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Advanced Interpretation of Instrumented Micropile Load Tests

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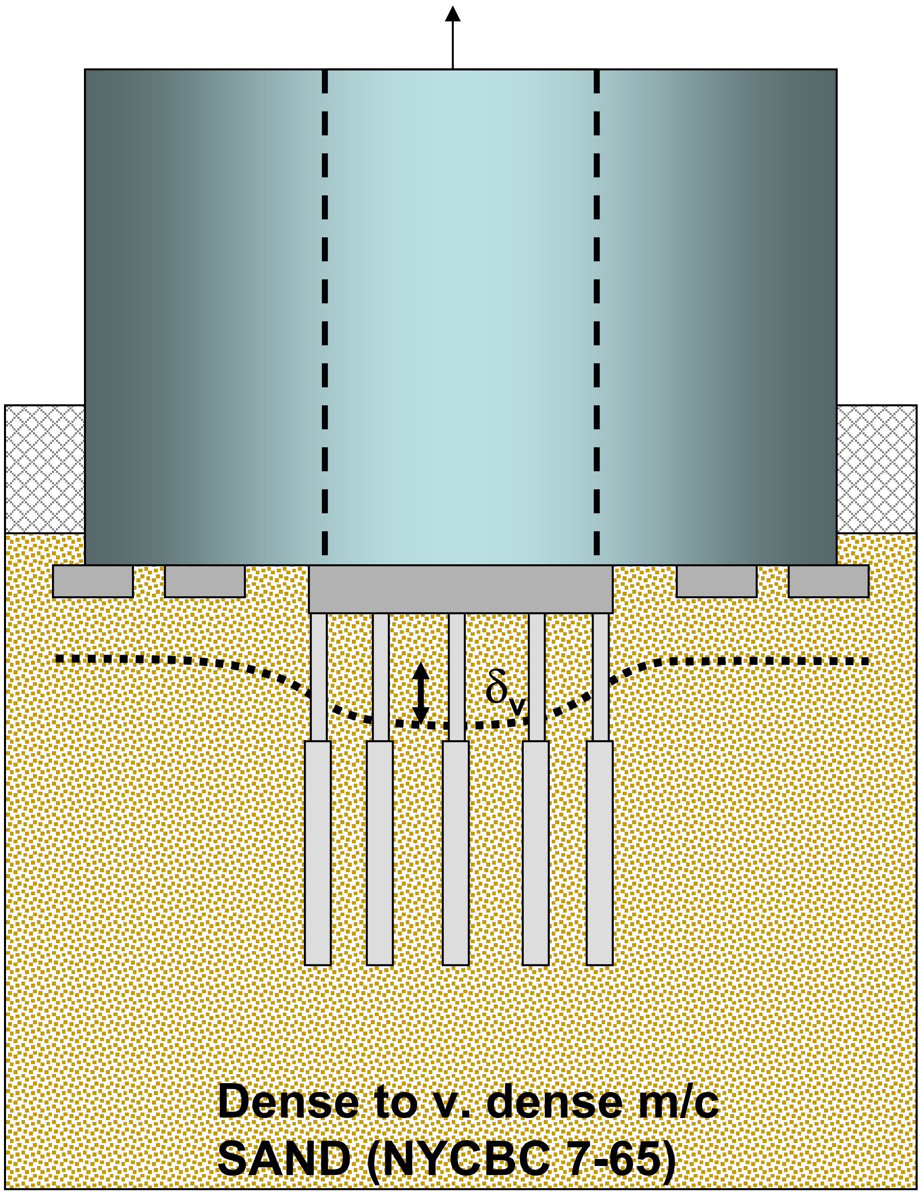
Introduction

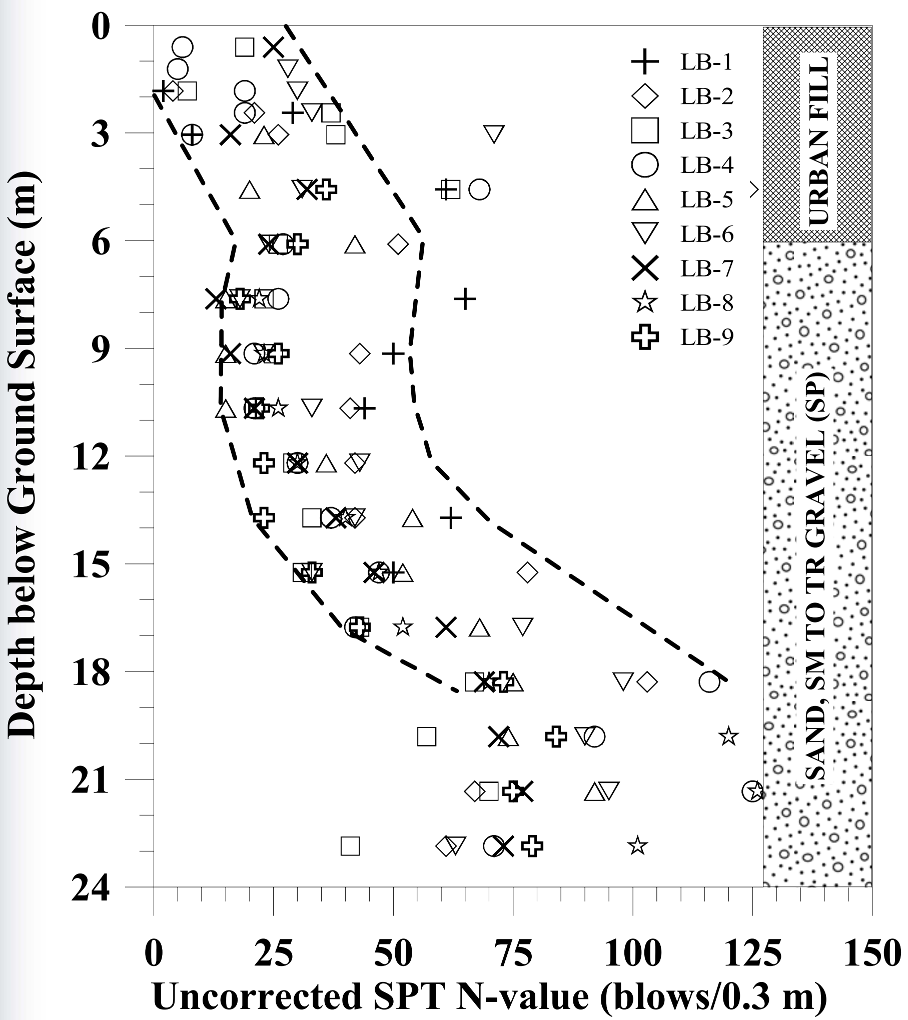
- Two case histories of strain gauge instrumented micropile load tests
  - Case History No. 1 – 167 Johnson Street
  - Case History No. 2 – Dublin Road Pump Station (DRPS)
  - All piles Type B pressure grouted with typically developed pressures of 345 kPa
- Highlight aspects of pile mechanics
  - Degradation of secant pile modulus
  - Nonuniform load distribution
  - Generation of micropile tip resistance and shaft resistance

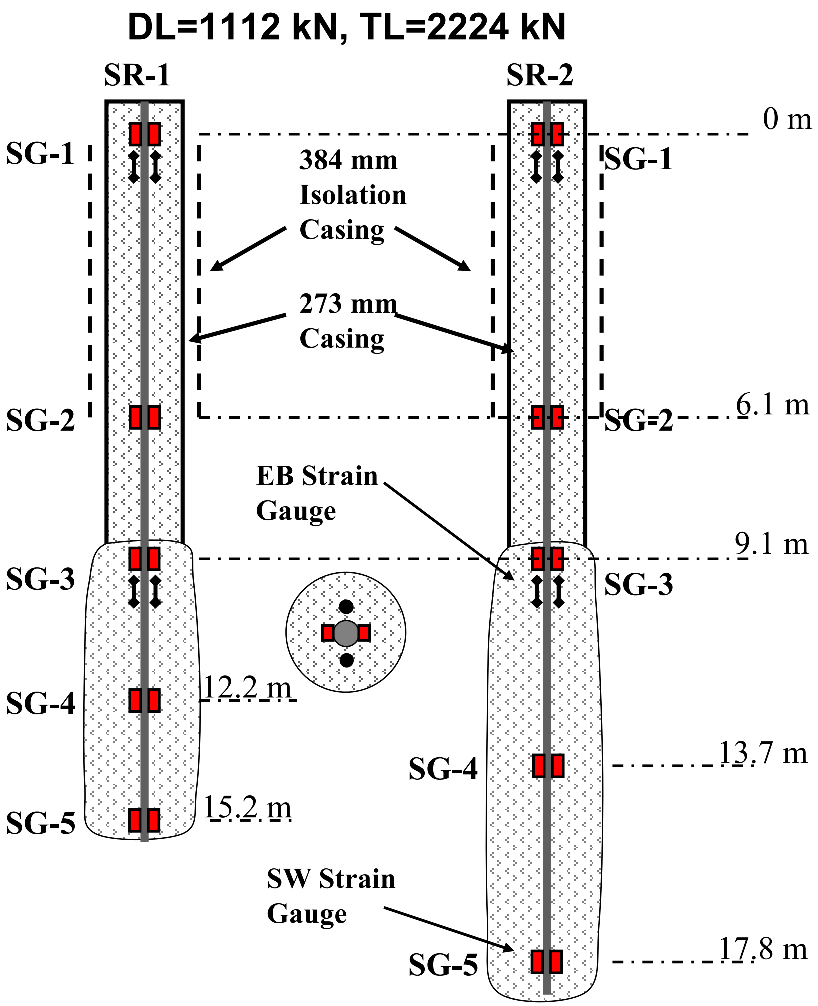
Case History No. 1-167 Johnson St

- 40+ story residential high rise on mixed mat/spread footing foundations
- Dense to v. dense sand and sand/gravel deposits
- Excessive δ_v beneath heavily loaded elevator core
- Minimize δ_v → incorporate micropiles to create "piled raft" effect
  - Allow high δ and low F.S.
- 2 strain gauge instrumented load tests
  - 14 gauges per pile



Ground Conditions and Pile Design





Instrumentation

- Spot-weldable gauges on bar (10 ea.)
  - Accuracy=15 $\mu\varepsilon$, Sensitivity=0.4 $\mu\varepsilon$
- Embedment gauges in grout (4 ea.)
  - Accuracy=15 $\mu\varepsilon$, Resolution=1.0 $\mu\varepsilon$
- Grout strength and unconfined modulus testing
  - E=13.5 to 14.5 GPa (Unconfined secant at ε=0.11%)
  - f'_c=44.8 MPa (cylinders) to 62.1 MPa (cubes)

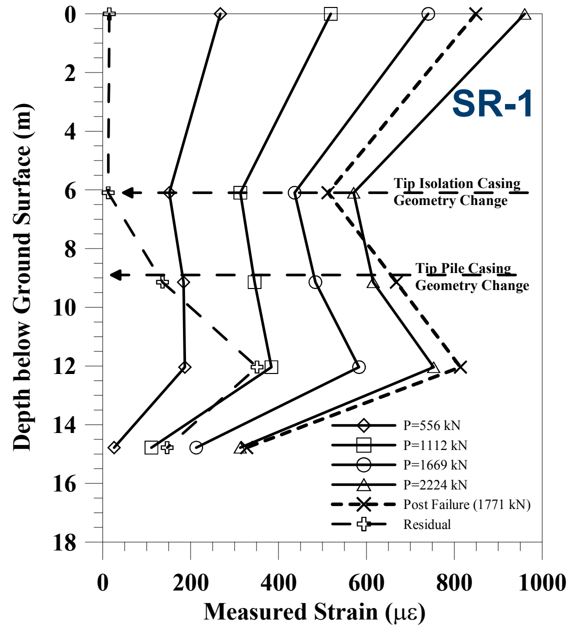
Test Pile Installation

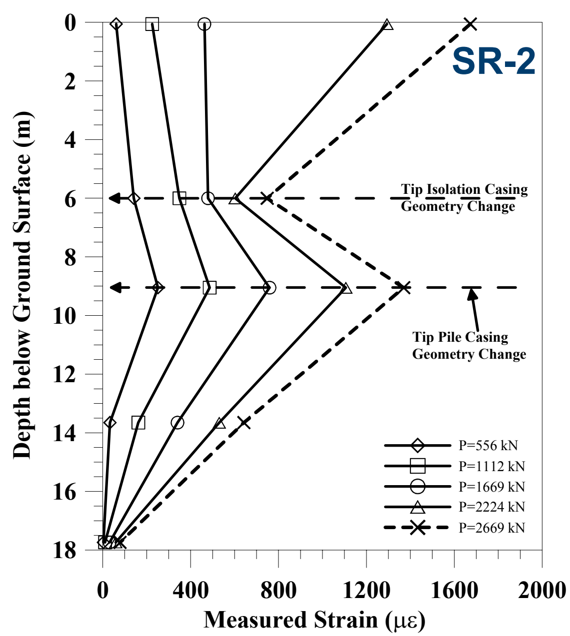
Left - Installation of 273 mm test element (pile)
Top – Installation of 194 mm diameter reaction anchor, 1334 kN capacity

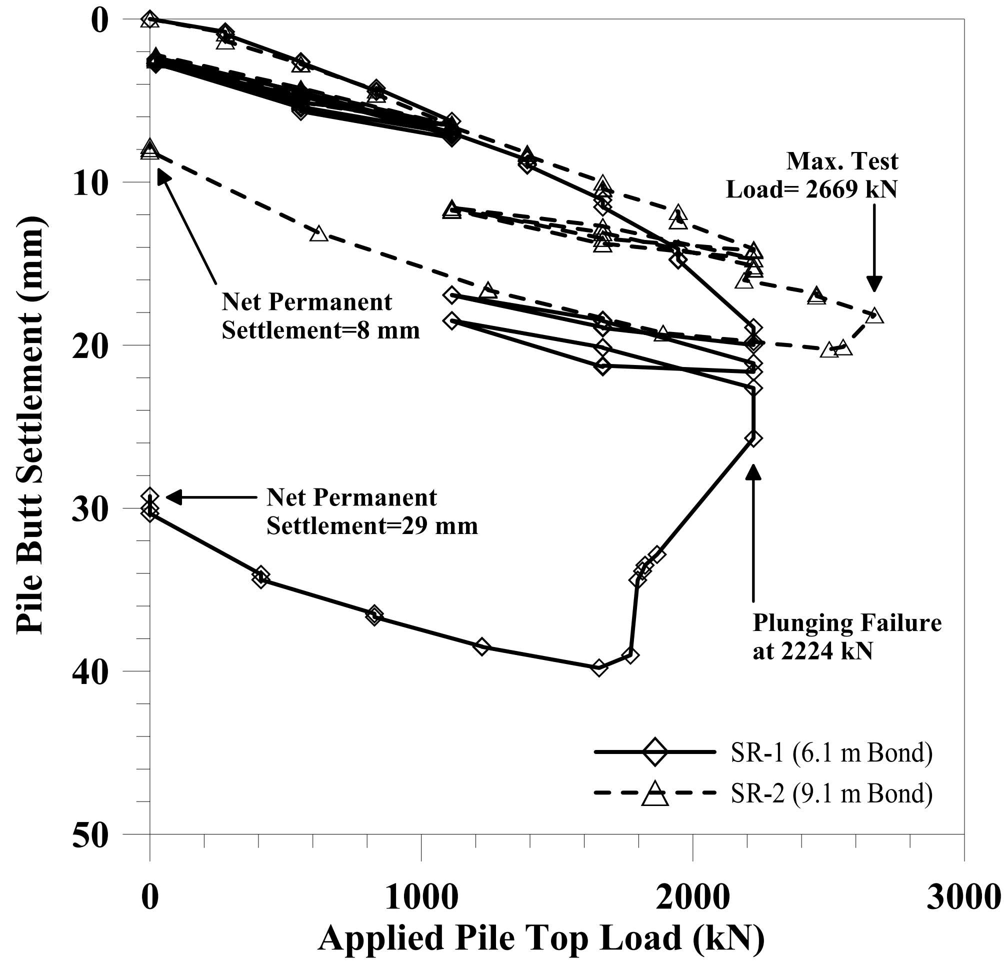
Test Pile Construction

Left - Installation of 273 mm test element (pile)
Top – Buried old foundation wall and obstructions

Load Testing Data

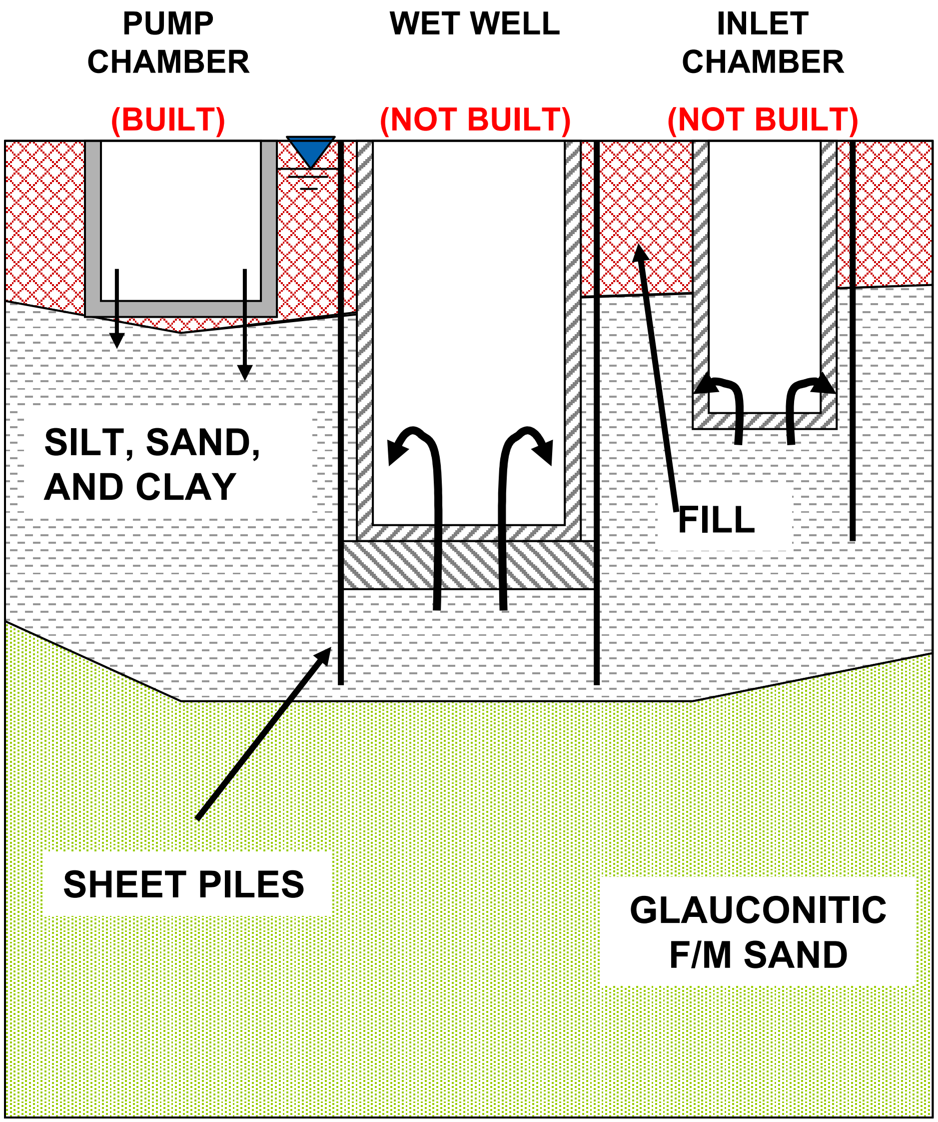




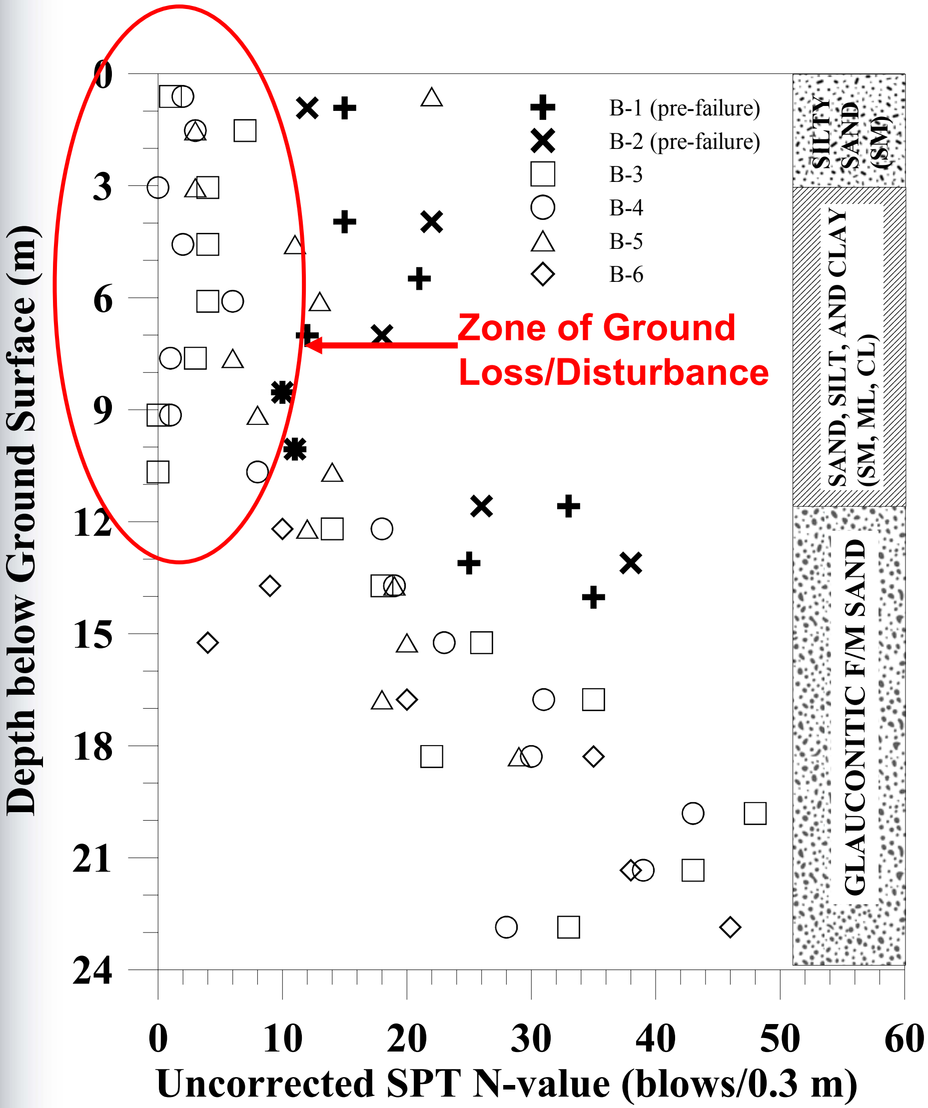


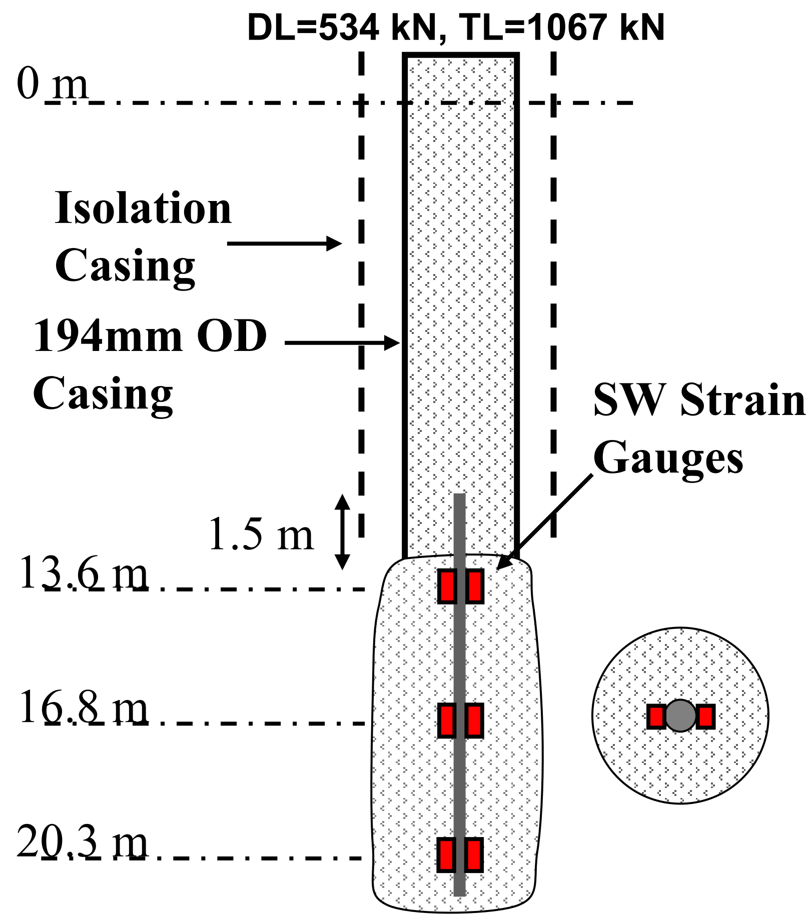
Case History No. 2-DRPS

- Ground loss, heave, and settlement around 3 pump station structures following excavation and pile driving
- Complex ground conditions
  - Excess head/high groundwater levels
  - Marine glauconitic silty fine sand deposits

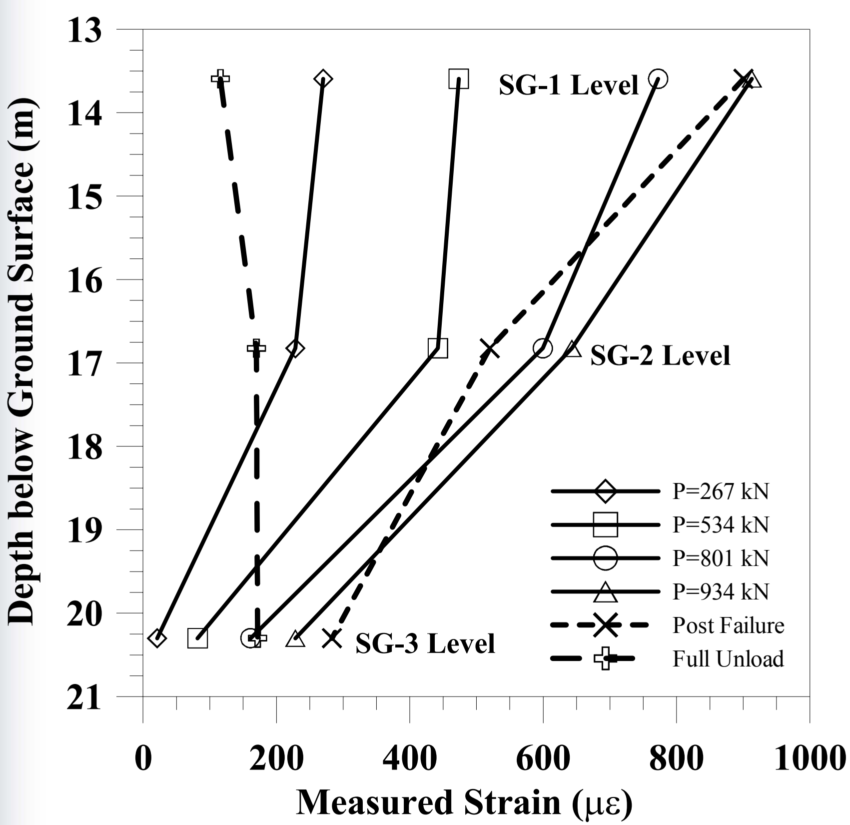


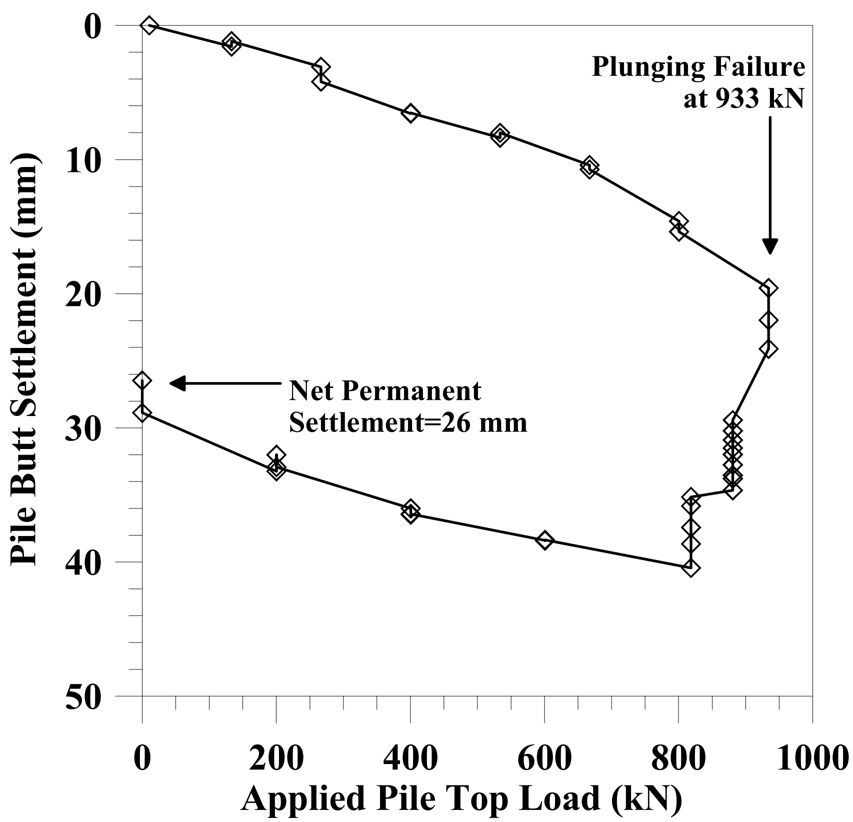
Ground Conditions and Pile Design





Load Testing Data



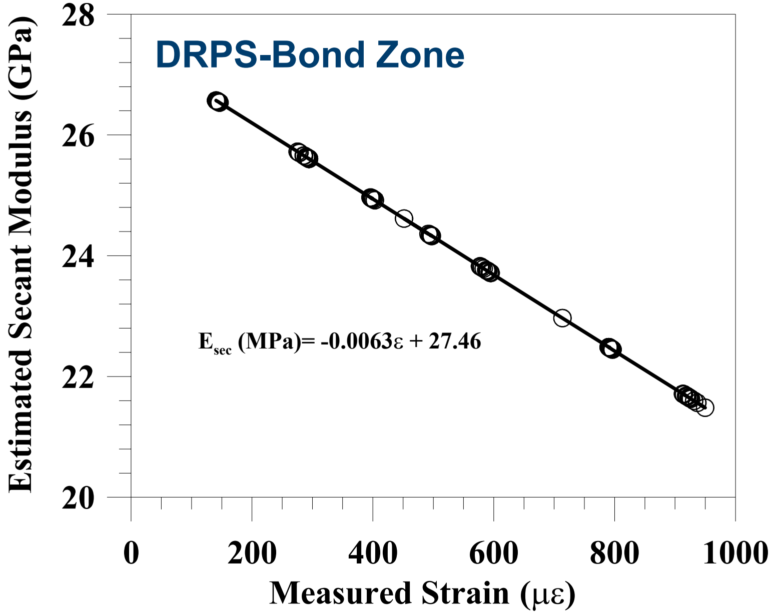


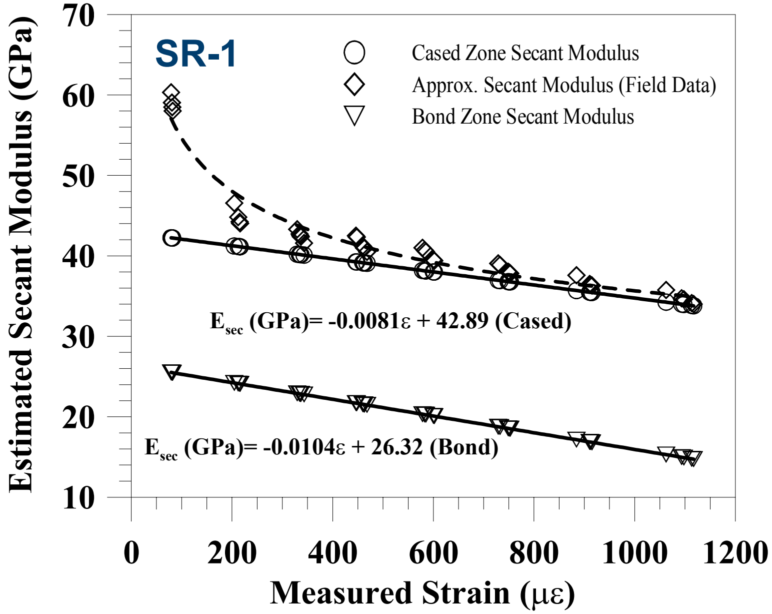
Analysis and Interpretation

- Nonlinear $\sigma-\varepsilon$ behavior of composite pile section
- Calculated load distribution along bond length
- Deformation-based generation of micropile tip resistance and bond resistance

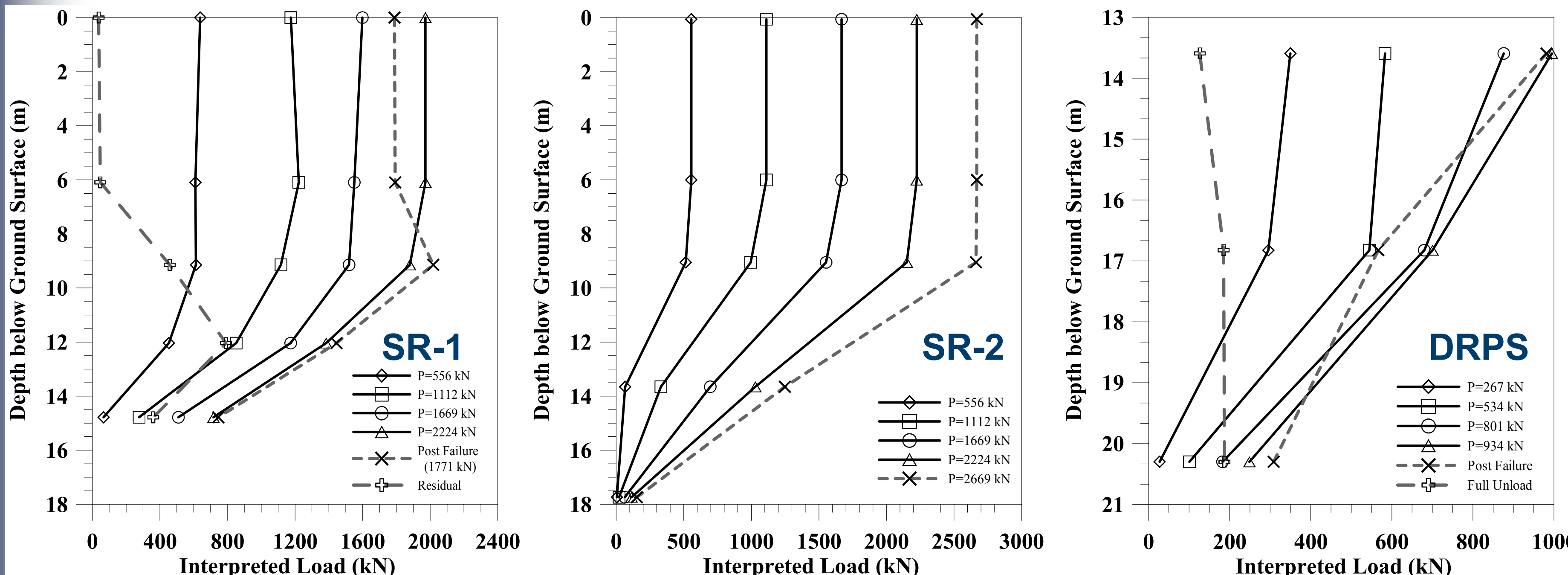
Composite Micropile Behavior

- Interpretation of load distribution
  - $P = \varepsilon A_p E_p$
- Composite pile has complex $\sigma - \varepsilon$ behavior
- Secant modulus of composite pile degrades with increasing strain
  - Linear degradation model invoked
- Calculate E_{sec} as $f(\varepsilon)$





Load Distribution



- Non-constant mobilized bond stress for piles with short bond length (SR-1 and DRPS)
  - Approaches constant value near failure
  - 16-23 kN/m for SR-1, 25-28.5 kN/m for SR-2, 8.5-12.1 kN/m for DRPS
- Significant ultimate tip resistance for SR-1 and DRPS
  - 19-25% of total ultimate capacity (300-700 kN)

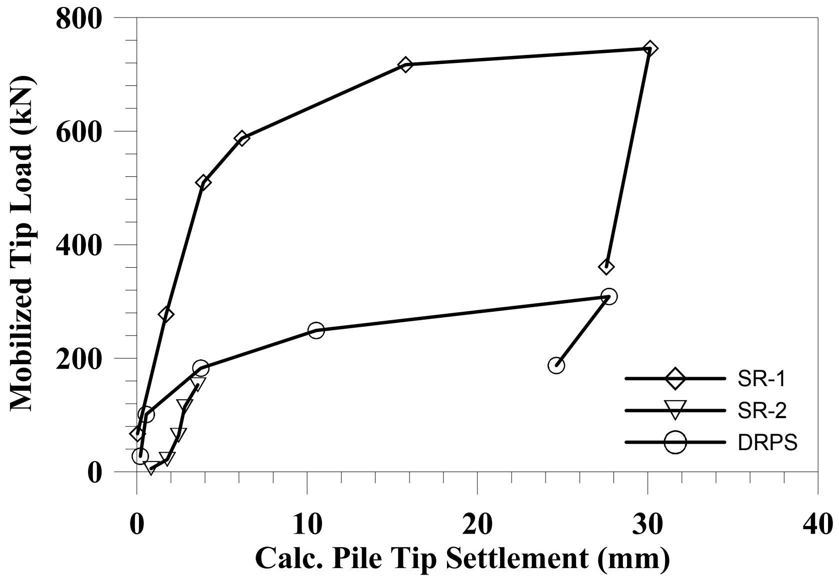
Generation of Tip Resistance

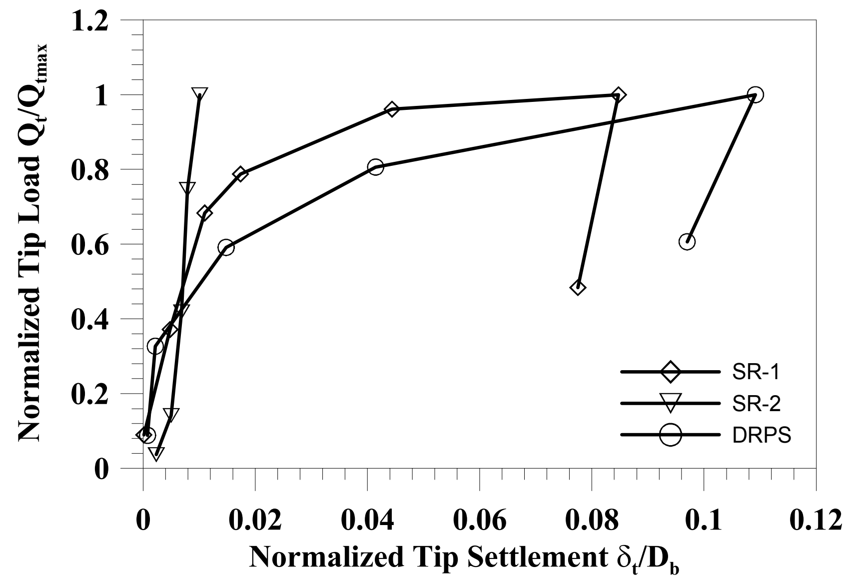
- Total pile deformation

$$\delta = \delta_c + \delta_b + \delta_t$$

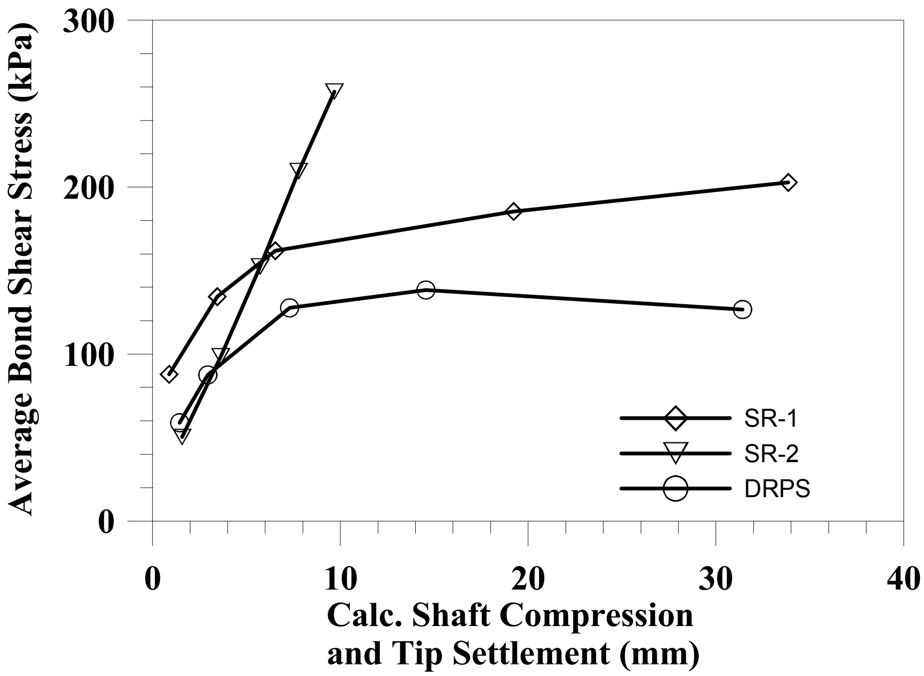
$$(\delta_c + \delta_b) = \int_L \varepsilon dz$$

- Tip resistance mobilizes nonlinearly for piles with short bond length
  - Initial yield at settlement ratio of 0.01 to 0.02
  - Limiting values at settlement ratio of 0.08 to 0.10
- Small tip resistance developed for SR-2
  - No failure condition
  - Denser soils at pile tip
- Trends similar to larger deep foundations





Generation of Bond Resistance



- Develops with compression of bond zone and tip displacement ($\delta_b+\delta_t$)
- 6 to 8 mm of deformation required to initiate failure for short bond length piles (≈0.1% L_b)
- Ultimate τ reached between 10 and 20 mm (≈ 0.2% L_b)
- No failure for SR-2 with long bond length

Summary and Conclusions

- Strain gauges can point out changes in pile geometry
- Composite, nonlinear nature of micropiles complicates stress-strain response
- Resistance distribution is nonuniform along bond length
- Significant micropile tip resistance may be mobilized for shorter bond length piles
- Instrument for better understanding!!

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Summary and Conclusions

- Implications for analysis and design
  - Structural assessment of micropile response should account for real $\sigma-\varepsilon$ behavior (i.e. nonlinear material behavior)
  - For controllable design scenarios micropile tip resistance could be considered
  - Short bond lengths for micropiles should be used cautiously due to the relatively small bond movement/compression required to reach ultimate capacity

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