Contract Title: Quantifying Pile Rebound with Detection Systems Best Suited for Florida Soils

Task Work Order: BDV28 Two 977-07

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Presentation Outline

- Background/Approach
- Objective
- Project Tasks
- Sites Tested
- Equipment Used
- Results
- Conclusion & Recommendations
- Further Research
- Project Benefits: Qualitative and Quantitative
- Implementation
- Closing Slide

Background

- Large Displacement Prestressed Concrete Piles (PCP's) rebound in Florida's Saturated Very Fine Sands with Silts and Clays
  - Rebound significantly decreases end bearing capacity
  - Elastic compression (PL/AE) is controlled by the large end bearing area, plus P and L are not really known
- Several Previous Projects has helped clarify the problem
  - The very fine sands must be relatively thick, possible 6B
  - Single Acting Hammers have been associated with rebound
- Digital measurements are not always reliable

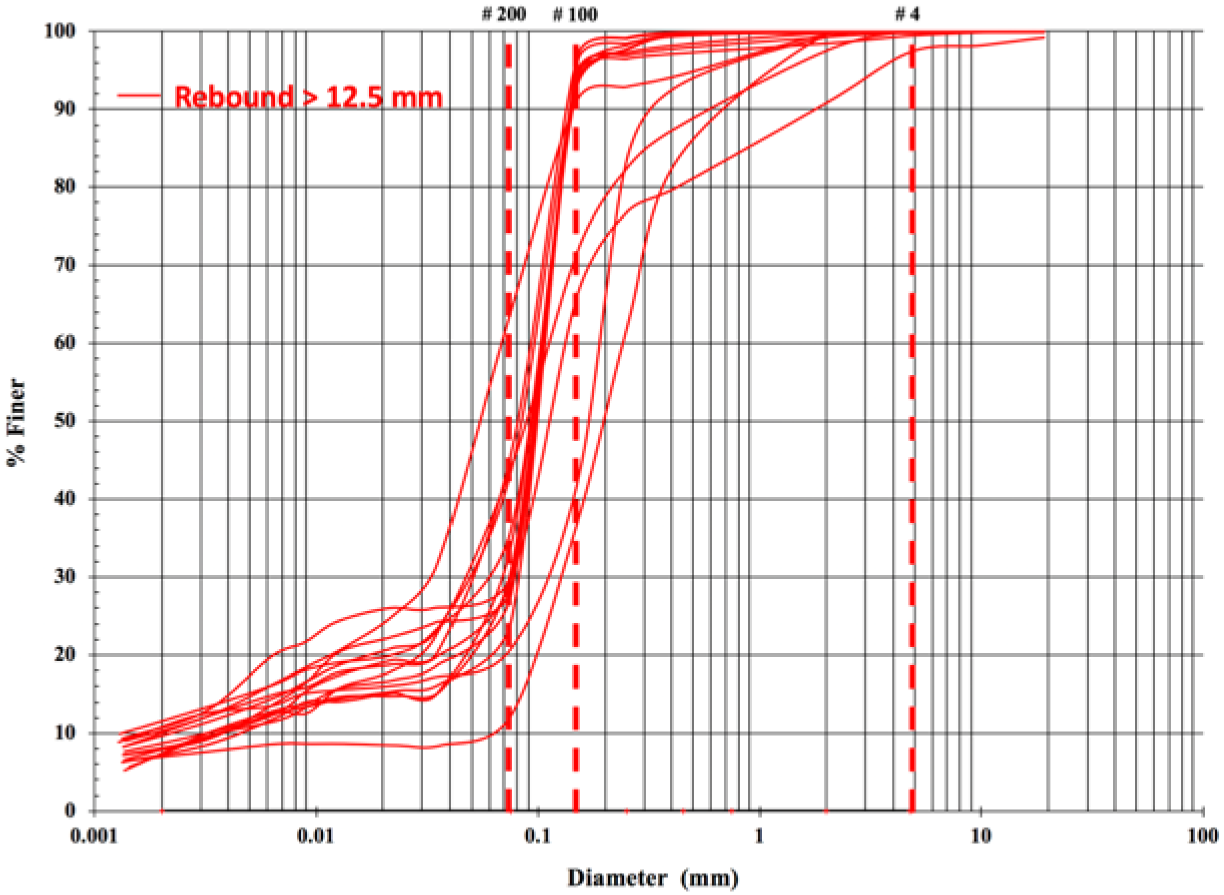
Approach

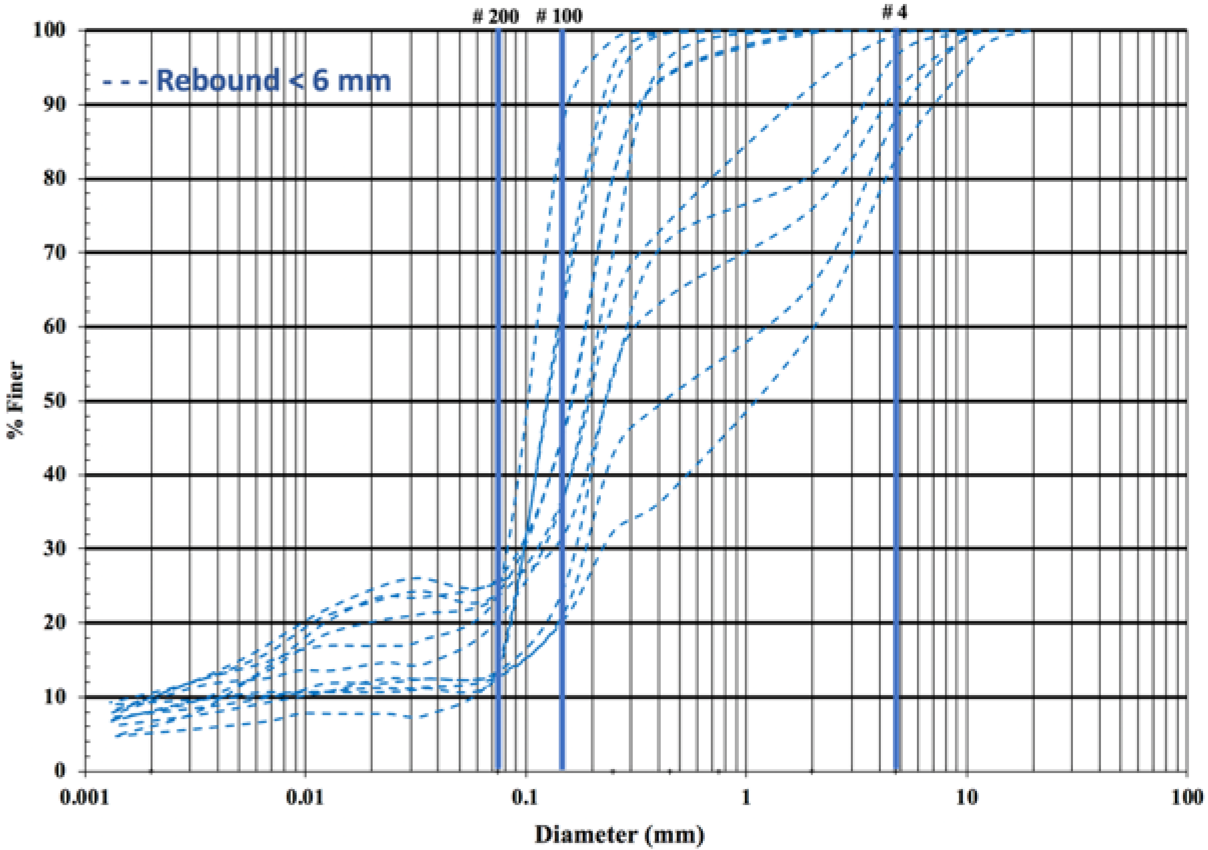
- Evaluate two new pile movement measuring systems
  - Inopiles PDM LASER deflection-measuring system
  - FIT camera measurement system (CMS)
- Cyclic Triaxial (CT) testing on 40 samples produced interesting findings
  - Evaluate damping from
  - Cyclic Triaxial (CT) Viscous Response
  - CAPWAP Signal Matching

Objective

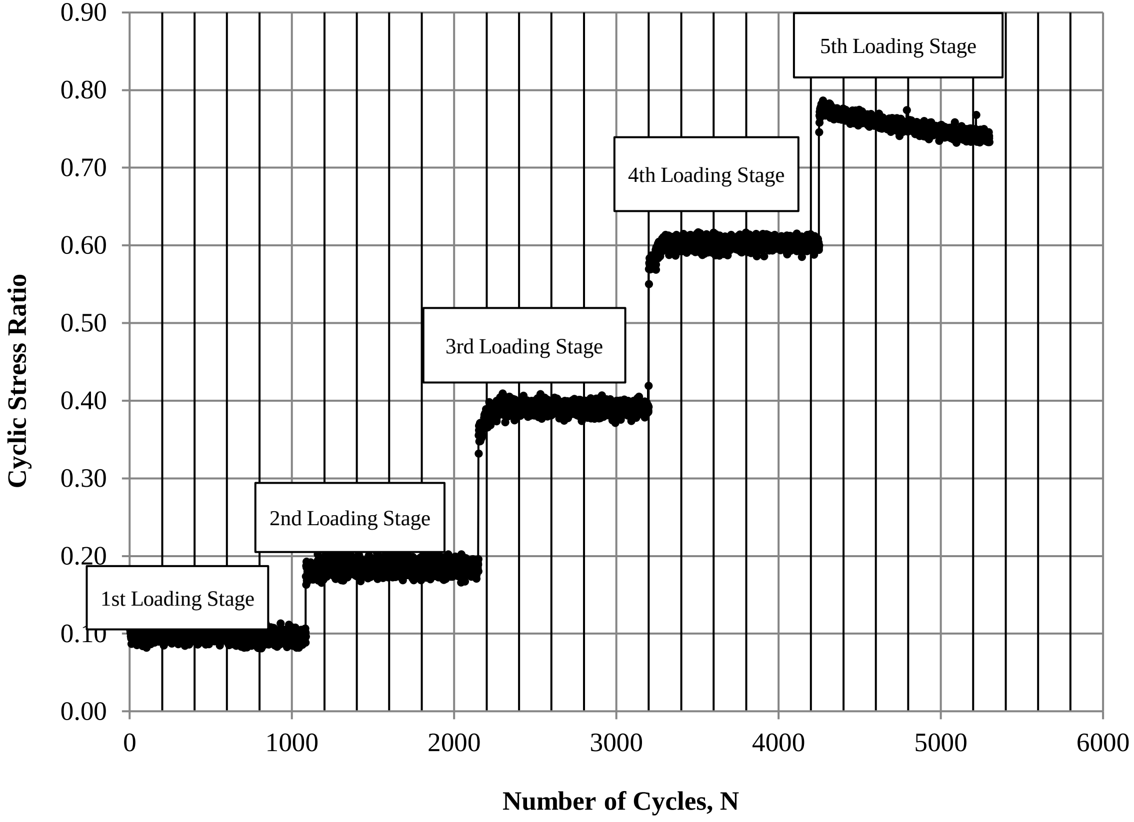
- Evaluate how the Inopiles PDM LASER and Florida Tech CMS deflection-measuring systems can be used to quantify pile rebound.
- Evaluate the damping and associated pile rebound observed during BDV 28 977-01 CT testing.

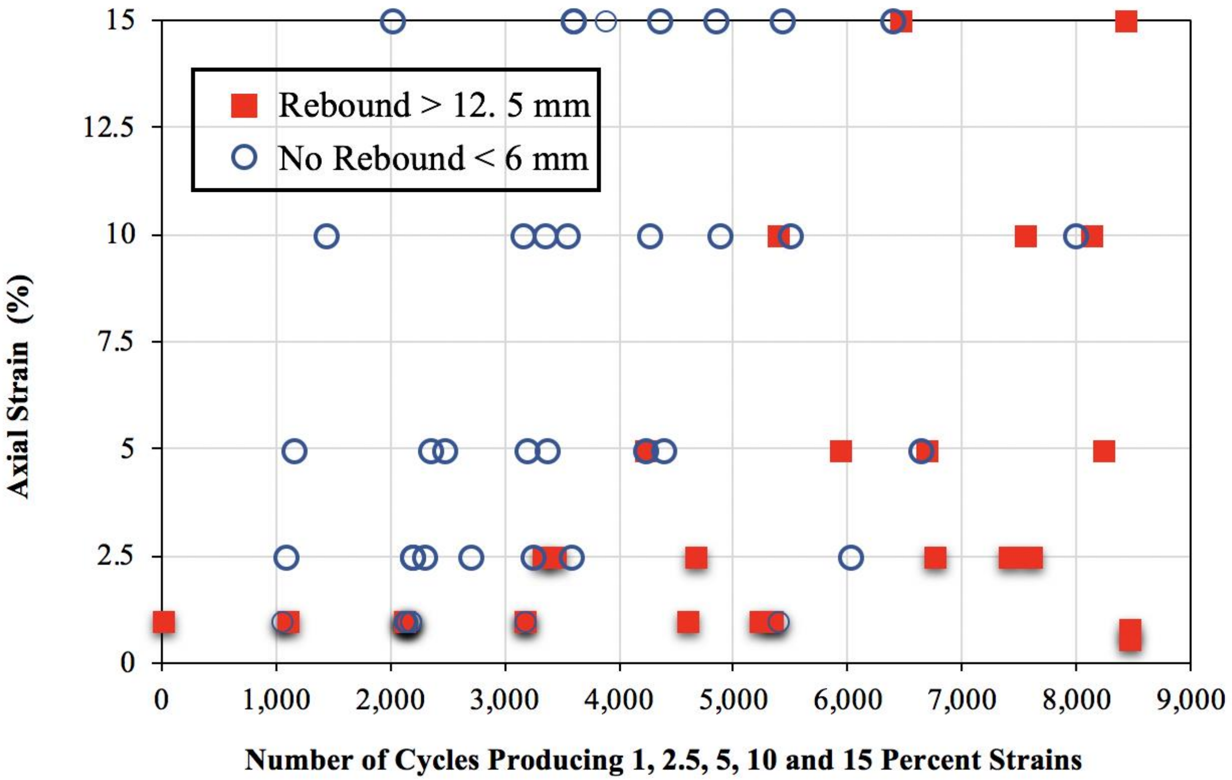
BDV 28 977-01 Course GSDC's



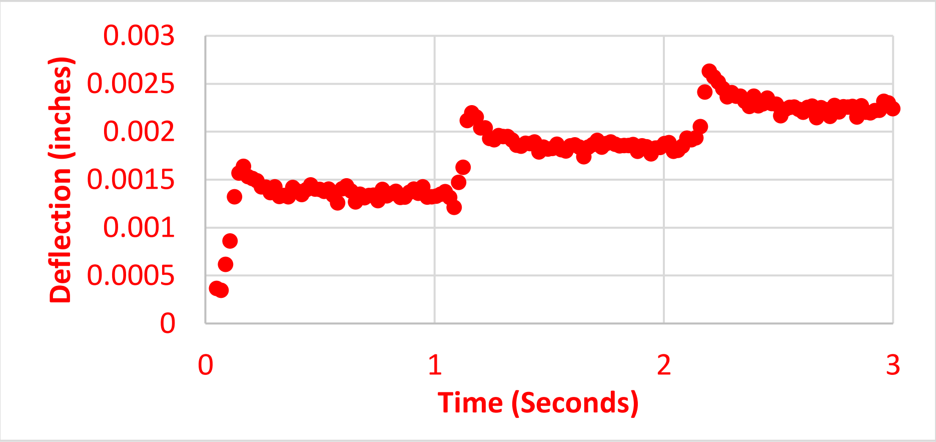


BDV 28 977-01 CT Results

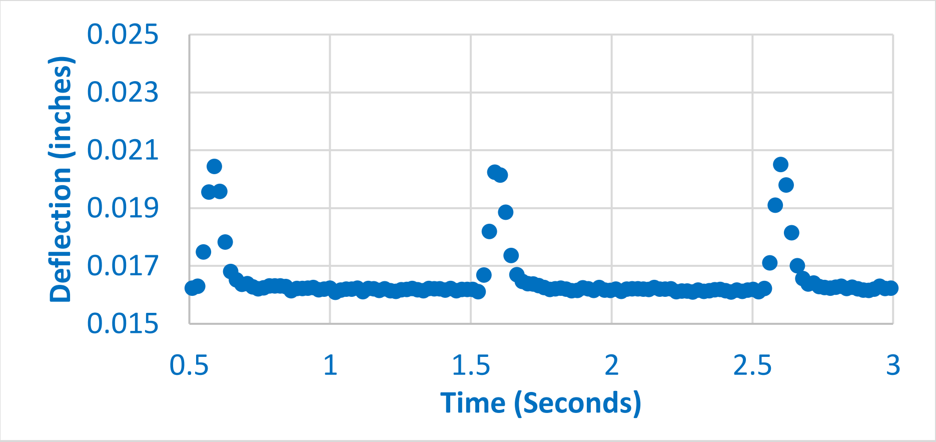




Cyclic Results show HPR Soils are Viscoelastic



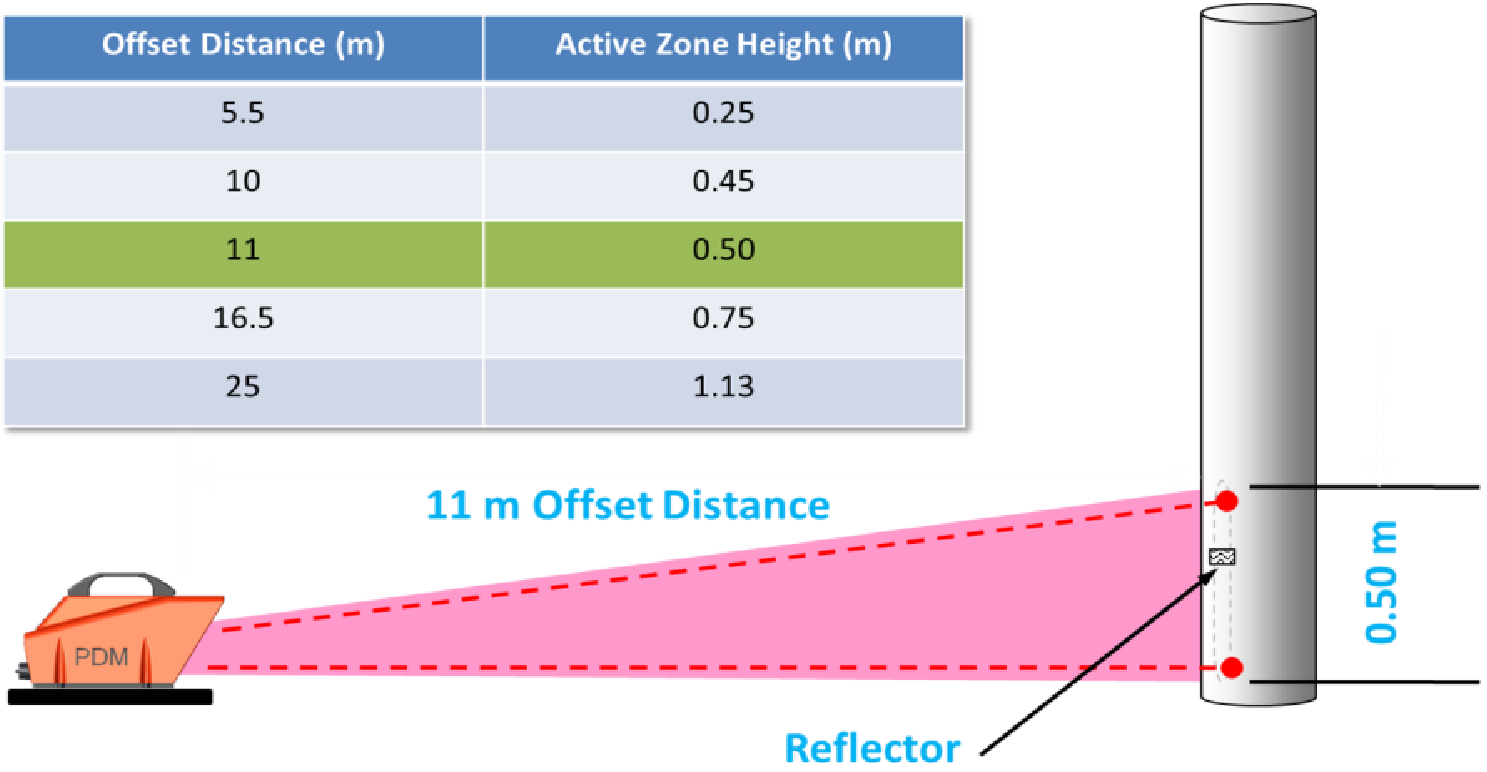
Three deflection versus time cycles @ Ramsey Branch - 63’ Site 12



Three deflection versus time cycles @ Heritage Parkway -57 ‘ Site 10

Inopiles PMD-Basic Usage

Offset Distance (m)	Active Zone Height (m)
5.5	0.25
10	0.45
11	0.50
16.5	0.75
25	1.13



- *Mount PDM to surveyors tri-pod*
  - *Measure distance to target*
- About 30-inches of data recorded
  - *Angle is* *2.6 ^{0}* *from horizontal*
  - *Reflective Tape must stay within Zone*
  - *Add Active Zone marks on pile leads*
- To record data during entire driving
  - *Each testing sequence or piece of tape requires new input data-Express Mode*
  - *Reflective Tape Quality May Affect Results*
- *Most reliable for set-checks or limited pile movement*

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Field Testing Set-ups

Bobby

Aline

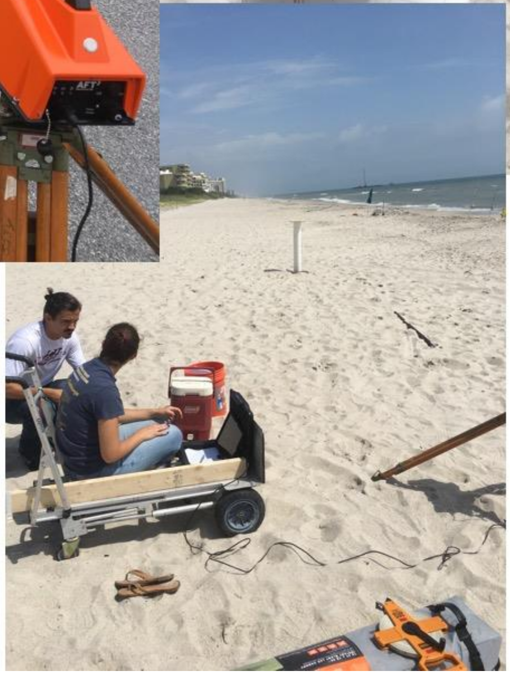
Chuck

Rain-rain go away you'll mess up the PDM today

PDM Evaluations

- Preliminary Lab and Field Testing
  - *Lab Testing using Metal Yard Stick Taped into Loose Sand*
  - *Field Testing on and near campus*
- Full-Scale Field Testing
  - *PDA Instrumented Piles- 6 sites*
  - *SPT Borings- 2 sites 3 locations*

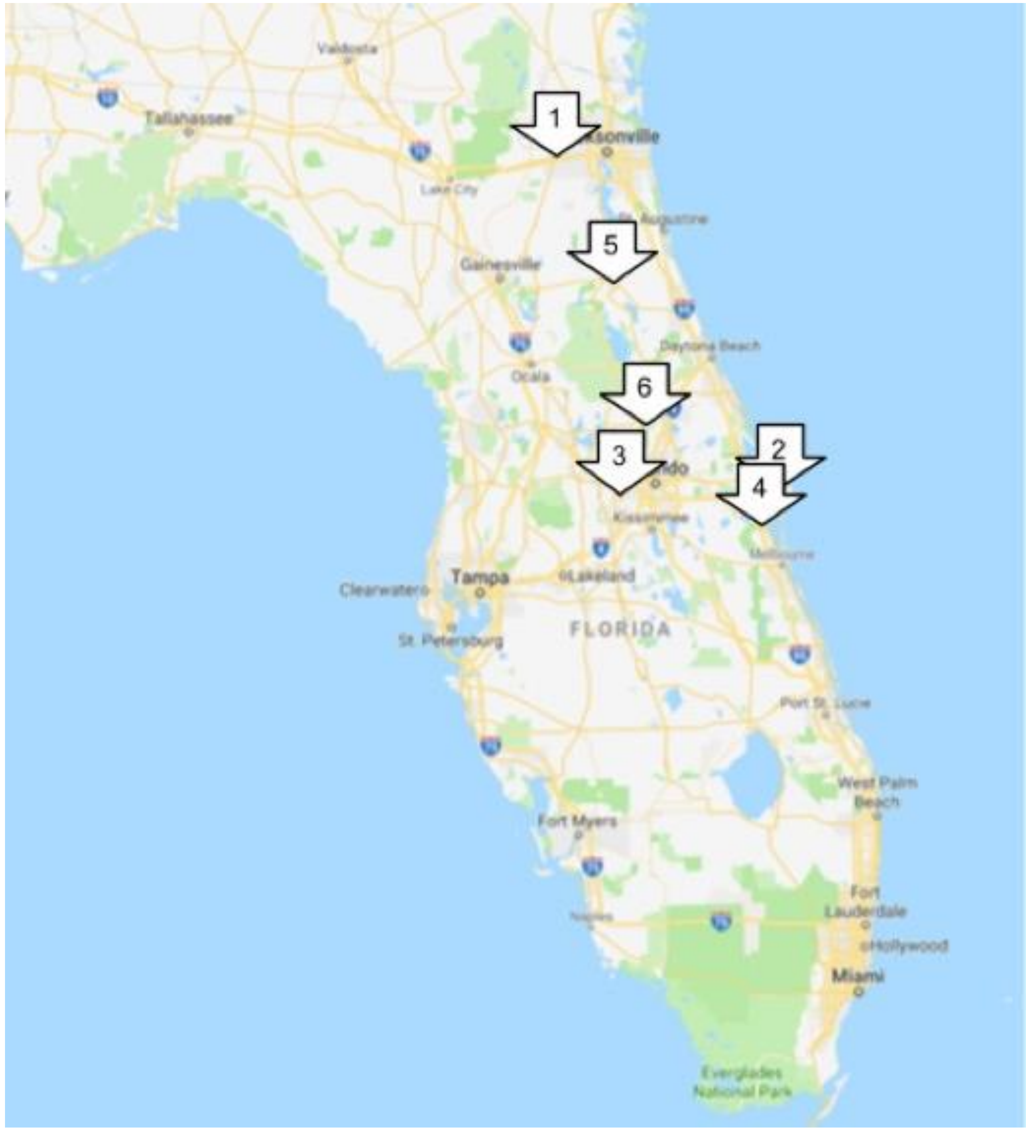
PDM Preliminary Testing



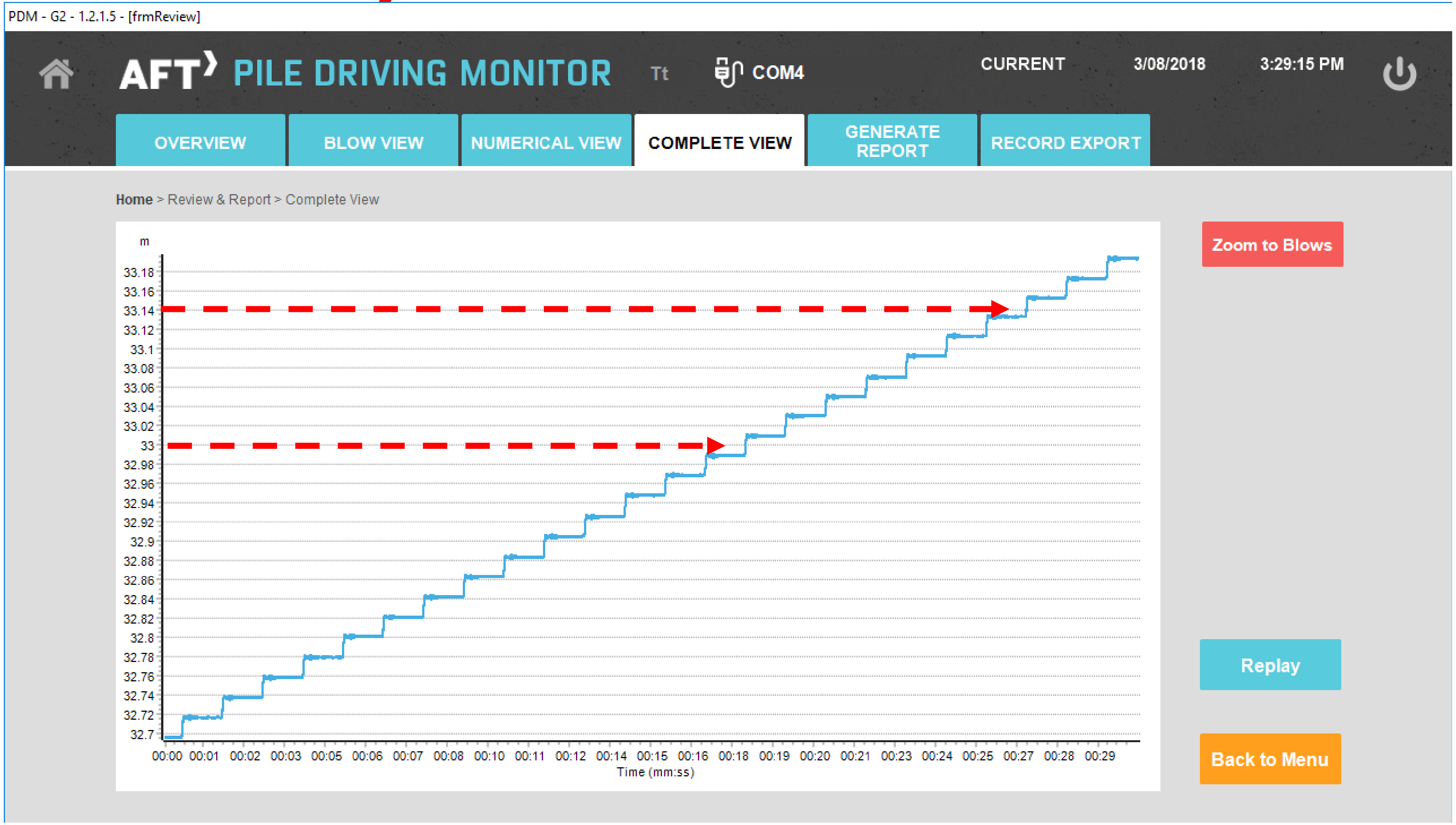
- Unit on Tripod to Allow Leveling & Proper Sighting on Pile-Rods
- Properly Use Reflective Tape to Produce Optimal Signal

Full-Scale Field Testing

Project # and Name	Rebound	Pile or *SPT*	PDM Data	Camera Data	PDA Data
1 Baldwin Bypass	Yes	Pile	No	Yes	Yes
2 Port Canaveral	No	Pile	Yes	N/A	N/A
3 Reedy Creek	No	Pile	Yes	Yes	Yes
4 Ellis Overpass	No	Pile	Yes	Yes	Yes
5 Dunns Creek	Yes	Pile	Yes	Yes	Yes
5 Dunns Creek	*Yes*	*SPT*	*Yes*	*Yes*	*N/A*
6 Wekiva Parkway	*Yes*	*SPT*	*Yes*	*Yes*	*N/A*

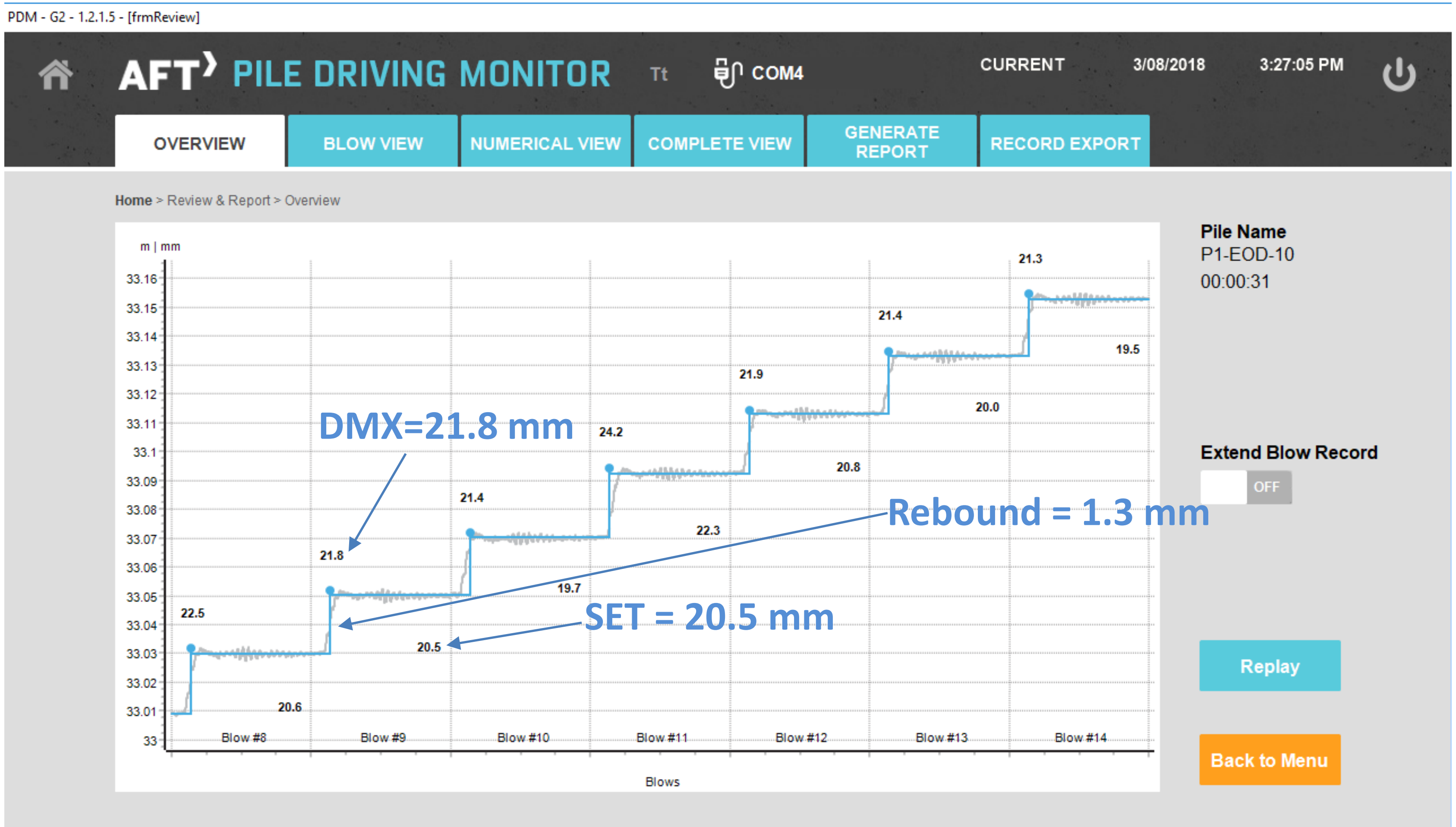


PDM Reedy Creek Test Pile Data Near 90 ‘



PDM Software: Displacement vs. Time

Zoom View: blue vs gray



Blue line and dot maximum displacement vs. Gray line continuous displacement

Blows 8 - 14

PDM Output
Rebound 1.5 mm (0.06-inches)

Blow	StartTime	Penetration (m)	Set (mm)	Rebound (mm)	Velocity (m/s)
8	16:00:15	33.334	20.6	1.9	*1.73*
9	16:00:17	33.354	20.5	1.3	1.65
10	16:00:18	33.374	19.7	1.6	1.58
11	16:00:18	33.396	*22.3*	*1.9*	1.65
12	16:00:20	33.417	20.8	*1.1*	*1.51*
13	16:00:21	33.437	20	1.5	1.68
14	16:00:22	33.457	*19.5*	1.8	1.55
Average			20.5	1.6	1.62
Range			*2.8*	*0.8*	*0.23*

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Dunns Creek
PDM from SPT

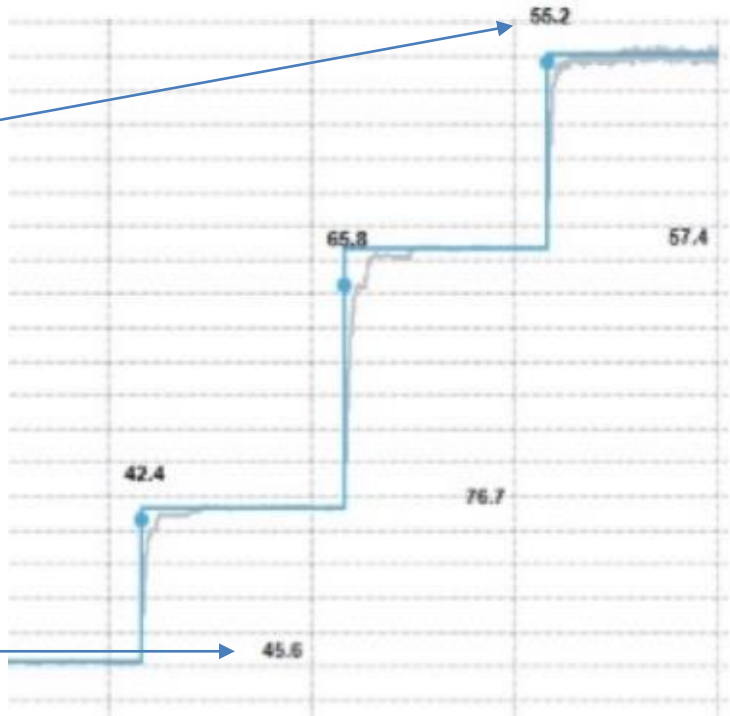
PILE DRIVING MONITOR

FDOT

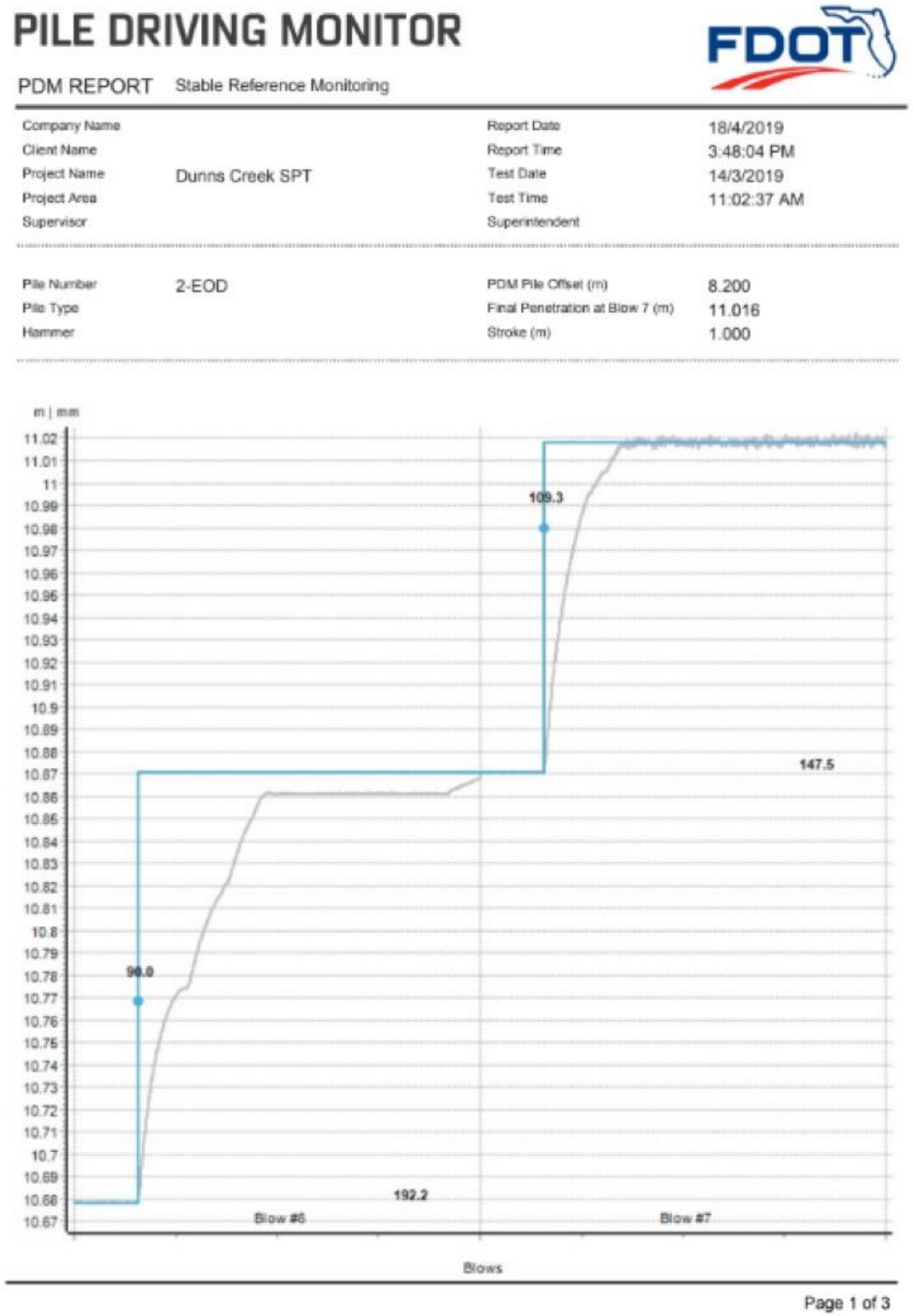
PDM REPORT Stable Reference Monitoring

Company Name		Report Date	10/4/2019
Client Name		Report Time	1:16:07 PM
Project Name	Dunns Creek SPT	Test Date	14/3/2019
Project Area		Test Time	11:33:38 AM
Supervisor		Superintendent	

Pile Number	3-EOD	PDM Pile Offset (m)	8.200
Pile Type		Final Penetration at Blow 6 (m)	12.404
Hammer		Stroke (m)	1.000



- Blue Dot and DMX are Not the Same Location
  - *Samples within Rebound Soil!*
  - *Possible Time-Dependent Soil Response*
  - *Possible Secondary Hammer Hit*



PILE DRIVING MONITOR

FDOT

PDM REPORT Stable Reference Monitoring

Company Name		Report Date	18/4/2019
Client Name		Report Time	3:48:04 PM
Project Name	Dunns Creek SPT	Test Date	14/3/2019
Project Area		Test Time	11:02:37 AM
Supervisor		Superintendent	

Pile Number	2-EOD	PDM Pile Offset (m)	8.200
Pile Type		Final Penetration at Blow 7 (m)	11.016
Hammer		Stroke (m)	1.000

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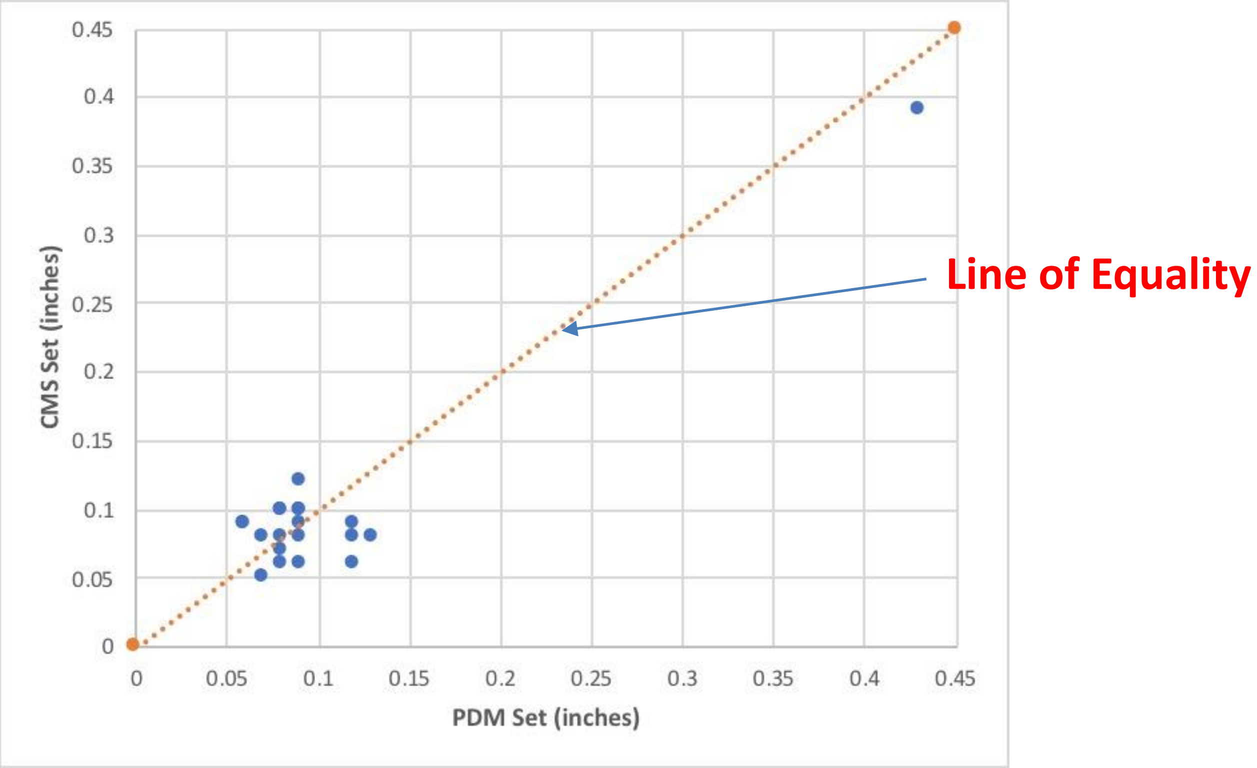
Dunns Creek (cont.)

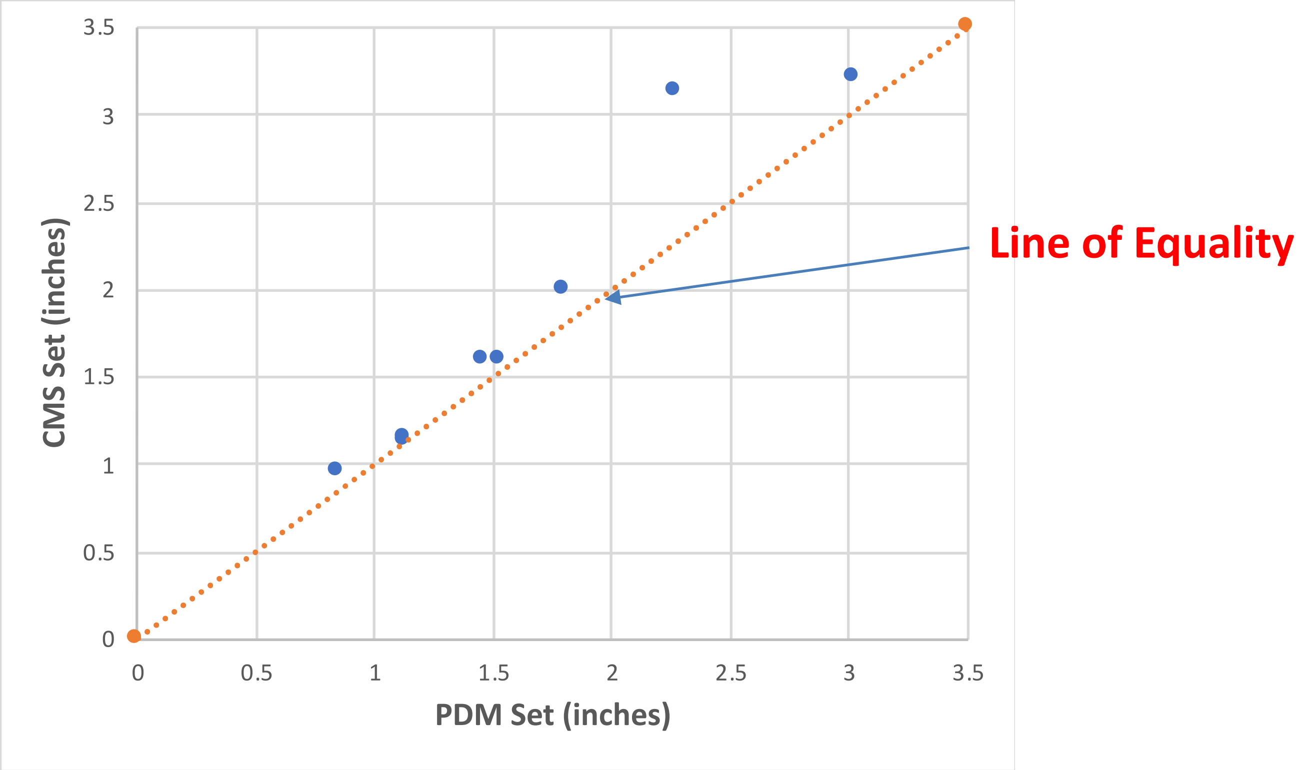
- *Possible Time-Dependent Soil Response*
- *Possible Secondary SPT Hammer Hit*

Test Pile Set Comparisons CMS vs PDM



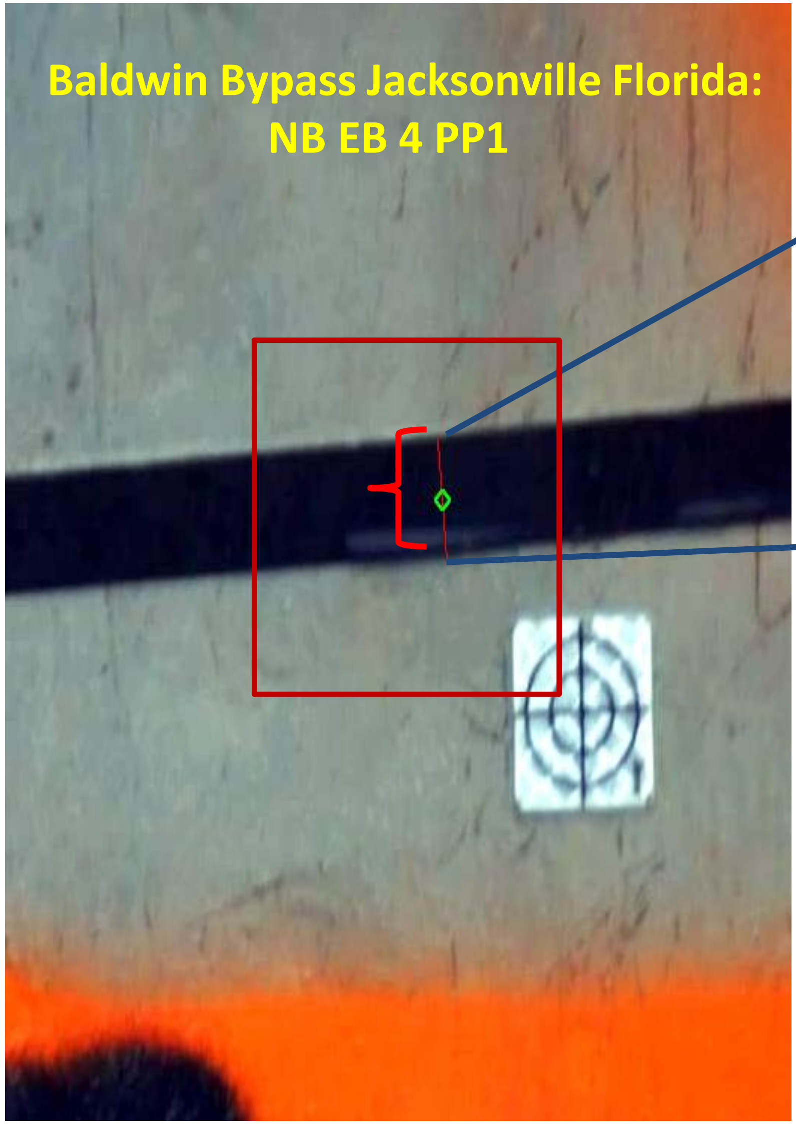
- *20 Data Points in about 0.2 feet of driving from Dunns Creek*
  - *Data are reasonably clustered around red line*
  - *Matching data points between systems complex (i.e. PDM Active Zone and Camera One Location on Pile)*
  - *Note # of plottable points from PDM testing is related to the # of blows per foot*
    - *i.e. 6 blows per foot would yield 6 points in 12 inches*
    - *Note the limit of PDM active testing zone was often about 18-inches*

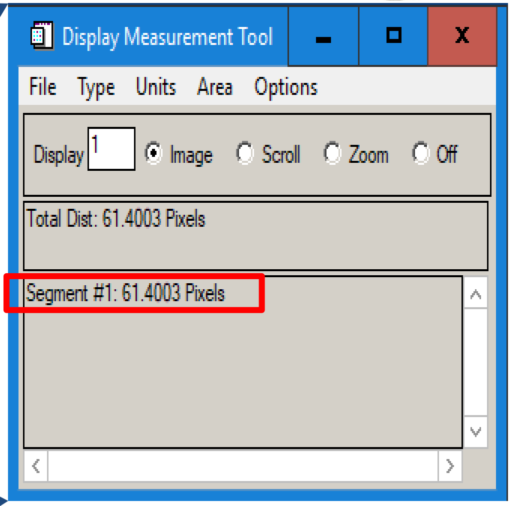
SPT Testing Set Comparisons CMS vs PDM



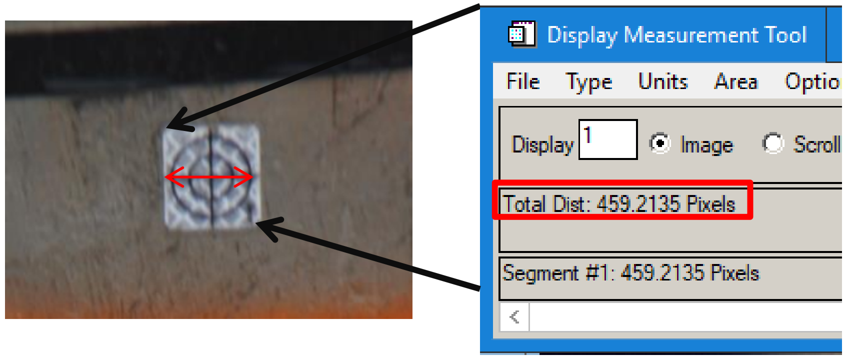
- *8 Data Points from Dunns Creek*
- *Matching data points worked well with SPT testing intervals*

CMS Overview



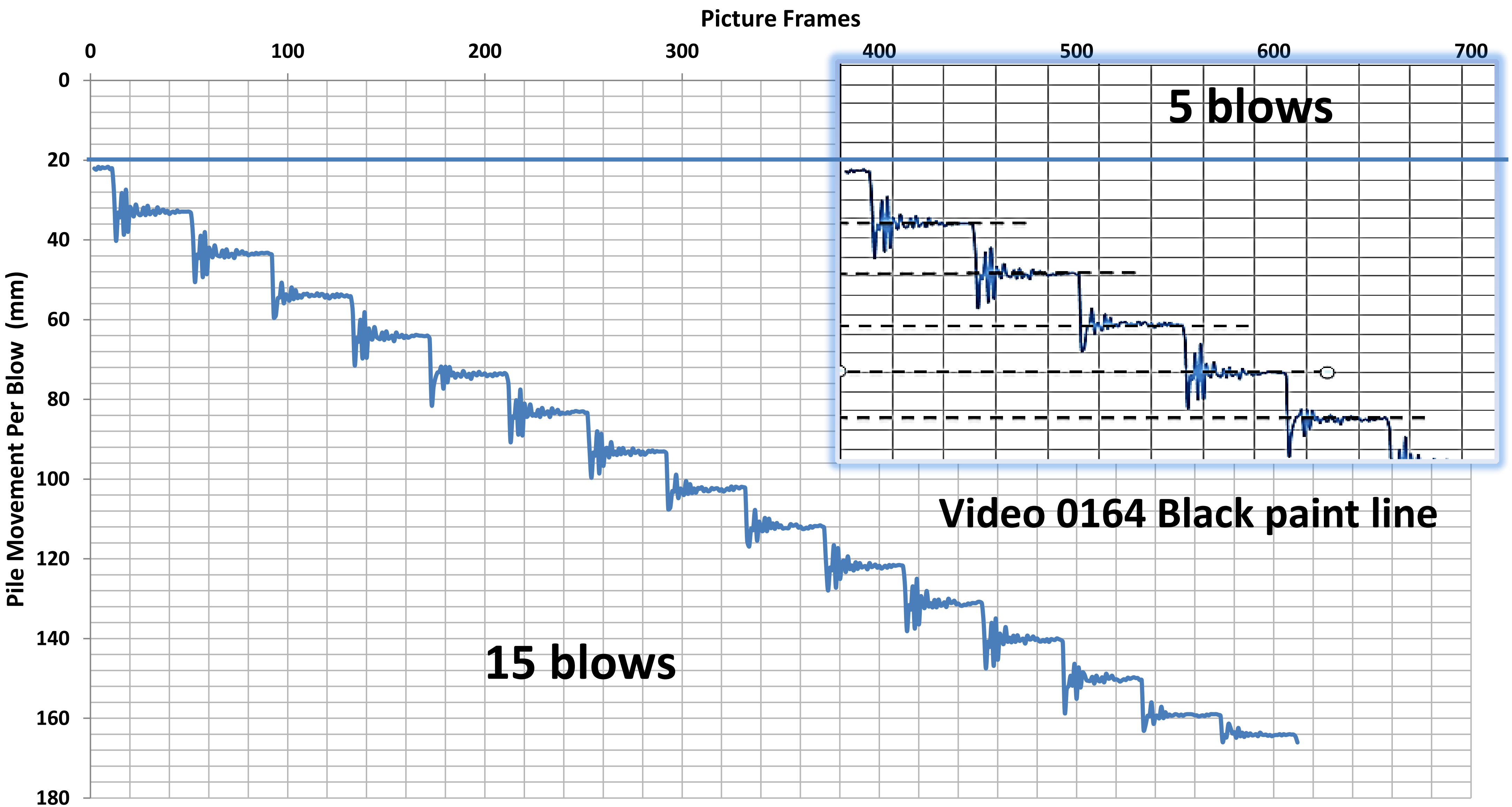


- Width of the **black tape** = 12 mm (Lupe measured)
- 61 pixels vertically within **black tape**
- Width per **pixel** = 12/61 = 0.197 mm (0.00774 inch)
- Error range = +/- **3 pixels** = +/- 0.591 mm (+/- 0.023 inch)

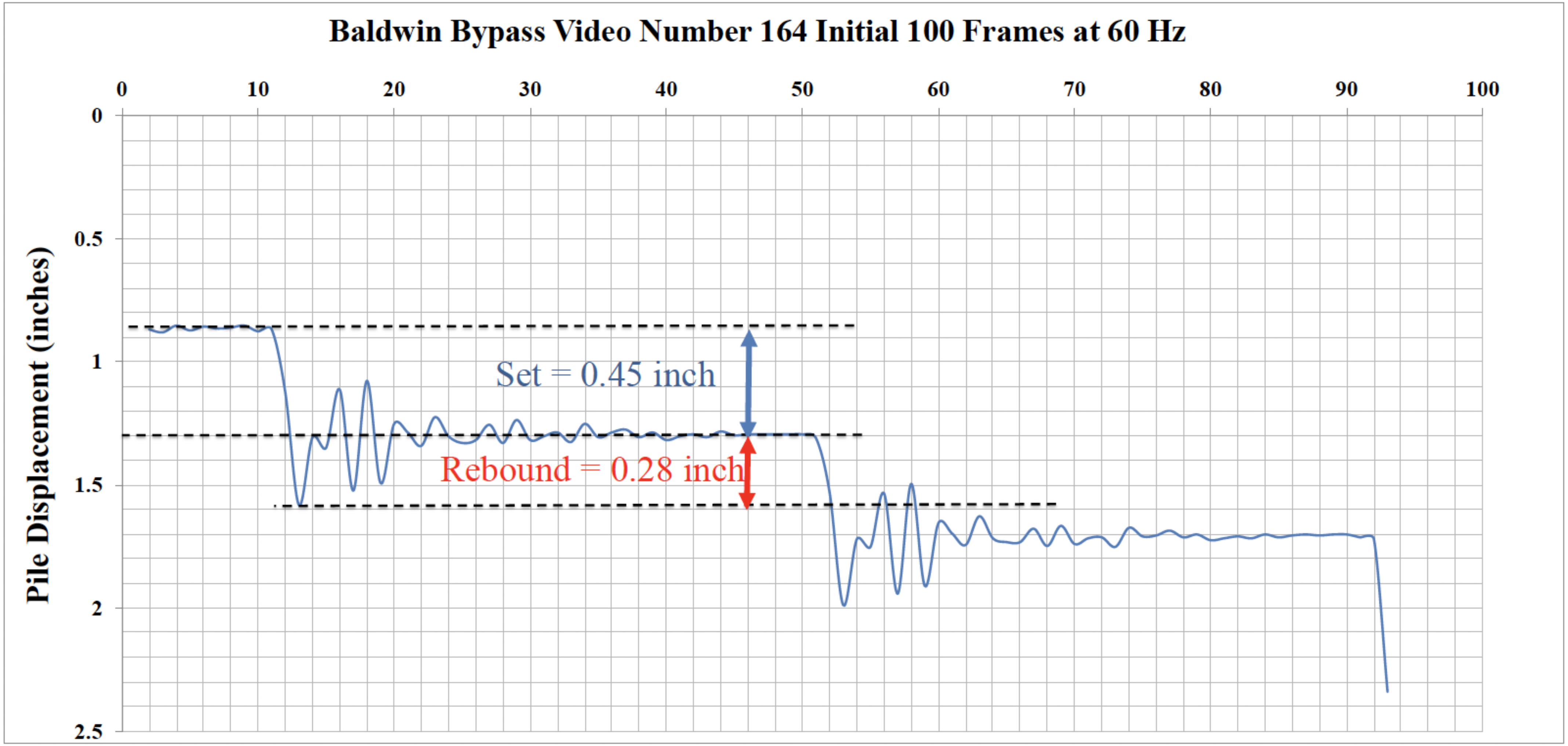


Horizontal distance : 459.2 pixel * 0.197 mm / pixel = 90.4 mm

Baldwin Bypass Test Pile Movement vs Frame #: black spray paint line



60 Hz Data from Marine Environmental Optics Lab, FIT



60 Hz Data from Marine Environmental Optics Lab, FIT

CMS Max Displacement and Rebound from Baldwin Bypass video: 0164

of Pixels

Hammer Blows	Width per pixel
12	0.197 mm

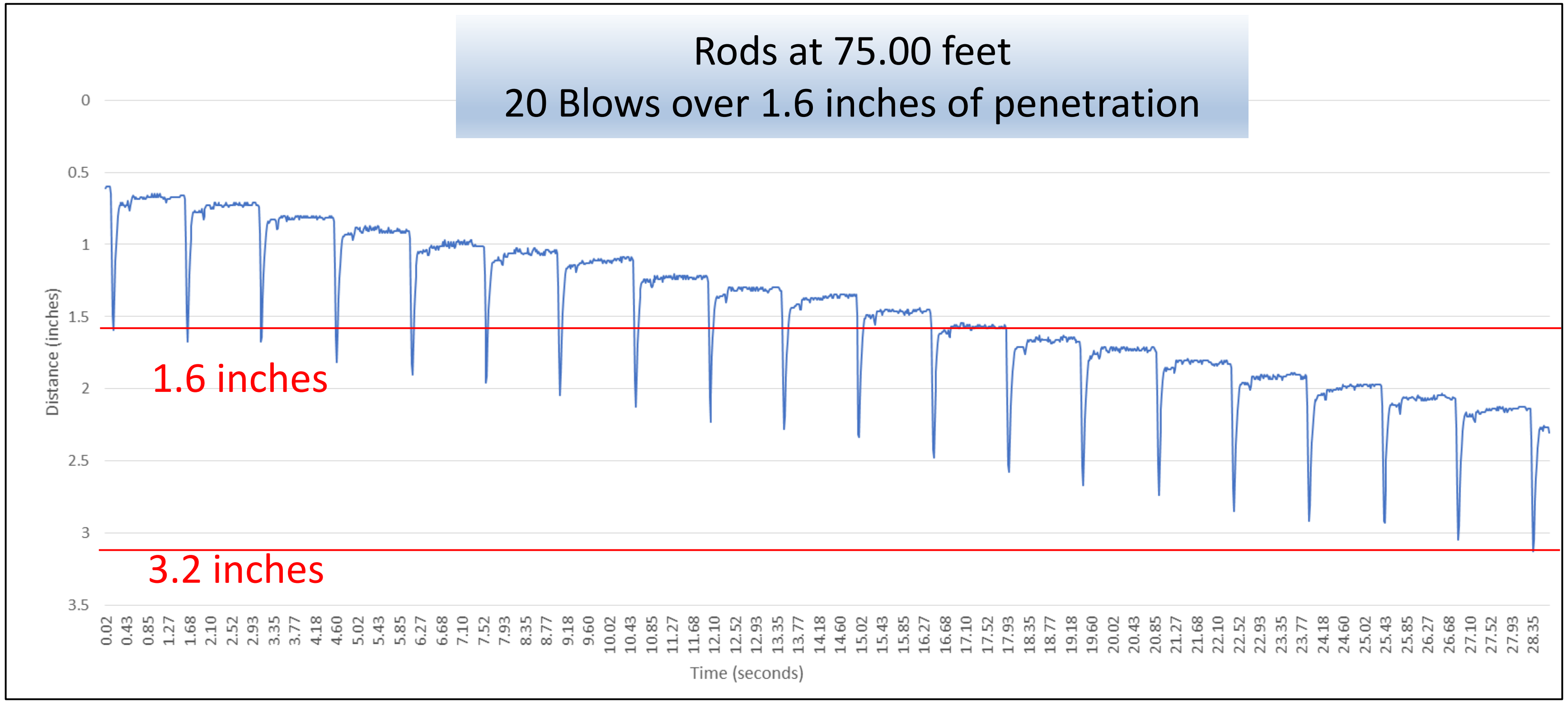
Hammer Blow	DMAX (pixels)	Rebound (pixels)
1	88	37
2	82	33
3	93	40
4	93	43
5	87	42
6	87	37
7	79	29
8	75	30
9	85	35
10	88	38
11	85	40
12	100	45
Mean	**87**	**37**
Std Deviation	**22**	**17**
Std Error	**6**	**5**

Video 0164 from Black Spray Paint Line

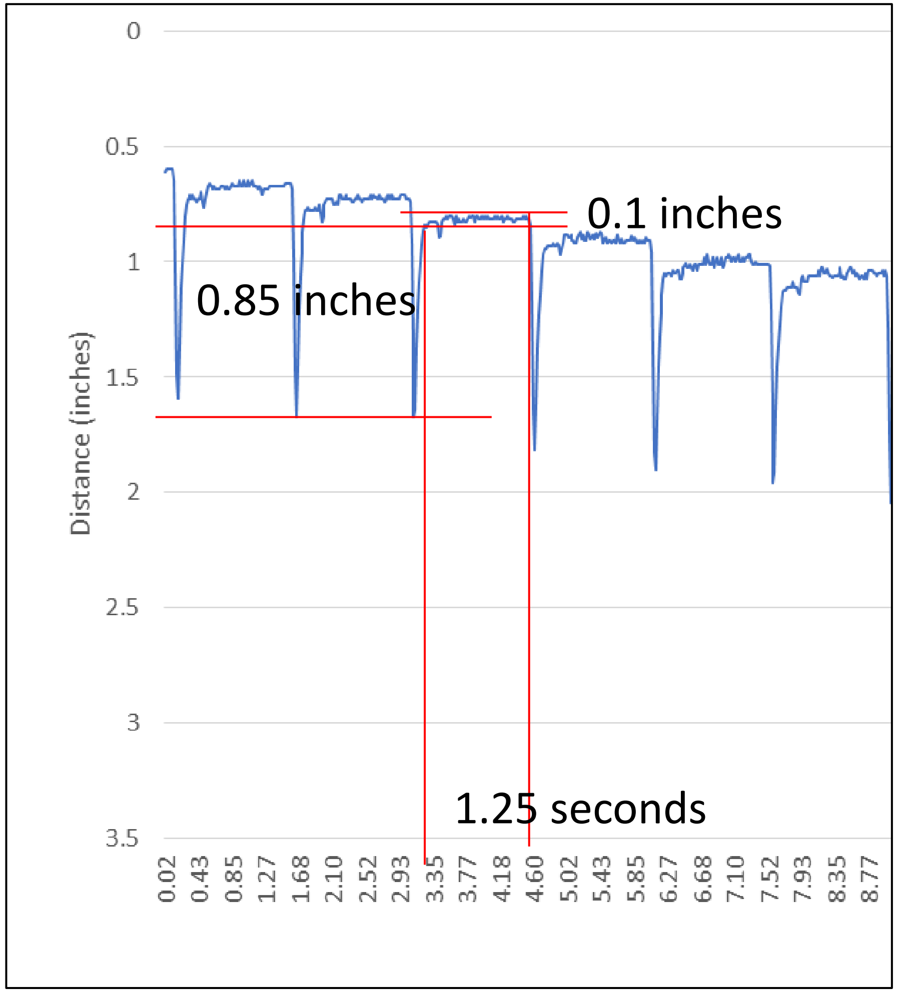
mm

Hammer Blow	DMAX (mm)	Rebound (mm)
1	17.336	7.289
2	16.154	6.501
3	18.321	7.88
4	18.321	8.471
5	17.139	8.274
6	17.139	7.289
7	15.563	5.713
8	14.775	5.91
9	16.745	6.895
10	17.336	7.486
11	16.745	7.88
12	19.7	8.865
Mean	**17.106**	**7.371**
Std Deviation	**4.327**	**3.265**
Std Error	**1.249**	**0.943**

60 Hz Video Plot from Dunns Creek SPT Rod Movements



Dunns Creek SPT Rod Movements: 60 Hz Video



0.1 inch of time-dependent movement following linear movement of 0.85 inch about 1.25 seconds

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Damping Coefficient Sensitivity Analysis of High Rebound Soils in Florida

Ms. Aline Franqui

Master's of Science - Civil Engineering

Soil Type at Pile Toe	Case Damping Coefficients Range (1975)	Updated Case Damping Coefficients Range (1996)
Clean Sand	0.05 to 0.20	0.10 to 0.15
Silty Sand, Sandy Silt	**0.15 to 0.30**	**0.15 to 0.25**
Silt	0.20 to 0.45	0.25 to 0.40
Silty Clay, Clayey Silt	0.40 to 0.70	0.40 to 0.70
Clay	0.60 to 1.10	0.70 or higher

BDV 28 977-01 Sites Evaluated

Ramsey Branch - Walton County

I-10 & Chaffee Road - Duval County

SR 417 & International - Seminole County

I-4 & US-192 - Osceola County

Saint John's Heritage Parkway - Brevard County

**Osceola Parkway - Osceola County*

*Only CT data.
PDA data is missing

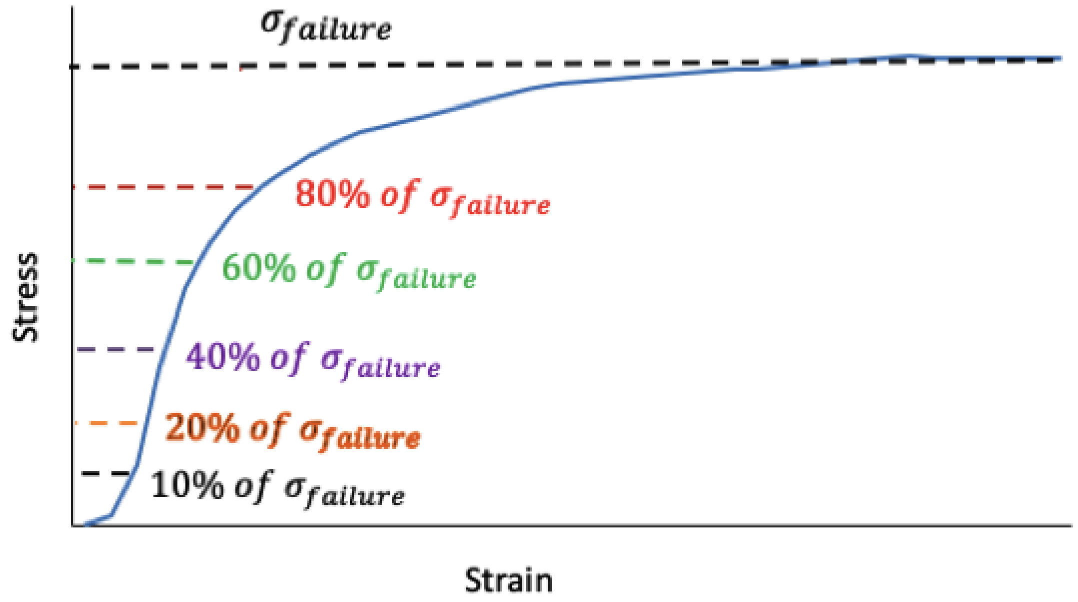
Rebound Levels from PDA data

Site	% Depths with Rebound Equal or Greater than		
	0.25 in	0.50 in	1.00 in
Ramsey Branch	95%	67%	29%
I10 & Chaffee	89%	35%	18%
I4 - 192	80%	37%	0%
Heritage Parkway	52%	8%	0%
I4 & 417	45%	1%	0%

Rebound = DMX (2nd derivative) – Set (visual blows/foot)

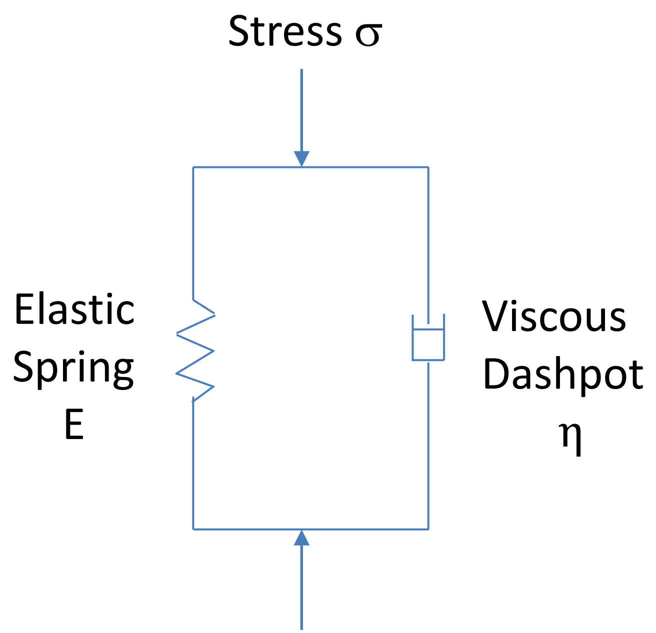
Cyclic Triaxial Testing

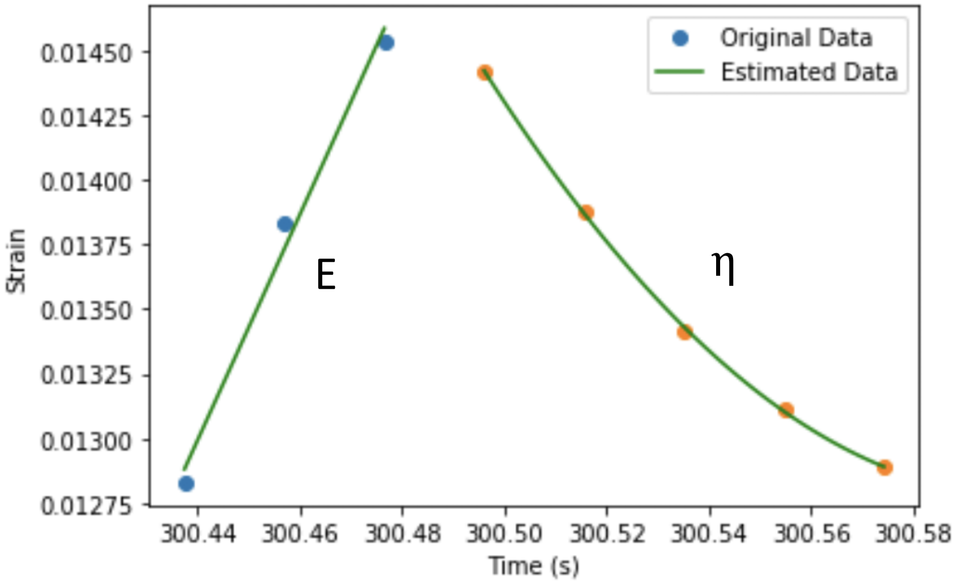
- Shelby Tubes from Rebound Zones
- Effective Stress Estimated
- CU Triaxial Tests Performed
- CT Tests run with 1000 cycles each at 10, 20, 40, 60, & 80 % of Failure



CT Damping Data (σ-t)

Complex Python® computer coding used to analyze, over 600,000 data points <u>per test</u> and there were 42 tests or over 25 millions data points





CT Damping Data (σ-t)

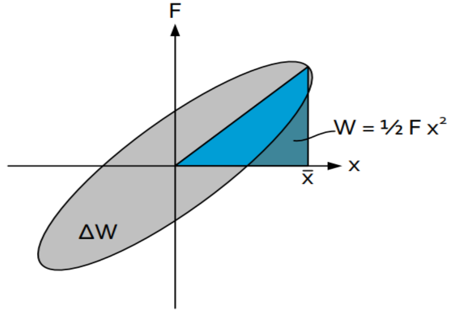
η_{ave} Range	Data Points	% Total	% Cumulative
0.001 - 0.01	5	1.1%	1.1%
0.01 - 0.1	106	23.6%	24.7%
0.1 - 1	214	47.6%	72.2%
1 - 10	84	18.7%	90.9%
10 - 100	19	4.2%	95.1%
100 - 1,000	13	2.9%	98.0%
1,000 - 10,000	3	0.7%	98.7%
10,000 - 100,000	4	0.9%	99.6%
100,000 - 1,000,000	1	0.2%	99.8%
1,000,000 - 10,000,000	0	0.0%	99.8%
10,000,000 - 100,000,000	1	0.2%	100.0%
Total	450	100%	

72% of the η_{ave} values obtained between 0 and 1 psi-sec

Case's Updated damping range for silty sands: 0.15 – 0.25 (dimensionless)

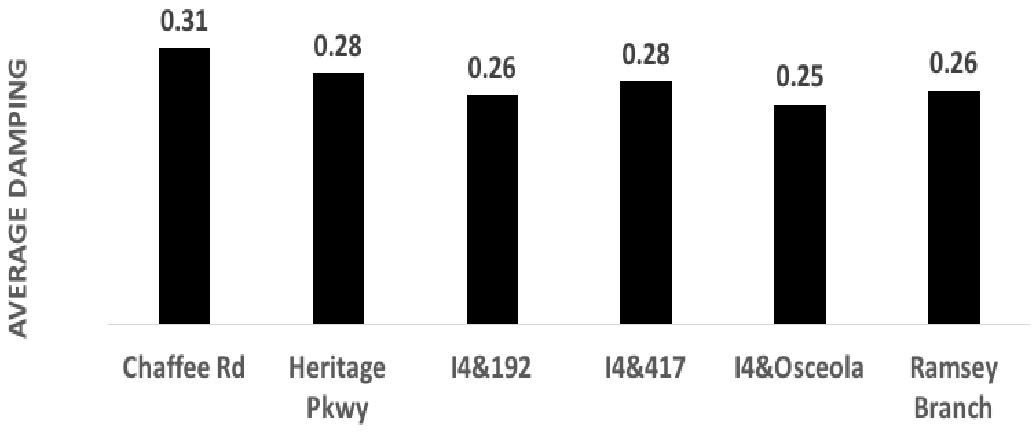
Additional Evaluations

A) Hysteresis Loop



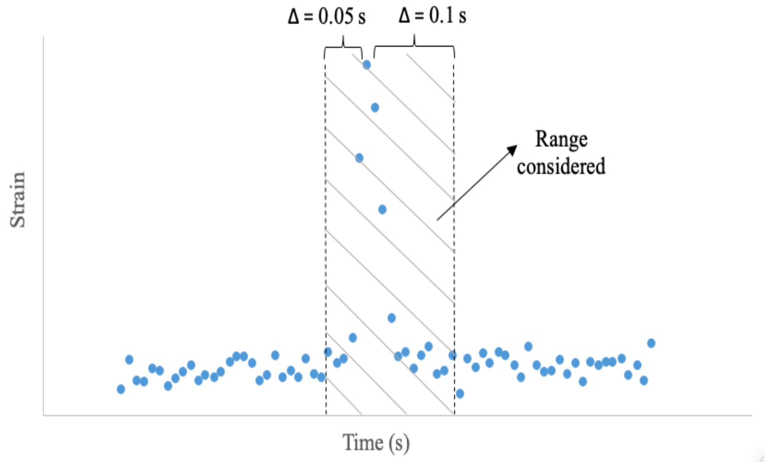
$$\eta_{eq}(dimensionless) = \frac{\Delta W}{4\pi W}$$

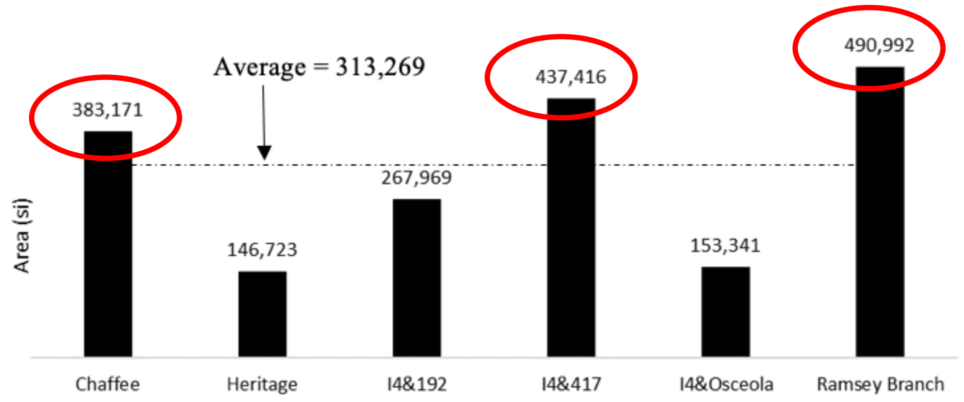
ΔW = Energy loss during a cycle



Silty Sand, Sandy Silt	0.15 to 0.30	0.15 to 0.25

B) Area Under Strain vs. Time Curve

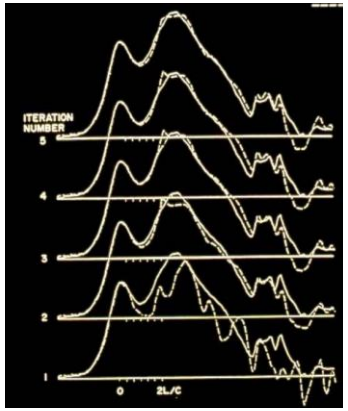




C) CAPWAP signal matching analysis on 12 piles @ 5 Sites

Evaluation criteria:

- *Blow counts: > 60 blows/foot*
- *Rebound > 0.45 inches*
- *Side friction < 110 kips*



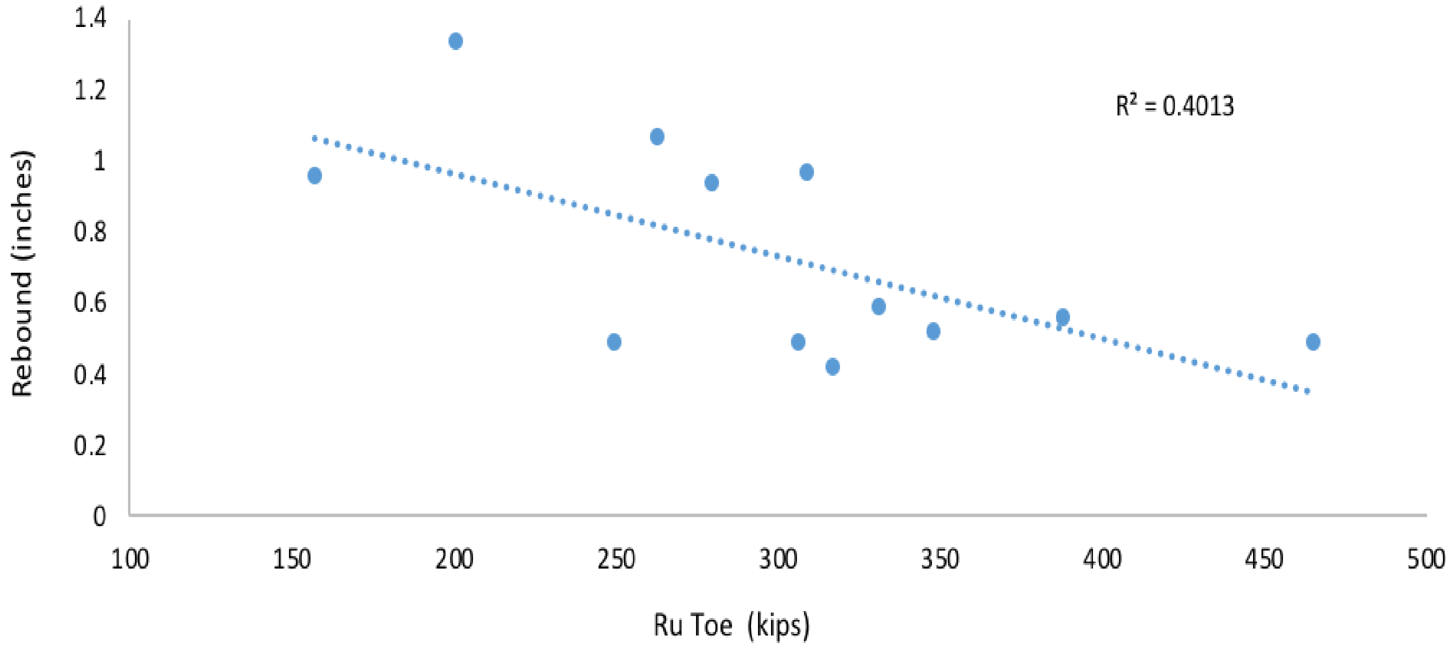
Signal matching:
Wave measured
versus
Wave computed

Hammer Blows Used

Site	Test Pile	BN	Elevation (ft)	Blows/ft	Rebound (in)	SFT (kips)
Chaffee Rd	PR2PL9	354	-9.15	75	0.48	77
Heritage Pkwy	EB1P1	279	-28.01	32	0.58	24
	EB5P1	450	-29.95	71	0.48	19
	IB3P1	280	-26.82	46	0.55	17
	IB4P10	158	-27.63	39	0.51	7
I4 & 192	P8P4	2260	17.71	100	0.93	76
417 & International	EB1P14	322	51.22	38	0.41	29
	EB2P5	1479	3.85	75	0.48	104
Ramsey Branch	EB1P1	654	-63.37	133	0.96	82
	EB1P3	600	-63.81	150	1.06	0
	EB4P5	1322	-60.61	171	0.95	51
	EB5P2	480	-51.61	109	1.33	0
Average				87	0.73	41
Standard Deviation				44	0.29	34

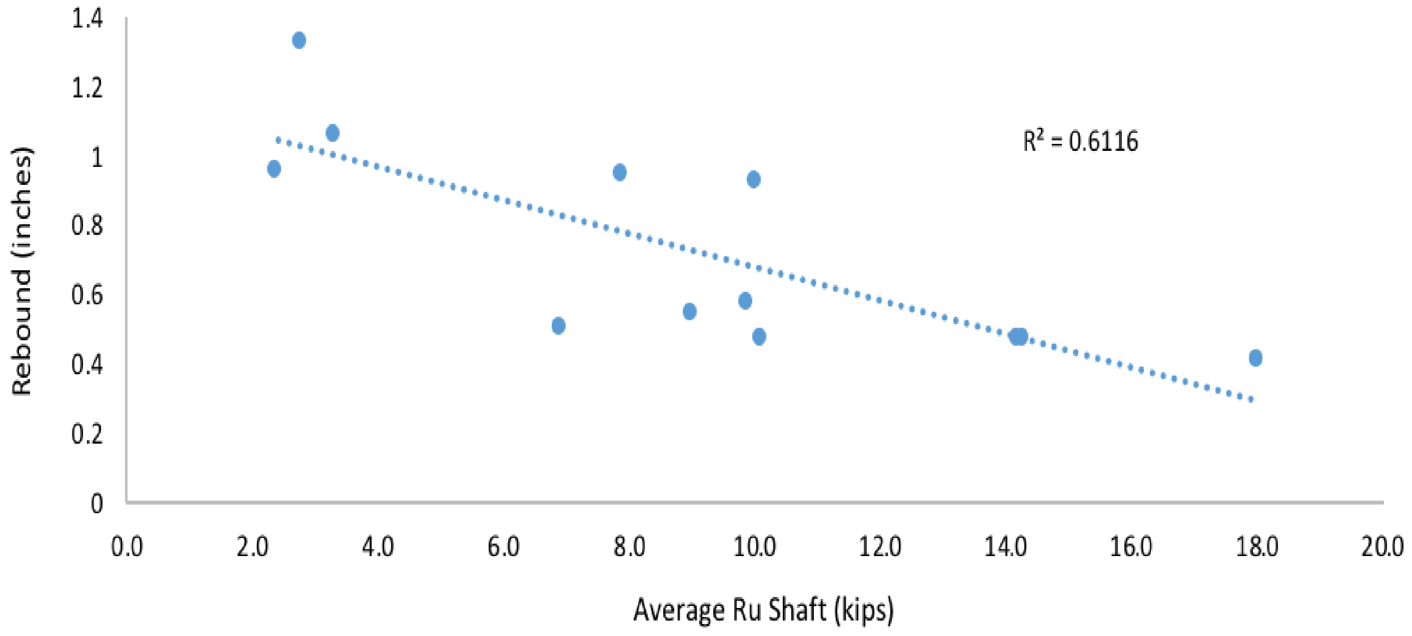
CAPWAP Findings

Rebound versus CAPWAP Ultimate Toe Resistance (Ru)



Maybe toe resistance has more of an effect on rebound than previously understood

Rebound vs CAPWAP Ultimate Shaft Resistance



More shaft resistance should decrease rebound

CT Damping Conclusions

Cyclic Triaxial Damping Evaluations

- *Measured stress-time damping coefficients somewhat match Case values but not units*
- *Dimensionless hysteresis loop values match Case's dimensionless values*
- *Area under the strain versus time curve might help indicate PDA rebound*

PDA Rebound & CAPWAP Signal Matching

- *Blow count, rebound and side friction criteria were successfully used to study rebound*
- *Higher shaft resistance decreases rebound*
- *Higher toe resistance decreases rebound*

PDM Conclusions

- PDM pile Set is comparable to CMS Set
- PDM pile Set is comparable to Inspector sets
- PDM pile Rebound roughly comparable to PDA Rebound
- PDM pile comparisons are limited to active zone
- PDM SPT rod movements successfully produced,
  - Viscous behavior may have occurred during SPT tests
  - Time-dependent soil responses or SPT hammer bounces occurred
- Concerns were identified with PDM equipment:
  - Heavy Rain prevented it from working
  - Limited time to input the required information for new testing zones

CMS Conclusions

- The CMS system produced reliable pile and SPT rod movement data at every site and climate condition encountered at frame rates of 60 Hz.
- It works best on piles when a black line is sprayed onto the pile and on SPT rods when white chalk lines are used
- The CMS system is relatively inexpensive and most likely comparable in cost to the PDM equipment, plus multiple cameras could be used, providing backup at all times.
- Currently the signals recorded in the field must be analyzed in the office, an easily addressed limitation.

Recommendations

- FDOT's PDM should be used at a variety of sites throughout Florida to help clarify when it should be used.
- The CMS system must be improved to produce real-time displacements on a rugged field laptop. The steps required to complete this task include shortening the duration of the videos and making the camera and laptop a single system.
- PDM most suitable for set-check type uses
- PDM during driving would require inspector to stop process
- PDM could be used following hammer cushion replacement

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Qualitative Benefits

- When PDM and CMS results become readily available, inspectors can be more confident in their work and as a result be more efficient, and thereby saving time and ultimately taxpayers money.

Quantitative Benefits

- The comparisons between the PDA, PDM and CMS pile movements indicate that CMS based measurements are the most reliable and that the PDM may be most suitable for monitoring pile driving when a limited number of hammer blows are being anticipated (such as when set-checks are performed).
- Providing engineers and field inspectors better knowledge of the pile driving movements will improve the installation and approval process.
- Both PDM and CMS equipment may be useful to record time-dependent or visco-elastic SPT rod movements in rebound type soils, during the design phase invesitgations

Closing Slide: Questions ?

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