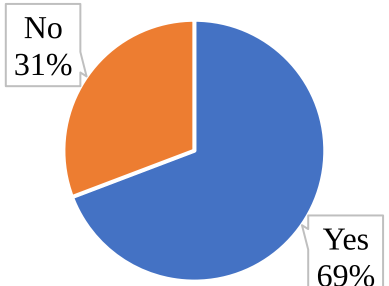
- Reference
- Site location
- Type of pile
- Number of piles
- Distance between piles
- Pile specifications (type, materials and dimensions)
- Pile length
- Type of hammer
- Type of soil
- Water table location
- Depth of penetration
- Distance from pile
- PPV
- Geophone depths
- Attenuation parameters
- Heave? Magnitude
- Settlement? Magnitude

Survey to practitioners (selected responses)

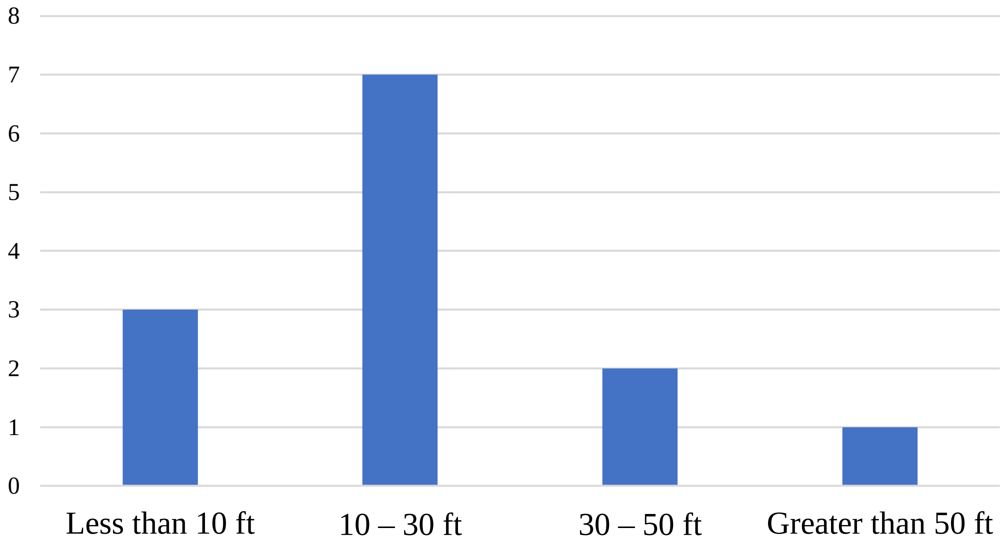
Q1. Have you experienced in any past designs or construction projects; any problem associated with ground surface settlement induced by pile driving installations?



Q2. Did you observe or experience any type of damage to adjacent infrastructure during pile driving because of high vibration levels (quantified in terms of high peak particle velocities) or large ground settlements or structural distortions?



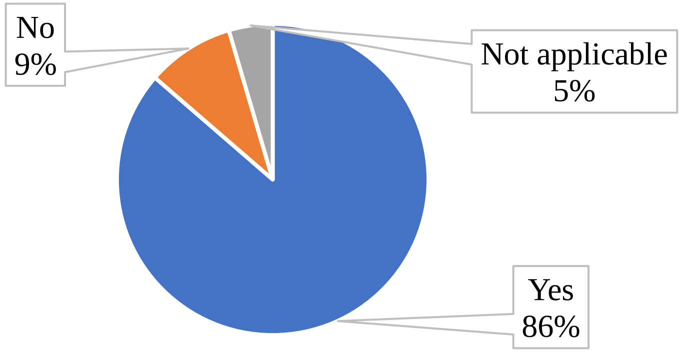
Q3. At what distance from the pile driving source did the previously-reported settlement occurred?



Number of questions: 20
Respondent population: 22

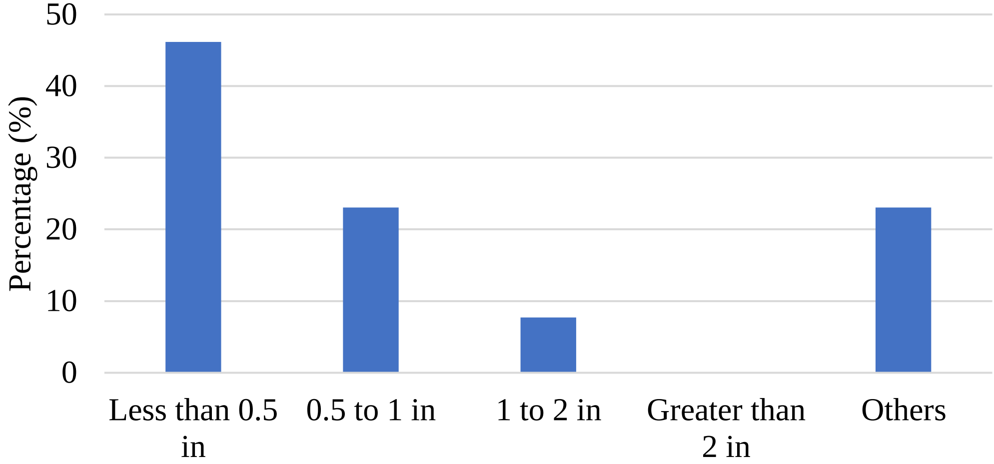
Survey to practitioners

Q4. Do you consider monitoring ground vibrations due to pile driving an important issue during the design phase of any deep foundation system?

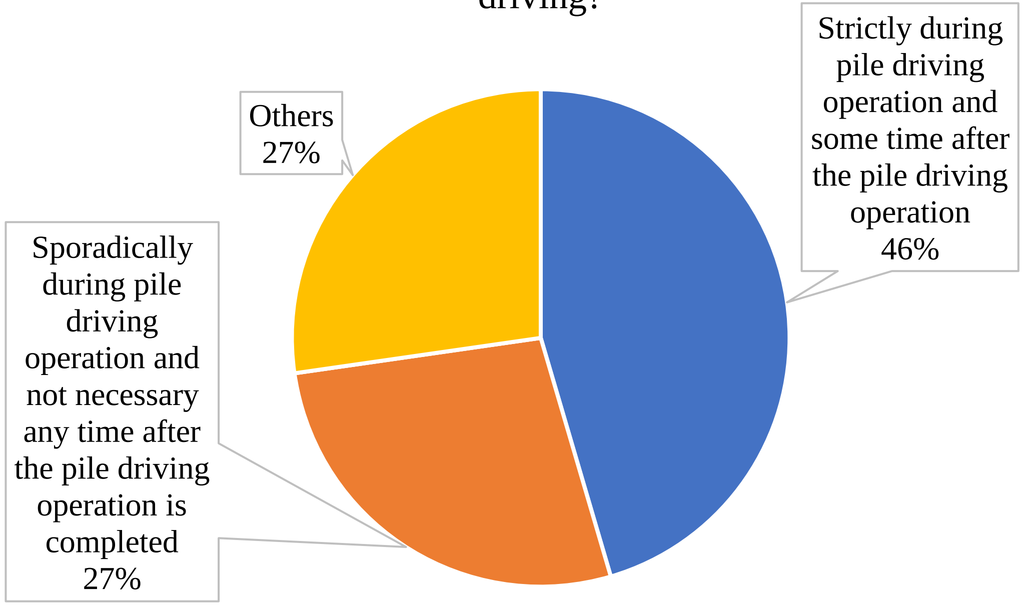


Yes

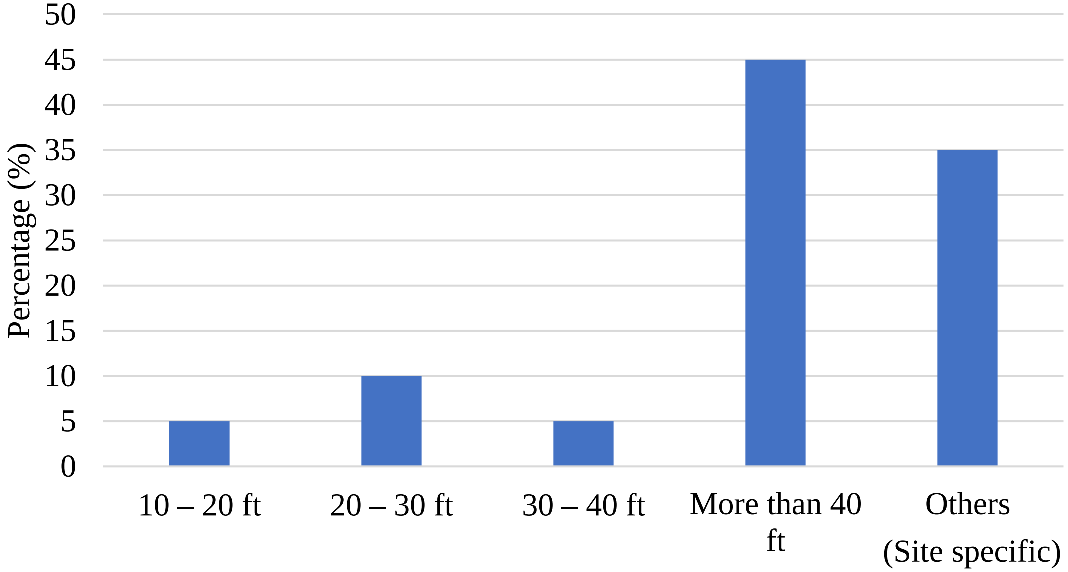
Q5. What was the approximate level of ground settlements experienced in the project?



Q6. How much time do you think is necessary to monitor ground vibrations and soil settlements induced by pile driving?

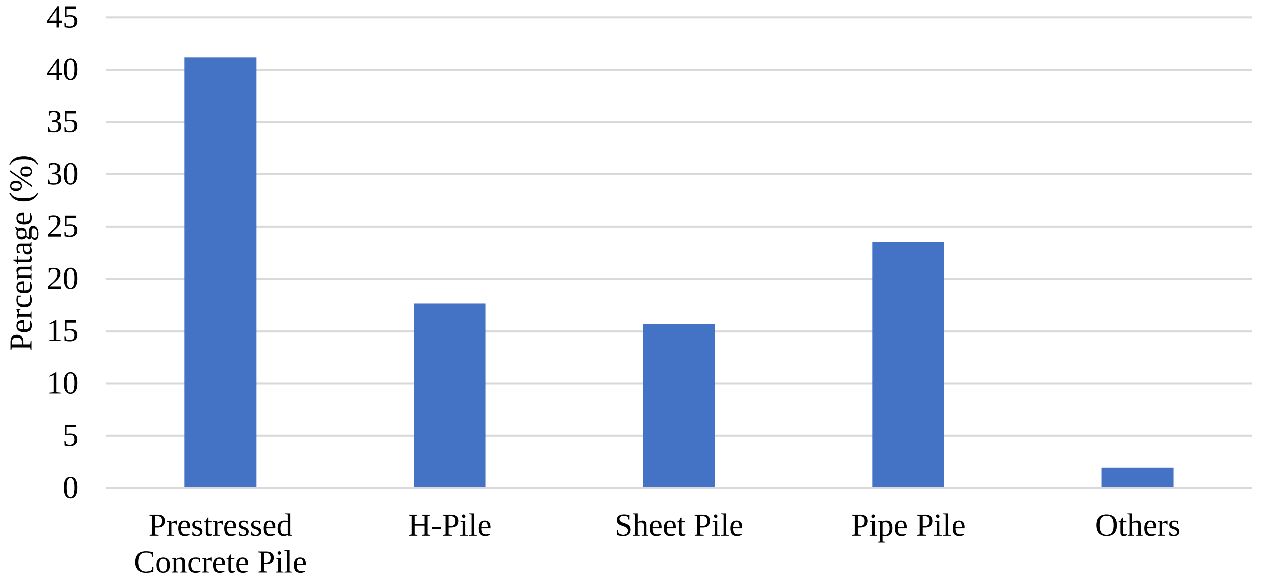


Q7. From your experience, what should be the location of the farthest sensor? (typically a geophone or settlement transducer)

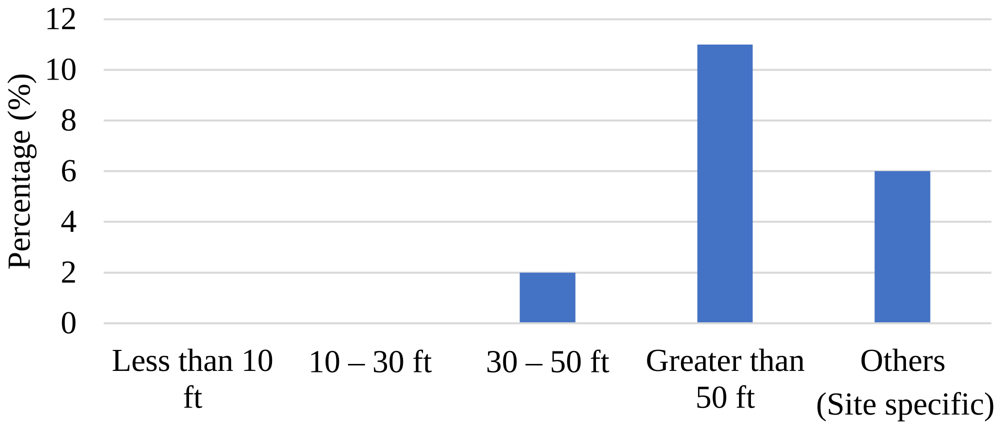


Survey to practitioners

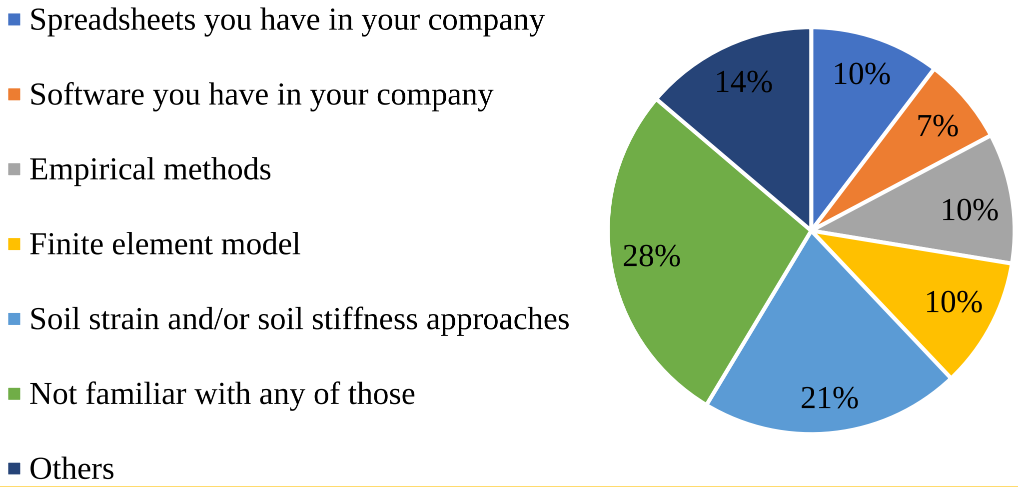
Q8. From your experience what are the type(s) of driven pile(s) that you commonly use for your projects?



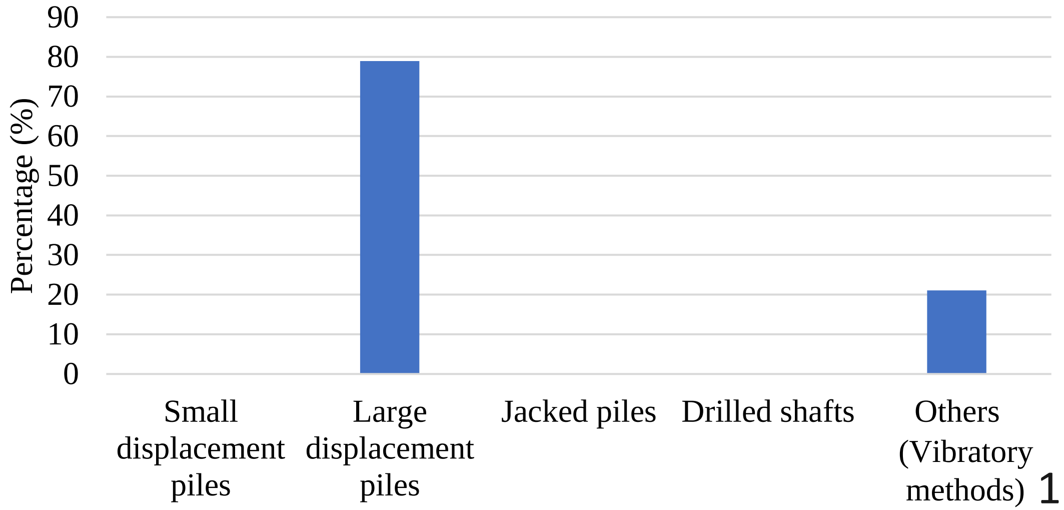
Q9. From your experience, what is the maximum distance from the pile driving source at which infrastructure (e.g., buildings, public utilities, bridges, etc.) is not affected by pile driving?



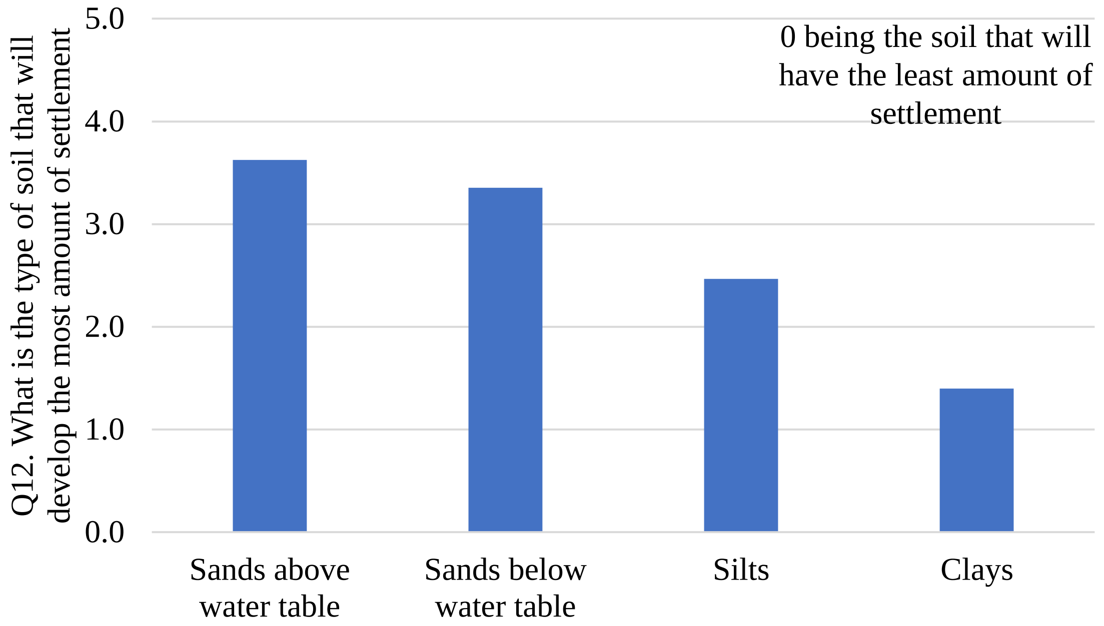
Q10. Which of the following methods and/or models do you use to estimate dynamic soil displacement due to pile driving and/or to determine the impact of construction vibrations?



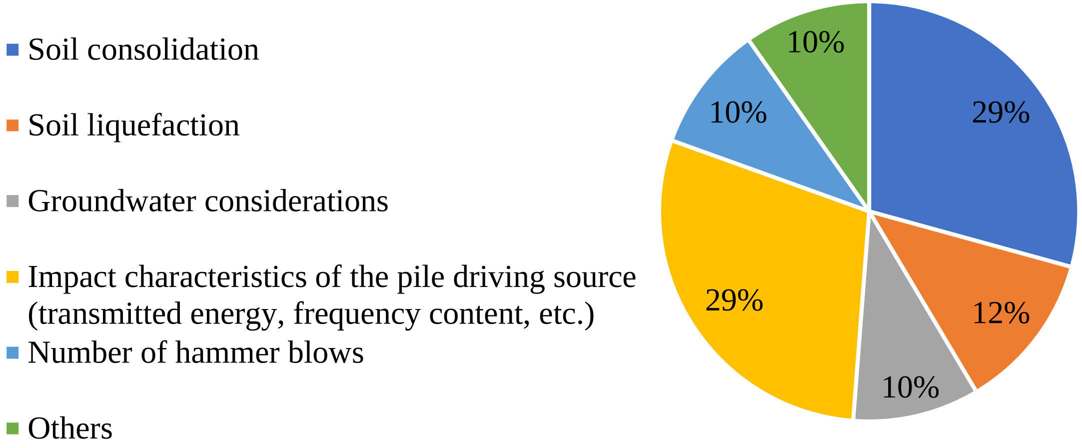
Q11. From your experience, the installation of what type of deep foundation system would potentially cause more damage to adjacent urban infrastructure?



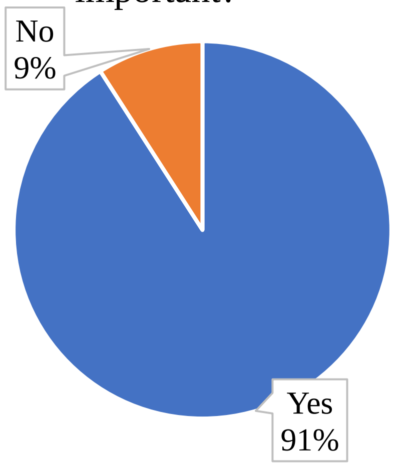
Survey to practitioners



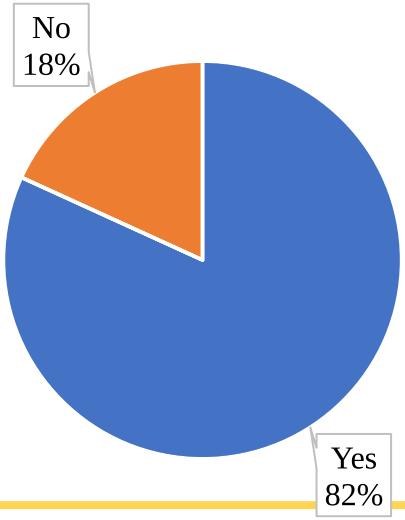
Q13. From your experience, what are the main sources of pile-driving induced settlements?



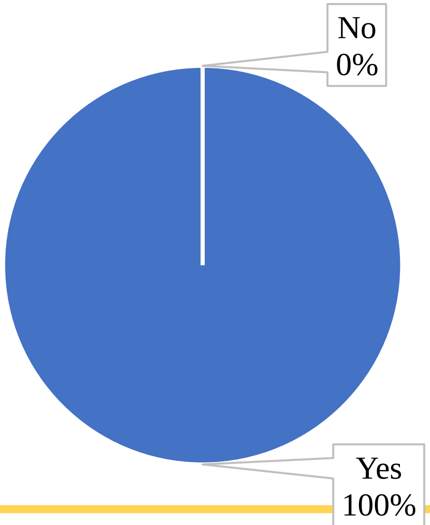
Q14. From your experience, do you think monitoring ground vibration due to deep foundation installations at multiple locations is important?



Q16. Do you think measuring the impact characteristics of the pile driving source is necessary?



Q17. Do you think performing a pre-construction survey of adjacent infrastructure before pile driving installations is necessary?



Field testing: instrumentation plan and sensor purchases

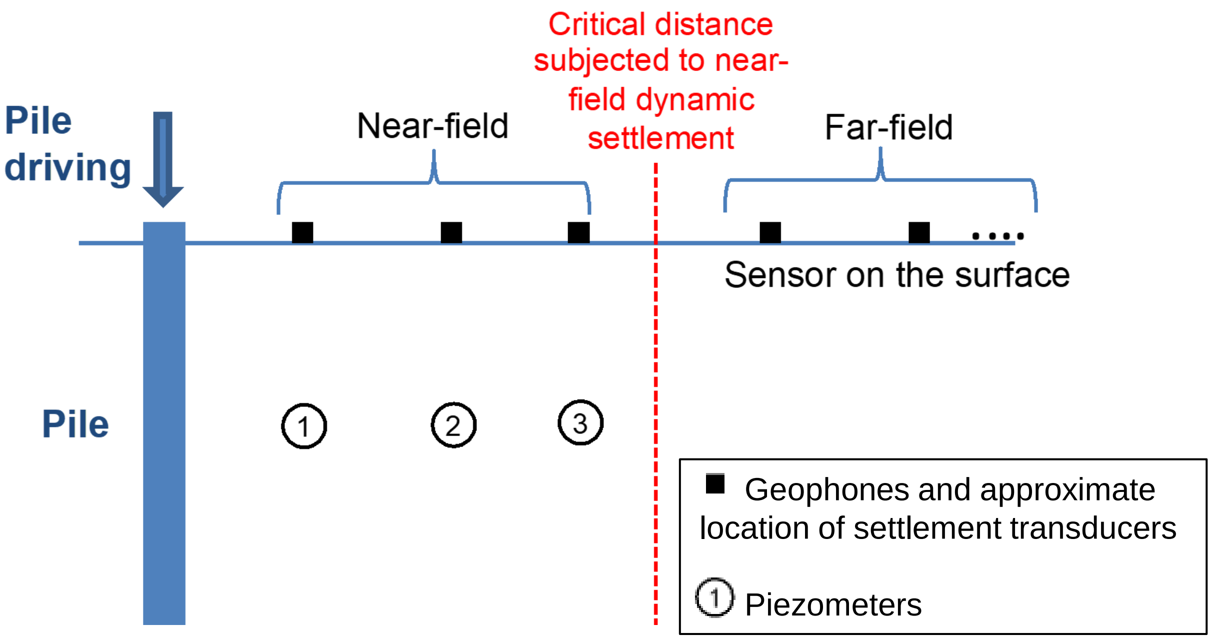
Procedure: Site selection → Instrumentation → Data collection → Analysis

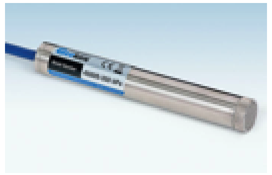
Field testing EDPs:

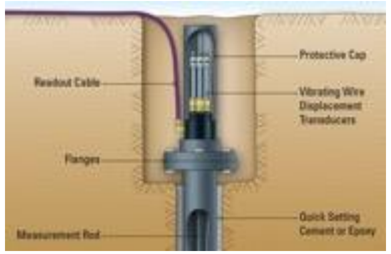
- Measure PPV
- Porewater pressures
- Settlements


Geophone and readers (SERCEL)

Schematic diagram







Piezometers, magnetic extensometer, VW continuous settlement (GEOKON)

Field testing: instrumentation plan and sensor purchases

- Geophones
(Purchased 9 from Sercel)
Delayed due to COVID

- Piezometers
(Purchased 5 from Geokon)
Received on March 16/2020

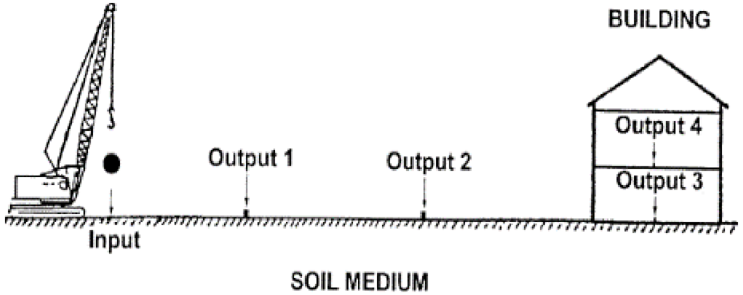
- VW Settlement
(Purchased 1, we had 1)

- Spider Magnets
(Purchased 5, we had 5)

Vibration wire piezometers, readout, and datalogger

Data acquisition system

Survey equipment



Measurement locations (Athanasopoulus and Pelekis 2000)

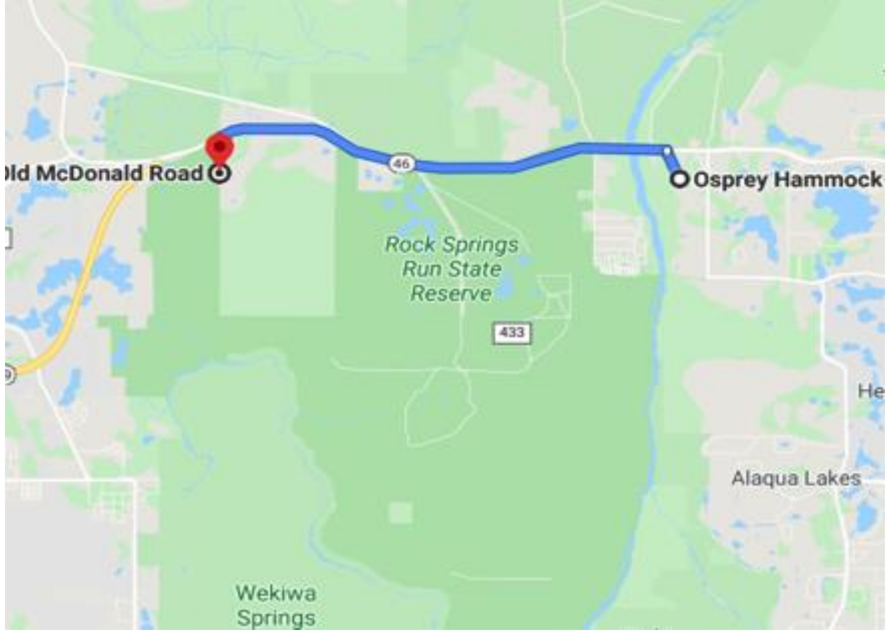
Geophones and acquisition system

In coordination with FDOT, District 5 and Turnpike Engineers:

- Roger Gobin (Turnpike)
- Michael Byerly (District 5)
- Larry Jones (FDOT)

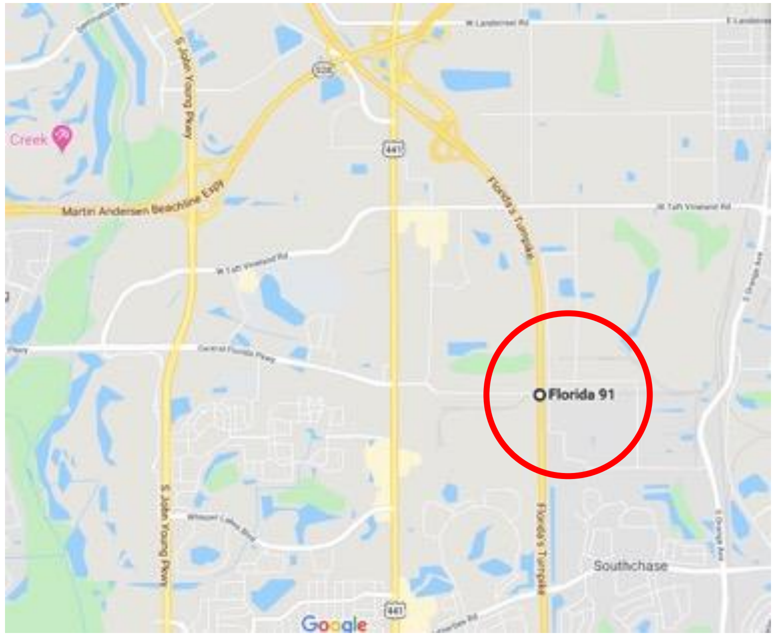
Project 1: I-4 and Turnpike Intersection

Project 2: Wekiva Parkway

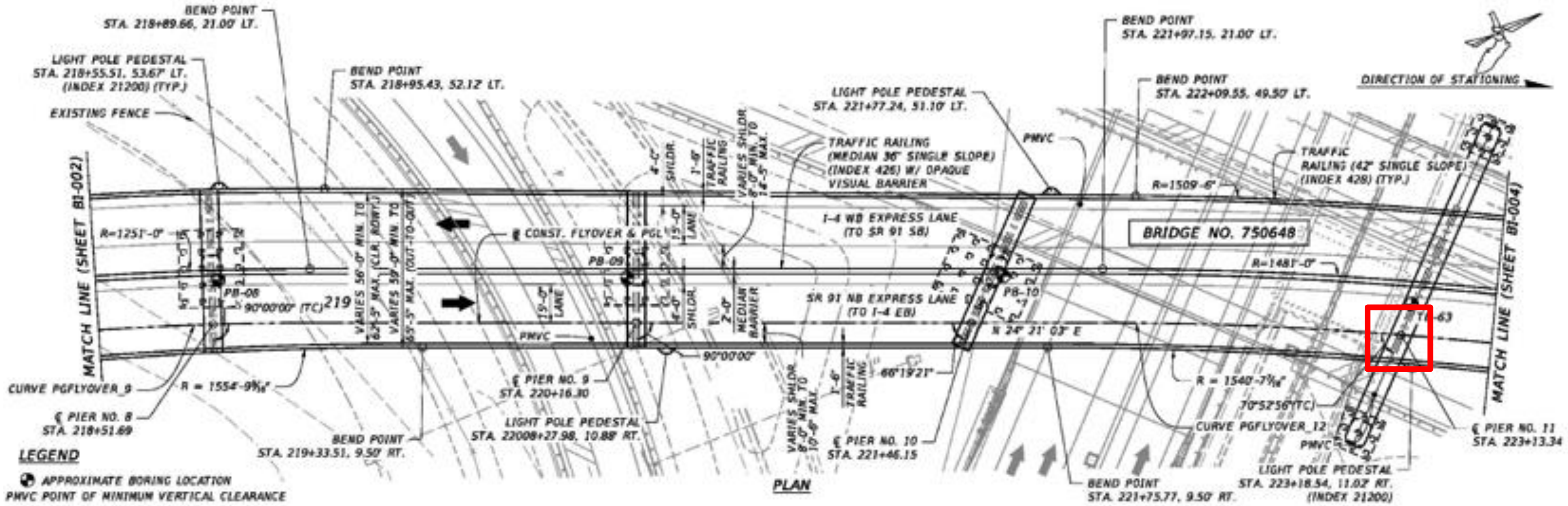


(Likely testing site)

Project 3: Turnpike over Central Florida Pkw and CSX Bridge



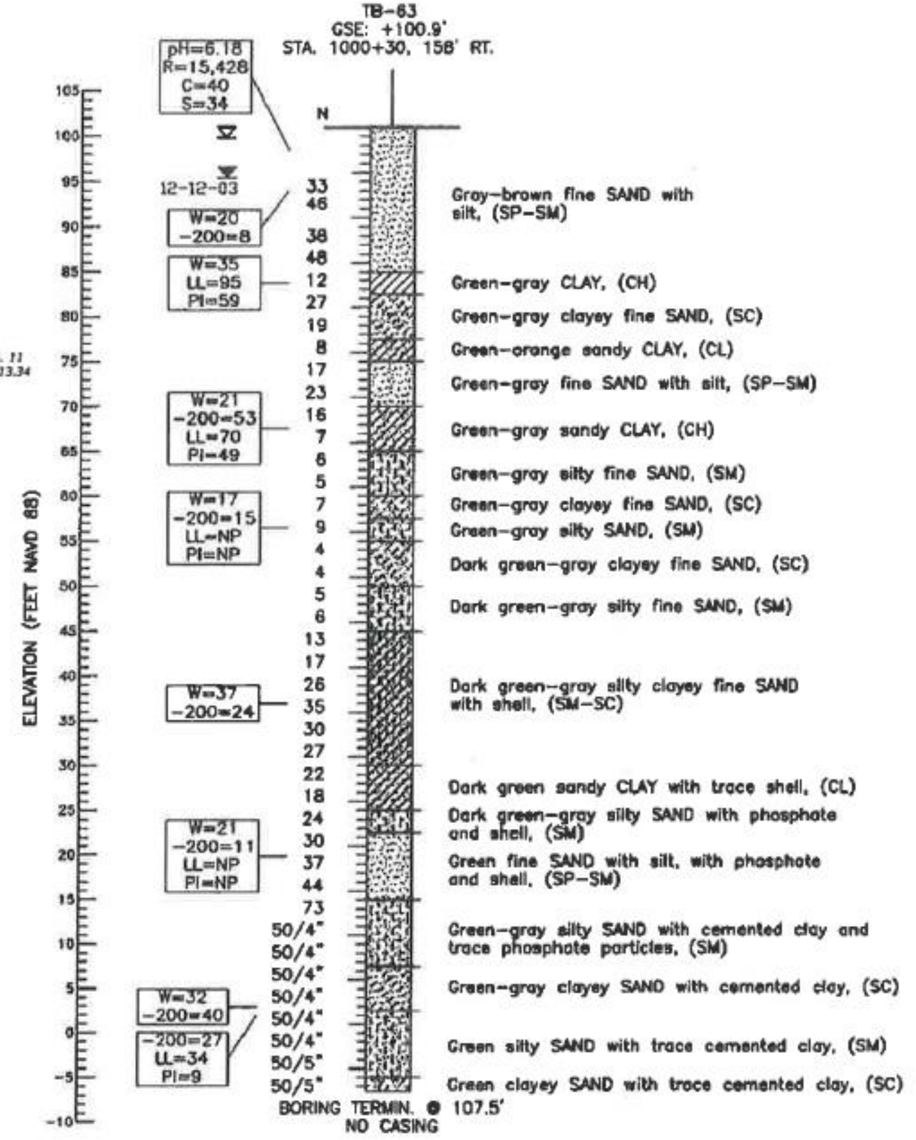
Project 1: project specifications (I-4 and Turnpike intersection)



Pier 11 Location

FDOT Soil Boring Viewer

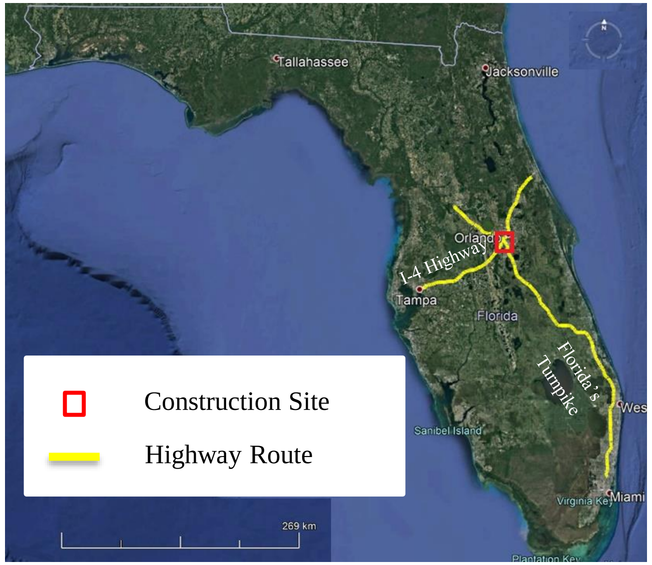
Pier 11L and 11R



Geotechnical Investigation Near Pier 11

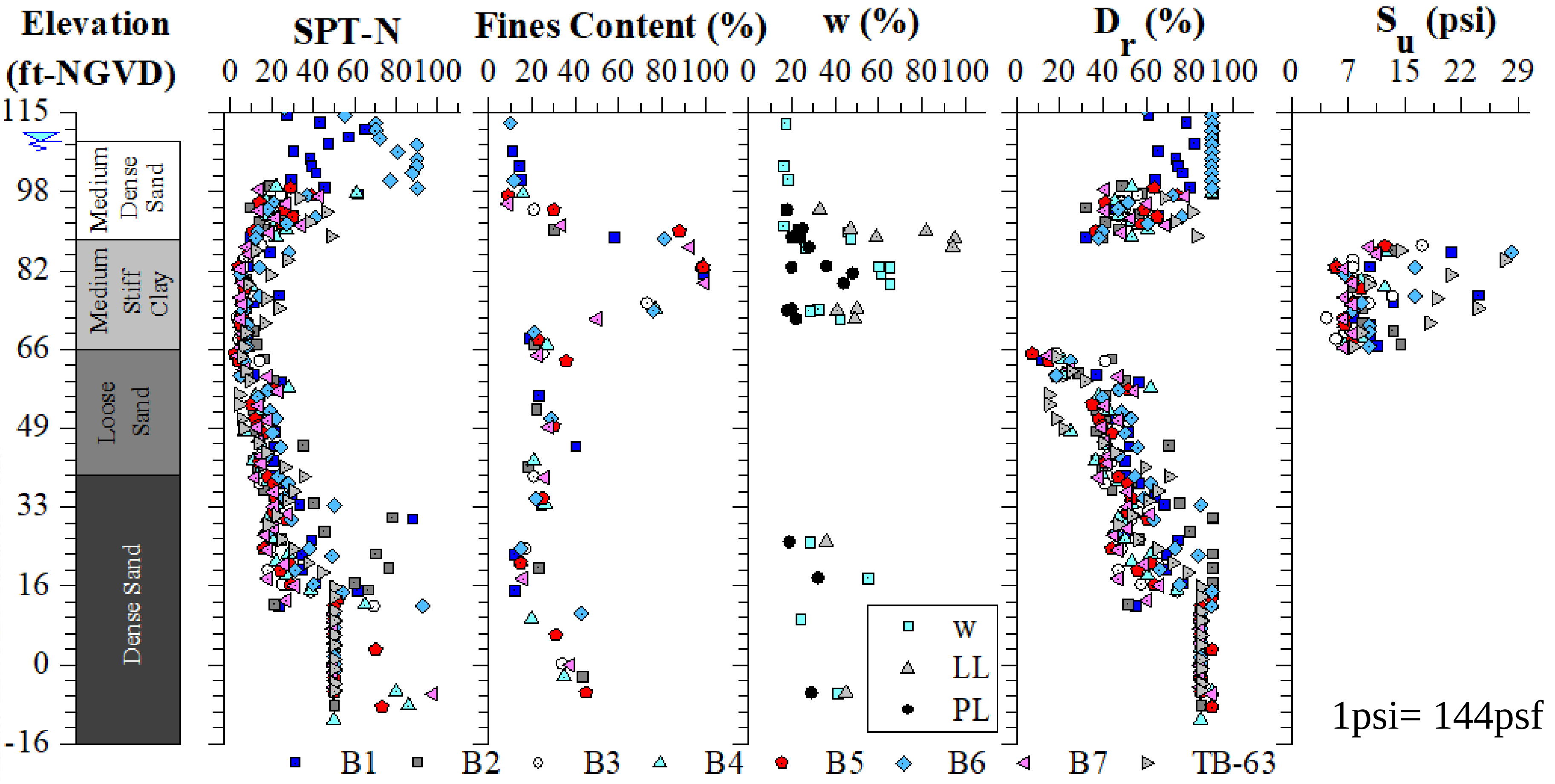
Project 1: project specifications (I-4 and Turnpike intersection)

Florida Turnpike and I-4



Soil borings

Summarized subsurface conditions at project site



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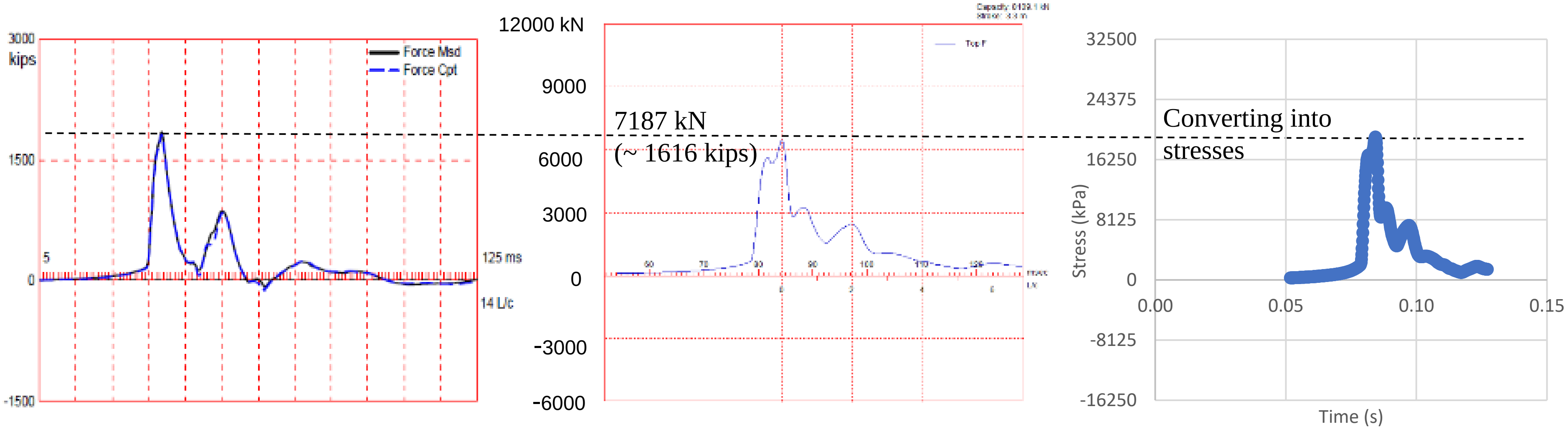
Modeling: progress flowchart

Testing Site Selection → **Summarize Soil Profile** → **Analyze CAPWAP/ PDA Results** → **GRLWEAP "Calibration" from PDA Results** → **PLAXIS**

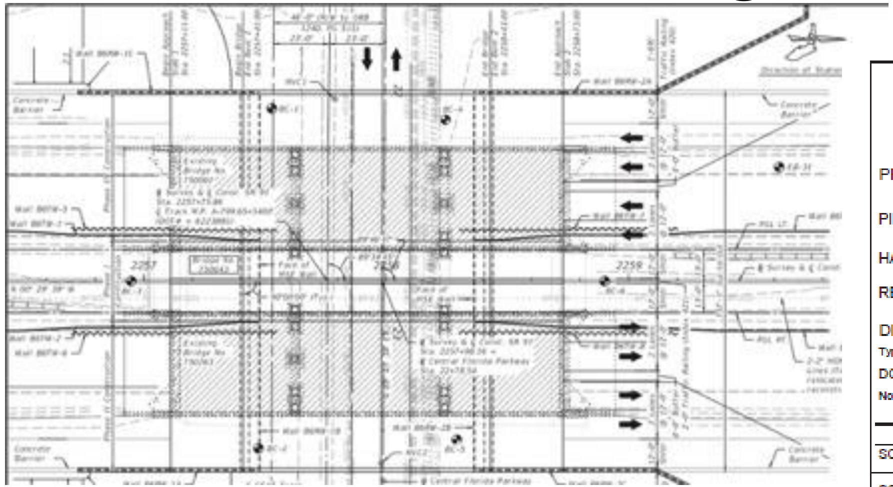
- **Testing Site Selection**
  1) I-4 and Turnpike Intersection
  2) Wekiva Parkway
  3) Turnpike over Central FL. Parkway and CSX Bridge
- **Summarize Soil Profile:** From soil borings and FDOT soil boring viewer
- **Analyze CAPWAP/ PDA Results:** From geotechnical reports provided by FDOT
- **GRLWEAP "Calibration" from PDA Results:** To calibrate forcing function and penetration displacement per blow
- **PLAXIS:** Apply forcing function to analyze response in soil continuum

Task in progress

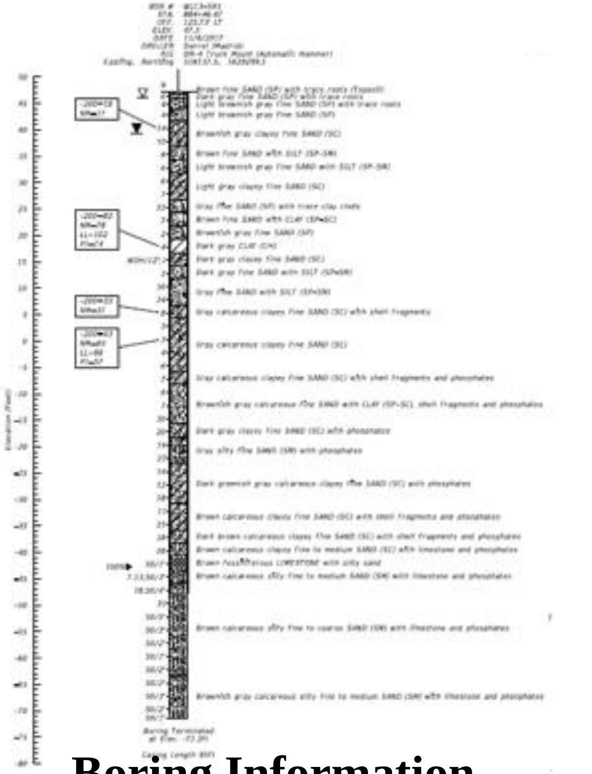
CAPWAP/PDA measurement ⟶ **GRLWEAP "calibration"** ⟶ **Numerical simulations**



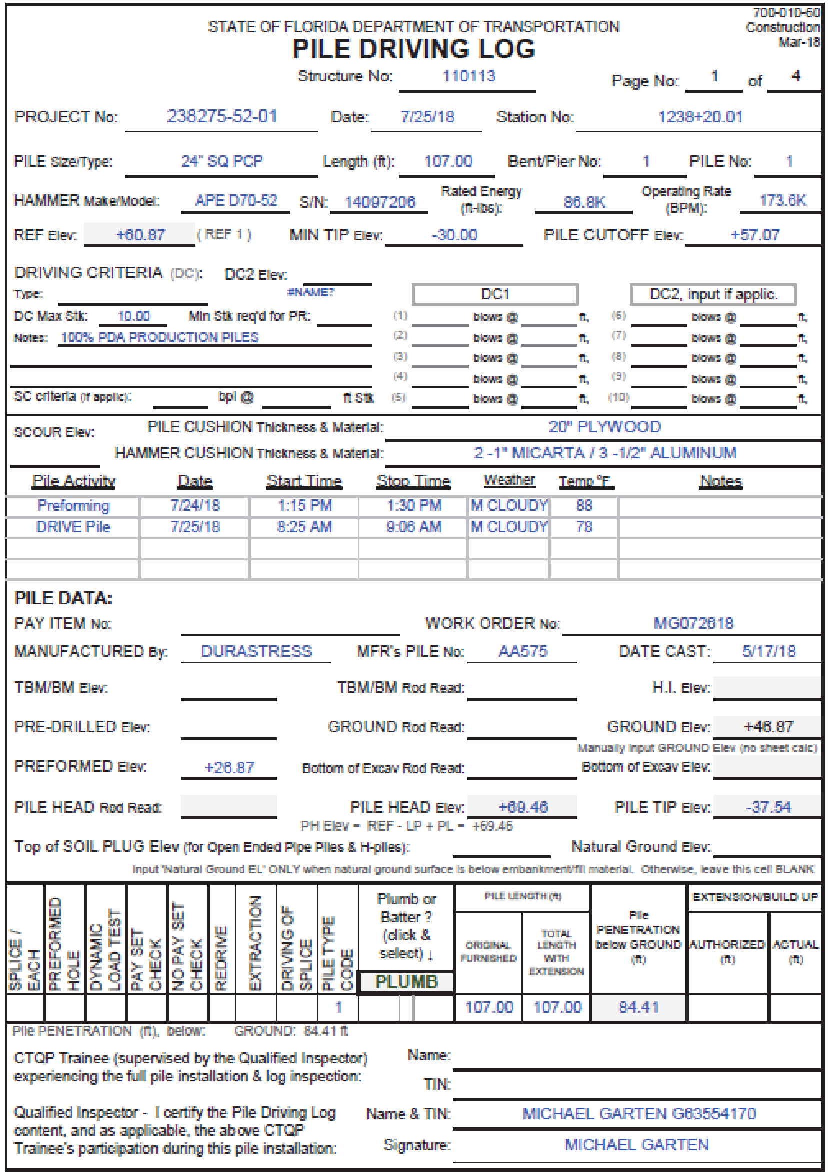
Modeling: information obtained from foundation reports



Structural Drawings



Boring Information



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
700-010-60 Construction Mar-18

PILE DRIVING LOG

Structure No: 110113 Page No: 1 of 4

PROJECT No: 238275-52-01 Date: 7/25/18 Station No: 1238+20.01

PILE Size/Type: 24" SQ PCP Length (ft): 107.00 Bent/Pier No: 1 PILE No: 1

HAMMER Make/Model: APE D70-52 S/N: 14097206 Rated Energy (ft-lbs): 86.8K Operating Rate (BPM): 173.6K

REF Elev: +60.87 (REF 1) MIN TIP Elev: -30.00 PILE CUTOFF Elev: +57.07

DRIVING CRITERIA (DC): DC2 Elev:

Type: #NAME?

DC Max Stk: 10.00 Min Stk req'd for PR:

Notes: 100% PDA PRODUCTION PILES

DC1		DC2, input if applic.
(1) blows @ ft,	(6)	blows @ ft,
(2) blows @ ft,	(7)	blows @ ft,
(3) blows @ ft,	(8)	blows @ ft,
(4) blows @ ft,	(9)	blows @ ft,
(5) blows @ ft,	(10)	blows @ ft,

SC criteria (if applic): bpi @ ft Stk

SCOUR Elev: PILE CUSHION Thickness & Material: 20" PLYWOOD

HAMMER CUSHION Thickness & Material: 2 -1" MICARTA / 3 -1/2" ALUMINUM

Pile Activity	Date	Start Time	Stop Time	Weather	Temp °F	Notes
Preforming	7/24/18	1:15 PM	1:30 PM	M CLOUDY	88	
DRIVE Pile	7/25/18	8:25 AM	9:06 AM	M CLOUDY	78	

PILE DATA:

PAY ITEM No: WORK ORDER No: MG072618

MANUFACTURED By: DURASTRESS MFR's PILE No: AA575 DATE CAST: 5/17/18

TBM/BM Elev: TBM/BM Rod Read: H.I. Elev:

PRE-DRILLED Elev: GROUND Rod Read: GROUND Elev: +46.87

Manually input GROUND Elev (no sheet calc)

PREFORMED Elev: +26.87 Bottom of Excav Rod Read: Bottom of Excav Elev:

PILE HEAD Rod Read: PILE HEAD Elev: +69.46 PILE TIP Elev: -37.54

PH Elev = REF - LP + PL = +69.46

Top of SOIL PLUG Elev (for Open Ended Pipe Piles & H-piles): Natural Ground Elev:

Input 'Natural Ground EL' ONLY when natural ground surface is below embankment/fill material. Otherwise, leave this cell BLANK

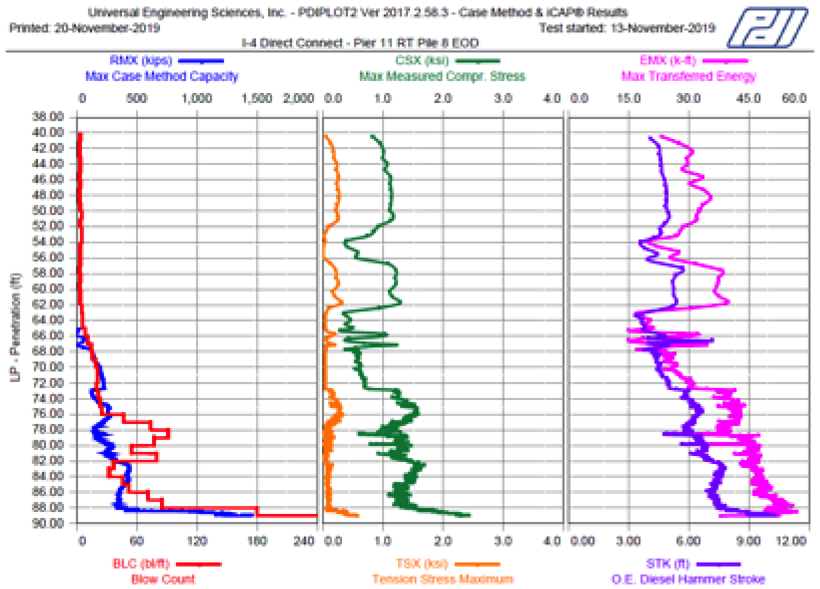
SPLICE / EACH	PREFORMED HOLE	DYNAMIC LOAD TEST	PAY SET CHECK	NO PAY SET CHECK	REDRIVE	EXTRACTION	DRIVING OF SPLICE	PILE TYPE CODE	Plumb or Batter ? (click & select) ↓	PILE LENGTH (ft) ORIGINAL FURNISHED	TOTAL LENGTH WITH EXTENSION	Pile PENETRATION below GROUND (ft)	EXTENSION/BUILD UP AUTHORIZED (ft)	ACTUAL (ft)
								1	PLUMB	107.00	107.00	84.41		

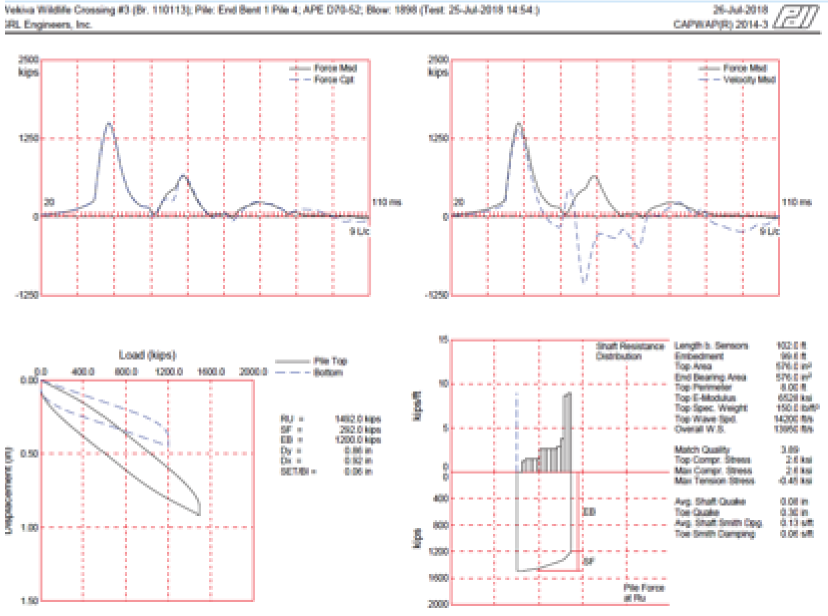
Pile PENETRATION (ft), below: GROUND: 84.41 ft

CTQP Trainee (supervised by the Qualified Inspector) experiencing the full pile installation & log inspection: Name: TIN:

Qualified Inspector - I certify the Pile Driving Log content, and as applicable, the above CTQP Trainee's participation during this pile installation: Name & TIN: MICHAEL GARTEN G63554170 Signature: MICHAEL GARTEN

Pile Driving Log





PDA/ CAPWAP Data

Modeling: pile driving log record and GRLWEAP

From pile driving records, CAPWAP/PDA, and foundation reports

Excel 2016 (v 16.0) STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION 700-010-60 Construction Aug-19

PILE DRIVING LOG

Structure No: 750648 Page No: 1 of 4

PROJECT No: 437166-2/437987-1 Date: 11/8/19 Station No: 223+13.34

PILE Size/Type: 24" SQ PCP Length (ft): 90.00 Bent/Pier No: Pier 11R PILE No: 1

HAMMER Make/Model: APE D70-52 S/N: 201305665 Rated Energy (ft-lbs): 173,644 Operating Rate (BPM): 34-53

REF Elev: +104.05 (REF 1) MIN TIP Elev: +36.00 PILE CUTOFF Elev: +91.50

DRIVING CRITERIA (DC): DC2 Elev:

Type: Test Pile DRIVING CRITERIA inputs n/a for TP

DC Max Stk: Min Stk req'd for PR:

Notes: 100% PDA For Pier

NBR=527 Tons=1,054kips

SC criteria (if applic): bpi @ ft Stk

DC1			DC2, input if applic.		
(1)	N/A	blows @ ft.	(6)	blows @	ft.
(2)		blows @ ft.	(7)	blows @	ft.
(3)		blows @ ft.	(8)	blows @	ft.
(4)		blows @ ft.	(9)	blows @	ft.
(5)		blows @ ft.	(10)	blows @	ft.

SCOUR Elev:

PILE CUSHION Thickness & Material: 15" Plywood/18" Plywood (Note 10) 11-12-19

HAMMER CUSHION Thickness & Material: 1" Micarta (2 EA) & 1/2" Aluminum (3 EA)

Pile Activity	Date	Start Time	Stop Time	Weather	Temp °F	Notes
Pre-Drill	11/8/19	9:10AM	9:24AM	Partly Cloudy	77	Ref Elev=Bottom of Excav
Standing	11/8/19	9:42AM	10:02AM	Overcast	77	
DRIVE Pile	11/8/19	2:42PM	3:53PM	Overcasr	72	
Re-Drive	11/12/19	10:03AM	10:21 AM	Clear	75	

PILE DATA:

PAY ITEM No: WORK ORDER No:

MANUFACTURED By: Std Conc Products MFR's PILE No: C-026 DATE CAST: 10/15/19

TBM/BM Elev: TBM/BM Rod Read: H.I. Elev:

PRE-DRILLED Elev: +72.30 GROUND Rod Read: GROUND Elev:

PREFORMED Elev: Bottom of Excav Rod Read: Bottom of Excav Elev: +90.30

Manually input BOE Elev (no sheet calc available)

PILE HEAD Rod Read: PILE HEAD Elev: +105.65 PILE TIP Elev: +15.65

PH Elev = REF - LP + PL = +105.65

Top of SOIL PLUG Elev (for Open Ended Pipe Piles & H-piles): Natural Ground Elev:

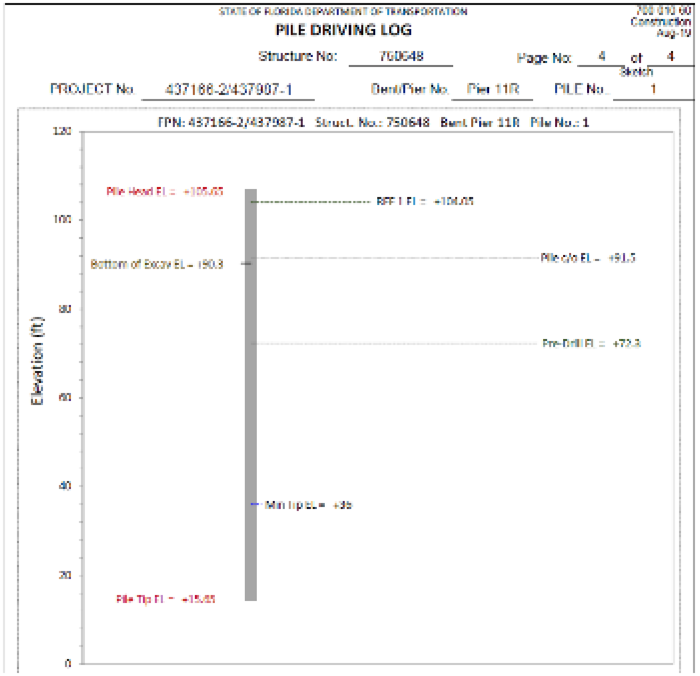
Input 'Natural Ground EL' ONLY when natural ground surface is below embankment/fill material. Otherwise, leave this cell BLANK

SPLICE / EACH	PREFORMED HOLE	DYNAMIC LOAD TEST	PAY SET CHECK	NO PAY SET CHECK	REDRIVE	EXTRACTION	DRIVING OF SPLICE	PILE TYPE CODE	Plumb or Batter ? (click & select) ↓	PILE LENGTH (ft) ORIGINAL FURNISHED	TOTAL LENGTH WITH EXTENSION	Pile PENETRATION below Bottom of Excav (ft)	EXTENSION/BUILD UP AUTHORIZED (ft)	ACTUAL (ft)
0	0	1	0	0	1	0	0	1	PLUMB	90.00	90.00	74.65	0.00	0.00

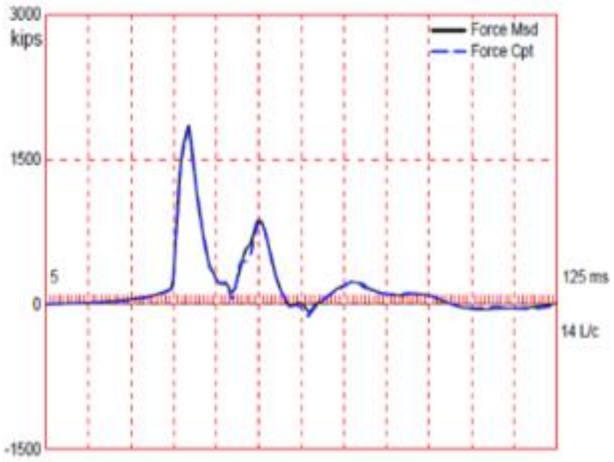
Pile PENETRATION (ft), below: Bottom of Excav: 74.65 ft

CTQP Trainee (supervised by the Qualified Inspector) experiencing the full pile installation & log inspection: Name: Tyler Hammett TIN: H53080395

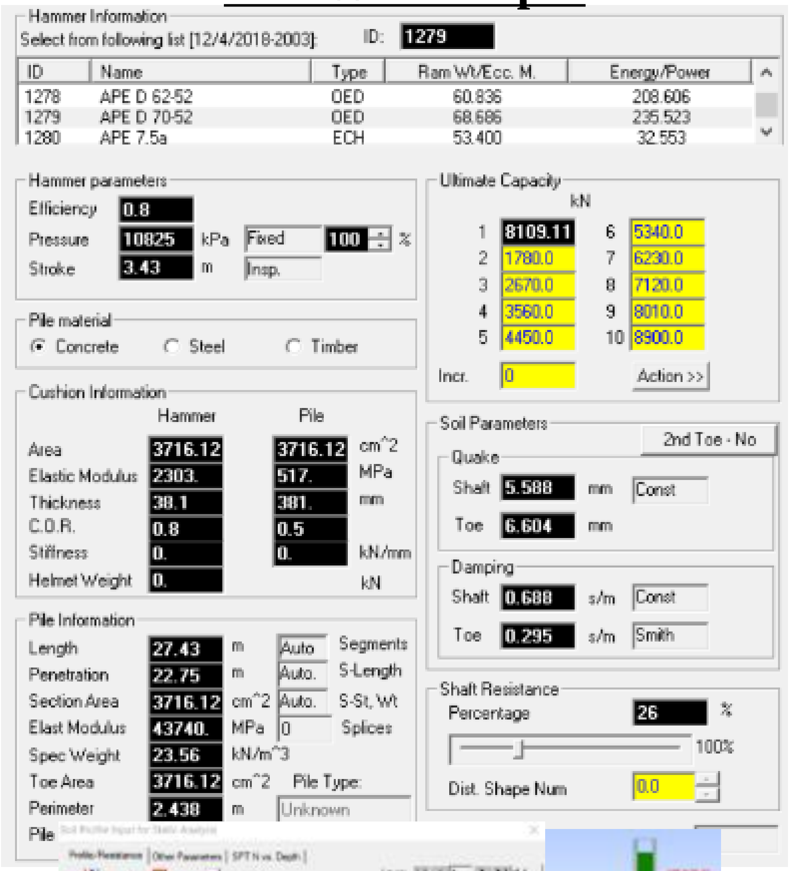
Qualified Inspector - I certify the Pile Driving Log content, and as applicable, the above CTQP Trainee's participation during this pile installation: Name & TIN: Luis Ballester B42352189 Signature:

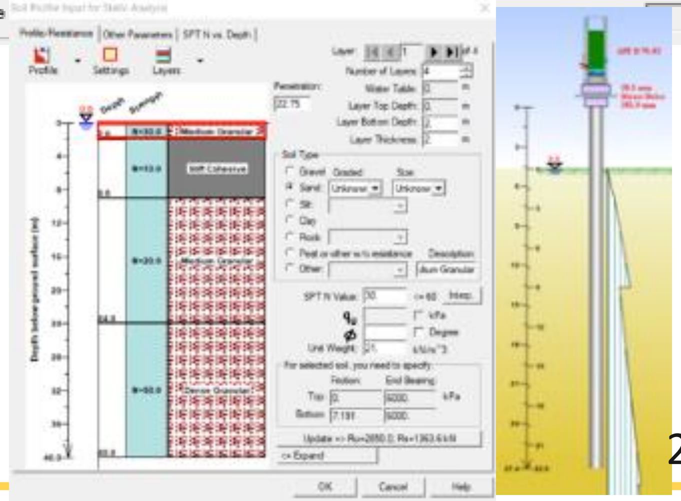


CAPWAP/PDA (measured)



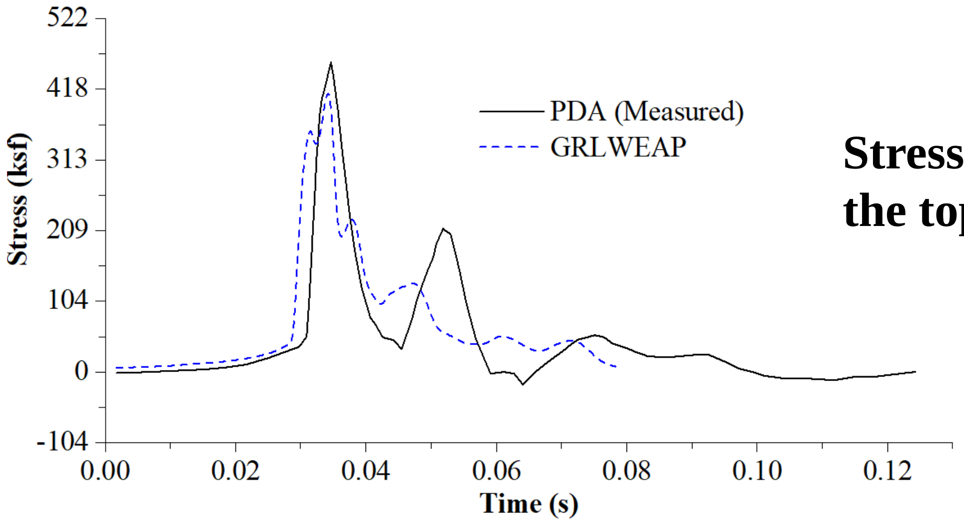
GRLWEAP input



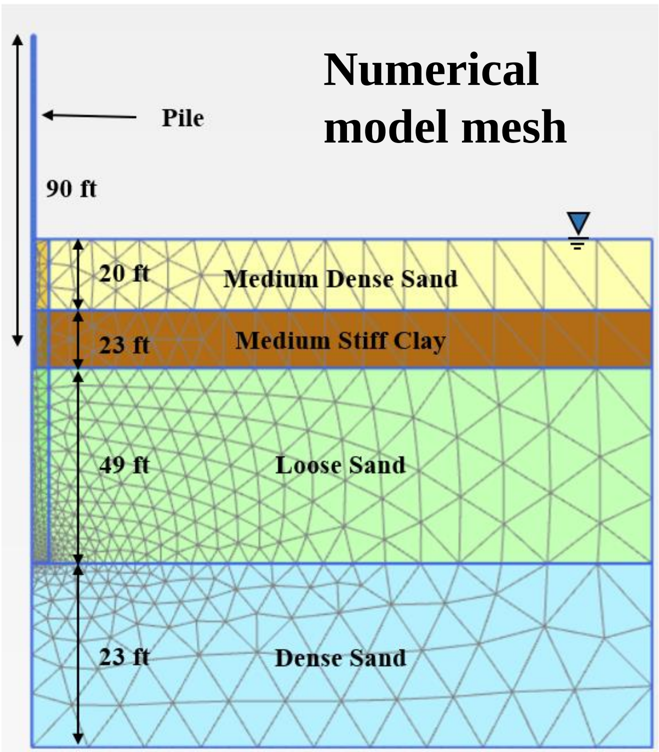


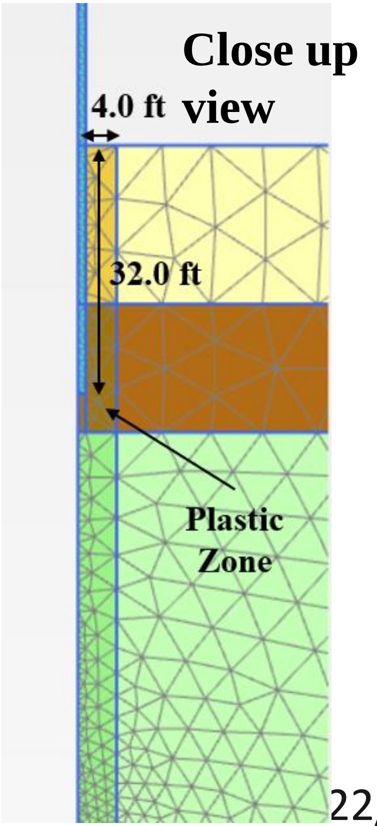
Pile driving numerical model stages:

1. Define material properties (HSS model) and drainage conditions
2. Define model geometry (pile, soil layers and `plastic zone clusters)
3. Mesh definition
4. Initialization of soil stress field
5. Activation stage: pile and plastic zone cluster
6. Dynamic analysis: application of 1824 blows separated one second between each other.



Stress function at the top of the pile





Modeling: numerical material parameters (HSS model)

Parameter	Units	Free-Field Zone				Plastic Zone			
		Medium Dense Sand	Medium Stiff Clay	Loose Sand	Dense Sand	Medium Dense Sand	Medium Stiff Clay	Loose Sand	Dense Sand
Thickness	m	6.2	7.0	15.0	16.0	6.2	7.0	15.0	16.0
SPT-N	-	30.0	10.0	20.0	50.0	30.0	10.0	20.0	50.0
D_r	(%)	60.0	-	45.0	85.0	60.0	-	45.0	85.0
R	-	-	-	-	-	0.4	0.4	0.4	0.4
R_s	-	-	-	-	-	0.12	0.12	0.12	0.12
γ_{sat}	kN/m^3	20.0	19.0	19.7	20.4	20.0	19.0	19.7	20.4
ϕ’	°	35.5	28.0	33.6	38.6	14.2	11.2	13.5	15.5
ψ	°	5.5	-	3.6	8.6	2.2	-	1.5	3.5
c'	kPa	1.0	11.5	1.0	1.0	0.0	11.5	0.0	0.0
S_u	kPa	-	110.0	-	-	-	44.0	-	-
E_{50}^{ref}	kPa	36000	9500	27000	51000	518	137	389	734
E_{oed}^{ref}	kPa	36000	12000	27000	51000	518	173	389	734
E_{ur}^{ref}	kPa	108000	30000	81000	153000	1555	432	1166	2203
G_0^{Ref}	kPa	100800	70000	90600	117800	1452	1008	1305	1696
m	-	0.5	0.7	0.6	0.4	0.5	0.7	0.6	0.4
ν'_{ur}	-	0.3	0.2	0.3	0.3	0.3	0.2	0.3	0.3
$\gamma_{0.7}$	$x10^{-4}$	1.40	9.95	1.55	1.15	1.40	9.95	1.55	1.15
α	-	2.7	2.6	1.9	2.0	0.7	0.6	0.3	0.3
β	$x10^{-4}$	9.4	9.2	6.7	6.9	2.6	1.9	1.0	1.1
R_f	-	0.9	1.0	0.9	0.9	0.9	1.0	0.9	0.9

Parameters used for the HS small model in our numerical simulations:

References used for definition of parameters:

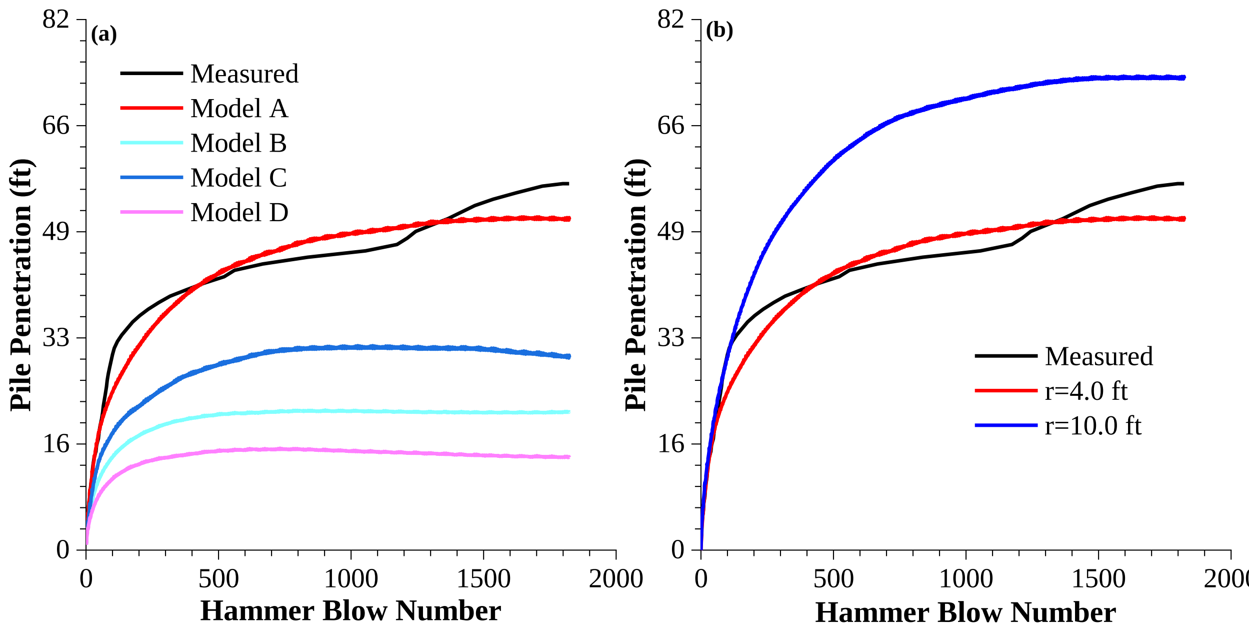
- For the sandy layers: Brinkgreve et al. (2010)

- For the clayey layers: Vucetic and Dobry (1991) Likitlersuang et al. (2013)

Reduction factors for the plastic soil adjacent to the pile

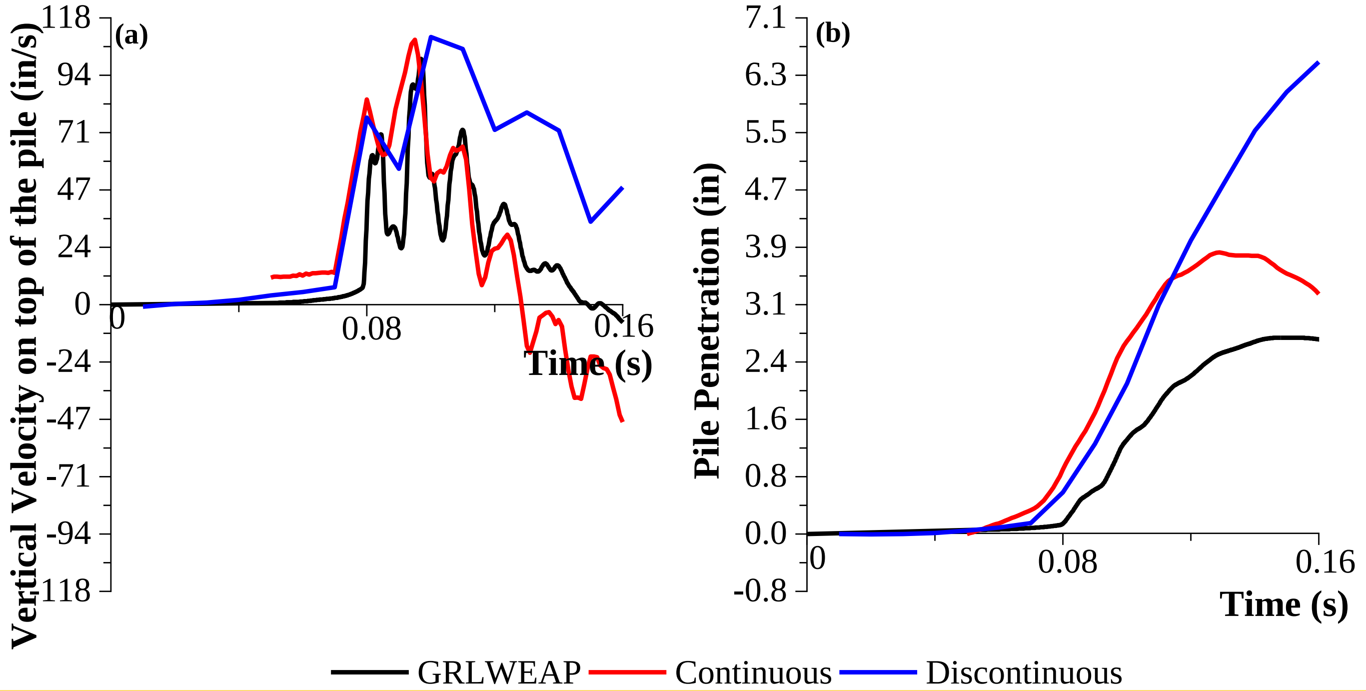
PLAXIS 2D Model Number	Strength Reduction Factor (*R*)	Shear Wave Velocity Reduction Factor (R_s)
Model A	0.4	0.12
Model B	0.4	0.2
Model C	0.5	0.12
Model D	0.5	0.2

Modeling: overview of results from numerical models



Comparison of different soil parameters and dimensions for the plastic zone.

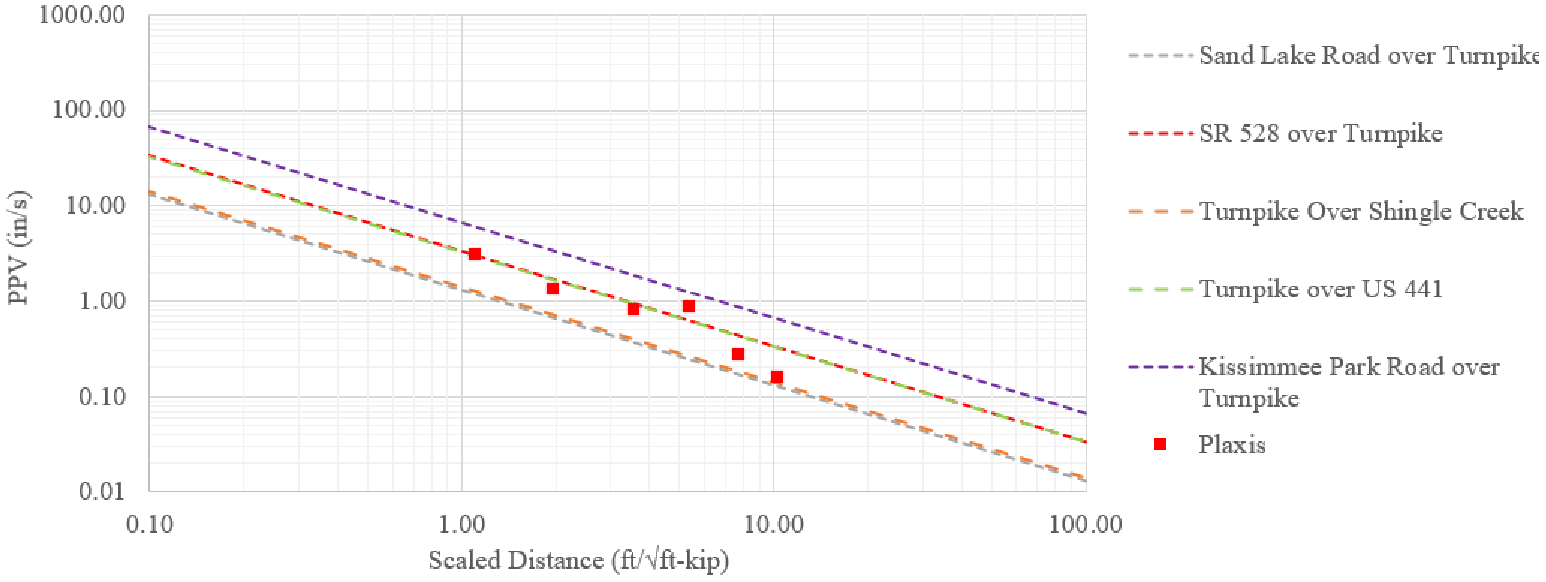
Comparison of discontinuous and continuous modeling approaches with values from GRLWEAP on top of the pile.



Modeling: comparison versus PPV values in nearby projects

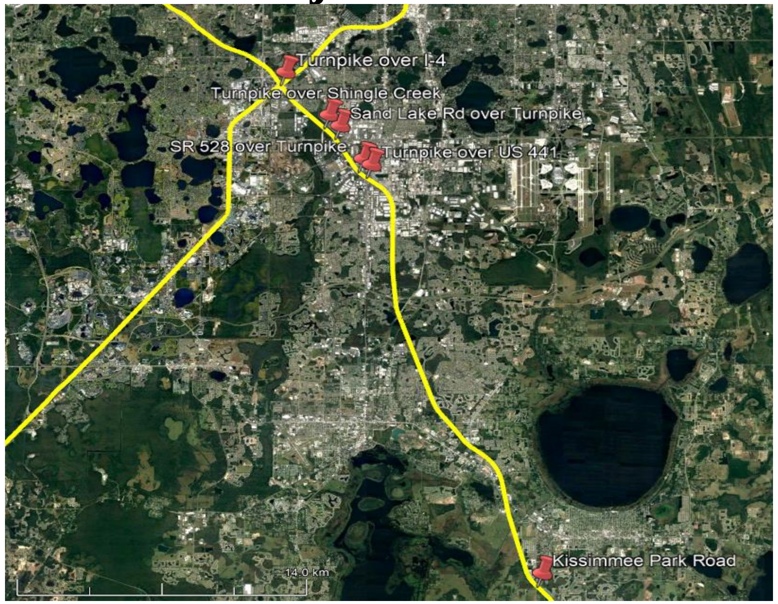
PPVs: Computed with model vs. measured values in nearby projects (Bayraktar et al. 2013):

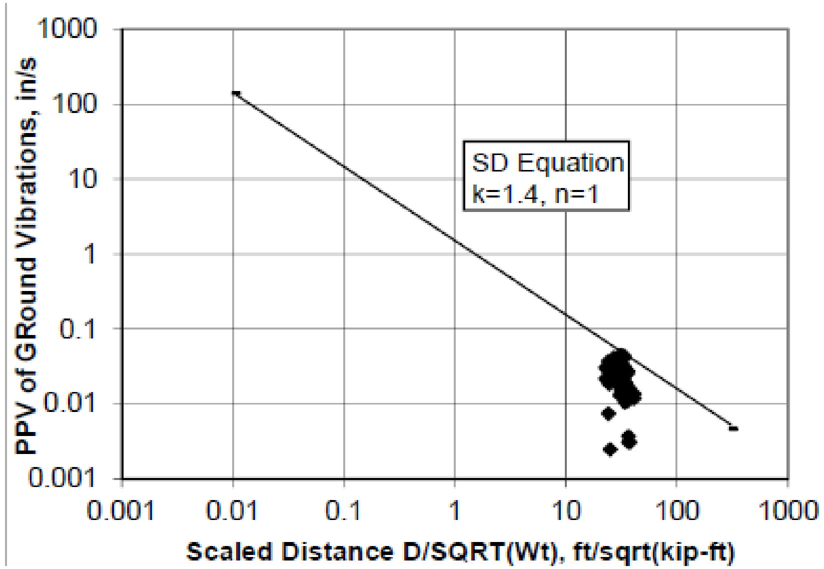
- Sand Lake Rd. over the Turnpike,
- SR 528 over the Turnpike,
- Turnpike over Shingle Creek,
- Turnpike over US 441, and
- Kissimmee Park Rd. over Turnpike.



Computed with model vs. measured values in nearby projects (Bayraktar et al., 2013)

Project locations





Data from Turnpike over Shingle Creek (Bayraktar et al. 2013)

Conclusions and challenges

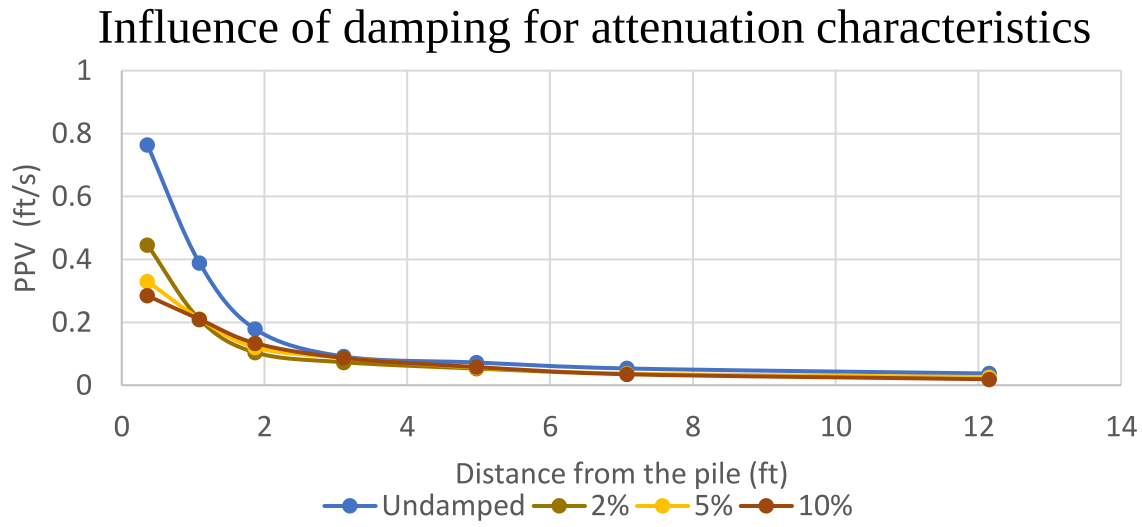
1. Continuous pile driving process is currently modeled successfully using plastic zone and soil-pile interaction concepts.

2. A continuous pile driving model matches better pile response than a discontinuous model. A continuous model considers changes in the state of stresses as the pile is installed.

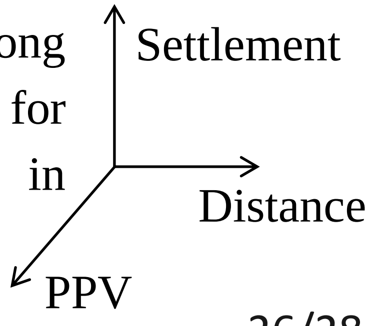
3. Results computed by assuming "wished-in-place" locations of the pile at different elevations applying single hammer blows at those locations, and accumulating those values (i.e., "discontinuous" approach) do not constitute an accurate method to study pile driving dynamics and can produce misleading results.

4. Some numerical issues were found: stiffness errors, model divergence, computational time, and characteristics of forcing function and stroke height changes with depth.

5. Rayleigh damping in the soil mass was used to supplement constitutive model damping. Definition of damping is key.



6. **<u>Ultimate goal</u>**: find relationships among PPV → distance from source → settlement for different input energies and soil types in Florida.



Tasks timeline and future plans

Task 1 – Technical review

Task 2 – Survey

Task 3 – Field testing

Task 4 – Numerical modeling

Task 5 – Prediction method

Task 6 – Recommendations

Future Plans

Deliverable # / Description of Deliverable as provided in the scope (included associated task #)	Anticipated Date of Deliverable Submittal (month/year)	Comments
Project kickoff teleconference	03/2019	Completed
Deliverable 1: A technical report presenting the results of the technical background on pile-driving induced settlement and past case studies.	05/2019	Completed
Deliverable 2: A survey instrument and technical report with the analysis of the survey data.	09/2020	Completed
Deliverable 3: A technical report summarizing the results of the first field test, including: (i) details of pile installation, (ii) soil properties at the selected site, (iii) data of excess pore water pressure and ground vibration (PPV) during pile driving, and (iv) measured settlement data during pile installation.	03/2021	Pending
Deliverable 3b: A technical report summarizing the results of the second field test.	06/2021	Pending
Deliverable 4: A technical report summarizing the results of the numerical models and parametric studies developed in this research.	09/2021	Working on it!
Deliverable 5: A technical report summarizing the correlations between settlement, PPV, and distance from source, including a prediction equation or chart for pile-driving induced settlement as a function of PPV, distance, and energy source.	11/2021	Pending
Deliverable 6a: Draft Final Report	12/2021	Pending
Deliverable 6b: Closeout teleconference meeting and PowerPoint presentation	1/2022	Pending
Deliverable 7: Final Report	2/2022	Pending

PRESENTED BY

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