2025 GRIP Meeting

BED26 TWO 977-20: Measuring Rebound and Evaluating Pile Resistance Using Ultra-High-Speed Photogrammetry

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Project Manager: Rodrigo Herrera

Patrick Sun, Ph.D. & Luis Arboleda, Ph.D.

Civil, Environ., & Constr., University of Central Florida

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Outline

- Objectives
- Justification and Methodology
- Technical Considerations and Background
- Some Baby Steps
- Tasks, Deliverables, and Timeline

Objectives

- To **develop** a **non-contact method** using **ultra-high-speed photogrammetry** to measure pile displacements and rebound during driving operations.
- To **create a processing code** to extract time histories of **displacement and velocity**.
- To **evaluate the use** of image-based measurements **for potentially estimating pile capacity**, including comparisons with conventional methods.
- To provide **recommendations** for integrating photogrammetry into **FDOT pile testing practices**.
- Propose **correlation for Rebound Risk Index (RRI)**: (e.g.,) input energy, toe resistance, relative density and total force at the bottom:

$$\mathrm{RRI} = 100 \cdot a \cdot \left(\frac{E}{R_{toe}}\right)^b \cdot \left(1 - \frac{D_r}{100}\right)^c \cdot \left(\frac{F_{dyn}}{F_{tot}}\right)^d$$

RRI < α:	low rebound risk
α ≤ RRI < β:	moderate risk, monitor for small rebound
RRI ≥ β:	high risk, expect measurable rebound and consider mitigation

Justification and Methodology

- Tracking pile movements using images have relied on low-speed cameras (e.g., 60 Hz), which do not capture high-frequency dynamic responses during pile driving.

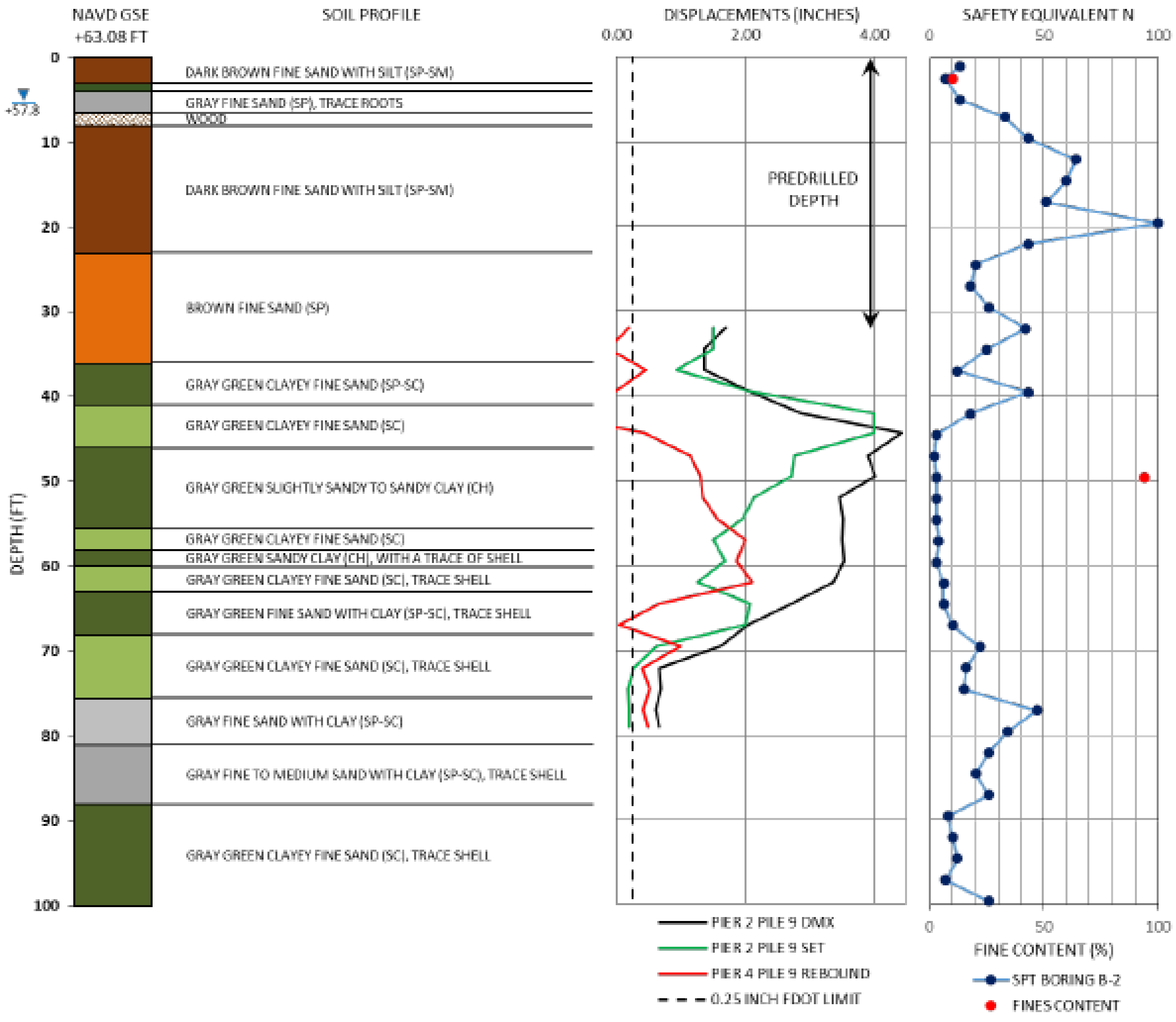
- Conventional systems for pile dynamic testing require attachment of strain gauges and accelerometers to the pile, increasing installation costs and other risks.

- Embedded sensor systems such as EDCs are limited to specific pile types (e.g., cast-in-place concrete).

- Proposed method minimizes obstruction to equipment and allows safe-distance measurements without sensor installation:
  - Ultra-high-speed photogrammetry (≥10,000 Hz) offers non-contact high-resolution measurements.
  - This will improve measurements of pile displacements and potentially estimate capacity.

Technical Considerations

- **Previous studies, mostly from Consentino et al. at FIU (2010-2020)**
  - FDOT Specifications are based on 0.25-inch rebound criterion
  - Monitored rebound for a wide range of pile geometries and materials in Florida
  - A newly proposed rebound correlation would improve assessments with a sampling rate > 10kHz



Selected site from Consentino et al. (2017)

Technical Considerations

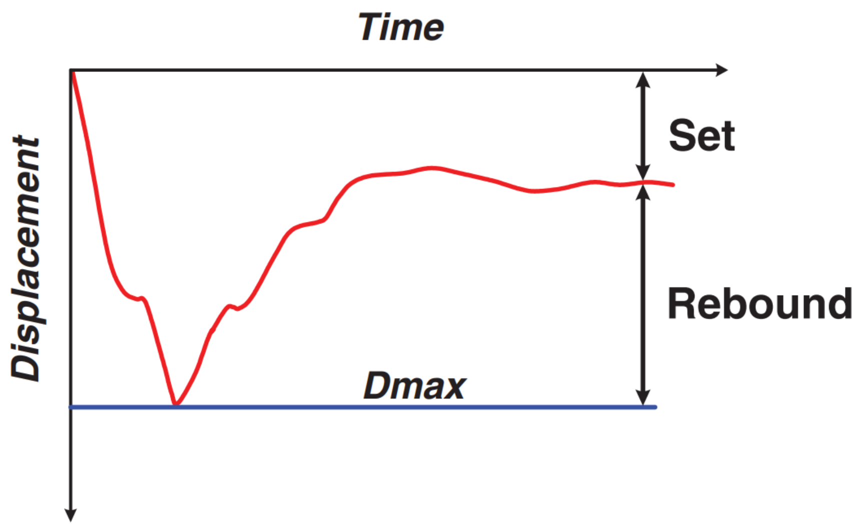
- **Current dynamic testing methods**
  - Pile Driving Analyzer (PDA) and Embedded Data Collector (EDC)
  - Require physical sensors either attached/embedded to pile

- **Photogrammetry approach**
  - Monitor rebound and potentially evaluate capacity for different pile geometries and materials w/o internal instrumentation
  - Previous studies using conventional cameras (≤ 60 Hz) showed limitations in capturing fast dynamic responses; sensitive to vibration interference during measurements

- **High-speed and high-resolution photogrammetry**
  - Proposed photogrammetry-based method enables non-contact, high-resolution monitoring with a sampling rate > 10,000Hz, allowing precise tracking of pile motion

Technical Background: Rebound

- **Pile rebound:**
  - Upward movement (elastic or plastic recovery) of a driven pile after driving operations.
  - Phenomenon influenced by the pile material properties, soil type, and pile-soil interaction mechanisms.

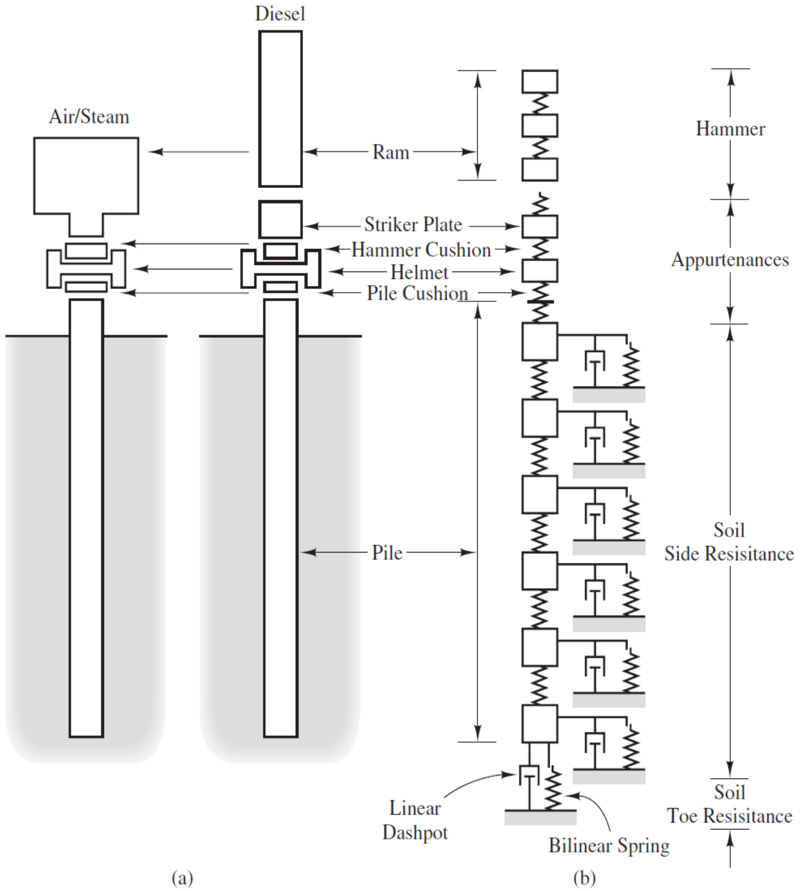


Typical behavior pile rebound
Jausgi et al., 2013, Cosentino et al. (2010-2020)

- **Previous studies:**
  - Excessive rebound is found when (Jarushi et al., 2013; Hannigan et al., 1998):
    - Encounter very competent soil layer or rock.
    - High pore water pressures in cohesive soils.
    - Insufficient energy transfer during pile installation.
  - Rebound has been monitored visually or using displacement sensors. Precise quantification remains difficult without high-resolution tracking (Cosentino et al., 2020).
  - In some soils clays or sandy silts, rebound can mask actual pile behavior, leading to premature refusal or installation errors (Jarushi et al., 2013).
  - Recent research highlights the importance of rebound (Reuter, 2019; Cosentino et al., 2010):
    - It might affect drivability analyses and bearing capacity predictions.
    - It may result in misleading pile capacity.

Technical Background: Pile Dynamic Testing

- **Pile dynamic testing (PDT):**
  - Non-destructive method to evaluate load-bearing capacity during and after installation.
  - Based on Wave Equation Analysis, which models stress wave propagation along the pile induced by an external dynamic load (Smith, 1960; Lee et al., 1988; Salgado et al., 2017).



Pile model used in wave equation analyses
(Coduto et al., 2016)

Sensor installation → Dyn. impact application and response recording → Displacement, force and velocity → Evaluation of rebound / Evaluation of pile capacity

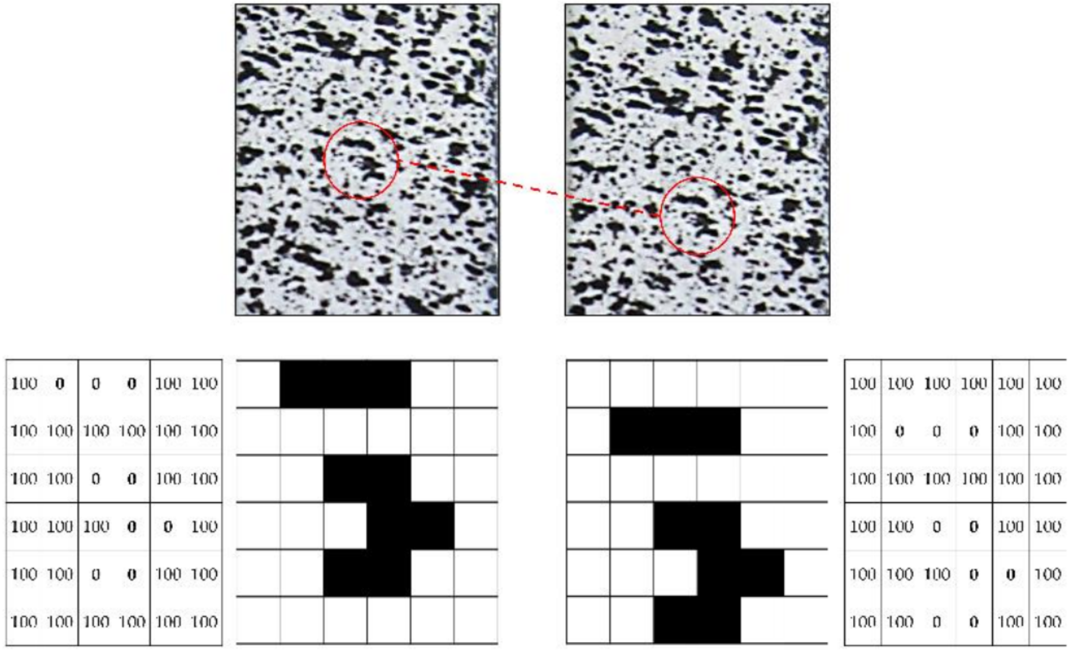
Pile Dynamic Testing →

Embedded Data Collector (EDC)
- Sensors embedded during pile casting.
(McVay et al., 2009)

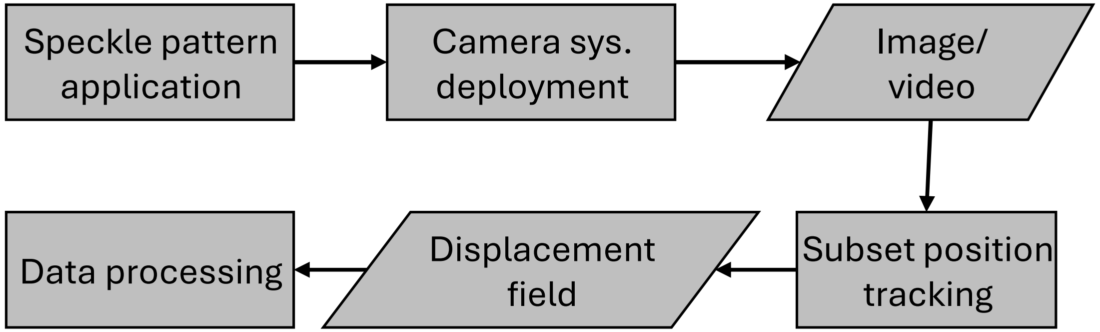
Pile Driving Analyzer (PDA)
- External sensors attached to the pile head.
(Pile Dynamics, Inc. 2000a)

Technical Background: Digital Image Correlation

- **Digital Image Correlation (DIC):**
  - Non-contact optical, full-field displacement/strain measurement technique based on the tracking pixel subsets between a reference and deformed image (Sutton et al, 2009).
  - Types: subset-based (local), finite element-based (global)
  - Challenges: motion blur, vibration of camera, poor pattern contrast



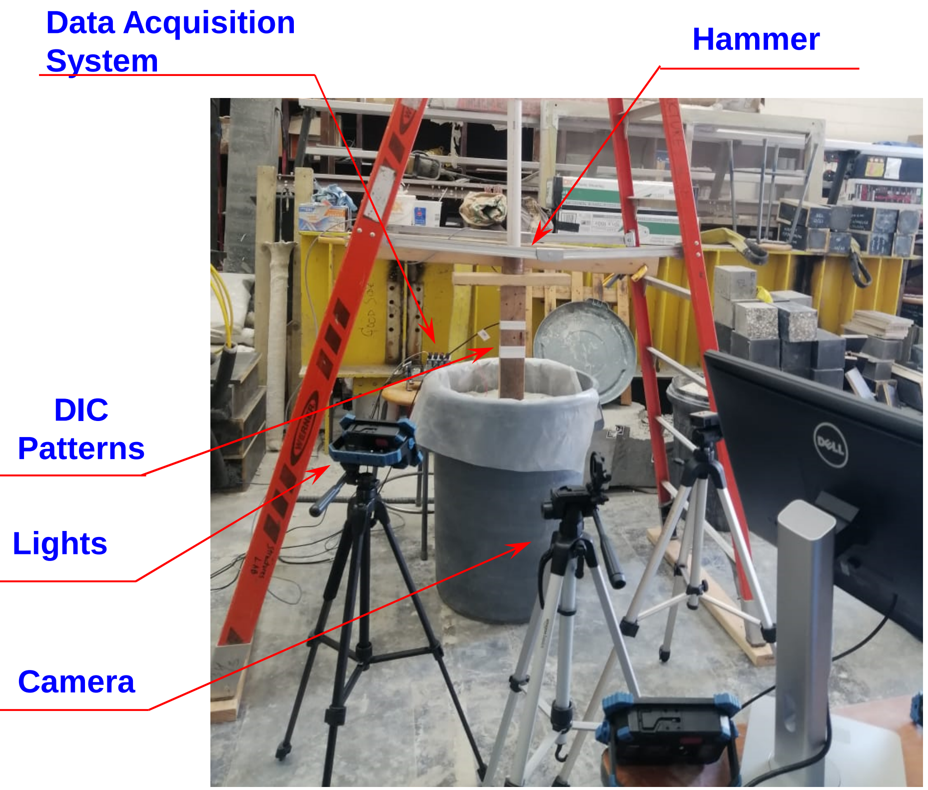
Subset deformation (left) before and (right) after deformation
(Gamboa et al., 2019)

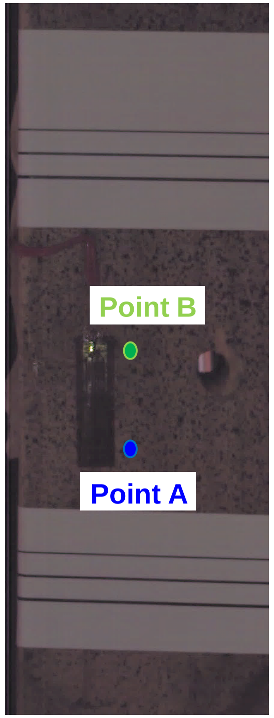


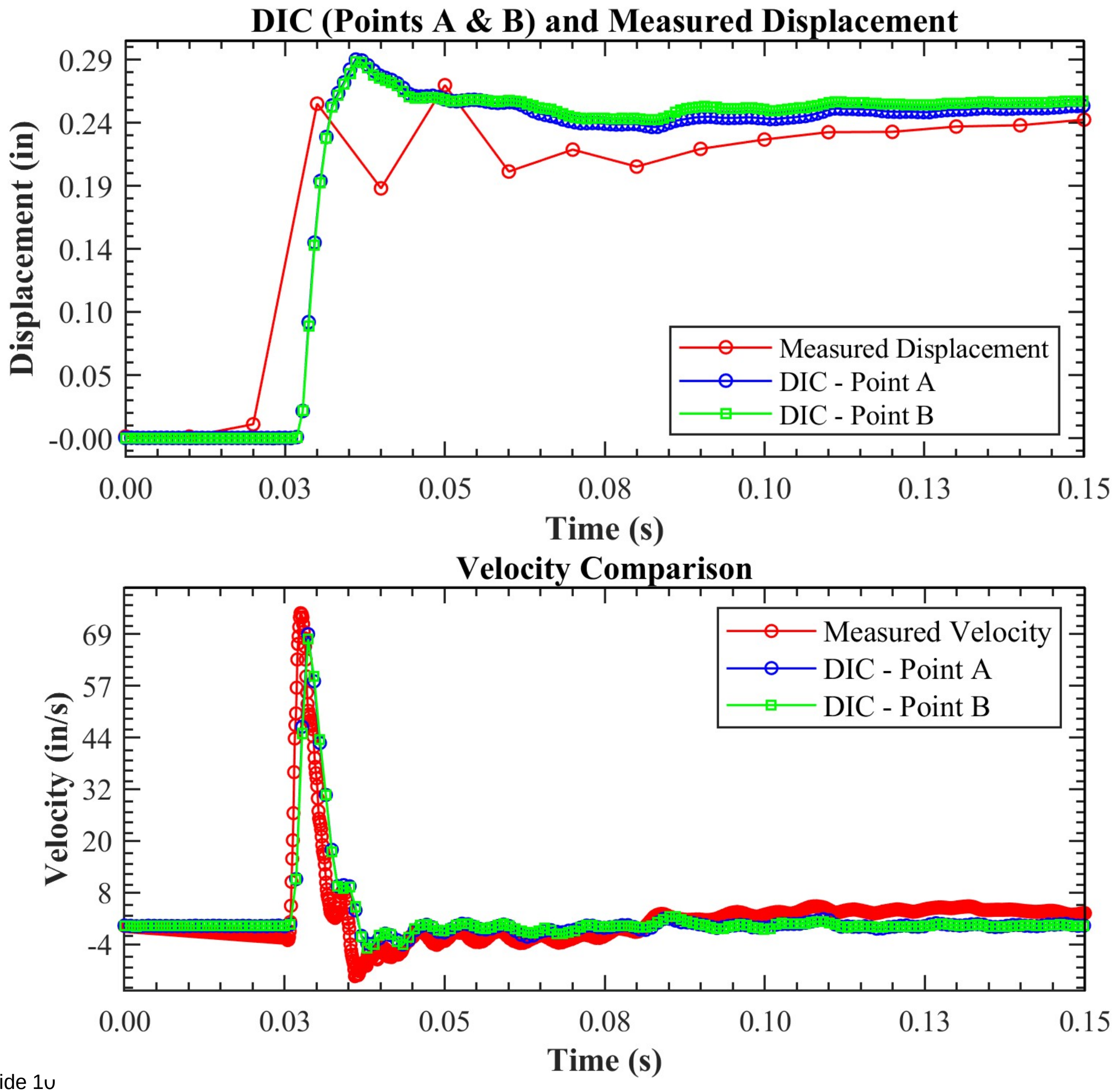
DIC flowchart

Some baby steps…

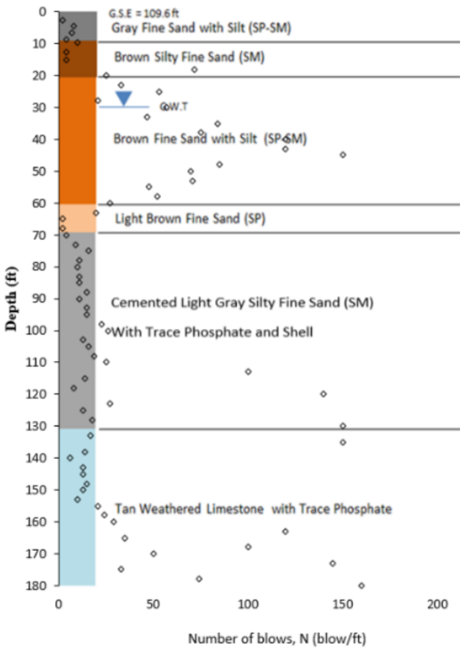
- **Progress:**
  - Preliminarily tracked pile displacement and velocity with 2D DIC at 1,000 Hz.



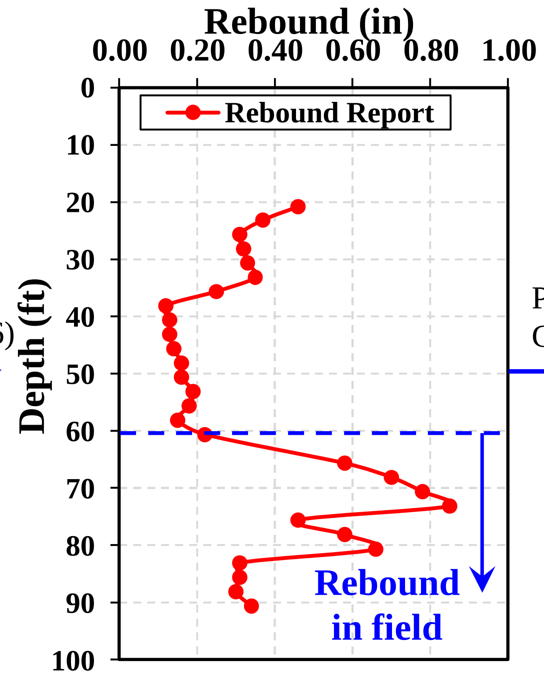




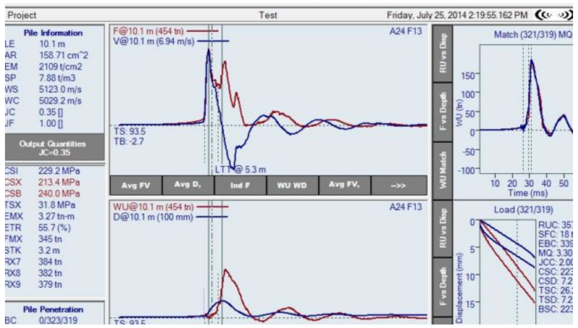
Some baby steps…

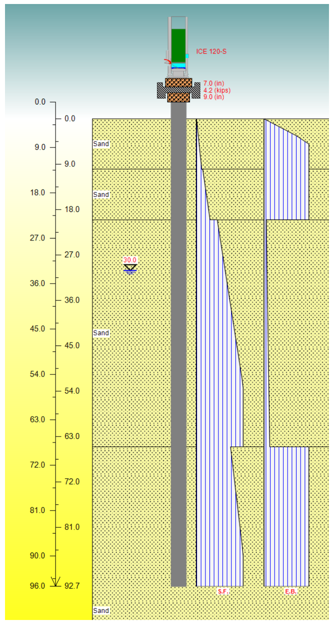


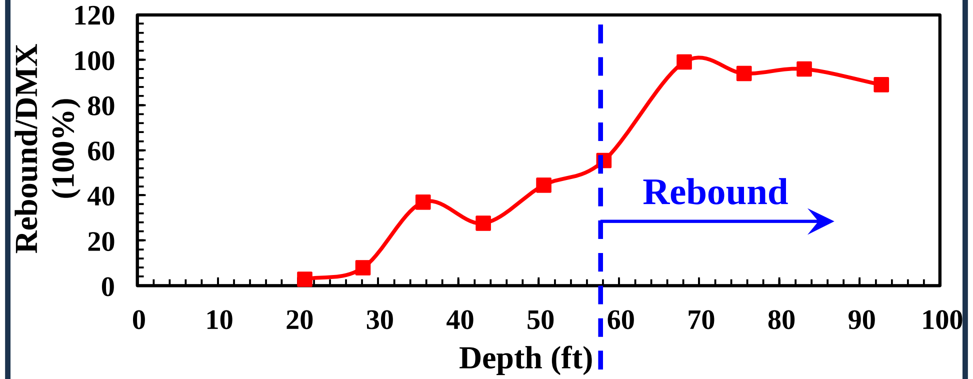
I-4/US 192: Consentino (2016)

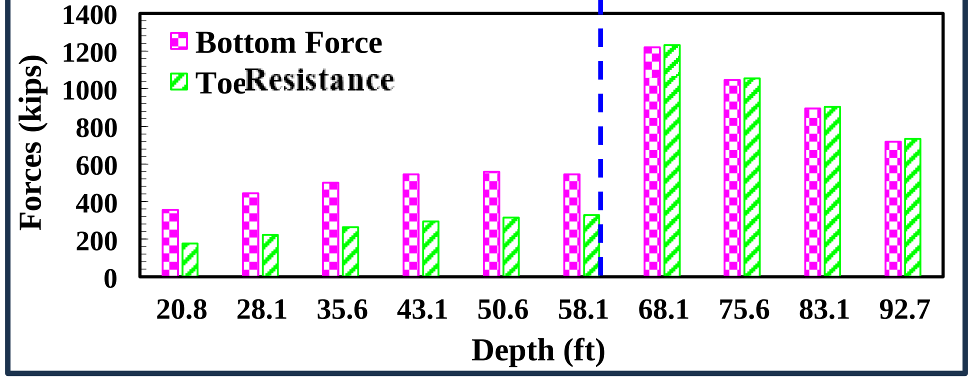


PDA information and GRLWEAP runs









- PDA information and GRLWEAP runs to correlate when rebound is triggered: input energy, toe resistance, total force (static and dynamic) at the bottom.
- Correlation to quantify the risk of rebound should account for key geotechnical and pile driving parameters influencing rebound behavior.

Deliverables and Timeline

TASKS AND ASSOCIATED DELIVERABLES	DATE
Kickoff teleconference	06/2025
Deliverable 1: A technical report presenting the results of the technical background on pile monitoring instrumentations, existing applications of ultra-high-speed cameras, image processing methods, and past case studies.	09/2025
Deliverable 2: Development of high-speed camera sensing system and data collection, and development of image processing algorithm for digital image correlation	02/2026
Deliverable 3: Small-scale rebound and pile resistance demonstrational testing in laboratory environment.	07/2026
Deliverable 4: Medium-scale physical model testing of rebound and pile resistance in high-bay structural laboratory.	12/2026
Deliverable 5: Full-scale field application and demonstration at selected pile driving sites	02/2027
Deliverable 6a: Draft final report	03/2027
Deliverable 6b: Closeout teleconference meeting and PowerPoint presentation	04/2027
Deliverable 7: Final report	04/2027

Thank you!