Deep Foundation Integrity How Do You Know?!

Rob Kramer
Geophysical Services Manager

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Outline

- What is Deep Foundation Testing (DFT)?
- Why is it important?
- Common DFT Methods with Case studies

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The Ask

- Make it a standard practice to recommend DFT (integrity or load) on projects that include deep foundations
  - We're doing this at Terracon, and there are various states and companies that are also making this the standard.

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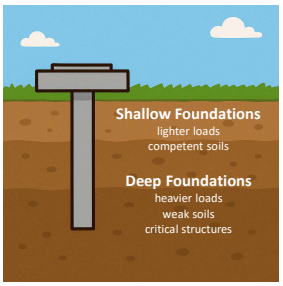
Shallow or Deep?




2024 Key Bridge Collapse, Baltimore


Millenium Tower, San Francisco

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Types of Deep Foundations?

Drilled Foundations
Shafts, piers, caissons

Auger Cast in Place (ACIP)

Driven Piles
H-piles, pipe piles, concrete piles, timber piles

Micropiles
Helical Piers
Rammed Aggregate Piers

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Why We Care

- Deep Foundations are a critical and expensive part of any project
- Observe consistent quality issues
  - Discrepancies in logs
  - Disagreements over means and methods
  - Failing equipment
  - General incompetence
- Believe DFT should be included on all projects with Deep Foundations
  - Frequency can range from 1 test pile/shaft to 100% of foundations.
  - Include SOME DFT in project to improve confidence in foundation system
- Protects all parties involved

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Avoid the Circular Firing Squad

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Deep Foundation Testing

Quality Inspections and Monitoring

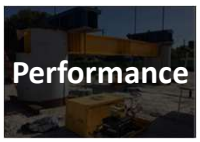
- Concrete/Grout Testing
- Manual/Visual Inspections and logs
- Shaft Inspection Device (SID)
- Shaft Area Profile Evaluator (SHAPE)/SoniCaliper

Integrity Testing

- Cross hole Sonic Logging (CSL)
- Thermal Integrity Profiling (TIP)
- Low Strain Integrity Testing/Pile Integrity Testing (PIT)

Load Testing

- High Strain Dynamic Testing/Pile Driving Analysis (PDA)
- Static/Lateral Load Testing
- Osterberg (O-cell) Testing



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Quality Inspections and Monitoring

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Concrete/Grout Testing

- 3 Primary Tests performed on Concrete or Grout
  1) Slump Test
  2) Compressive Strength Test
  3) Drying Shrinkage Test
- These are all performed on concrete as it comes out of the truck, not testing the actual concrete placed in the foundation.

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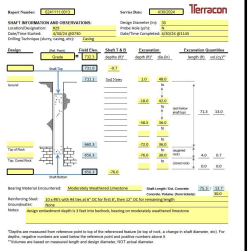
Manual/Visual Inspection or Logs

- Confirm important as-built information
- Concrete Foundations
  - Elevations
  - Dimensions
  - Deviations
  - Delays in concrete
  - Head pressure
- Driven Foundations
  - Tip and cut off elevations
  - Pile type and length
  - Weld inspections
  - Stroke height
  - Fuel setting
  - Drive log



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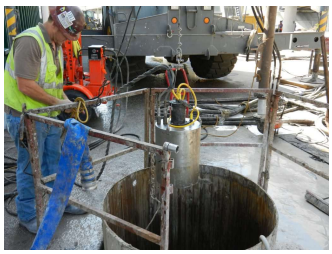
Shaft Inspection Device (SID)



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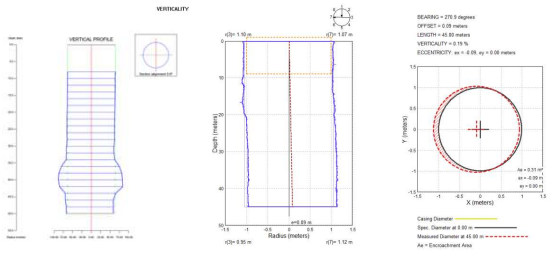
Shaft Area Profile Evaluator (SHAPE) Sonic Caliper



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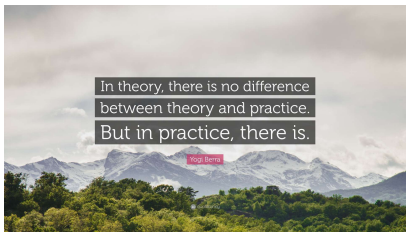
Integrity Testing



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Cross-hole Sonic Logging (CSL)

- Diagnostic tool for:
  - Integrity of drilled shafts
    - Repair Evaluation
  - Anomalies in arrival time and relative energy
  - Information for inside of the cage
  - Capable of limited 3D modeling
  - FHWA Rating Criteria
- Many false positives
  - Debonding
  - Cross-bracing
  - Large shaft – signal strength

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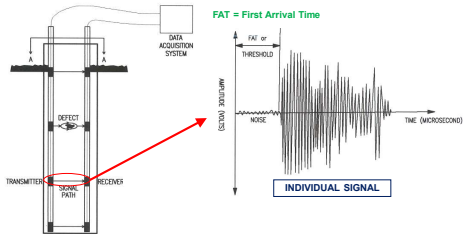
CSL Analysis



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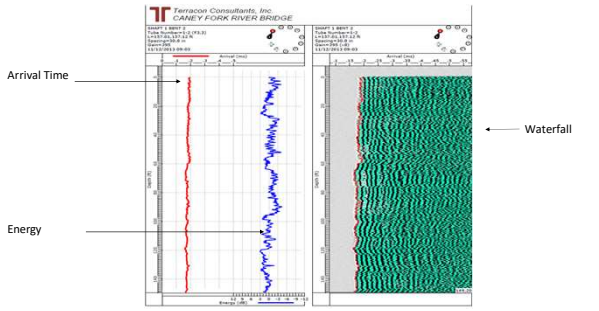

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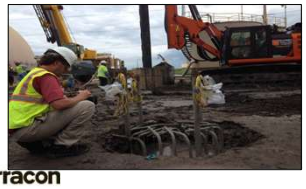
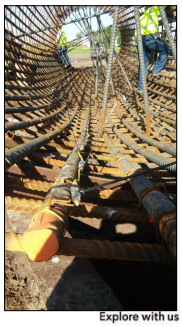
Thermal Integrity Profiling (TIP)

- Diagnostic Tool for:
  - Integrity of drilled shafts/auger cast piles/soil nail walls
  - Anomalies
  - Cage alignment
  - Amount of concrete cover
  - Information outside of the cage
    - Increase and/or reduction in section
- Lesser false positives, but no established rating criteria





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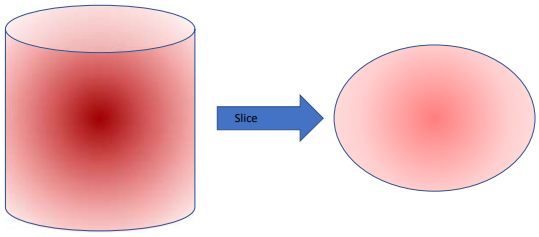
THERMAL INTEGRITY PROFILING



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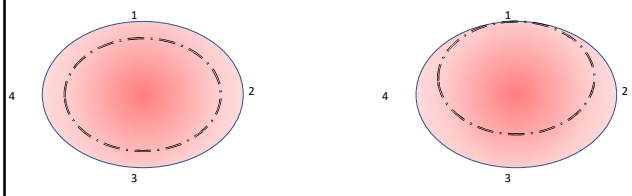
THERMAL INTEGRITY PROFILING
CAGE SHIFT



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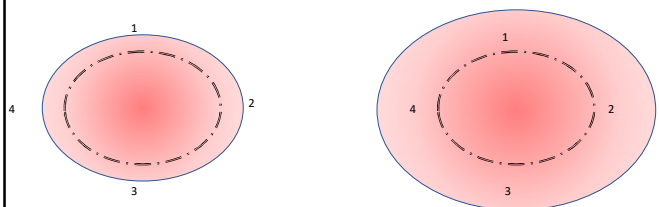
THERMAL INTEGRITY PROFILING
CONCRETE COVER



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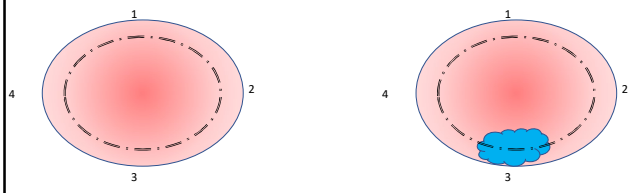
THERMAL INTEGRITY PROFILING
ANOMALY



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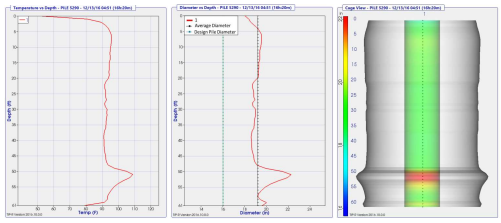
Auger Cast-In-Place (ACIP) Piles



Temp vs. Depth | Diameter vs. Depth | Calculated Diameter

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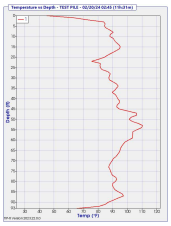
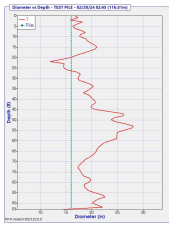
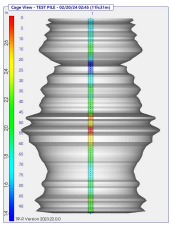
Auger Cast-In-Place (ACIP) Piles



Temp vs. Depth



Diameter vs. Depth



Calculated Diameter

*Load test was performed after anomaly observed and failed

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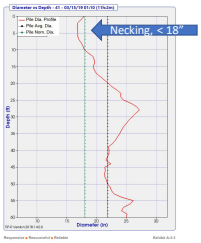
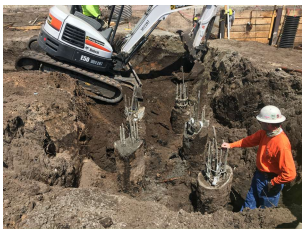
Auger Cast-In-Place (ACIP) Piles



Temp vs. Depth



Field Confirmation

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Auger Cast-In-Place (ACIP) Piles

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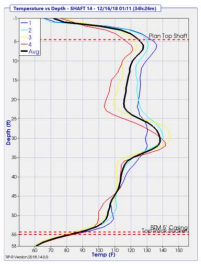
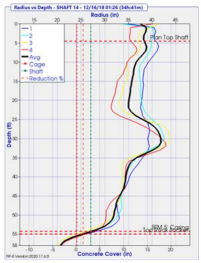
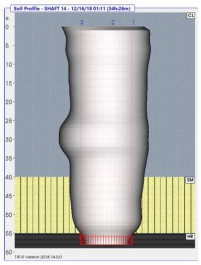
Drilled Shafts



Temp vs. Depth



Diameter vs. Depth



3D Model

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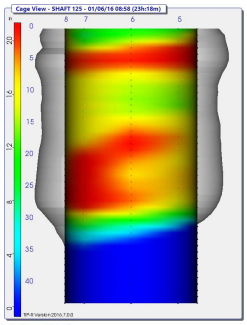
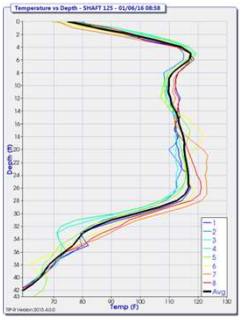
Drilled Shafts





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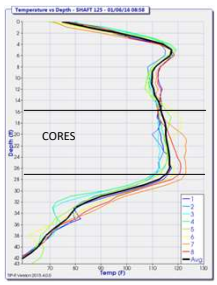
THERMAL ANALYSIS

Structure 125 – Southwest Core. Concrete cores from 15 to 25 feet.



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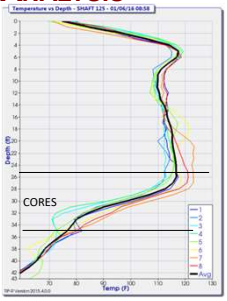
THERMAL ANALYSIS

Structure 125 – Southwest Core. Concrete cores from 25 to 35 feet.



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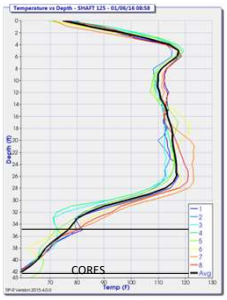
THERMAL ANALYSIS

Structure 125 – Southwest Core. Concrete cores from 35 to 44 feet.



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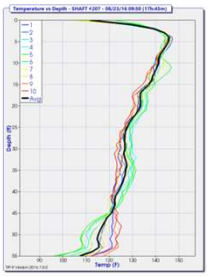
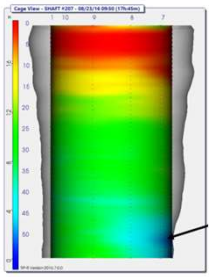
THERMAL ANALYSIS





"Isn't that the shaft that the chute fell off the concrete truck?"

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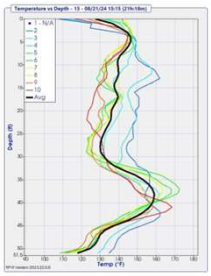
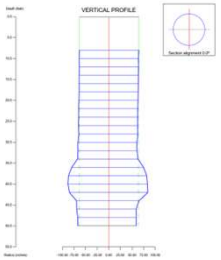
TIP and SHAPE





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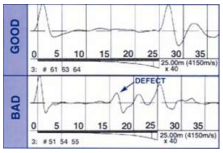
Pile Integrity Test (PIT)

aka Low Strain Integrity Test, Sonic Echo/Impulse Response



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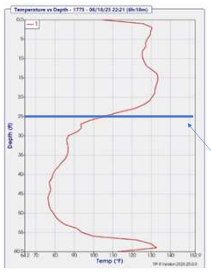
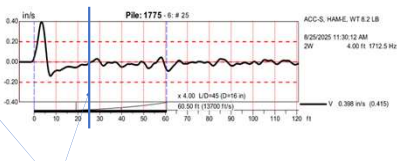
PIT and TIP





Apparent necking at 25 ft

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Load Testing

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Wave Equation Analysis of Pile (WEAP)

- THEORETICAL driveability analysis
- Analyses:
  - Soil Conditions
  - Pile size/type
  - Hammer size/type/fuel setting
- Provides:
  - Theoretical max capacity
  - Theoretical drive criteria for nominal design capacity

Pile Driving Analysis (PDA)

- High Strain Dynamic Testing
- Real time measurements of force and velocity on every hammer blow
- More economical than static load testing
- Tested with same pile driving equipment as production
- Confirms capacity is being met
- Evaluates hammer performance
- Confirms driving criteria
- Ensures piles aren't over stressed
- Confirm setup or relaxation with retap

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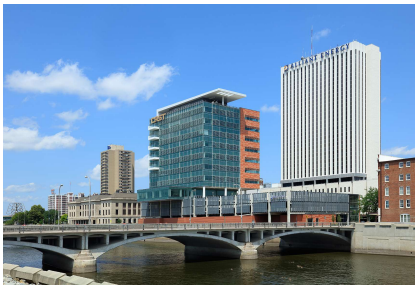
Mississippi River Bridge, MO


Structure Near River

- WEAP ≠ reality
- Original hammer not sufficient to achieve capacity
- All material ordered and already on-site
- Already experienced delays in other parts of the project
- Redesigned some foundations to account for change. 3-pile groups change to 4-pile groups, etc

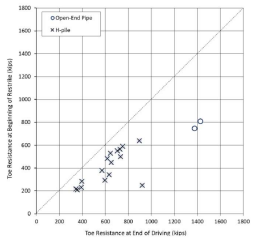


Broken Piles

- Hammer too big or pile too small to achieve capacity
- Piles can begin to bend/deform or even break during unforeseen driving conditions
- Not always observed during PDA, sometimes apparent in manual drive logs
- Better to catch it with PDA when strains are starting to increase rather than actually compromise the pile


Potential Relaxation in Shale

- Driven piles are widely used for foundation support. In the vast majority of cases, an increase in pile capacity occurs with time which is referred to as "set-up." However, in a very limited number of cases, a decrease in capacity with time can occur. This phenomenon is referred to as "relaxation." – Hannigan (GRL Engineers), 2019
- Piles driven into shales had an average toe relaxation loss of 35%. The average toe resistance loss was greater for the two open-end pipe piles (44%) than for the 16 H-piles (34%). Additional data is needed for all pile types in these end bearing materials. – Hannigan (GRL Engineers), 2019
- Should be performing PDA with = 7 day restrike to confirm set and no relaxation if bearing in shale



– Hannigan (GRL Engineers), 2019

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Static Load Testing

- Loads slowly applied to foundation, often in 10% increments. Measured with load cell and applied with hydraulic equipment.
- Required test loads often exceed 200-300% of design capacity
- Foundation settlement observed with dial gauges mounted to a stationary reference beam
- Compressive and lateral loads can be tested

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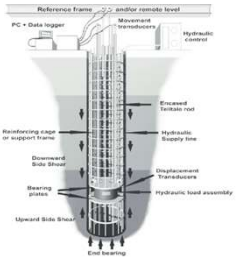
Bi-Directional O-Cell Testing

- The O-cell, or Osterberg cell, is a loading device that's placed inside the pile under test.
- Apply high loads, sometimes exceeding 220 MN, that are not possible with other static test methods.
- Simultaneously measure upward skin friction, downward end bearing, and lower frictional resistance.



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APPLE Test

- Like PDA, but dynamic testing of cast in place or augured concrete/grout piles.
- Can get capacity and skin friction information cheaper than the O-cell testing
- Specialty testing performed by GRL or limited number of foundation testing companies.

Pile Buck Magazine, 2014

Conclusion

Deep foundations are a critical and expensive part of any project

DFT has aided in identifying:
Integrity issues
Poor records keeping
Inappropriate means and methods
Failing equipment

Trust, but verify
with all 3 DFT buckets – or at least more than 1

The Ask

- Make it a standard practice to recommend DFT (integrity or load) on projects that include deep foundations
  - We're doing this at Terracon, and there are various states and companies that are also making this the standard.

Questions

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