# Quantifying Pile Rebound with Detection Systems Best Suited for Florida Soils

*Task Work Order BDV28 Two 977-07*

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PM: Juan Castellanos, P.E

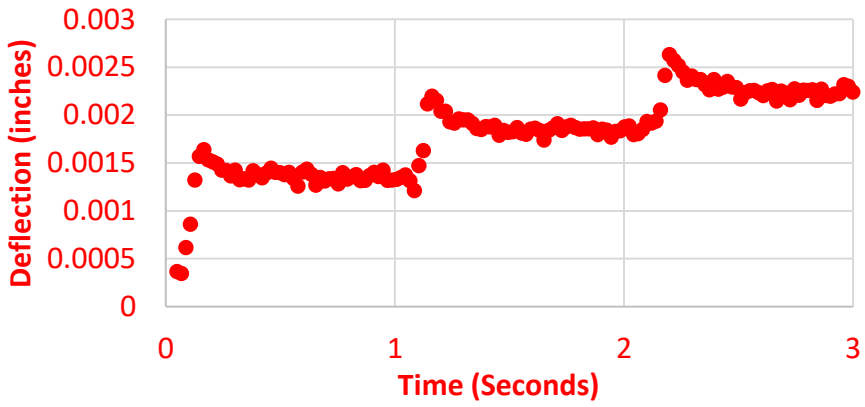
# Today's Presentation

- Evaluate two new measuring systems
  - Inopiles PDM LASER deflection-measuring system
  - FIT camera system
- Evaluate Cyclic Triaxial Viscous Response

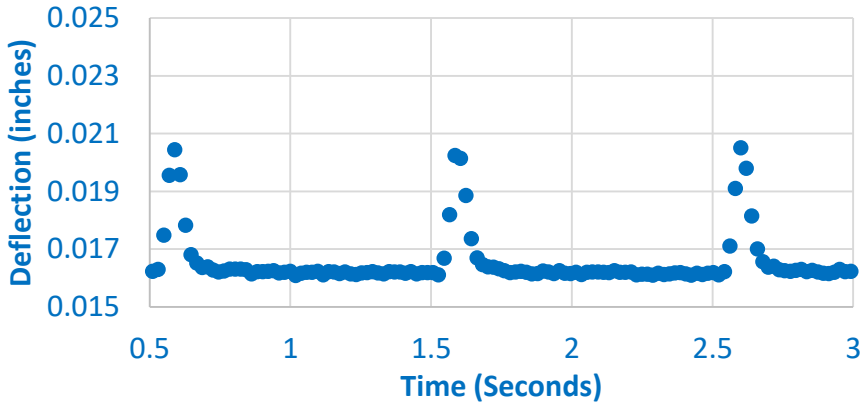
# New Technologies

- Inopiles PDM Measuring System
- FIT High Speed Cameras

# 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

# Schedule of Tasks (overview)

FLORIDA DEPARTMENT OF TRANSPORTATION
RESEARCH CENTER

**PROJECT SCHEDULE**

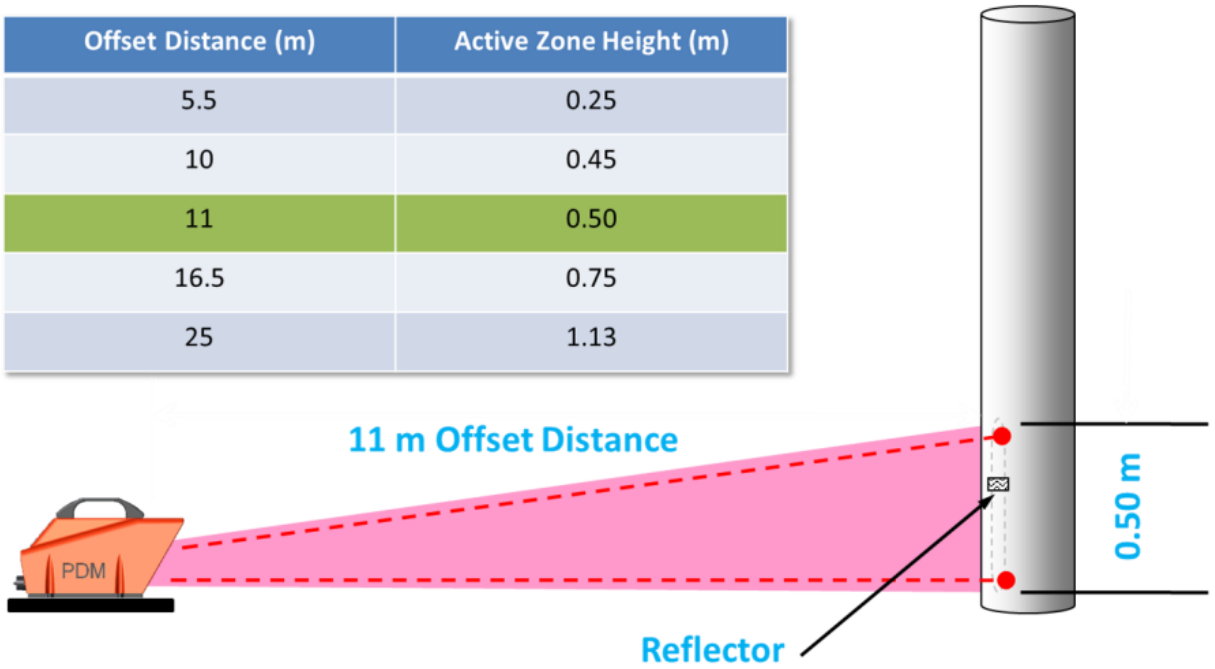
| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Project Title** | Measuring System for Pile Rebound During Construction and Desig | | | | | | | | | | | | | Geotechnical Investigation | | | | | | | | | | | |
| FDOT Project No. | | | | | | | | | | | | | | | | | | | FY | 2017 | | Month | April | | |
| Research Agency | Florida Institute of Technology | | | | | | | | | | | | | | | | | | | | | | | | |
| Principal Investigator | Paul J. Cosentino, Ph.D. P.E. | | | | | | | | | | | | | | | | | | | | | | | | |
| | Jun-17 | Jul-17 | Aug-17 | Sep-17 | Oct-17 | Nov-17 | Dec-17 | Jan-18 | Feb-18 | Mar-18 | Apr-18 | May-18 | Jun-18 | Jul-18 | Aug-18 | Sep-18 | Oct-18 | Nov-18 | Dec-18 | Jan-19 | Feb-19 | Mar-19 | Apr-19 | May-19 | **Comments** |
| RESEARCH TASK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | |
| Project Kickoff Meeting | 1 | | | | | | | | | | | | | | | | | | | | | | | | Cosentino |
| Task 1 Literature Search on Existing Pile Driving Deflection Measuring Systems and Soil Damping | 1 | 2 | 3 | 4 | 5 | | | | | | | | | | | | | | | | | | | | Cosentino |
| Task 2 Viscoelastic Analysis of Existing Cyclic Triaxial Load versus Time Data | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | | | | | | | | | | | Cosentino |
| Task 3 Wave Equation Software Damping Factor Sensitivity Analysis | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | | | | | | | | | Cosentino |
| Task 4 High Speed Camera Validation for Inopiles PDM LASER Measuring System | | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | | | | | | Jensen/Cosentino |
| Task 5 Determine SPT and PDA Test Piles Field Testing Locations | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | | | | | | | | | | | | Cosentino |
| Task 6 Measuring System Evaluations | | | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | | | | | Cosentino/Jensen |
| Task 7 Draft Final Report and Closeout Conference | | | | | | | | | | | | | | | | | | 1 | 2 | 3 | 4 | | | 1 | Cosentino/Jensen |
| Task 8 Final Report | | | | | | | | | | | | | | | | | | | | | | 1 | 2 | 3 | Cosentino/Jensen |

Tasks 4, 5 & 6: Three Sites Tested To Date

- Baldwin Bypass, Jacksonville: PDM didn't function: Surface Pro wasn't ☺
- Port Canaveral Cargo Birth: Concentrated ONLY on PDM: no Camera
- Reedy Creek, Kissimmee: Signals from Camera and PDM

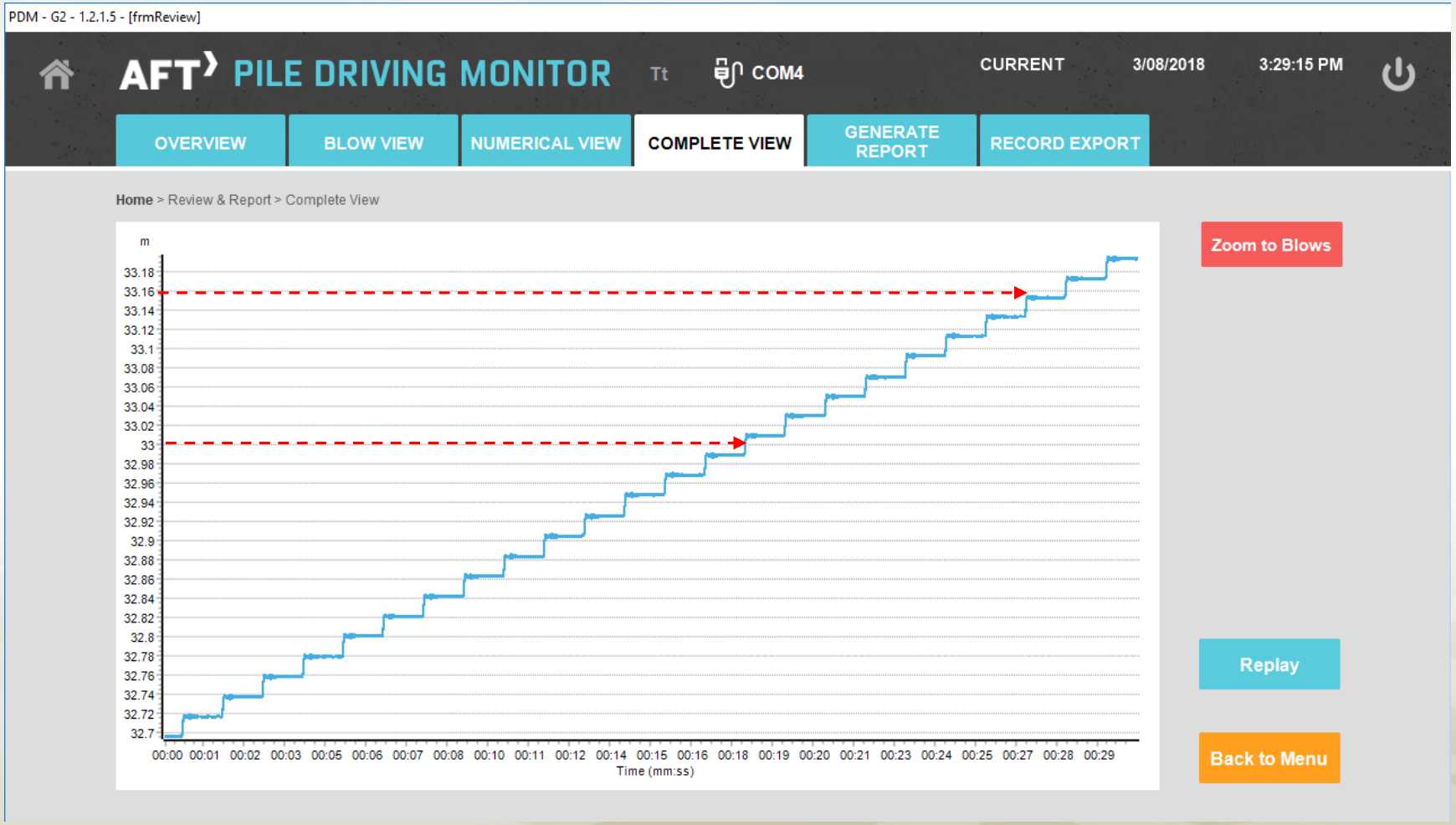
# Inopiles PMD

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

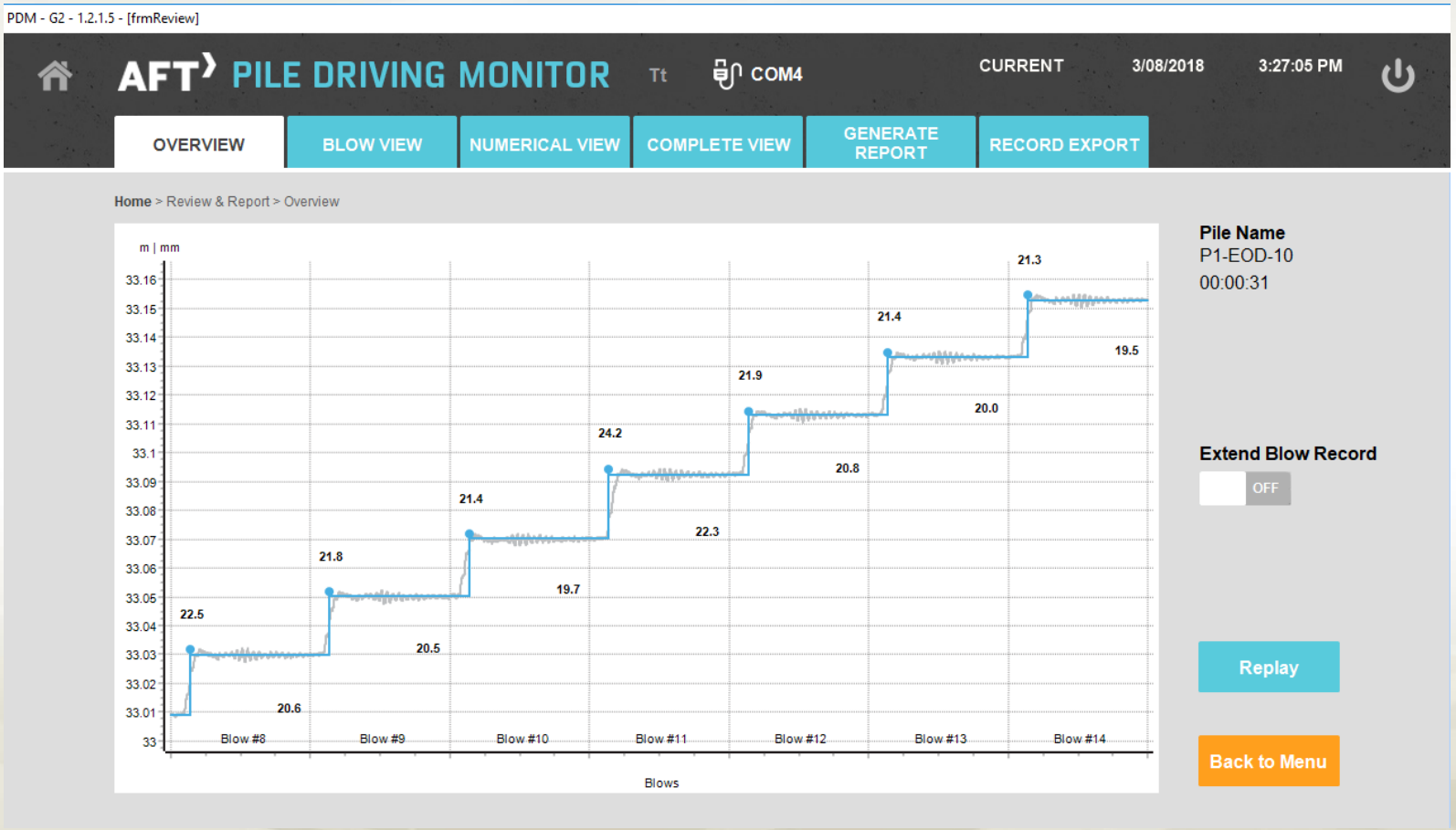



- Only about 30-inches of data can be recorded at a time
- Not practical to record data during entire driving process

# Reedy Creek PDM Data Near 90 ‘



# Zoom View: 20 mm: blue vs gray




*Blue maximum displacement = Gray continuous displacement* ***= No Rebound?***

# PMD Accuracy 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 |

# Video Camera Signal Analysis of Pile Rebound

by

**Charles R. Bostater Jr. & Samin T. Aziz**

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Background

1. 30 to 120 Hz Video Signals tested to date at 3 highway sites.
2. Built and tested a laboratory testing pile.
3. Used Existing Software and Cameras for Signal & Image Processing

# Approach:

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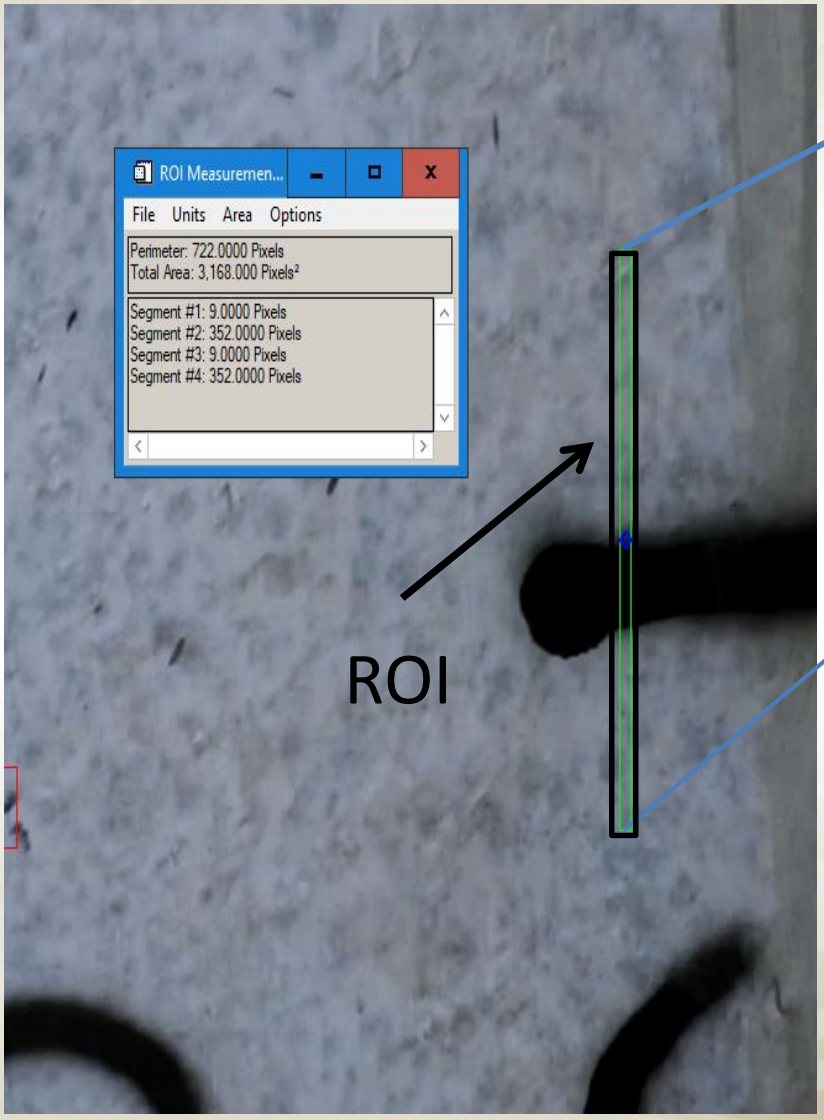


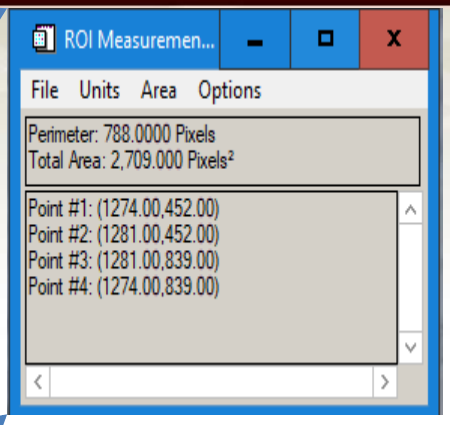


**General Methodology:**

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

*Next Slide represents a video picture*

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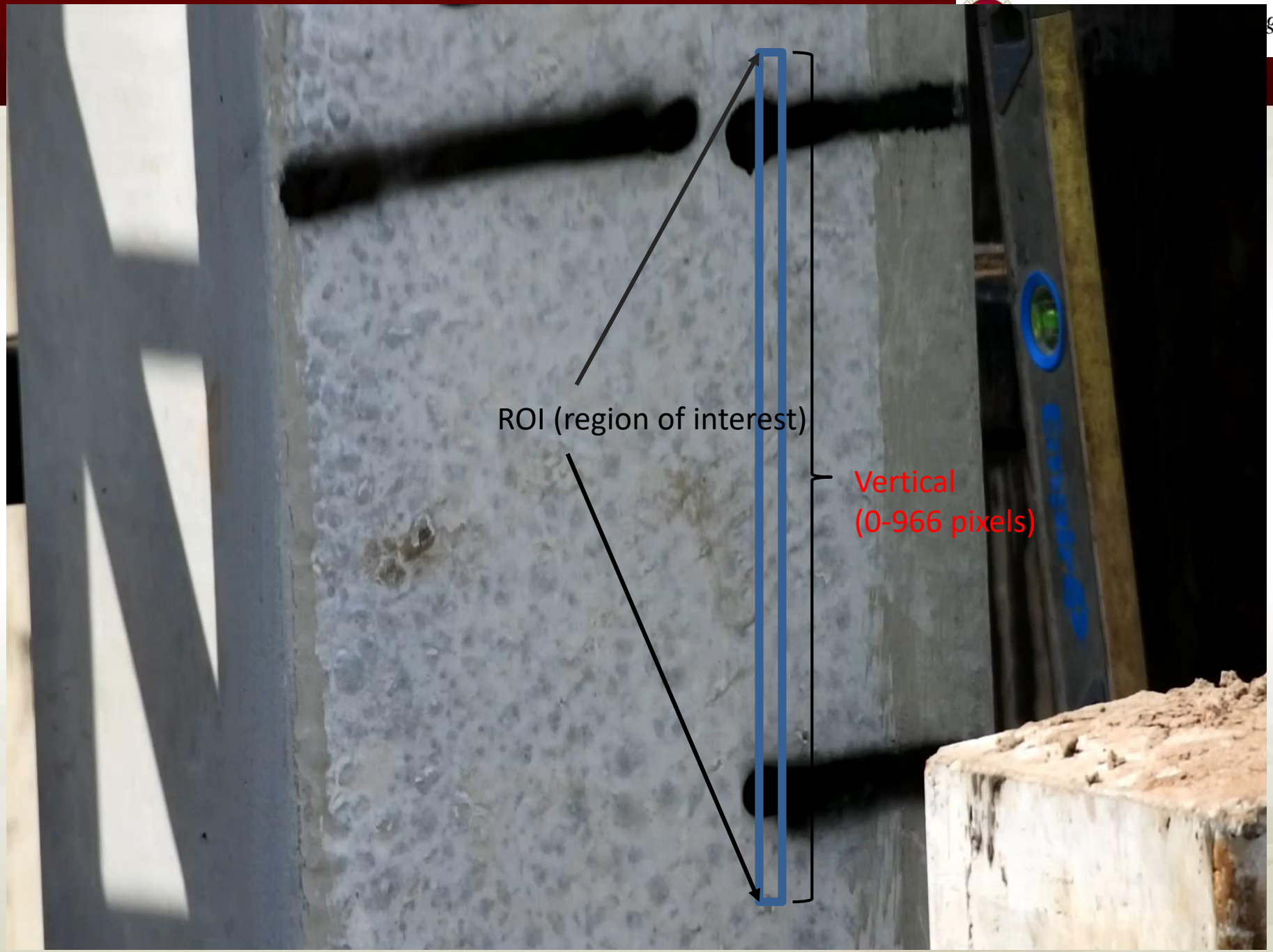
ROI (region of interest)
Vertical
(0-966 pixels)

# Pile driving Test Pile in Lab

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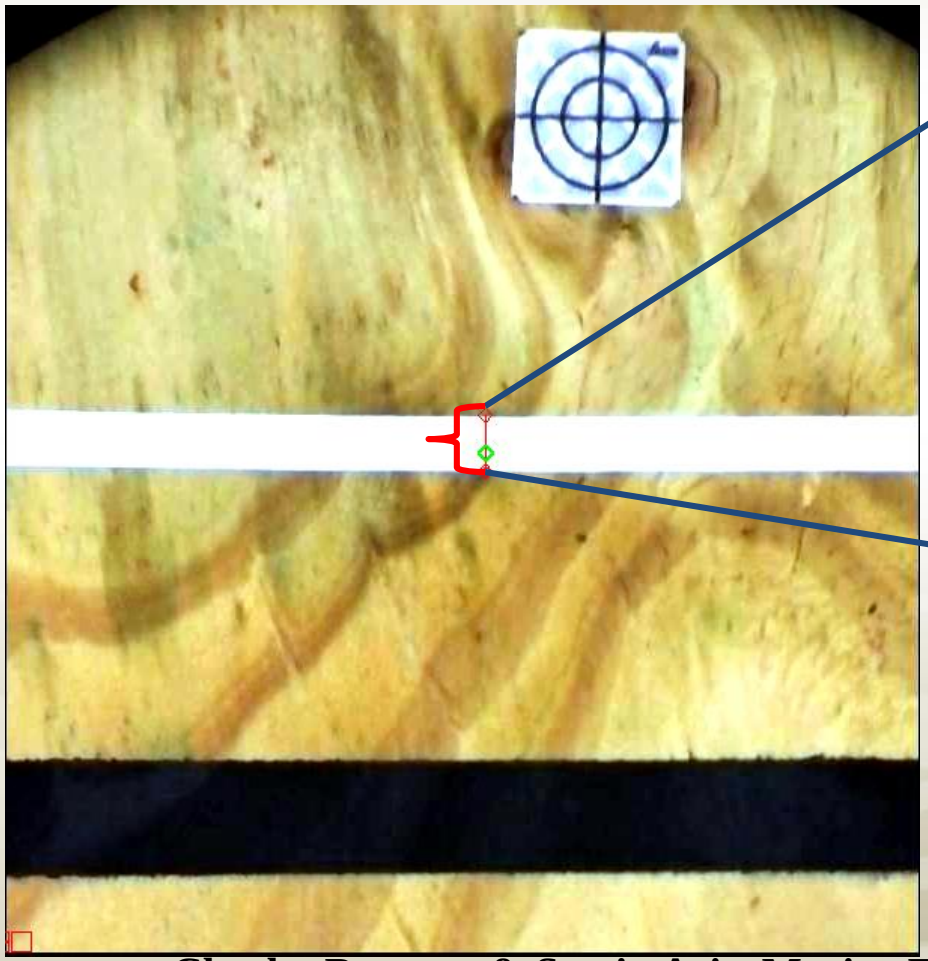
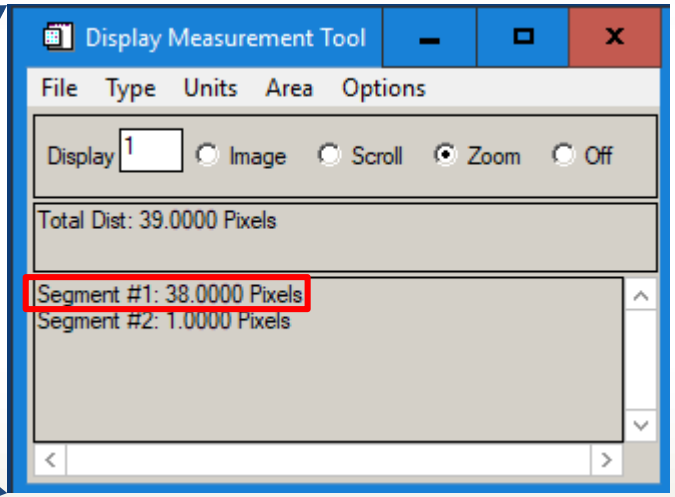
Number of pixels in vertical width of white line = 38 pixels
Width of the line = 6.3 mm ( measured using lupe scope)
Width per pixel = 6.3/ 38 = 0.166 mm (0.0065 inches)
Error range = +/- 3 pixels ( ~ 0.039 inches error range)







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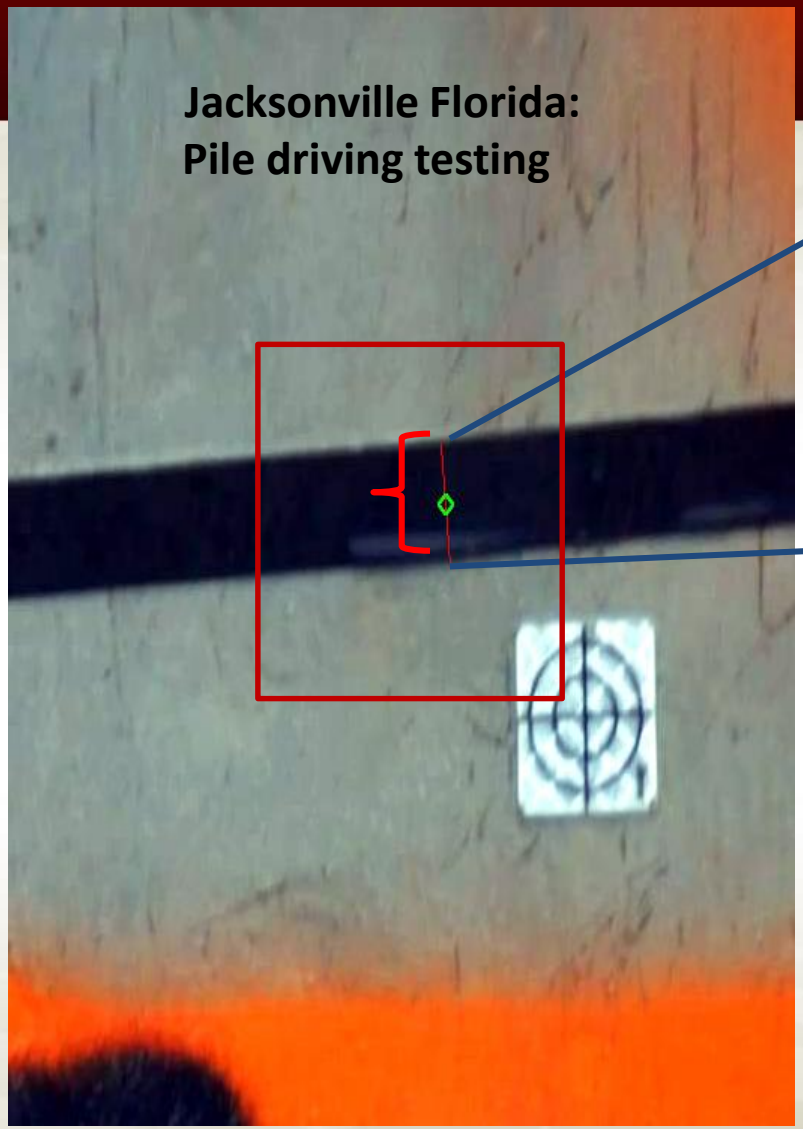
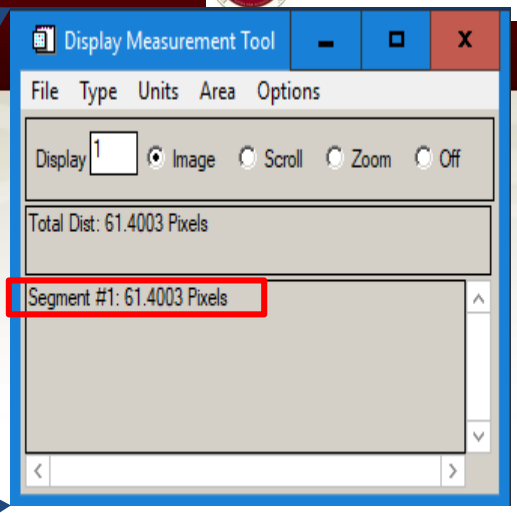
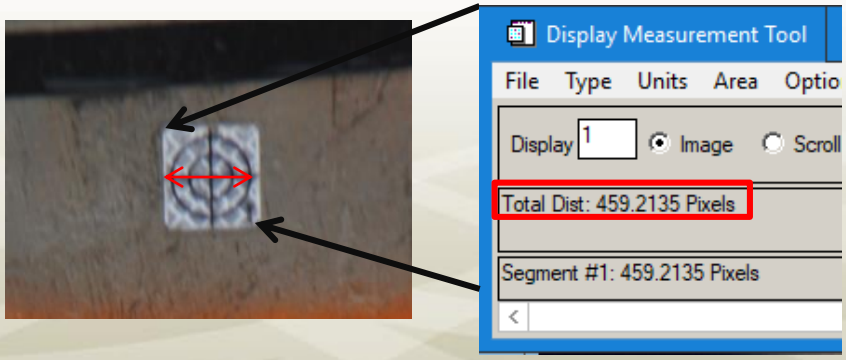



No. of pixels in within the **black tape** = 61 pixels
Width of the line = 12 mm (lupe measured)
Width per pixel = 12/61 = 0.197 mm (0.00774 inch)
Error range = +/- 3 pixels = +/- 0.591 mm
( +/- 0.023 inch error range)




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

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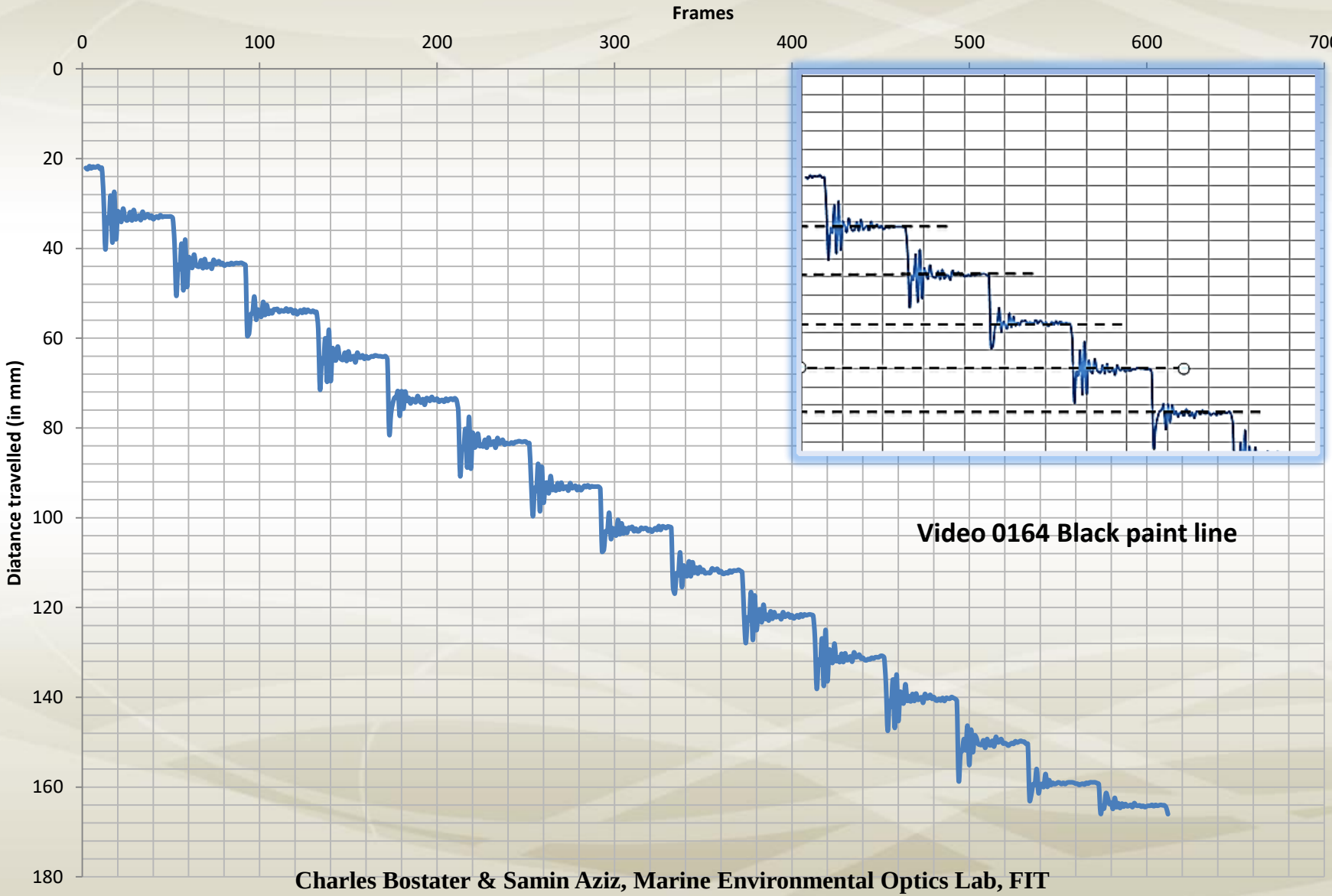
# (mm) vs 60 HZ Frames for Baldwin Bypass Jacksonville Pile: black spray paint line

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

| Hits | 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** | **86.83333333** | **37.41666667** |
| **standard deviation** | **21.96403837** | **16.57581139** |
| **Standard error** | **6.340471732** | **4.785024583** |
| | | |
| Hits | 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** | **17.10616667** | **7.371083333** |
| **standard deviation** | **4.326915559** | **3.265434843** |
| **Standard error** | **1.249072931** | **0.942649843** |

| hits | width/pixel |
|---|---|
| 12 | 0.197 mm |

**Baldwin Bypass Test Pile driving 60HZ Video**

**Video 0164 Using Black Spray Paint Line**

# Orlando Reedy Creek Site:

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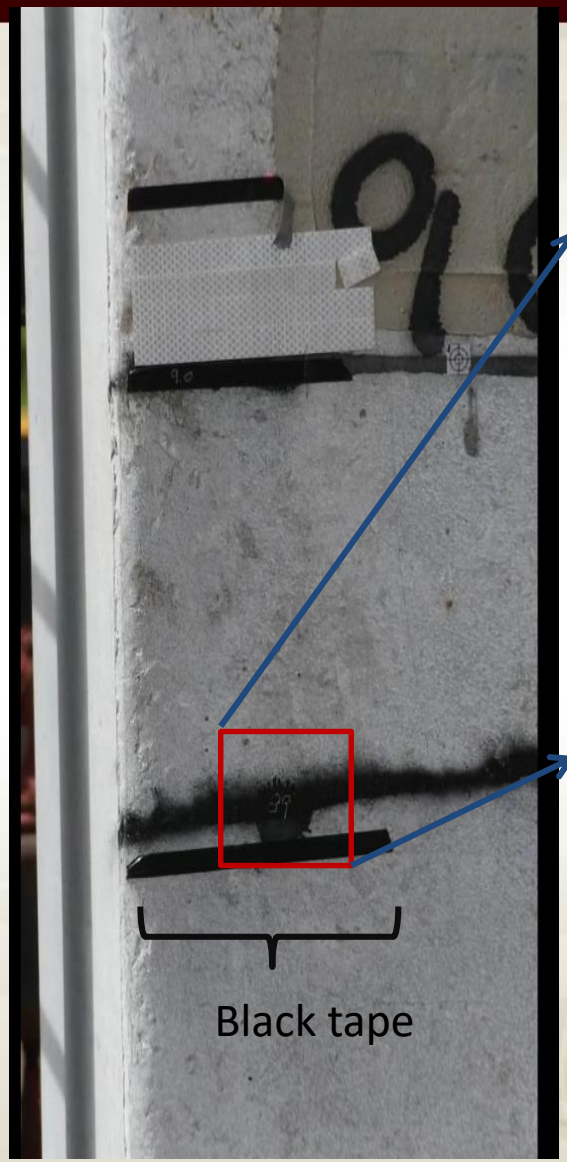


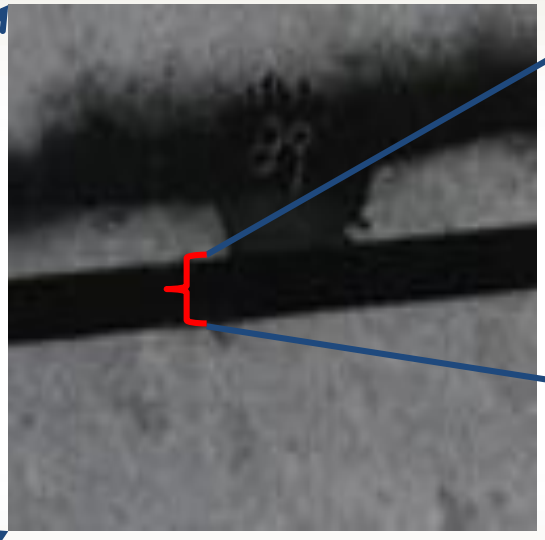

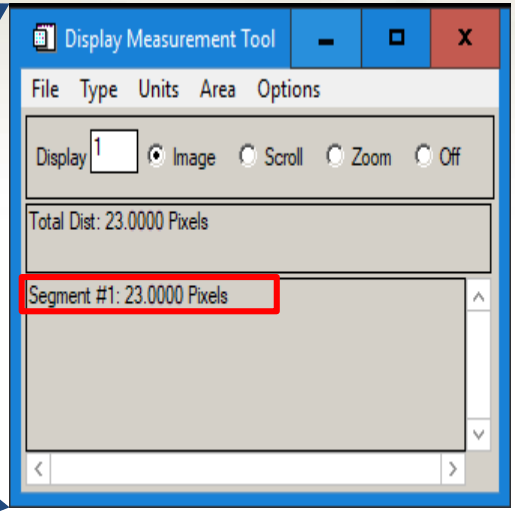


No. of pixels in Vertical width of the Dark line = 23 pixels
Width of the line = 15 mm (measured using eye scope)
Width per pixel = 15/23 = 0.652 mm ( 0.0256 inches)
Error range = +/- 3 pixels = +/- 1.956 mm ( +/- 0.077 inches error range)

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# Vertical distance travelled (mm) vs 60 HZ frame graph
## Orlando Reedy Creek Site - 90th ft mark on pile - little rebound detected

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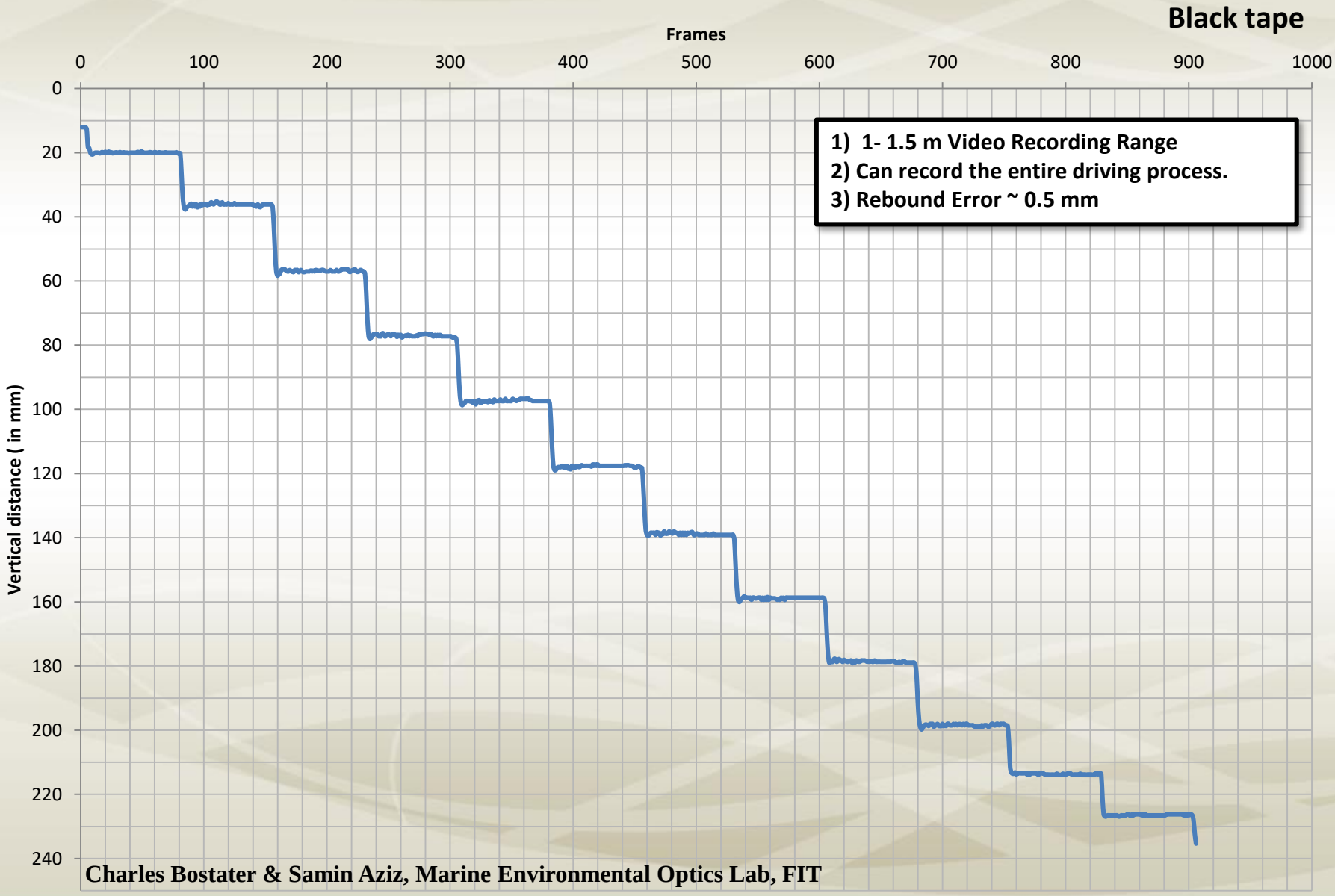


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# Task 2 Viscoelastic Analysis of Existing Cyclic Triaxial Load versus Time Data

- Existing BDV 28 977-01 results from 30 cyclic triaxial tests
- The results include
  - a list of the sites evaluated,
  - soil profiles from each site that include
    - the locations of undisturbed samples,
    - SPT N values,
    - pile driving blow counts and
    - displacement per hammer blow data,
  - results from the cyclic triaxial data analyses and
  - correlations between the rebound near the sample depth and cyclic responses.

# Viscoelastic Analysis of Existing Cyclic Triaxial Data

**Presented by: Aline Franqui, Graduate Student**

**August 2018**

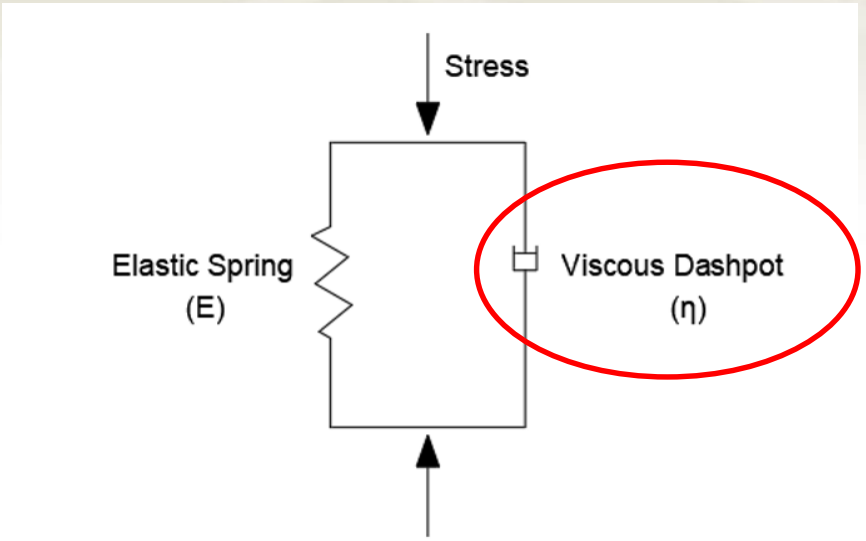
# AGENDA

- **Objective**
- Literature Review
- PDA & SPT Tests
- Cyclic Triaxial Test
- Results
- Conclusions

# Viscoelastic Analysis of Existing Cyclic Triaxial Data

Paul J. Cosentino, Ph.D, P.E.

Cyclic Triaxial Test




| Site | PDA Test | SPT Test | CT Test |
|---|---|---|---|
| SR 417 & I4 | ✓ | ✓ | ✓ |
| Saint John's Heritage Parkway | ✓ | ✓ | ✓ |
| I10 & Chaffee Road | ✓ | ✓ | ✓ |
| I4 - US192 | ✓ | ✓ | ✓ |
| Ramsey Branch | ✓ | ✓ | ✓ |
| I-4 Osceola Parkway | | | ✓ |

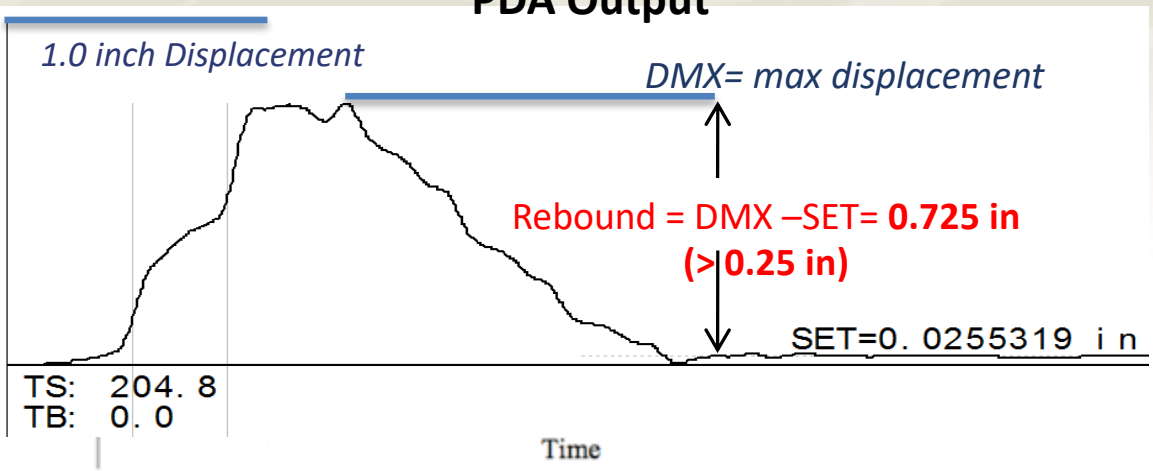
# AGENDA

- ❑ Objective
- ❑ **Literature Review**
- ❑ PDA & SPT Tests
- ❑ Cyclic Triaxial Test
- ❑ Results
- ❑ Conclusions

# Viscoelastic Analysis of Existing Cyclic Triaxial Data

Paul J. Cosentino, Ph.D, P.E.

## PDA Output




## Kelvin-Voigt model (parallel)

$$\sigma = E \times \varepsilon + \eta \times \dot{\varepsilon}$$

**Unit: Stress-Time (psi-s)**

## Case's Damping Coefficient

**Dimensionless**

$$J_c = \frac{R(t)}{Z \times v_p(t)}$$

$$Z = \frac{E \times A}{v_p(t)}$$

| Soil Type at Pile Toe | Case Damping Correlation Range (1975) | Updated Case Damping Correlation 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 |

# AGENDA

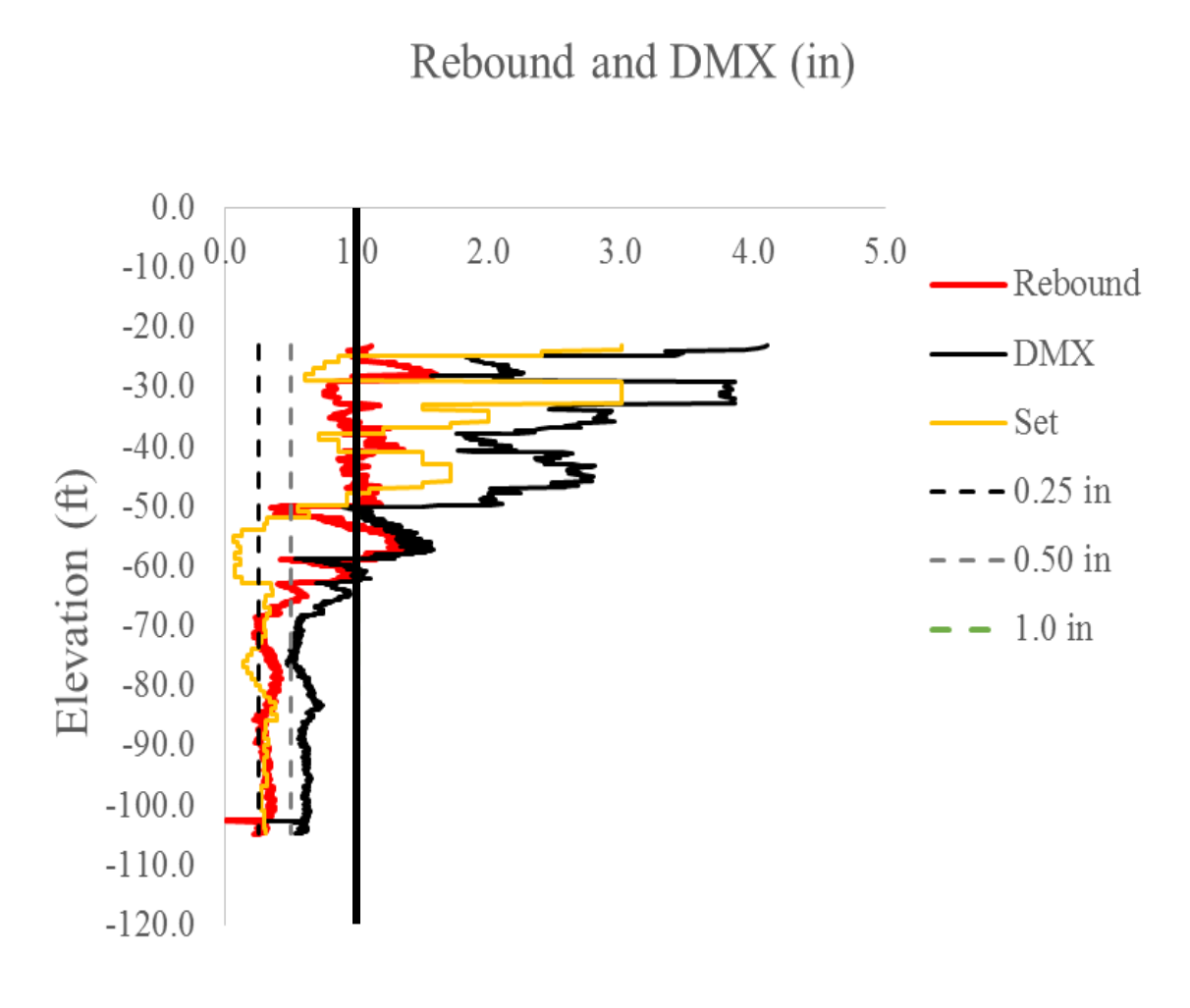
- ❑ Objective
- ❑ Literature Review
- ❑ **PDA & SPT Tests**
- ❑ Cyclic Triaxial Test
- ❑ Results
- ❑ Conclusions

Table 6 - Percentage of Depths with Rebound ≥ 0.25, 0.50 and 1.00 inch

| 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% |

# Viscoelastic Analysis of Existing Cyclic Triaxial Data

Paul J. Cosentino, Ph.D, P.E.



# AGENDA

- ❑ Objective
- ❑ Literature Review
- ❑ PDA & SPT Tests
- ❑ **Cyclic Triaxial Test**
- ❑ Results
- ❑ Conclusions

# Python™

Data Input

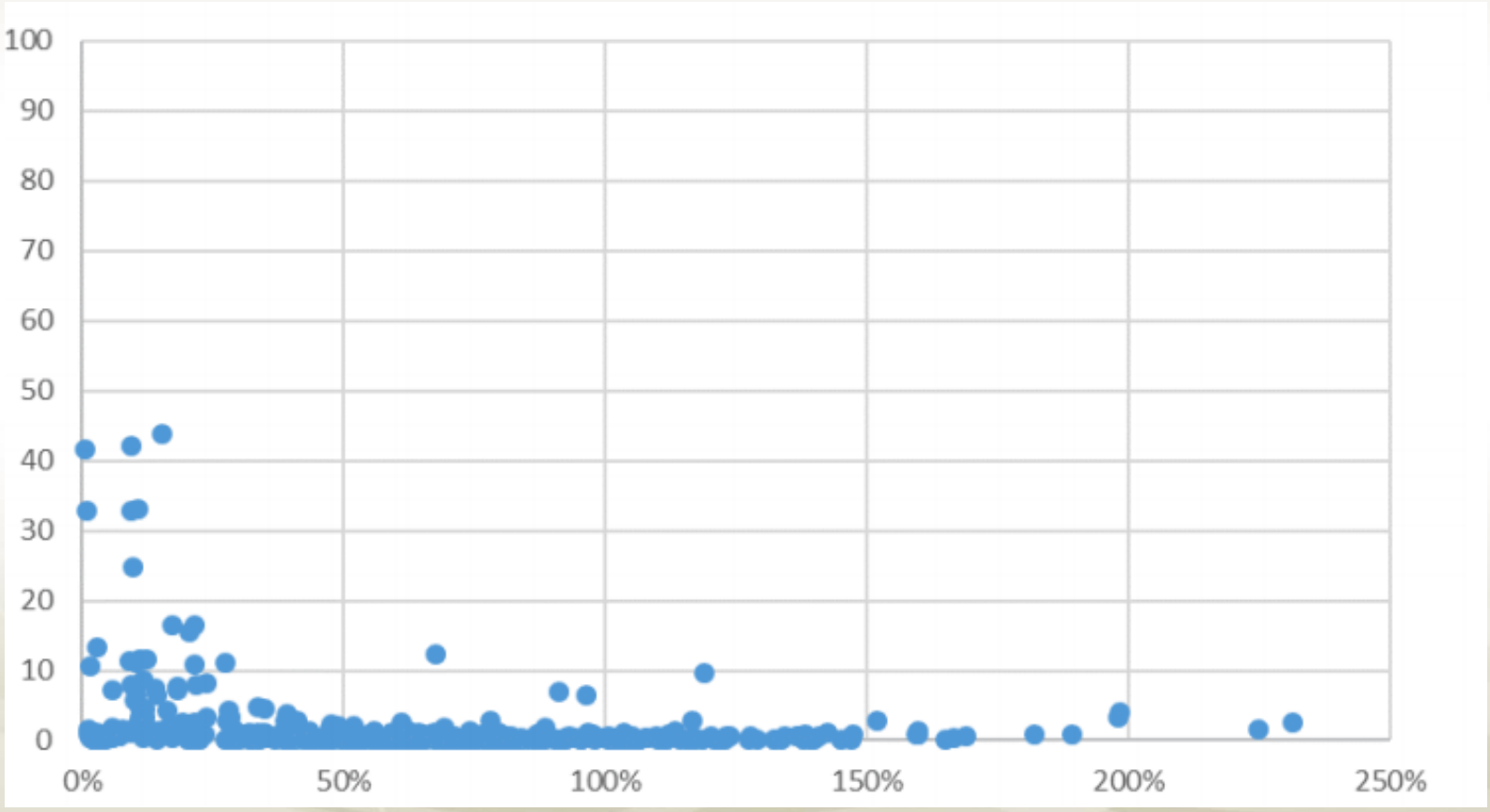
Data Management (Cycle numbers, Stress Levels, Noise Reduction, Fitting) ★

Calculations (E, Damping Coefficient, Area)

# AGENDA

- ❑ Objective
- ❑ Literature Review
- ❑ PDA & SPT Tests
- ❑ Cyclic Triaxial Test
- ❑ **Results**
- ❑ Conclusions

## Damping Coefficient Plot – All Sites

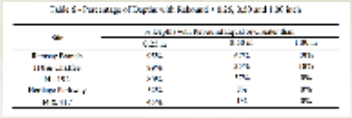


## Damping Coefficient Histogram Table – All Sites

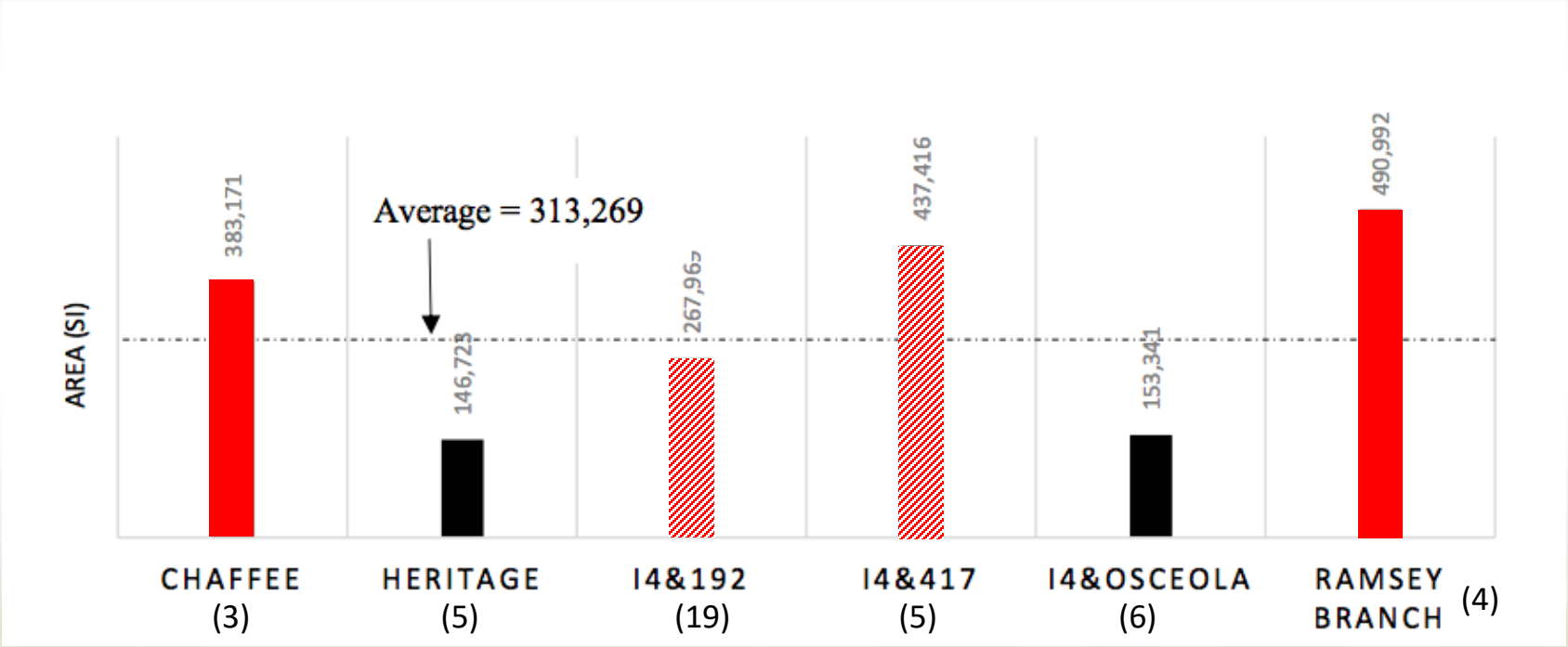
| Range | Data Points | % Total | % Cumulative |
|---|---|---|---|
| 0 - 0.01 | 5 | 1.1% | 1.1% |
| ***0.01 - 0.1*** | ***106*** | ***23.6%*** | ***24.7%*** |
| ***0.1 - 1*** | ***214*** | ***47.6%*** | ***72.2%*** |
| ***1 - 10*** | ***84*** | ***18.7%*** | ***90.9%*** |
| 10 - 100 | 19 | 4.2% | 95.1% |
| 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% | |

# Viscoelastic Analysis of Existing Cyclic Triaxial Data

Paul J. Cosentino, Ph.D, P.E.



## Average Strain-Time Area



# AGENDA

- ❑ Objective
- ❑ Literature Review
- ❑ PDA & SPT Tests
- ❑ Cyclic Triaxial Test
- ❑ Results
- ❑ **Conclusions**

# Preliminary Conclusions

- Damping coefficient successfully calculated from 42 CT tests
- η (psi-s) results similar to dimensionless $J_c$
- Area under the strain vs time curve may be related to rebound
- Data ready for subsequent task of Wave Equation Sensitivity Analysis

# Questions ?

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