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DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

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DEPARTMENT OF CIVIL AND COASTAL ENGINEERING

Residual Stresses in Bored Piles (Pending approval of scope)

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Presentation Outline

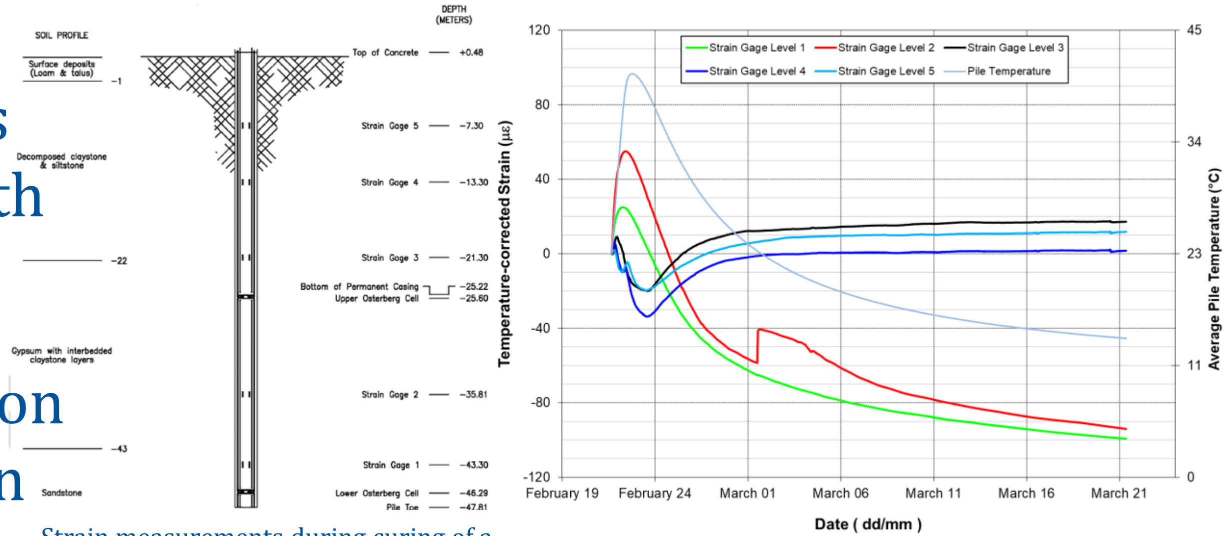
- Introduction
- Research Motivation
- Project Objectives
- Project Tasks

Introduction: Residual Stress in Deep Foundations

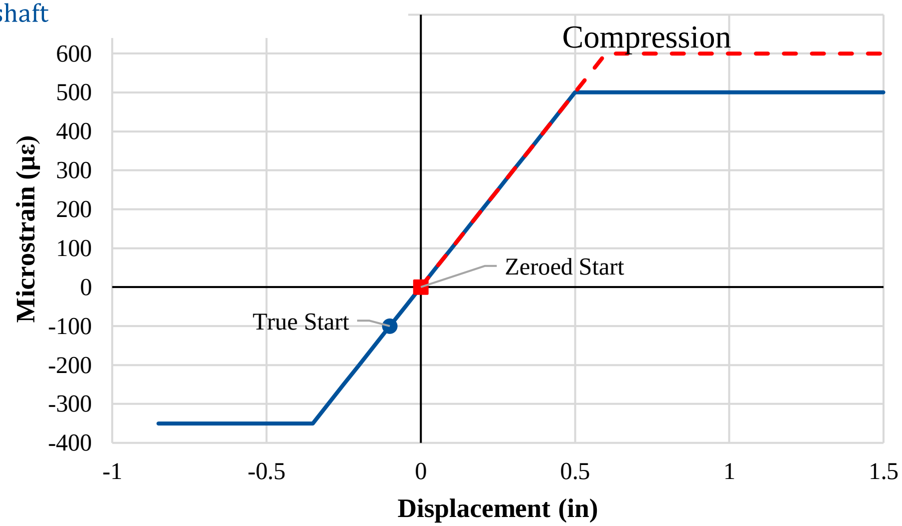
- Residual stresses are tension stresses that develop in the pile/shaft during the grout curing phase; influenced by
  - Length of the pile/shaft - 25 ft vs 125 ft ACP
  - Layering – interbedded layers of soil and rock vs just soil
  - Drilling/grouting with highly variable pile/shaft diameters
  - Grout mix design/selection and volumetric change during curing
- Residual stress leads to
  - Different top down or bottom up mobilized side shear in a segment of pile/shaft
  - Microcracks of sufficient size (high residual stresses) that result in higher axial strains in pile/shaft further from the applied load than strains closer to the load
  - Shortened pile/shaft integrity (life span)
  - Introduces epistemic uncertainty in the MWD QA/QC – Can be addressed!
- Little work has been done to quantify it and account for it in load test results
- Distributed Fiber Optic Sensing (DFOS) allows cm scale resolution of temperature and strain measurements on single cables

Research Motivation – Grout Curing Tension Strain

- Small residual compression strains in shaft segment with steel casing
- Large residual tension strains in segment in soil/rock layer – unpredicted compression
- Zeroing gages for load test leads to erroneous mobilized side friction



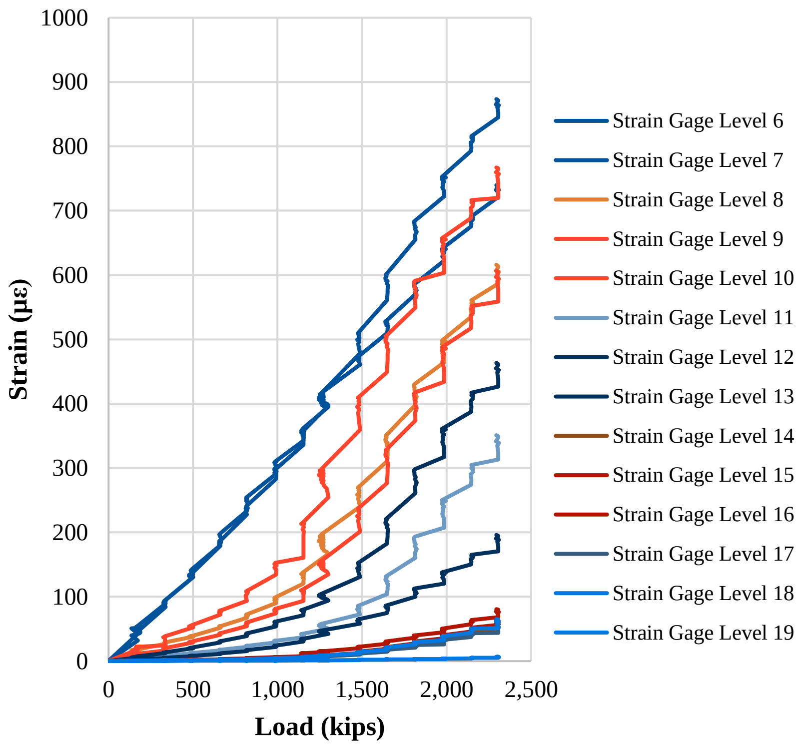
Strain measurements during curing of a drilled shaft



Theoretical load path for strain gage 1

Research Motivation – Load Test Observations

- Tension strains neglected in load test data
- Irregular strain profile
- Absolute strain needed

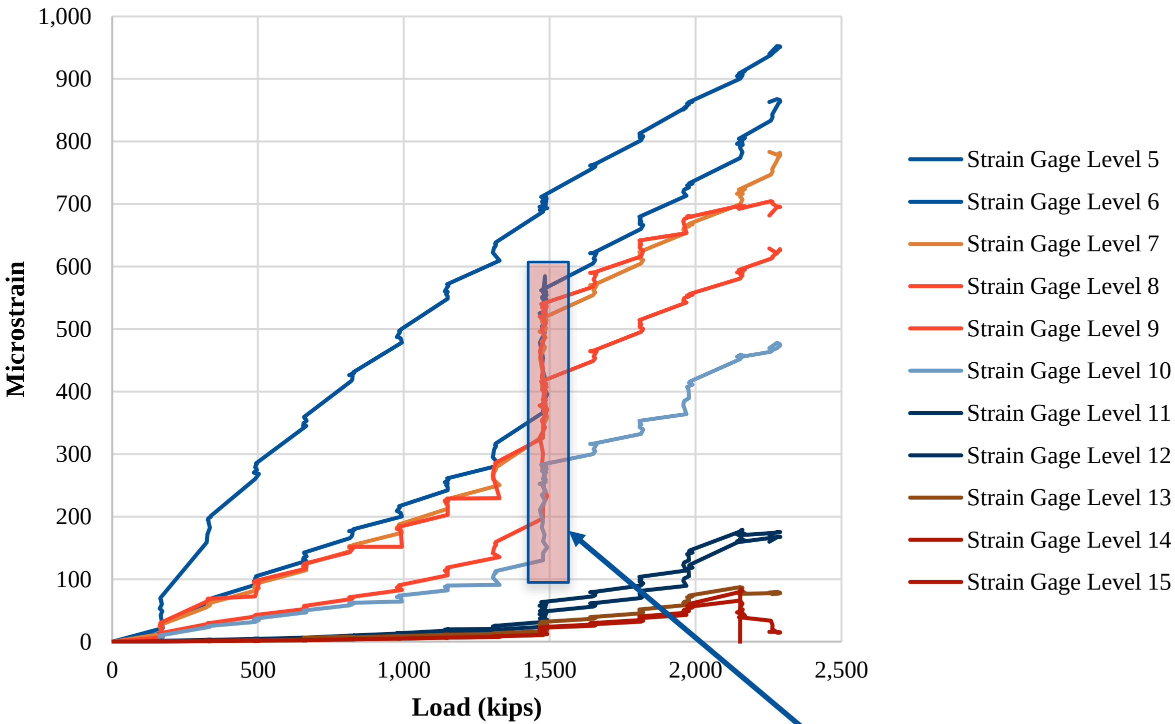


I-395 test pile axial strains as a function of applied load in LTA test

Strain Gauge Level	Maximum Strain (με)
7	873.6
9	767.0
6	739.8
8	615.8
10	606.3
12	463.2
11	350.9
13	196.0
15	80.5
18	65.6
16	65.0
14	60.9
17	55.9
19	6.6

Research Motivation – Tensile Micro-Fracturiing

- Micro-fracturing in concrete during curing may be occurring
- Resulting in highly non-linear pile rigidity (EI)
- Increased pile compression before mobilization
- Increases moisture and oxygen ingress, steel corrosion of piles/shafts in porous limestone



SR-836 test pile axial strain as a function of load

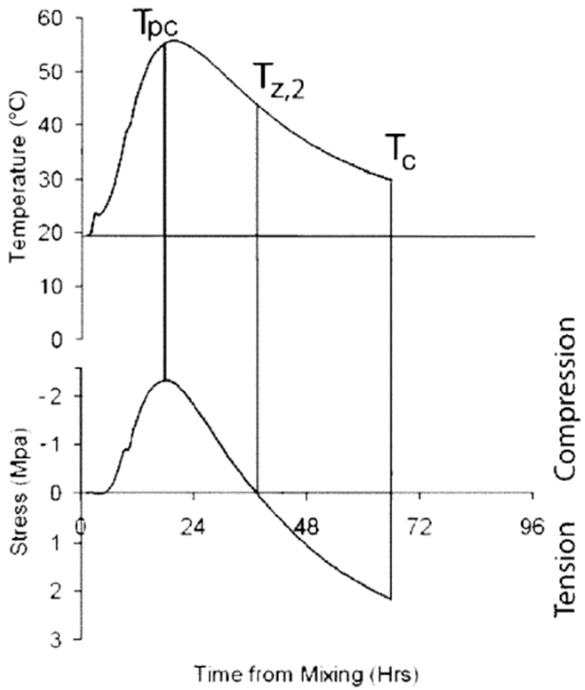
200 με of micro-fracture closures during 1,500 kips sustained for 1 hr and LTA movement of 0.09 inches

Research Motivation – Contributing Factors

- Geologic layers may contribute to residual stress development
  - MWD profiles indicated multiple shaft segments in low strength soil/rock bounded by higher strength rock layers in Miami-Dade
  - TIP profile in these segments indicated larger shaft radius than design
    - Agreed with MWD strength profiles
  - Large tension strains measured in “bound” pile segments
- Drilling process
  - Drilling penetration rate is high in weaker geomaterials and low in stronger geomaterials
  - TIP profiles show non-uniform and larger diameter holes made with high penetration rate
  - Large residual stresses measured in piles/shaft segments with non-uniform diameter holes (high penetration rate)

Research Motivation – Contributing Factors

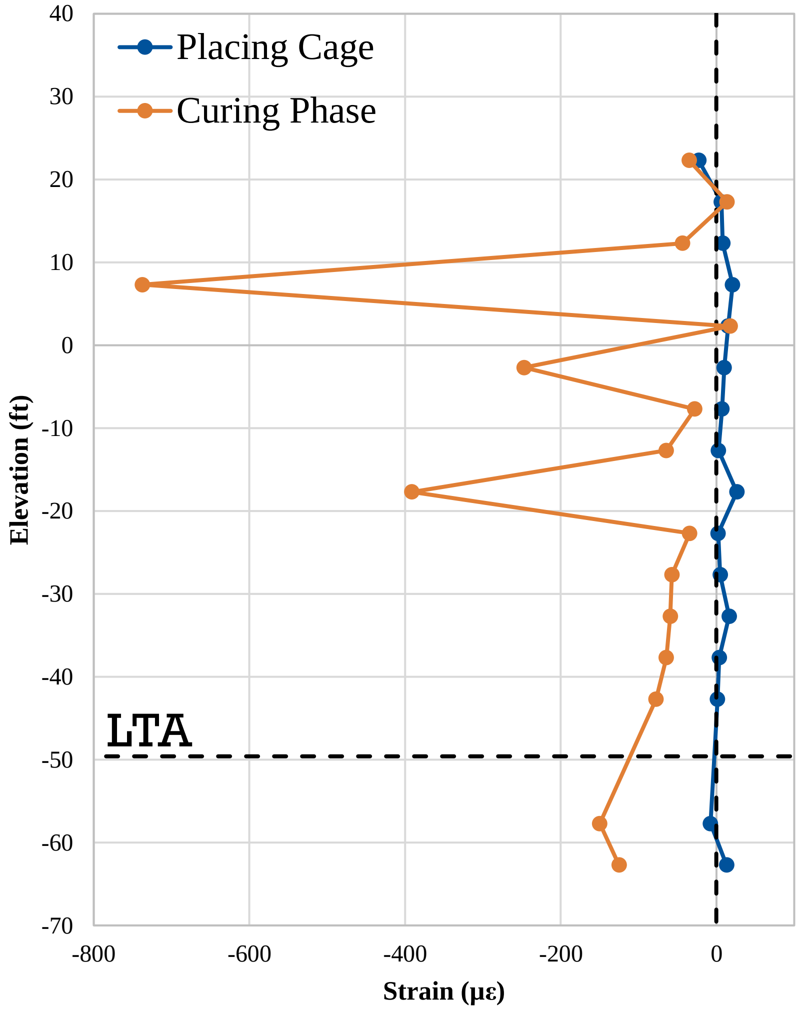
- Concrete curing process
  - Rigid cracking frame tests (concrete specimens cast with fixed ends) , weak geomaterial bound by strong geomaterial, (permanent casing in drilled shaft) exhibits compression then tension during heat of hydration.
  - Fixed ends like weak geomaterial bound by strong geomaterial and permanent casing in drilled shaft (test piles/shafts the exhibited tension and compression strains).



Curing temperature and strains in rigid cracking frame

Research Motivation – Contributing Factors

- LT Consultant stated "high tensile curing strains were observed in strain readings" for multiple Miami-Dade load test reports
- UF recorded strain readings at multiple phases prior to load test
  - Cage lying on ground
  - Immediately after cage placement
  - Prior to start of load test
- Limited strain change noticed during cage placement
- Significant strain changes observed during curing phase



Research Motivation – Contributing Factors

- Geomaterial thermal conductivity and concrete mix
  - Thermal strains influenced by surrounding geomaterial conductive property
  - Thermal conductivity of geomaterials a function of mineralogy, dry density, moisture content, gradation, time, temperature
  - Concrete heat of hydration are sensitive to additives in mix design
  - Fast setting-high strength mix designs may be commonly used
  - Geology may need to be considered in mix design for piles/shafts

Project Objectives

The project's primary objective is to study the thermal influence on residual stress development in bored piles and identify an appropriate design method for axial capacity of ACIP piles with residual stress while adding to the MWD dataset of South Florida limerock.

We will conduct a test program on 3 ACIP piles that includes MWD with rock core testing for strength and thermal properties, grout mix design study and lab testing of curing temperatures and strains using DFOS, monitoring pile temperatures and strains during curing using DFOS and strain gages, measuring strains during axial load tests using DFOS and strain gages, modeling of curing bored pile, and establish T-Z model(s) for bored piles with residual stress.

Proposed Tasks

1) Task 1: MWD Controlled Drilling Investigation
   - Controlled drilling vs. high penetration rates through weak geomaterial
   - Identify strength of rock and maximum expected side friction
   - Build new correlation or add data points to South Florida set

2) Task 2:Grout mix and thermal conductivity investigation
   - Thermal conductivity measurements of geomaterials in the lab
   - Controlled testing grout mixes with varied additives
   - Measure temp. and thermal stress using DFOS

Proposed Tasks

3) Task 3: Monitor ACIP Pile Temperature and Strain
   - Install DFOS and strain gages to continuously measure temperature and thermal stress during curing
   - Pile top movement and ambient temperature required

4) Task 4:Load Test Program and FB-Multipier Analysis
   - Load test ACIP piles in South Florida where axial strain is measured on 10 cm increments using DFOS and strain gages are employed for validation
   - Higher resolution strain distribution will provide more points for correlation to MWD in formations tested
   - Establish residual stresses in piles based on curing strains and temperatures (moduli)
   - Establish T-Z models that account for residual stresses that can be used in soil and rock using FB-Multipier

Thank You!