Quantifying Pile Rebound with Detection Systems Best Suited for Florida Soils

Task Work Order BDV28 Two 977-07

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Today's Presentation

- Evaluate two new pile movement measuring systems
  - Inopiles PDM LASER deflection-measuring system
  - FIT camera measurement system (CMS)
- Evaluate Damping from
  - Cyclic Triaxial (CT) Viscous Response
  - CAPWAP Signal Matching

New Technologies

- Inopiles PDM Measuring System
- FIT High Speed Cameras

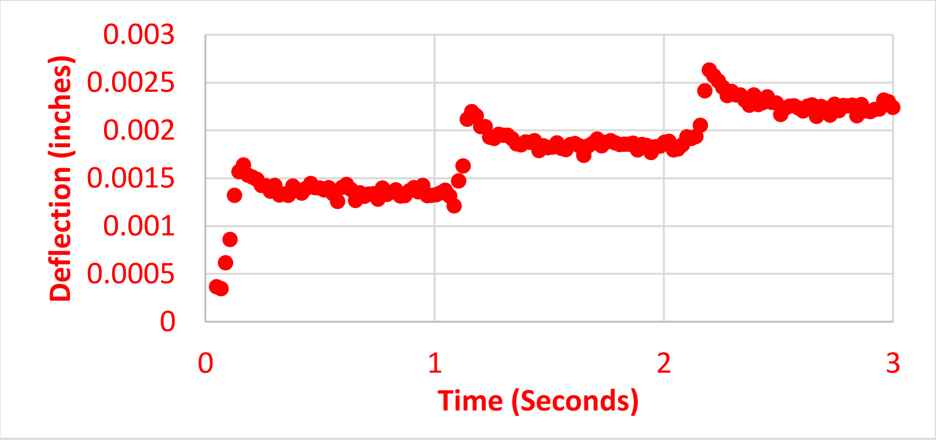
Bobby

Aline

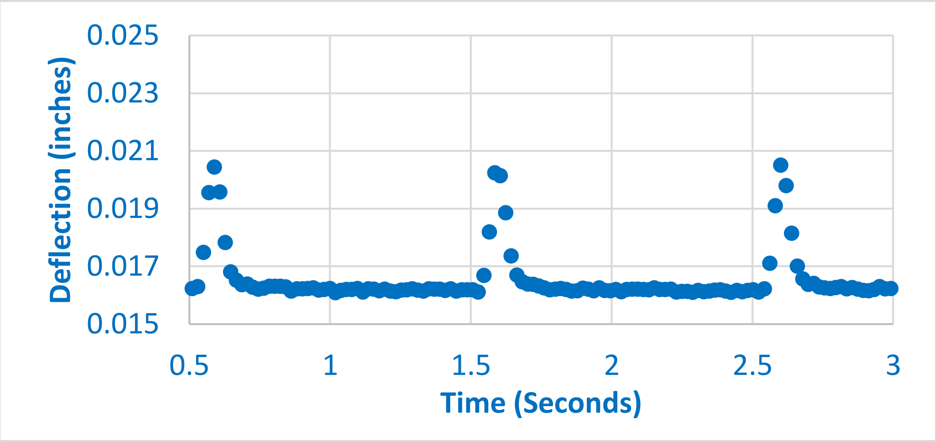
Chuck

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

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

PDM Evaluations

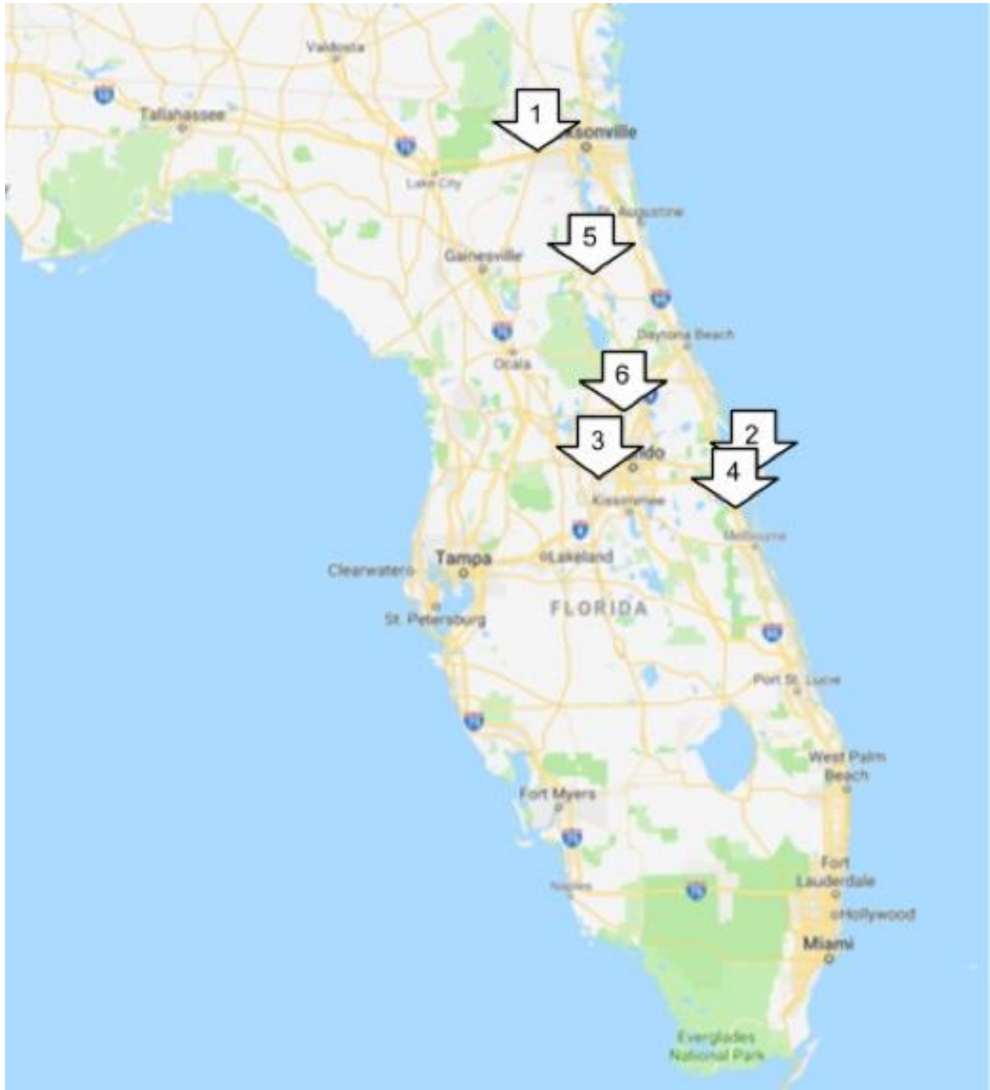
- Preliminary Lab and Field Testing
  - *Lab Testing using Metal Yard Stick Taped into Loose Sand*
  - *Field Testing on and near campus*
- Full-Scale Field Testing
  - *PDA Instrumented Piles- 6 sites*
  - *SPT Borings- 2 sites 3 locations*

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

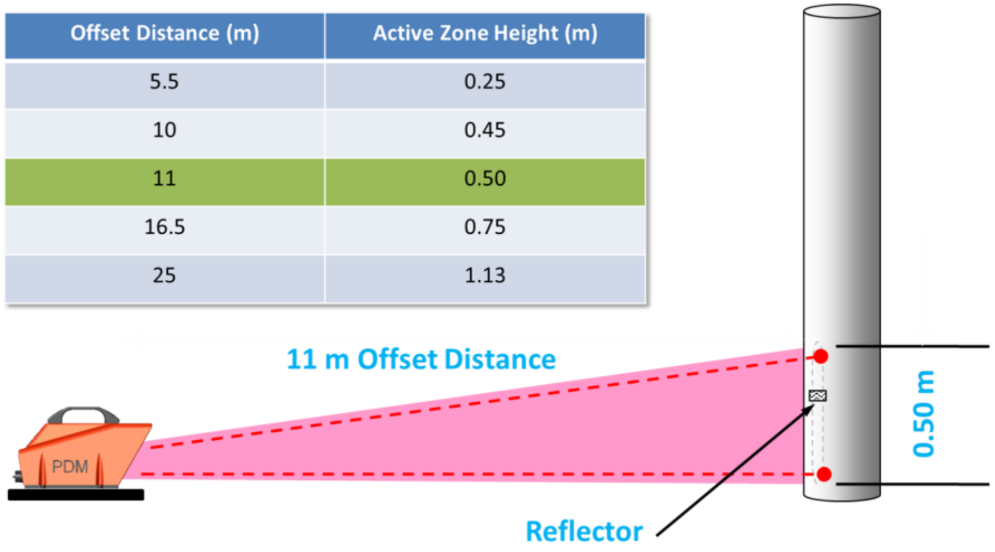
Project # and Name	Rebound	Pile or *SPT*	PDM Data	Camera Data	PDA Data
1 Baldwin Bypass	**Yes**	**Pile**	**No**	**Yes**	**Yes**
2 Port Canaveral	**No**	**Pile**	**Yes**	**N/A**	**N/A**
3 Reedy Creek	**No**	**Pile**	**Yes**	**Yes**	**Yes**
4 Ellis Overpass	**No**	**Pile**	**Yes**	**Yes**	**Yes**
5 Dunns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



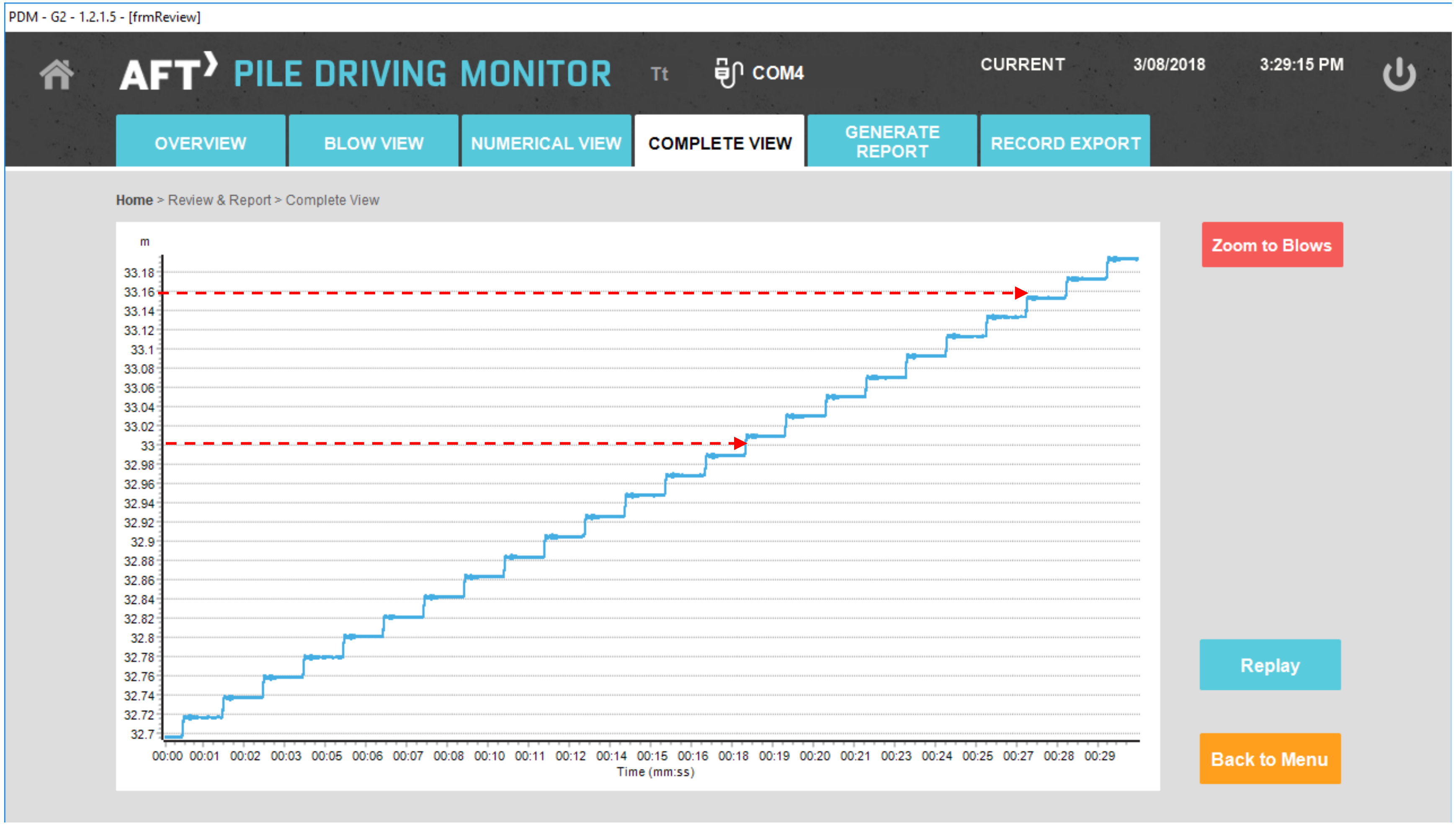
Inopiles PMD-Basic Usage Limitations

- Only about 30-inches of data can be recorded
  - *Angle is 2.6 ^{0} from horizontal*
  - *Reflective Tape must stay within Zone*
- Difficult to record data during entire driving process
  - *Each testing sequence requires new input data-Express Mode*
  - *Reflective Tape Quality May Affect Results*

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

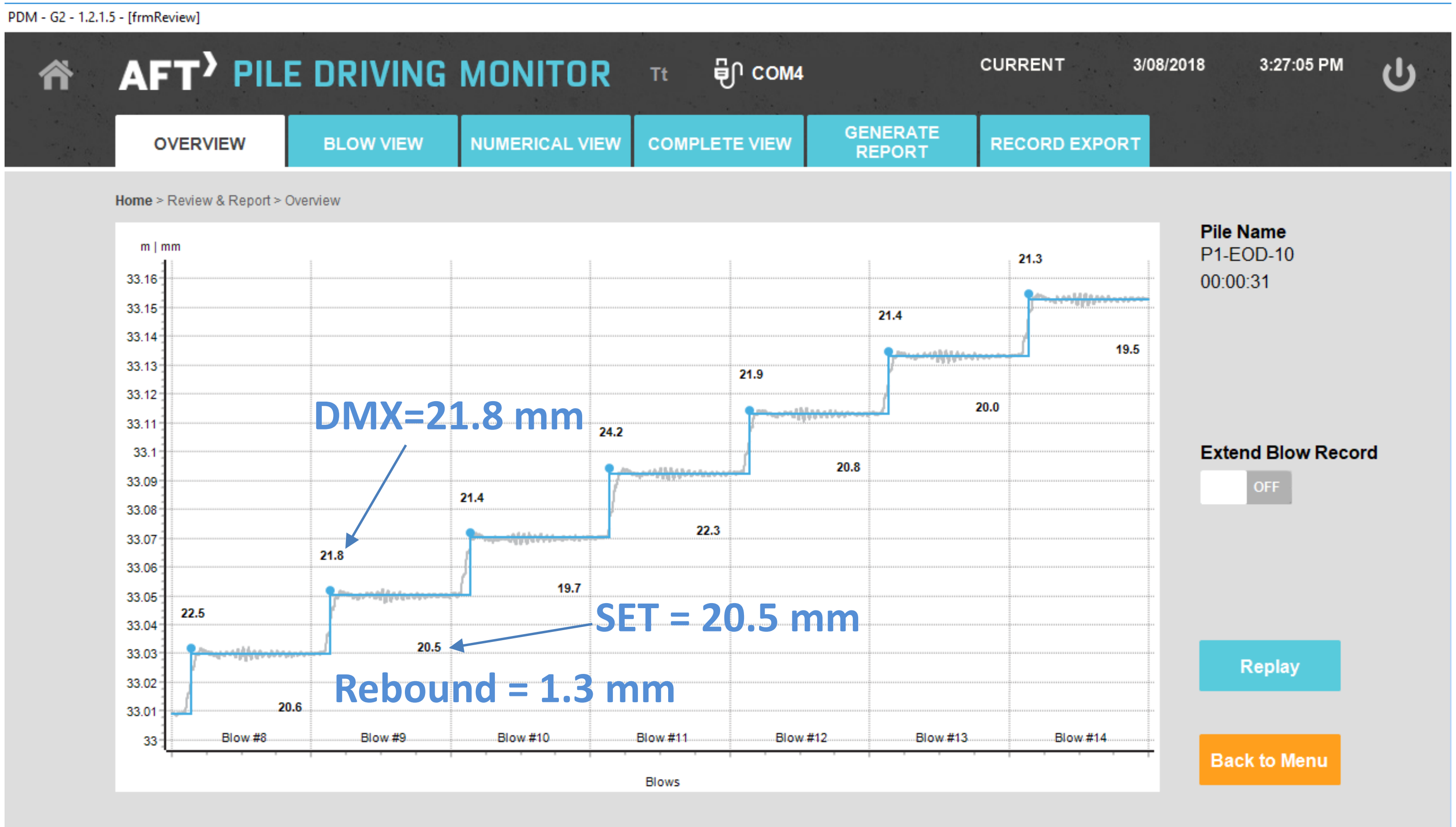


Reedy Creek Test Pile PDM Data Near 90 ‘



PDM Software: Displacement vs. Time

Zoom View: 20 mm: blue vs gray



Blue maximum displacement = Gray continuous displacement

Blows 8 - 14

PDM Output
1.5 mm rebound

Blow	StartTime	Penetration (m)	Set (mm)	Rebound (mm)	Velocity (m/s)
8	16:00:15	33.334	20.6	1.9	1.732
9	16:00:17	33.354	20.5	1.3	1.645
10	16:00:18	33.374	19.7	1.6	1.581
11	16:00:18	33.396	22.3	1.9	1.651
12	16:00:20	33.417	20.8	1.1	1.506
13	16:00:21	33.437	20	1.5	1.68
14	16:00:22	33.457	19.5	1.8	1.553
Average			20.5	1.6	1.62
Max Variation			2.8	0.8	0.23

PDM eliminates inspectors average set versus PDA DFN

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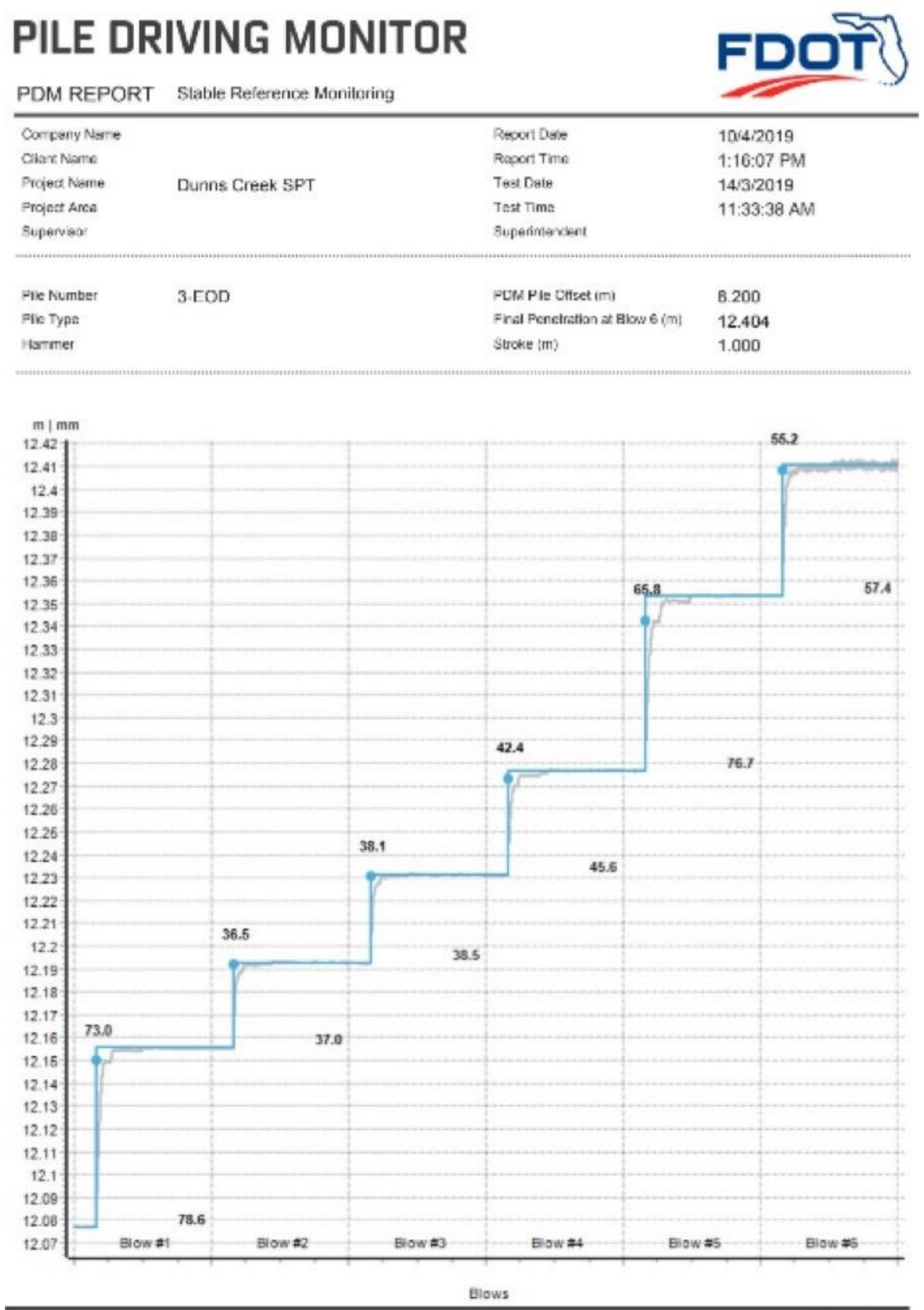
Dunns Creek PDM on SPT

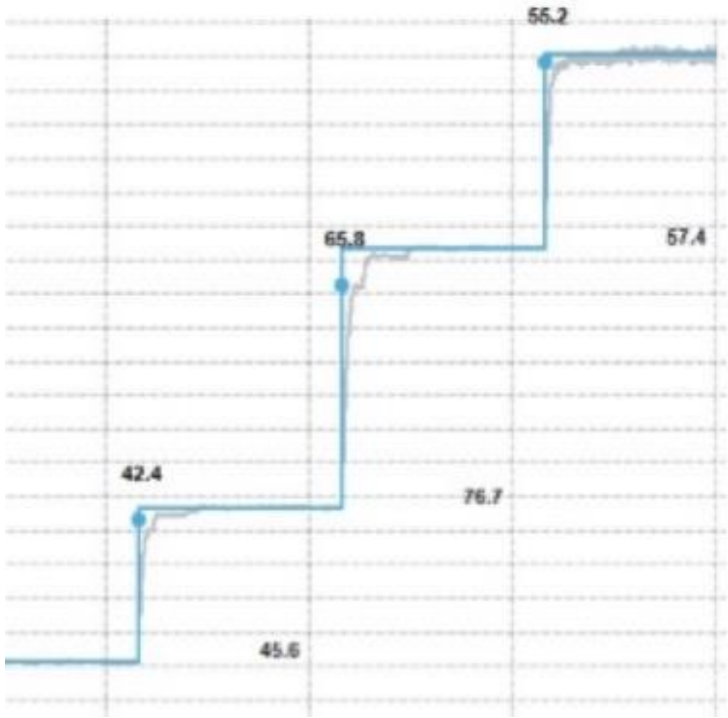

PILE DRIVING MONITOR

FDOT

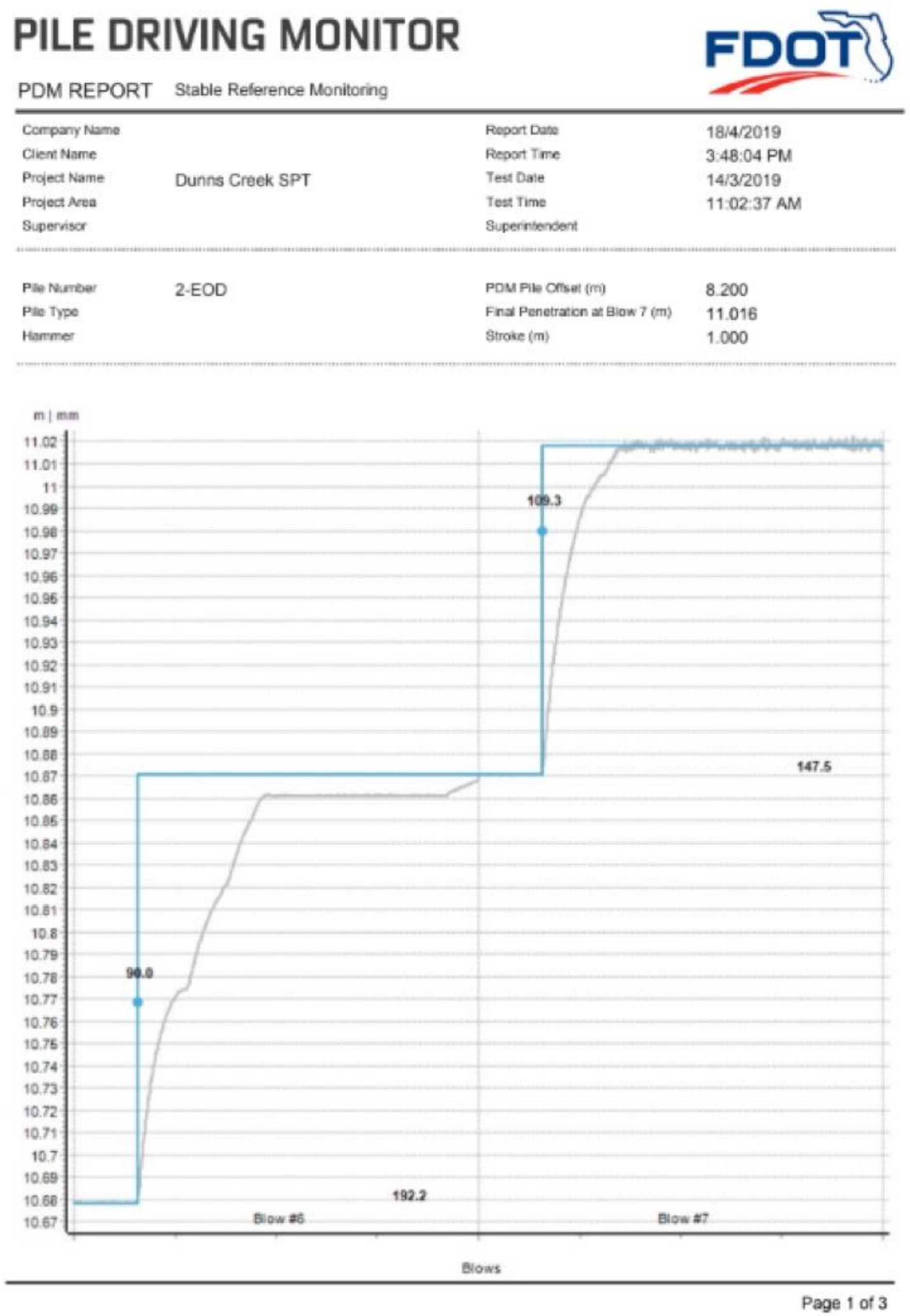
PDM REPORT Stable Reference Monitoring

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
  - *Possible Time-Dependent Soil Response*
  - *Possible Secondary Hammer Hit*
  - *Samples within Rebound Soil!*


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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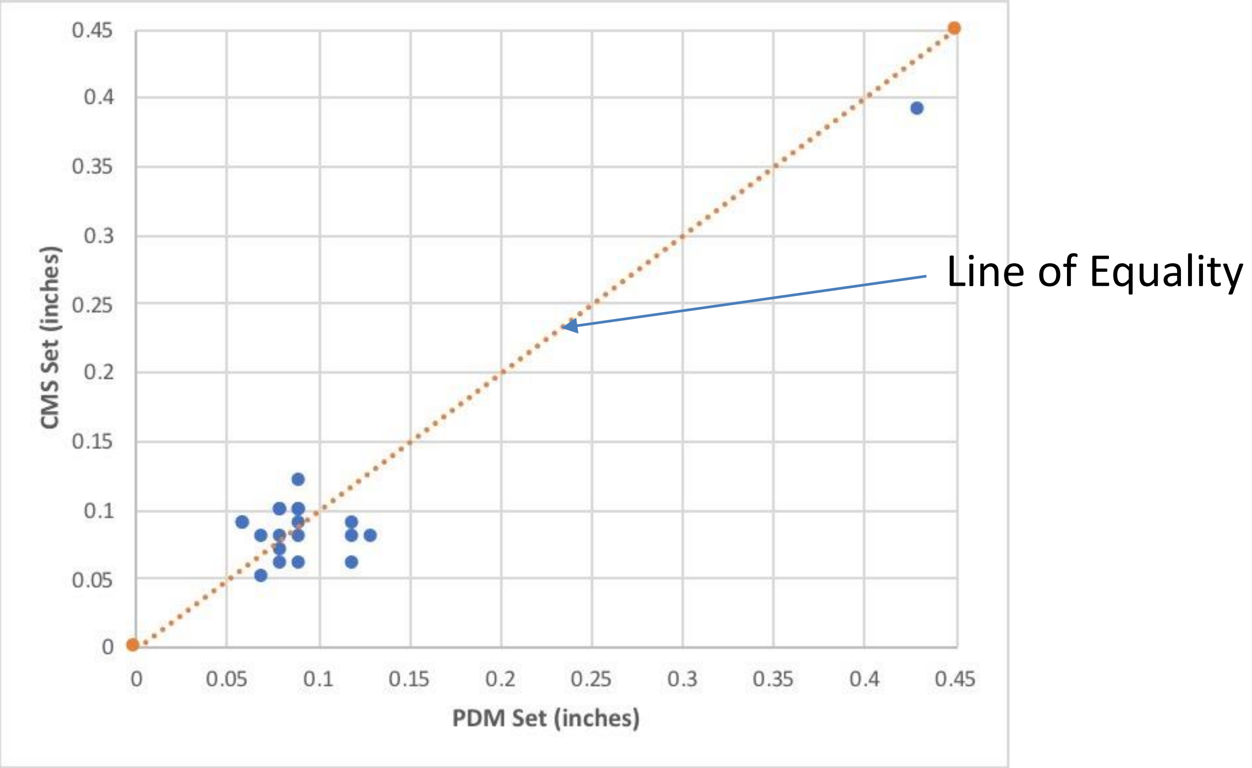
Dunns Creek (cont.)

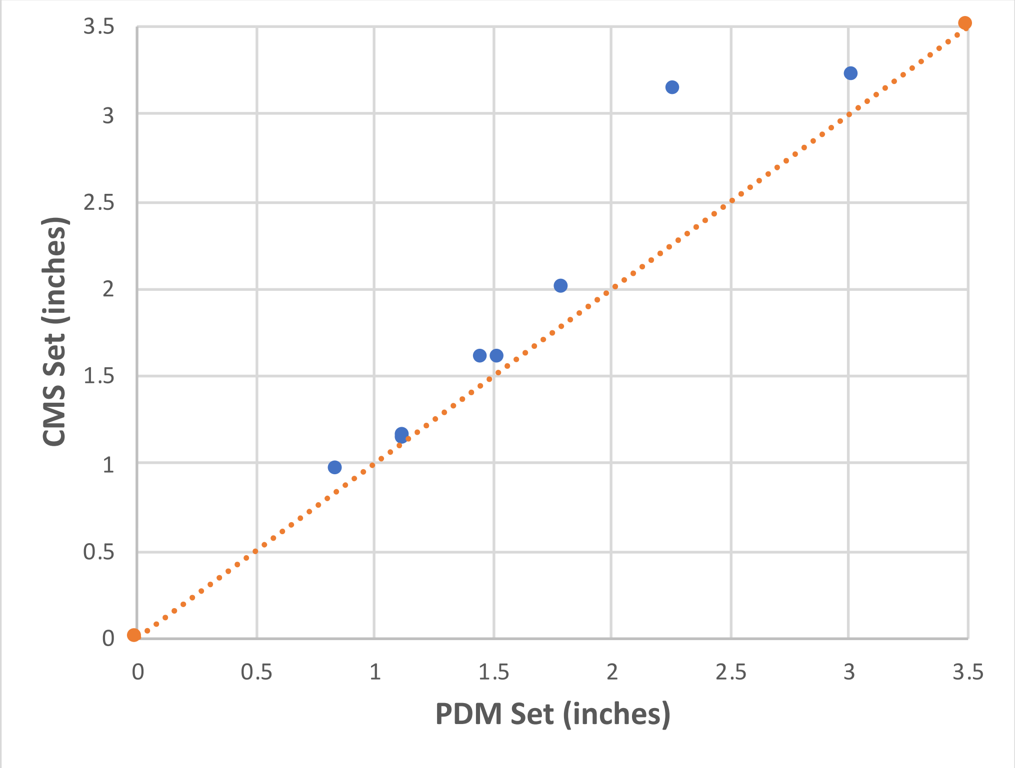
- *Possible Secondary SPT Hammer Hit*

CMS vs PDM Set from Pile testing



- *20 Data Points in about 0.2 feet of driving from Dunns Creek*
  - *Data are reasonably clustered around red line*
  - *Matching data points complex*
  - *Note # of points per PDM test sequence related to Blows per foot*
    - *i.e. 6 blows per foot would yield 6 points in 12 inches and reach limits of PDM testing region*

CMS vs PDM Set from SPT testing



- Red dotted line is line of equality
  - *8 Data Points from Dunns Creek*
  - *Wekiva Parkway data to be added*
  - *Matching data points worked fairly well*

PDM Summaries

Summary of PDM data for Piles

Tests	% Of Useable Test Data	Average % Of Active Zone
PDM-Pile	55	52
PDM-SPT	88	68

Highlights concerns about using PDM throughout driving

CMS - PDM SET/Rebound for Piles and SPT

Average % Difference In Set From PDM For Piles	Average % Difference In Rebound From PDM For Piles	Average % Difference In Set From PDM For SPT	Average % Difference In Rebound From PDM For SPT
-7	-25.25	6.16	-121.33

PDM and Inspector Sets are reasonably close
PDM and SPT movements are also close
Rebound from PDM on piles is much better than on SPT rods

PDA - PDM DFN vs SET

Average % Difference In Set From PDM Using DFN	Average % Difference In Rebound From PDM Using DFN	Average % Difference In Set From PDM Using SET	Average % Difference In Rebound From PDM Using SET
255.71	18.49	55.08	33.26

PDM Set and PDA DFN poorly related

PDM Conclusions

- PDM Set similar to camera movements
- PDM Set similar to Inspector sets
- PDM Rebound roughly similar to PDA Rebound
- PDM comparisons are limited to higher Blow counts

PDM Recommendation

- PDM more suitable for set-check than full driving

Video Camera Signal Analysis of Pile Rebound

by

Charles R. Bostater Jr., Samin T. Aziz, Jennifer Clossen &
ME☺

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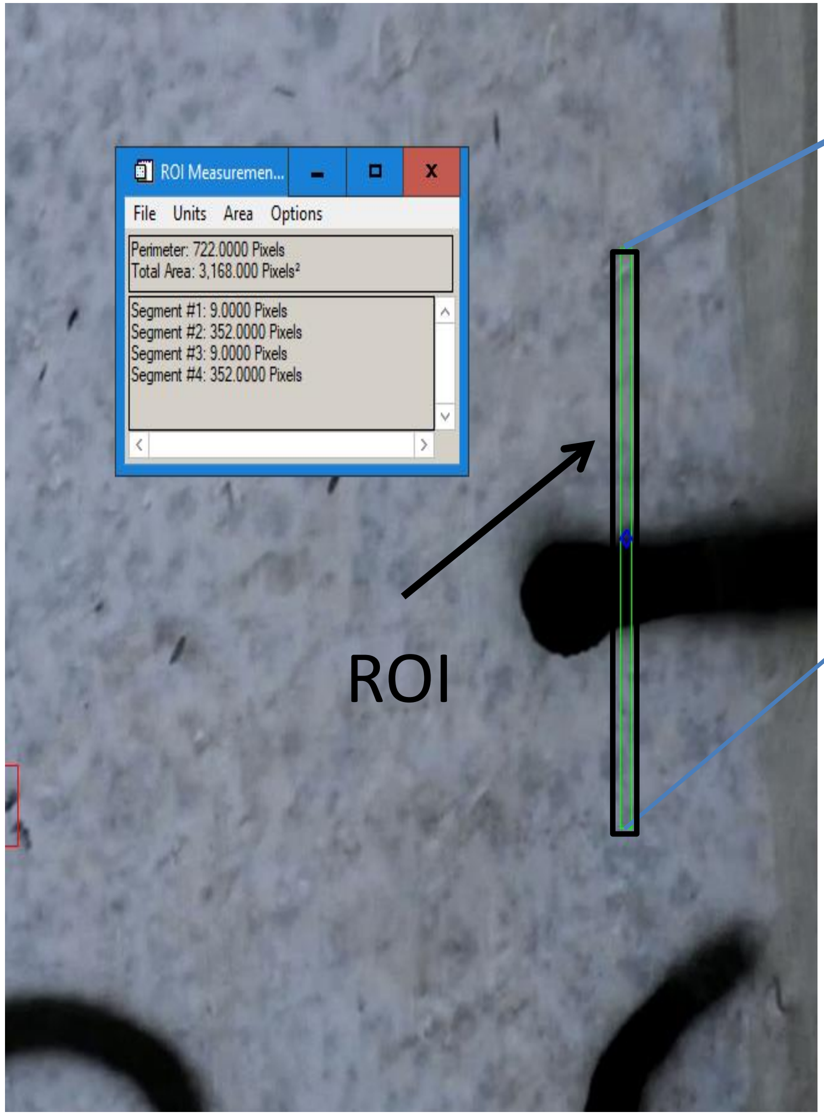
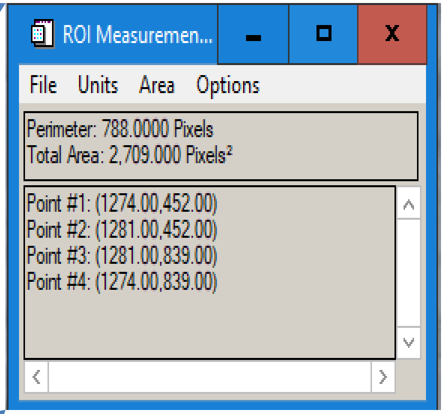
Background

- 30 to 120 Hz Video Signals tested in lab and at 6 sites.

Approach:

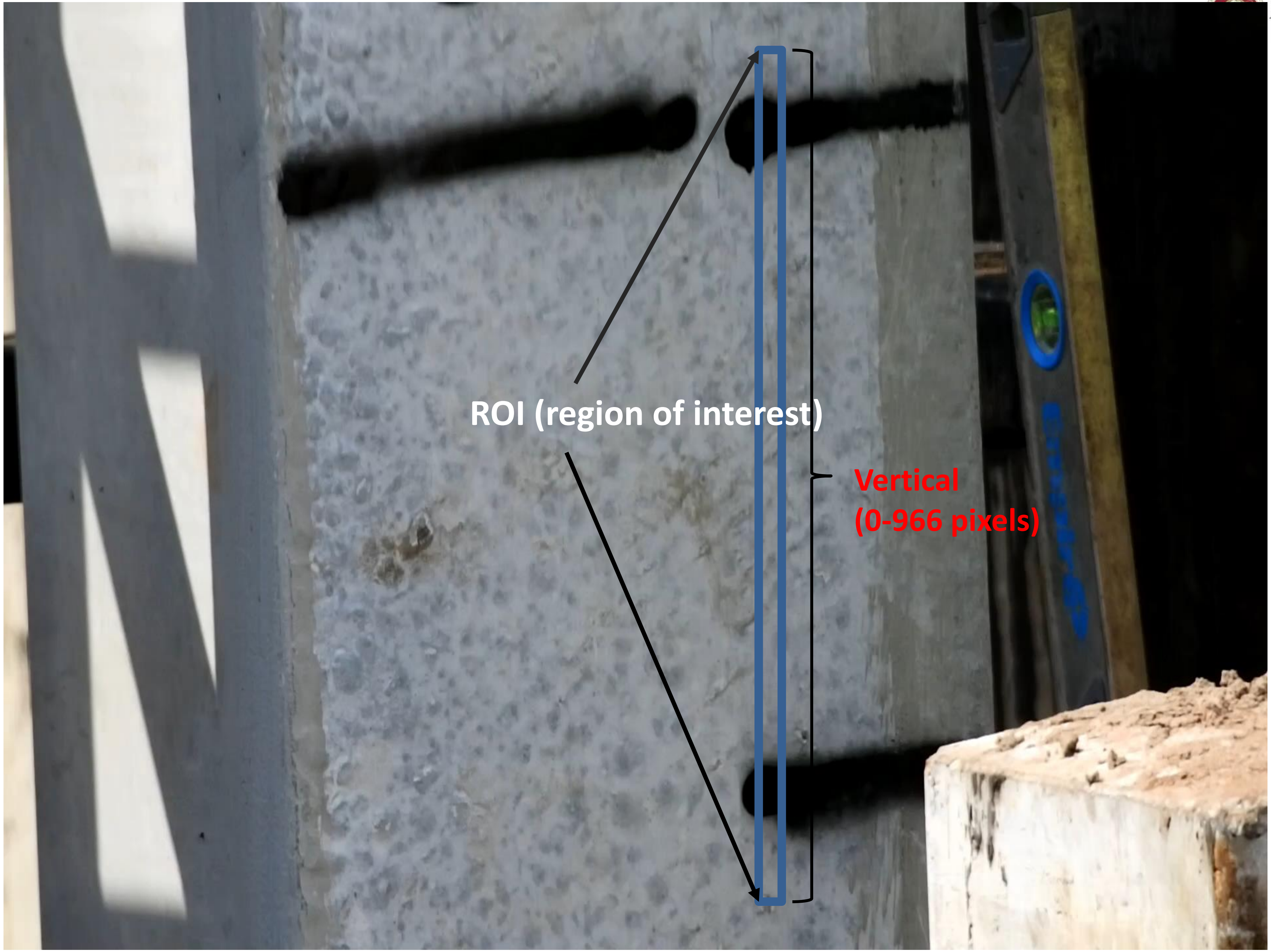




General Methodology:

1. Each video frame converted to an image.
2. Region of interest (ROI) selected for signal analysis
3. Each ROI analyzed to detect edge of paint line/tape
4. Position movement tracked within image
5. Position movement plotted for each frame signal
6. Error analysis performed
7. Pixel space converted to actual distance

Next Slide represents a video picture



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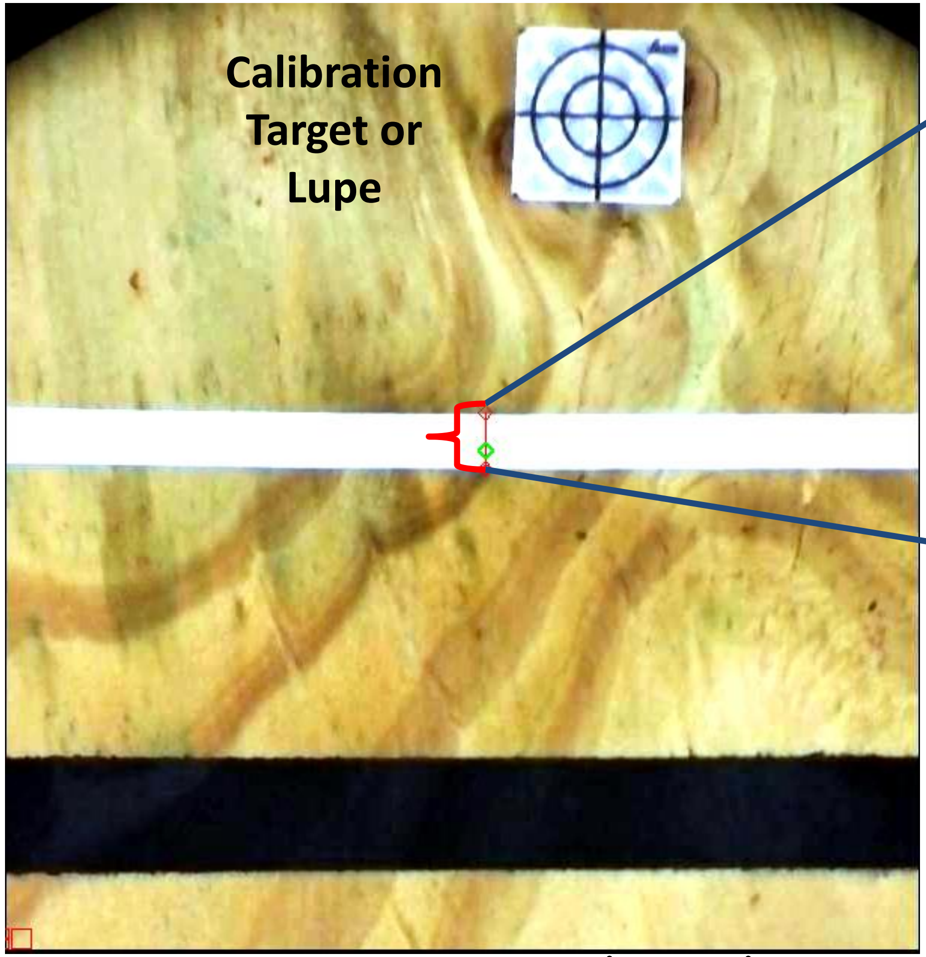
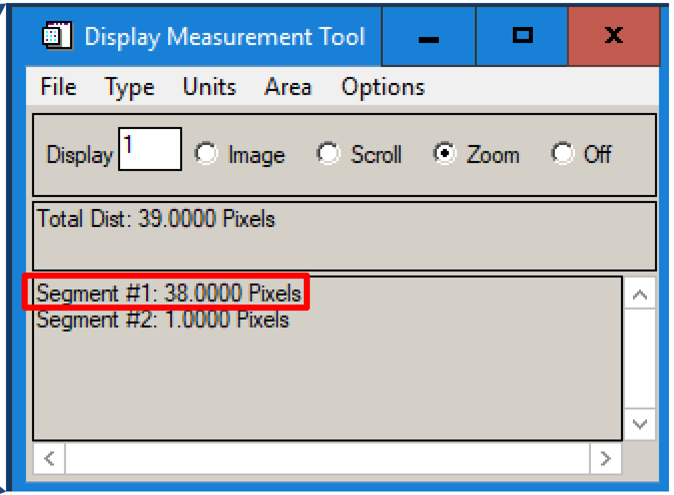
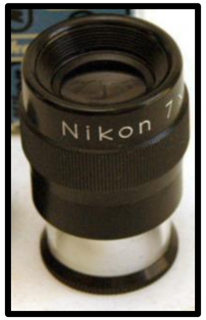
Basic Equipment Descriptions

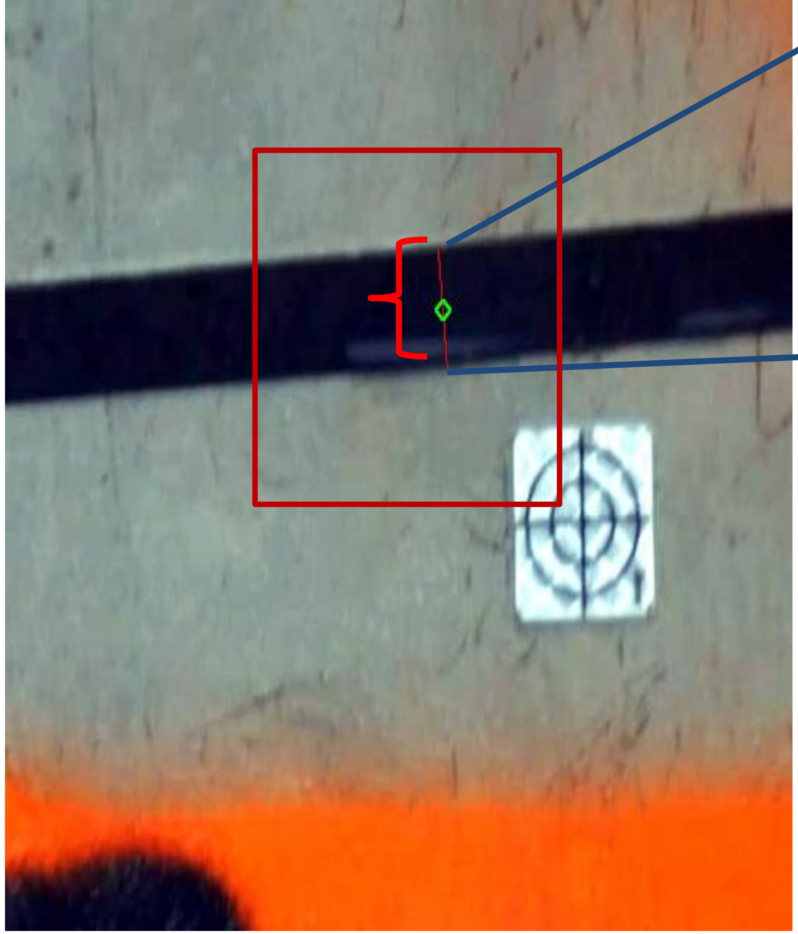


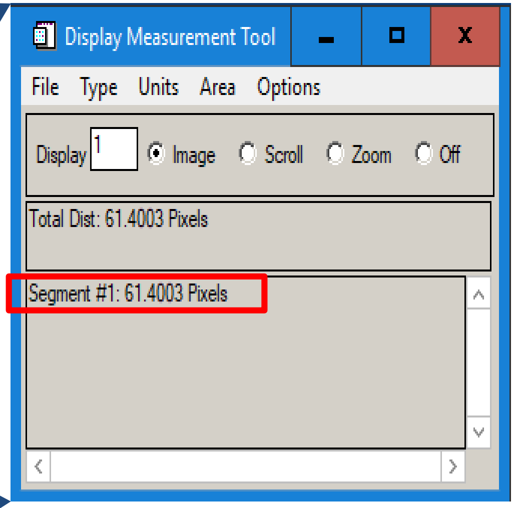




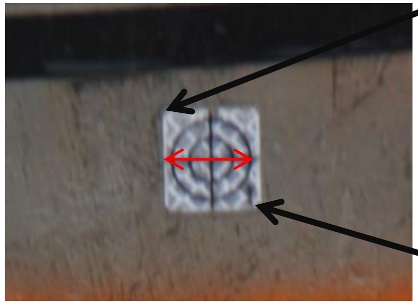
Eye Scope

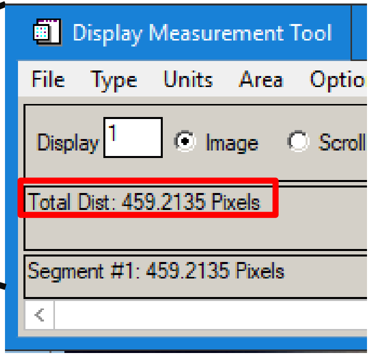
Baldwin Bypass Jacksonville Florida: Pile driving testing





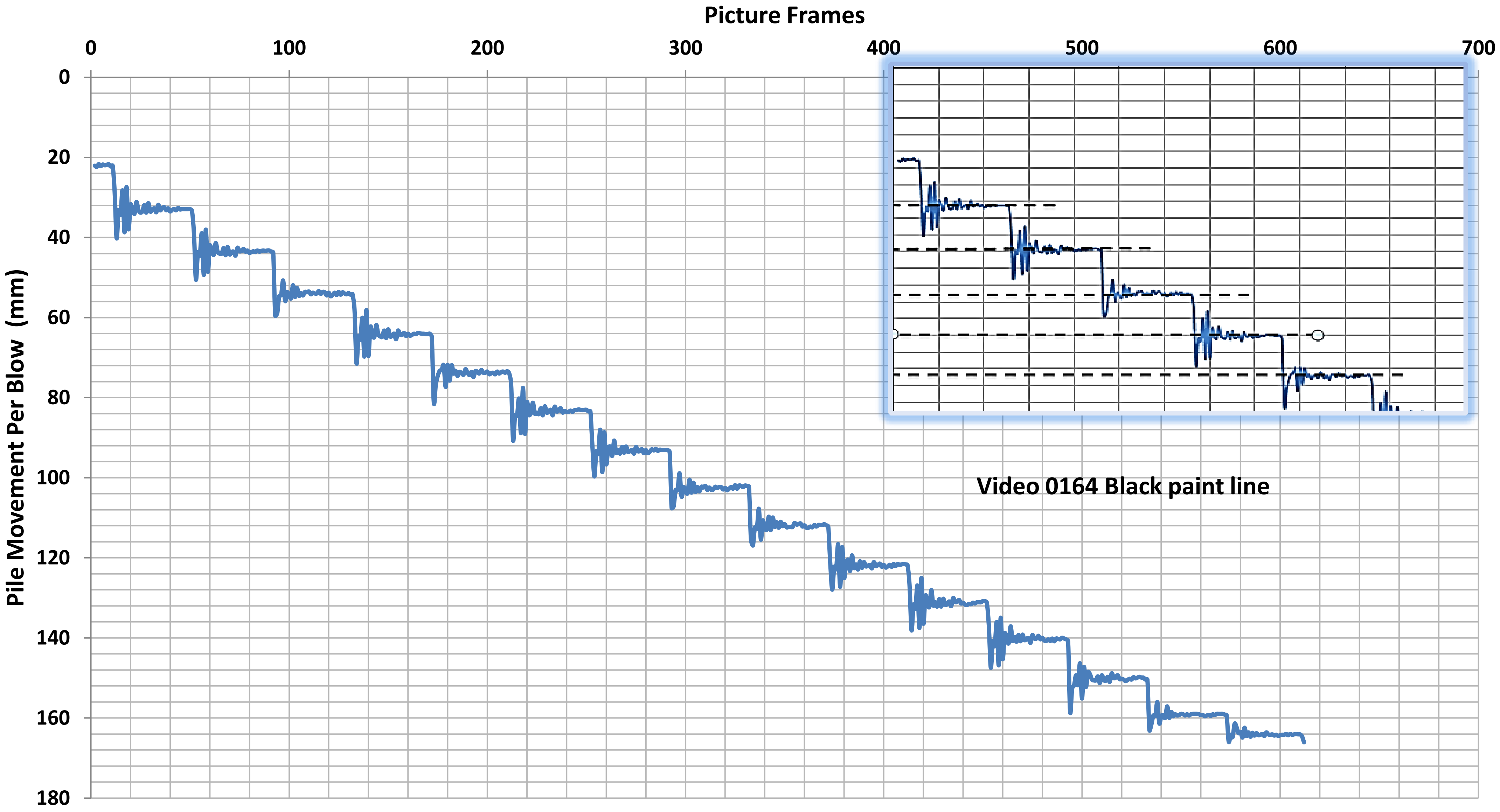
No. of pixels vertically within **black tape** = 61
Width of the line = 12 mm (Lupe measured)
Width per pixel = 12/61 = 0.197 mm (0.00774 inch)
Error range = +/- 3 pixels = +/- 0.591 mm
(+/- 0.023 inch error range)





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

Movement (mm) vs 60 HZ Frames for Baldwin Bypass Jacksonville Pile: black spray paint line



Max Displacement, Set and Rebound of Baldwin Bypass video: 0164

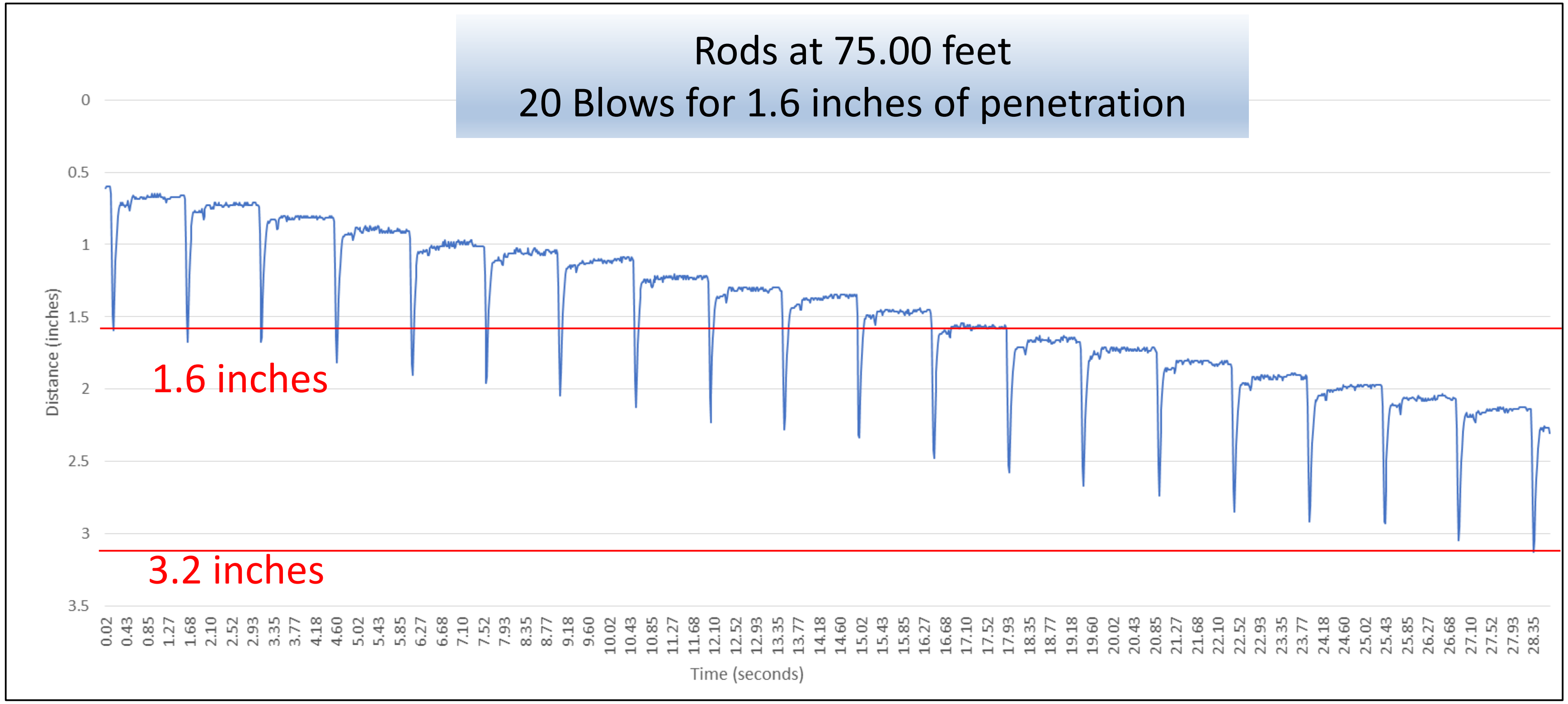
Hammer Blow	Max displacement (pixels)	Rebound (pixels)
1	88	37
2	82	33
3	93	40
4	93	43
5	87	42
6	87	37
7	79	29
8	75	30
9	85	35
10	88	38
11	85	40
12	100	45
Mean	**87**	**37**
Standard Deviation	**22**	**17**
Standard Error	**6**	**5**
Hammer Blow	**Max displacement (mm)**	**Rebound (mm)**
1	17.336	7.289
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**
Standard Deviation	**4.327**	**3.265**
Standard Error	**1.249**	**0.943**

Hammer Blows	Width per pixel
12	0.197 mm

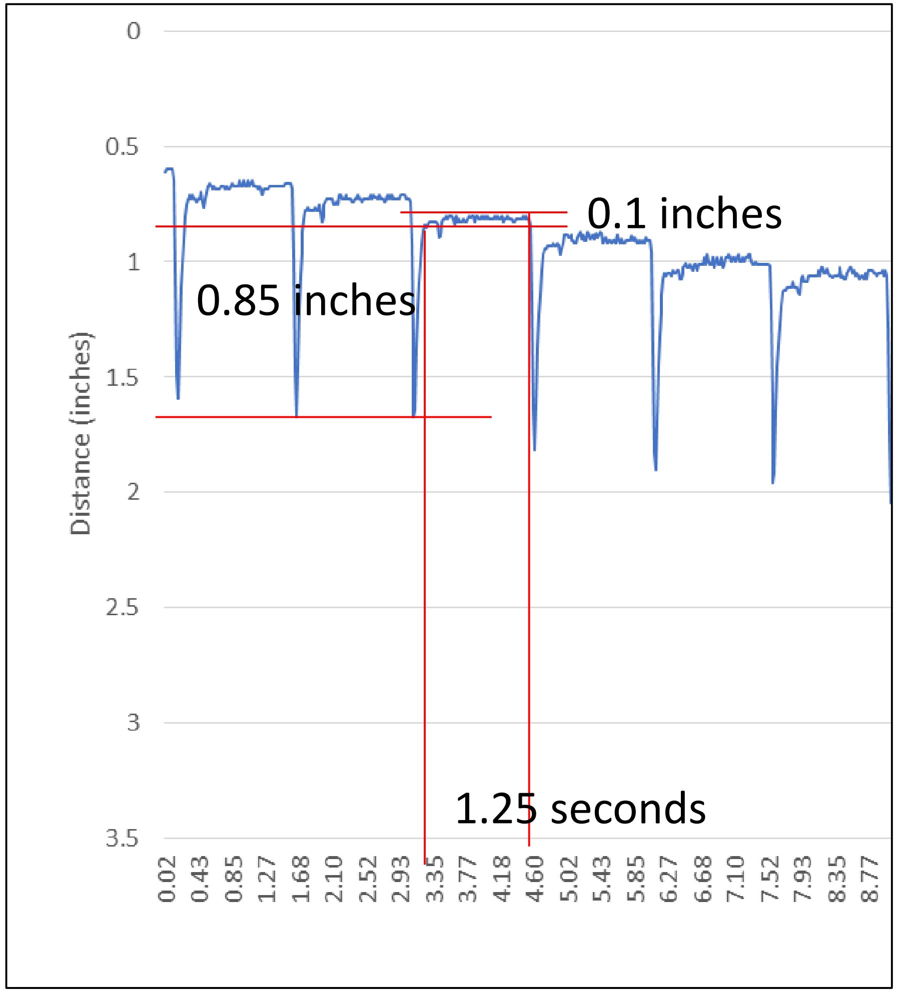
Baldwin Bypass Test Pile driving 60HZ Video

Video 0164 Using Black Spray Paint Line

60 Hz Video Recording Software Plot from Dunns Creek SPT Rod Movements



60 Hz Video Dunns Creek SPT Rod Time-Dependent Movements



0.1 inches of movement following linear movement of 0.85 inches about 1.25 seconds

Damping Coefficient Sensitivity Analysis of High Rebound Soils in Florida

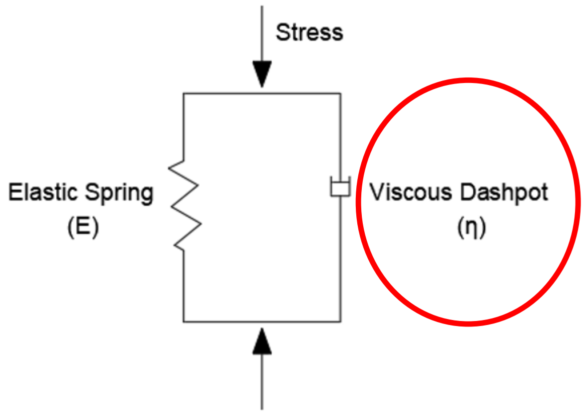
Aline Franqui

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

Damping

Relates to energy loss during a cyclic loading



Case's damping factor (Jc) - dimensionless

$$J_c = \frac{R_{smax}}{Z \times c} \qquad Z = \frac{EA}{c}$$

Smith's damping factor (Js) – units of time/displacement

$$J_s = \frac{R(t)}{R_{smax} \times c}$$

R_{smax} = max load
Z = impedance
c = particle or wave velocity

E = Young's modulus
A = pile's cross section
R(t) = load

Sites

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

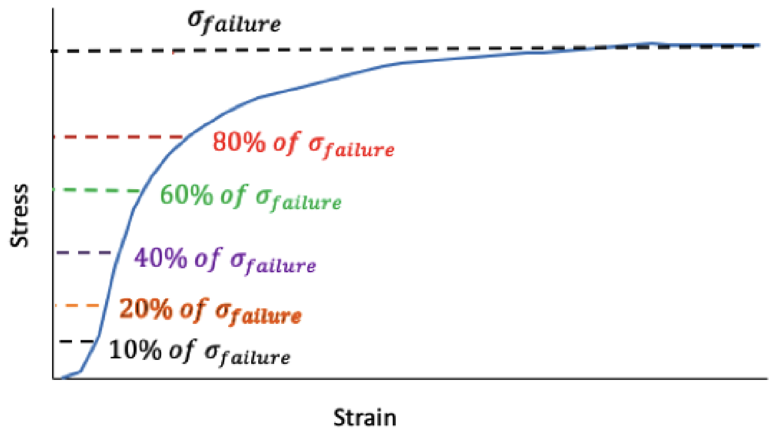
Rebound from PDA data

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 in 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 Results

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

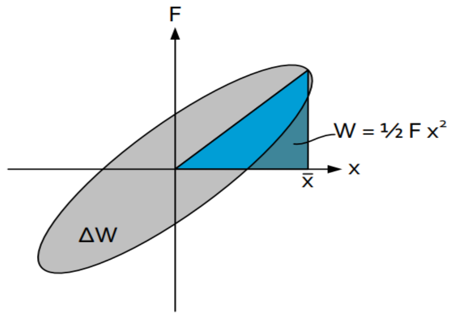
η_{ave}

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 are within 0 and 1 psi-sec

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

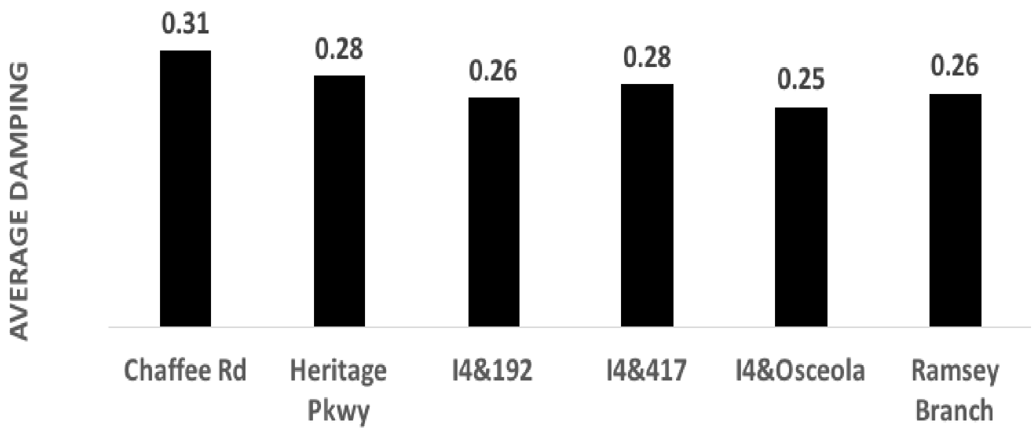
Hysteresis Loop



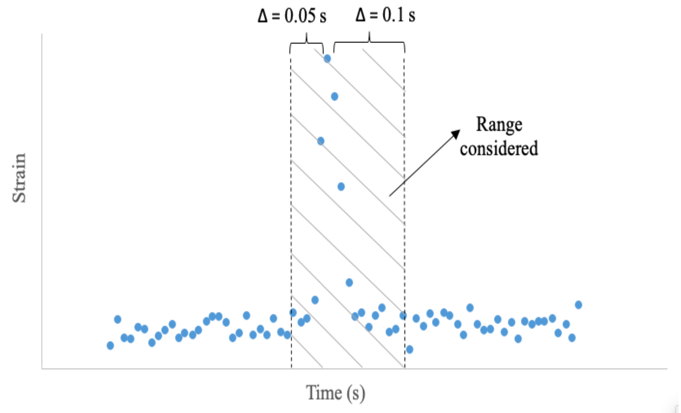
$$\zeta_{eq}(dimensionless) = \frac{\Delta W}{4\pi W}$$

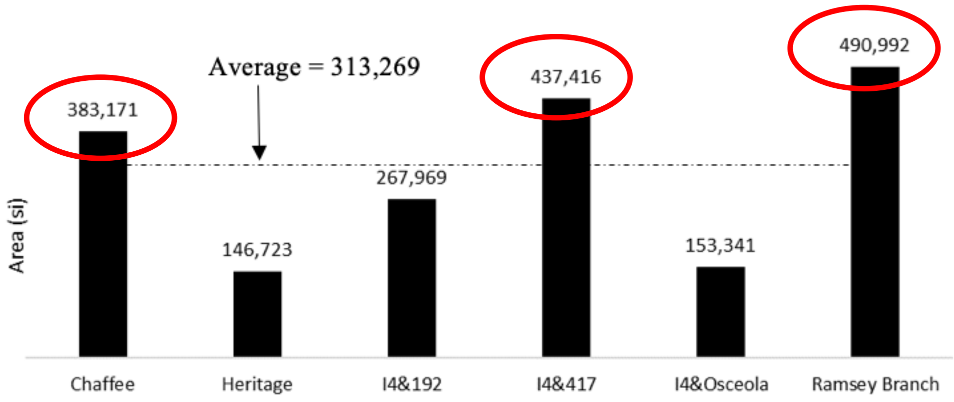
ΔW = Energy loss during a cycle

W = Maximum strain energy



Area Under Strain versus Time Curve

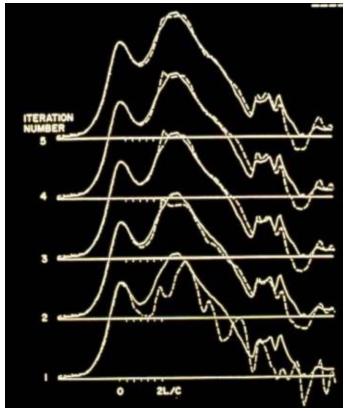




CAPWAP signal matching analysis on 12 piles @ 5 Sites

Evaluation criteria:

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

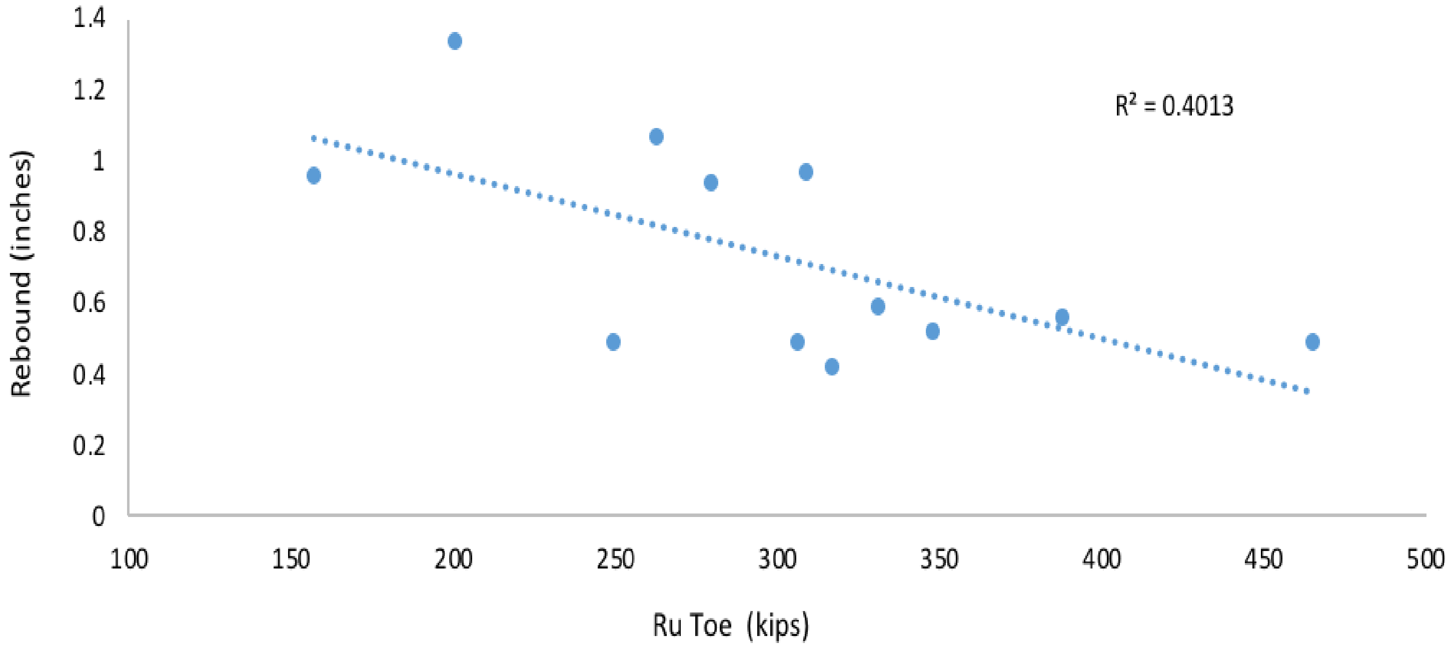


Signal matching:
Wave measured
versus
Wave computed

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 and CAPWAP ultimate TOE resistance



Unexpected.

Why would rebound decrease with increasing toe resistance?

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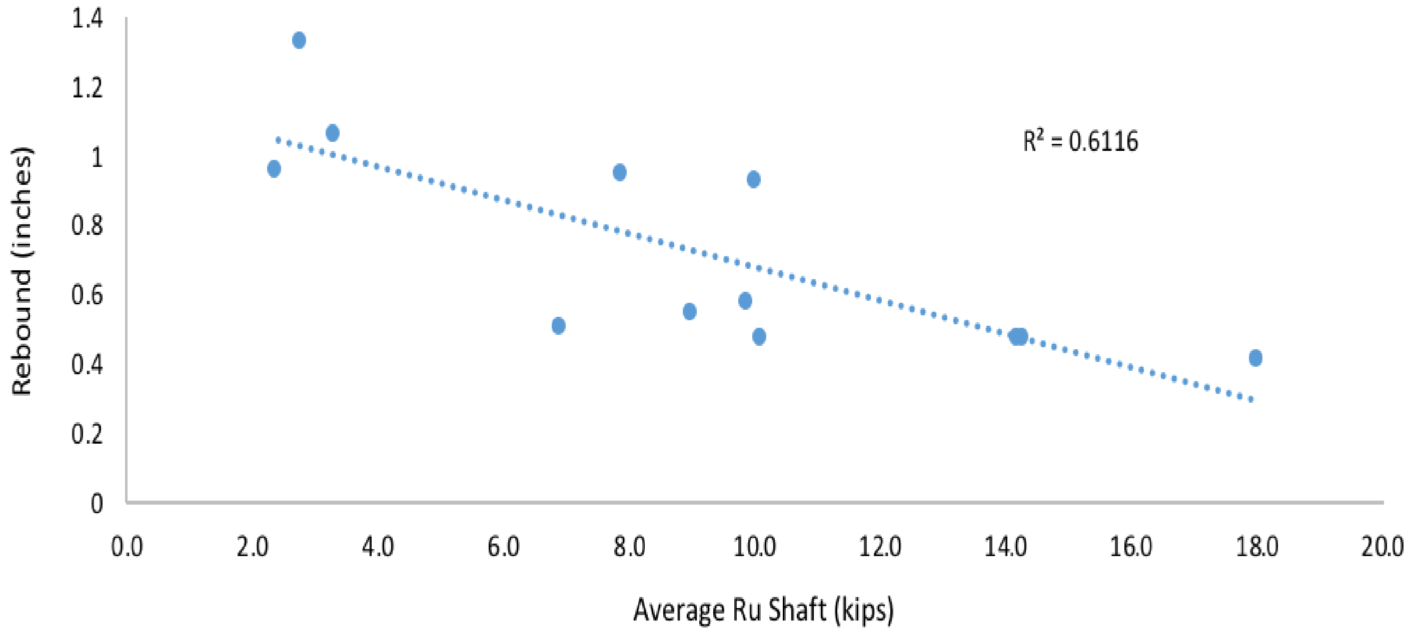
Rebound and CAPWAP ultimate SHAFT resistance



Expected
More shaft resistance should prevent rebound

Conclusions

Cyclic Triaxial Damping Evaluation

- *Hysteresis Loop matches Case's damping factor better than Kelvin-Voigt Model*
- *Area under the curve strain versus time seems to be proportional to PDA rebound*

PDA Rebound & CAPWAP Signal Matching

- *Expected behavior: higher damping = lower rebound was verified for Smith's toe but not for Smith's shaft*
- *Higher ultimate TOE resistance seems to produce higher rebound*
- *PDA rebound data is most useful when analyzed in CAPWAP*

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Questions ?