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Column Supported Embankments: Applications and examination of installation effects and soil-column interaction on system efficacy

Kyle Shatzer, PE, Menard USA

Aaron Gallant, PhD, PE, University of Maine

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Overview

- **Introduction to Menard**
- **Controlled Modulus Columns (CMCs)**
- **Typical CMC Design for CSES**
- **Case Studies**
  - Rail embankment slope failure and remediation, Burns Harbor, IN
  - Council Bluffs Interstate System (CBIS) – I-80 / I-29 / US-275, Council Bluffs, IA
- **CBIS research: Applications and examination of installation effects and soil-column interaction on system efficacy**

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No, not that "Menards"

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Menard USA Office Locations

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Soletanche Freyssinet Group

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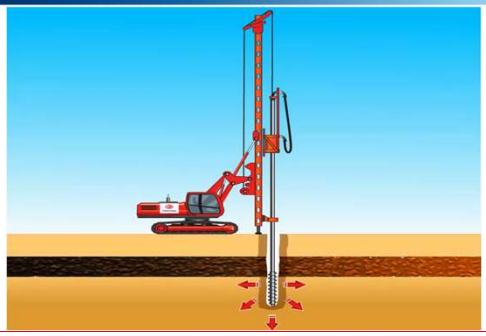
Controlled Modulus Column (CMC)



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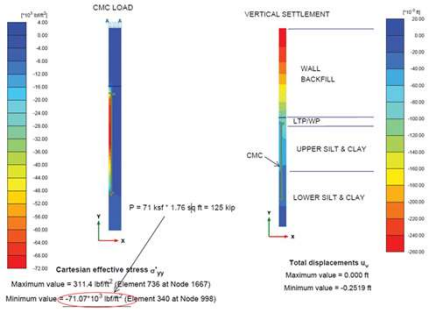
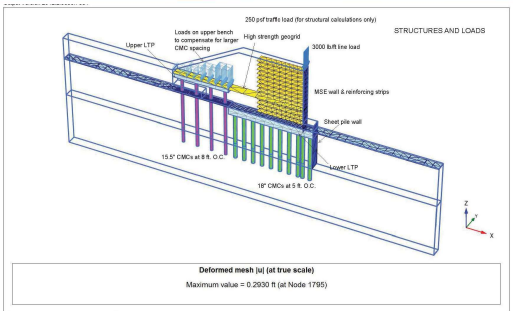
Typical CMC Design for CSES

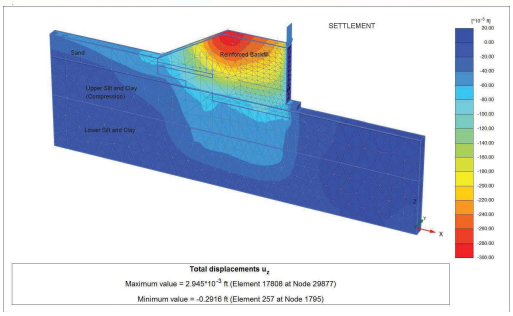
Start with: 2D Axisymmetric Finite Models



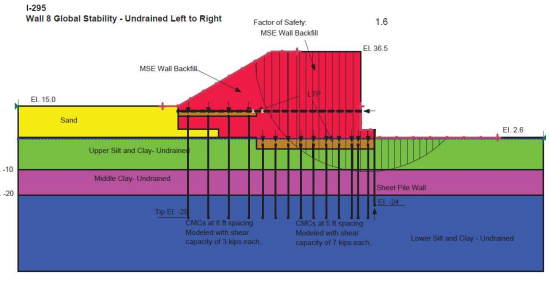
Next: 2D Plane Strain or 3D Strip FE Models



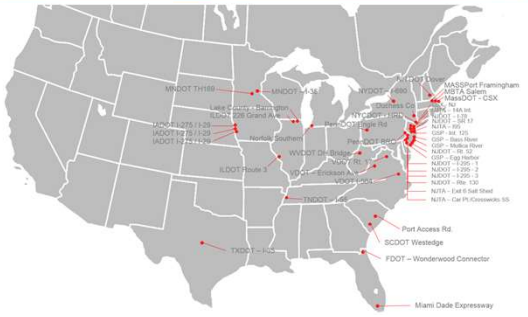
2D Plane Strain or 3D Strip FE Models



Finally: Check stability with SLIDE

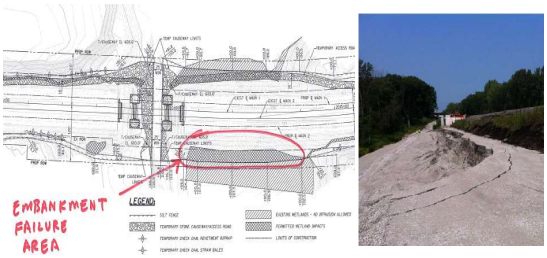


CMC-Supported Embankment Project Locations



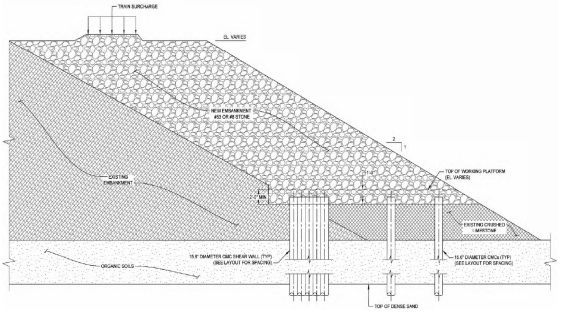
Case Study: Rail Embankment – Burns Harbor, IN

Case Study: Rail Embankment – Burns Harbor, IN

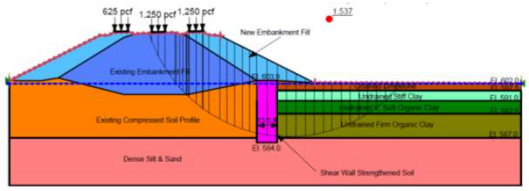


Slope failure remediation for rail embankment widening

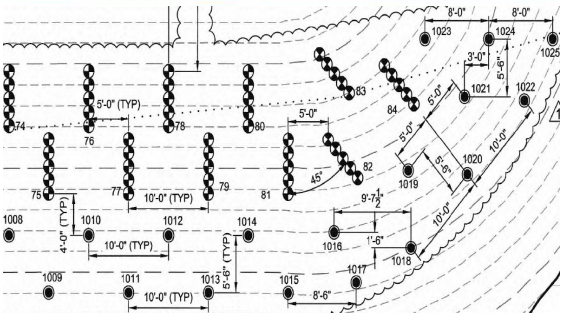
Case Study: Rail Embankment – Burns Harbor, IN



Case Study: Rail Embankment – Burns Harbor, IN



Case Study: Rail Embankment – Burns Harbor, IN

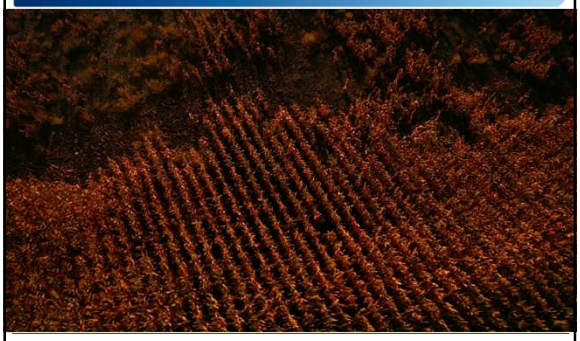


Case Study: Rail Embankment – Burns Harbor, IN

Case Study: Rail Embankment – Burns Harbor, IN

Case Study: CBIS I-80 / I-29 / US-275

Case Study: CBIS I-80 / I-29 / US-275 (97) – Summer 2014



Case Study: CBIS I-80 / I-29 / US-275

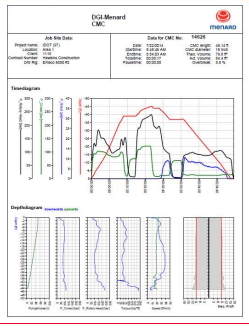
(97) Contract – 2014 – Hawkins

- 7 work areas
- 14,200 CMCs (519,000 lf)
- 8 ASTM D1143 load tests
- Design: CH2M

(102) Contract – 2015 – Ames

- 6 work areas
- 11,500 CMCs (377,000 lf)
- 5 ASTM D1143 load tests
- Design: CH2M

Quality Control: Rig Logs, CIT, Load Testing



Case Study: CBIS I-80 / I-29 / US-275

Column-Supported Embankments: Performance of CSE's at Council Bluffs Interchange System (CBIS)

Geo-Omaha 2018

Aaron Gallant, PhD, PE
University of Maine

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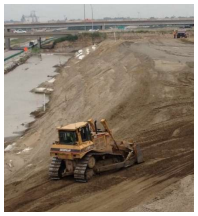
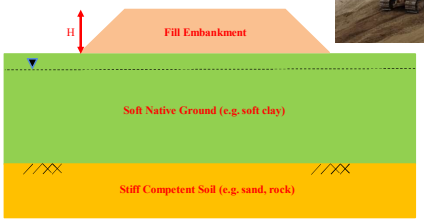
Fill Embankments





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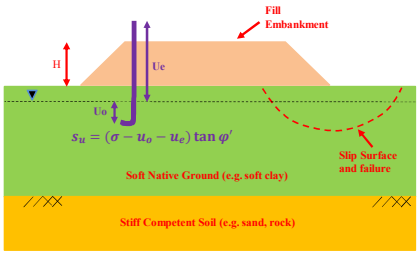
Fill Embankments (Stability)



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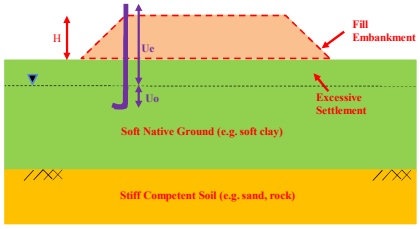
Fill Embankments (Settlements)



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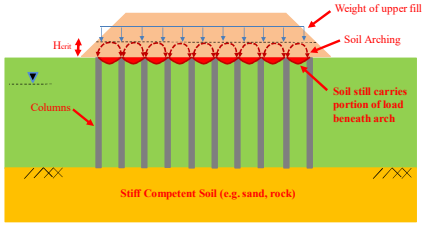
Column-Supported Embankments



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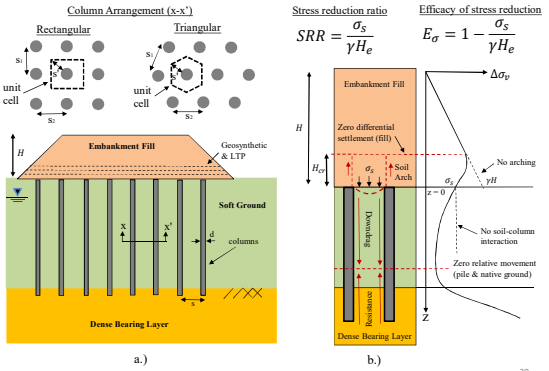
Subsurface arching and hang up effects



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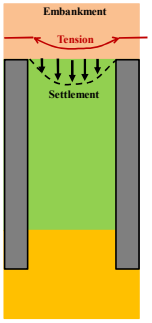
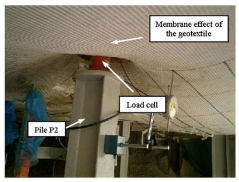
Geosynthetic and LTP:

Geosynthetic helps bride loads between columns and reduce σ_s applied to soil.





After, Le Hello and Villard (2009)

Le Hello, B., Villard, P. (2009). "Embankments reinforced by piles and geosynthetics-numerical and experimental studies dealing with the transfer of load on the soil embankment." *Engineering Geology*, 106, 78-91.

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Why use column-supported embankments?

- Stability
  - How is strength impacted by your ground improvement?
  - Is strength gain time-dependent?

Ground Improvement Compatible with Schedule and Stability Constraints?

- Schedule
  What are the time constraints?

Ground Improvement Compatible with Schedule and Deformation Constraints?

- Deformations
  - Are their constraints on allowable deformations?
  - Are deformations time-dependent?

Choose Ground Improvement Accordingly

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Previous work

- Lots of work has been done to investigate:
  - Soil arching theory
  - Vertical stresses applied to native ground at original ground surface
  - Stresses in geosyntheic reinforcement
  - Performance
- Reliability of design has improved, though still based largely on empirical design.
- Less focus has been given to:
  - **Load in native ground at depth**:
    - "Depth of stress influence" between columns
    - "Ground improvement" due to installation method
    - Predicting settlements
    - Necessity of geosynthetic reinforcement

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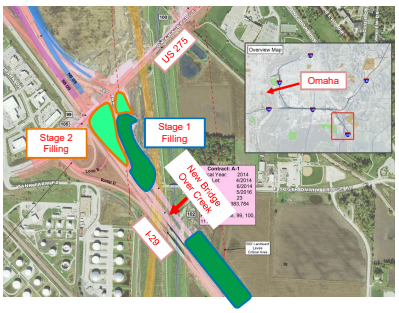
Project Location: Council Bluffs Interchange System (CBIS)



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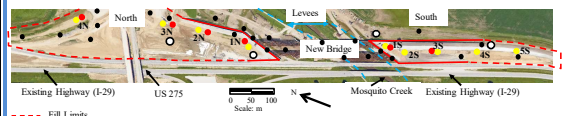
Site and Instrumentation Layout



Elevation view facing south during construction

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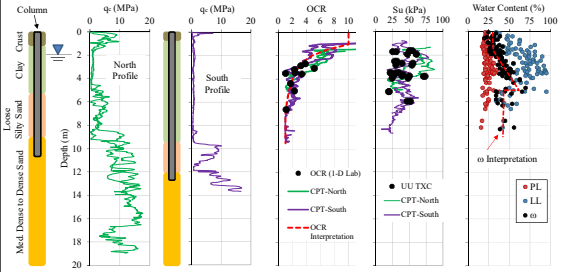
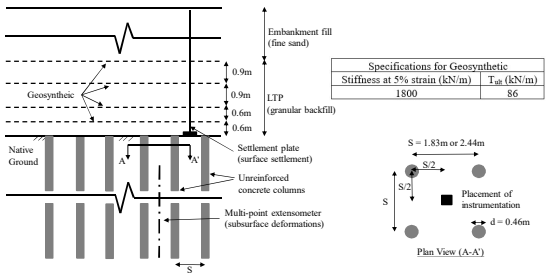
Subsurface Conditions

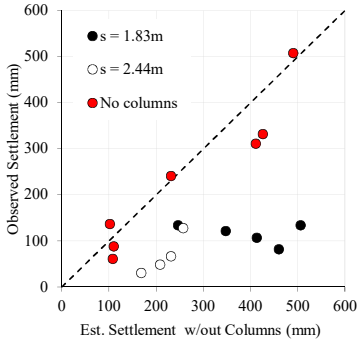


Instrumentation Details

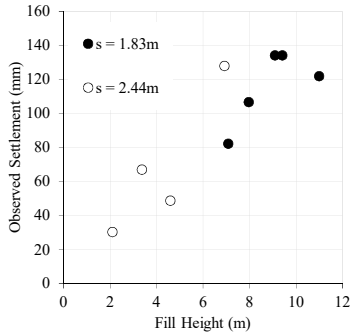


Specifications for Geosynthetic	
Stiffness at 5% strain (kN/m)	T_{ult} (kN/m)
1800	86

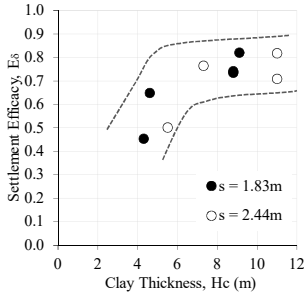
Performance: Measured vs. Estimated Settlement (w/out columns)



Performance: Settlement vs. Load



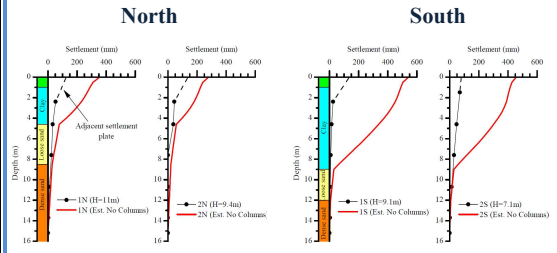
Summary of Settlement Plate Measurements



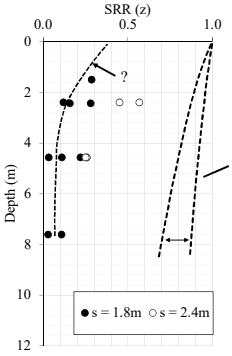
Efficacy of *settlement* reduction

$$E_\delta = 1 - \frac{\delta}{\delta_{NC}}$$

Subsurface deformations (s = 1.83m)



Inferred Stress Changes in Clay (from extensometers)

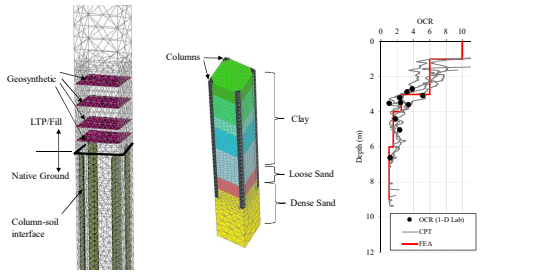


$$SRR_z = \frac{\sigma_{s(z)}}{\gamma H_e}$$

Est. stress influence values (I_σ) without column Support

$$I_\sigma = \frac{\sigma_{v(z)}}{\gamma H_e}$$

FEA Model: Investigating influence of soil-column interaction



a.) FEA Mesh b.) Layering of native ground c.) OCR Profile

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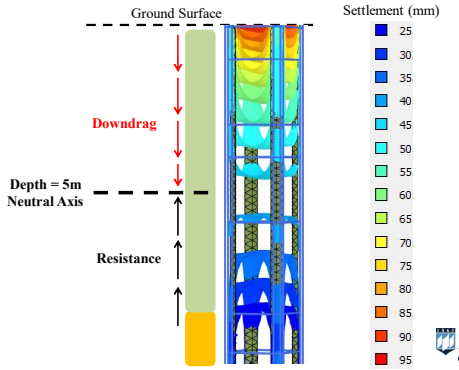
Computed Settlement Contours: FEA (S = 1.83m)



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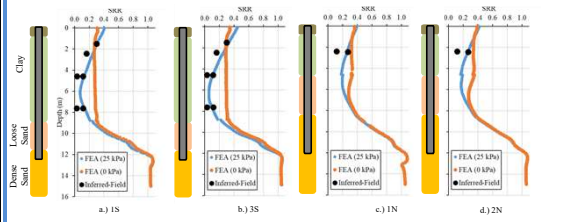
Computed and inferred SRR



Note:
1.) H=fill height
2.) Field deformations are measured relative to D = 15.2m
3.) FEA (column-soil interface shear strength in clay)

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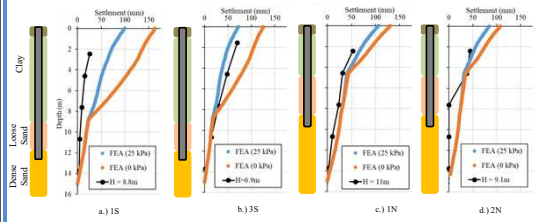
Computed and measured subsurface deformations



Note:
1.) H=fill height
2.) Field deformations are measured relative to D = 15.2m
3.) FEA (column-soil interface shear strength in clay)

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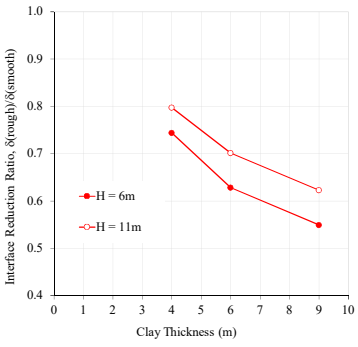
Computed influence of soil-column interaction on settlement



$$IRR = \frac{\delta_{rough}}{\delta_{smooth}}$$

Necessity of LTP and Geosynthetic?

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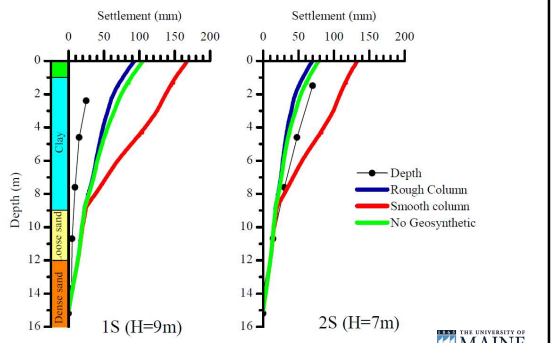
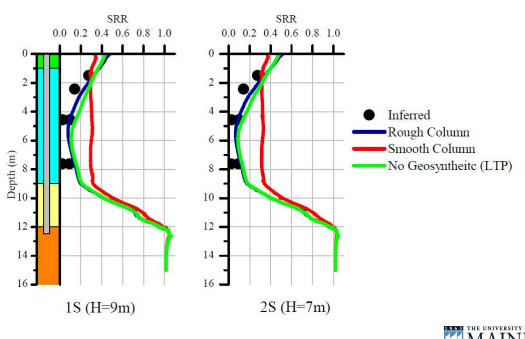
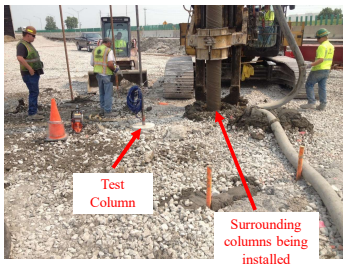
Influence of Geosynthetic and LTP



Influence of Geosynthetic and LTP



Influence of column installation: Load Test Comparison



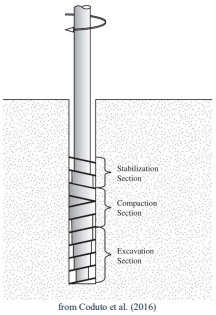
Test 1: Single Column

Test Column

Test 2: Multiple Columns

Test Column

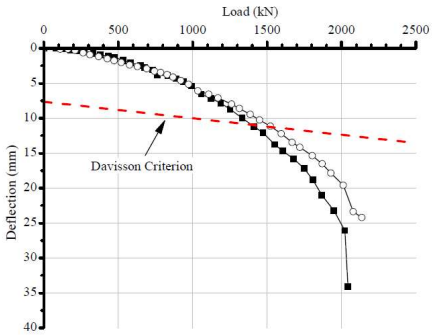
Installation: Grouted Rigid Inclusions with Drilled Displacement Tool



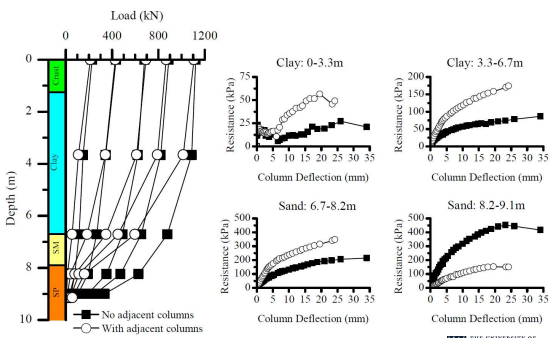
from Coduto et al. (2016)

Coduto, D.P, Kitch, W.A., Yeung, M.R. (2016). "Foundation Design: Principles and Practices." Pearson Education, Inc., Upper Saddle River, NJ.

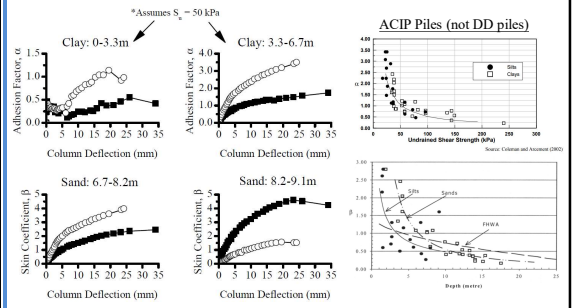
Load Test Comparison and interpreted side friction



Load Test Comparison and interpreted side friction



Load Test Comparison



Coleman, D.M. and Arcement, B.J. (2002). "Evaluation of Design Methods for Auger Cast Piles in Mixed Soil Conditions," *Proceedings of the International Deep Foundations Congress 2002*, February 14-16, 2002 Orlando, Florida; M.W. O'Neill and F.C. Townsend (Eds.), ASCE, pp. 1404–1420.

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Final Remarks:

1. Soil-column interaction and hang up effects reduce load in native ground *at depth*, and contribute to the efficacy of settlement reduction.

2. The efficacy of settlement reduction increases with clay thickness due to limited influence of embankment stress in clay at depth.

3. Load tests indicate increases in side resistance due to installation effects.

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Thank You

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