HAYWARD BAKER
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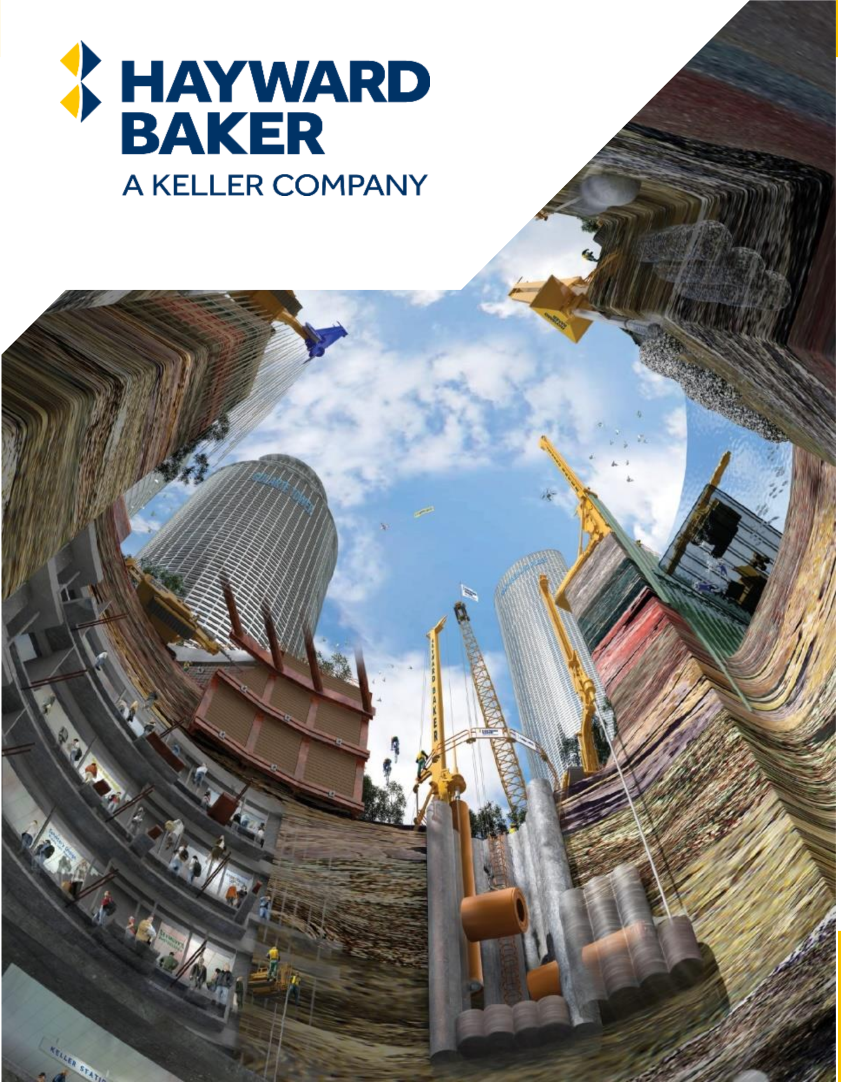


OHIO DEPARTMENT OF TRANSPORTATION

Geotechnical Consultant Workshop
June 18, 2019

Ground Improvement:
Options and Guidance for Ohio

Allen Sehn, Ph.D., PE, Chief Engineer

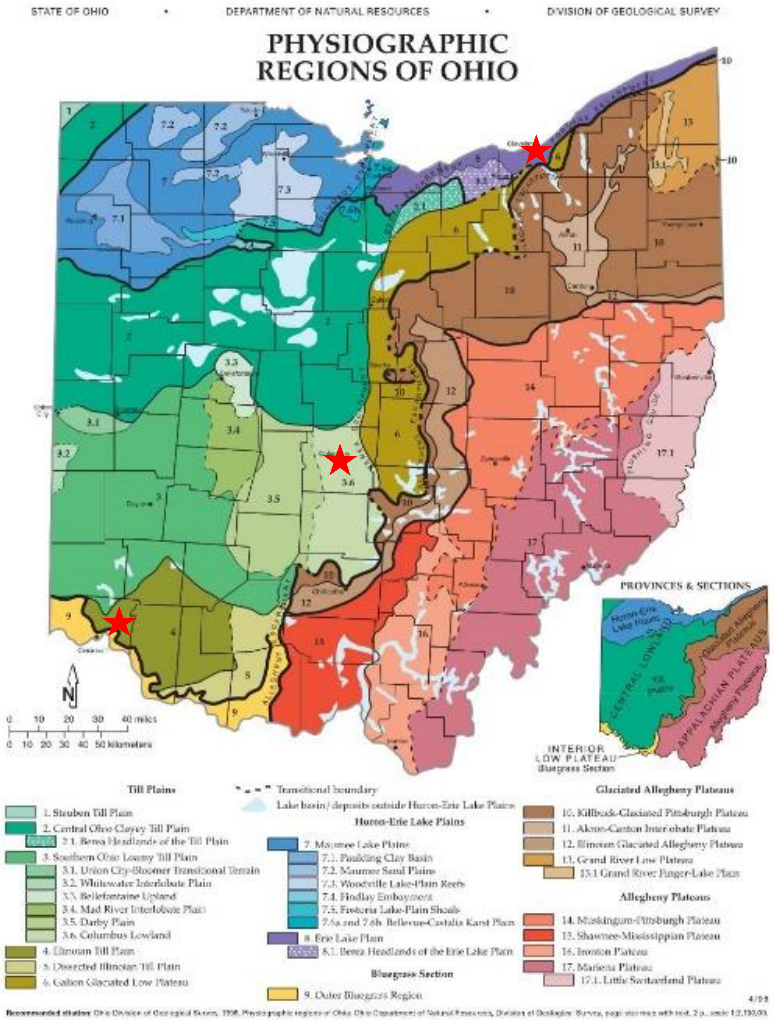
Mike Minton, PE, Division Manager - Ground Improvement

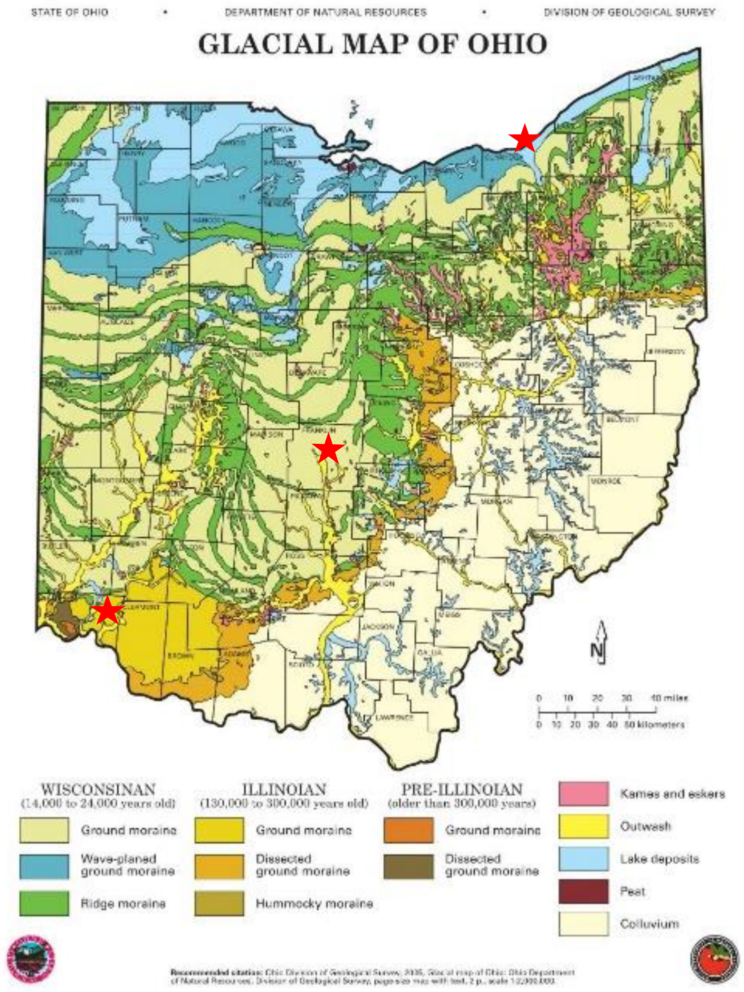
Ray Franz, PE, D.GE, Vice President

Ground Improvement for Transportation Projects

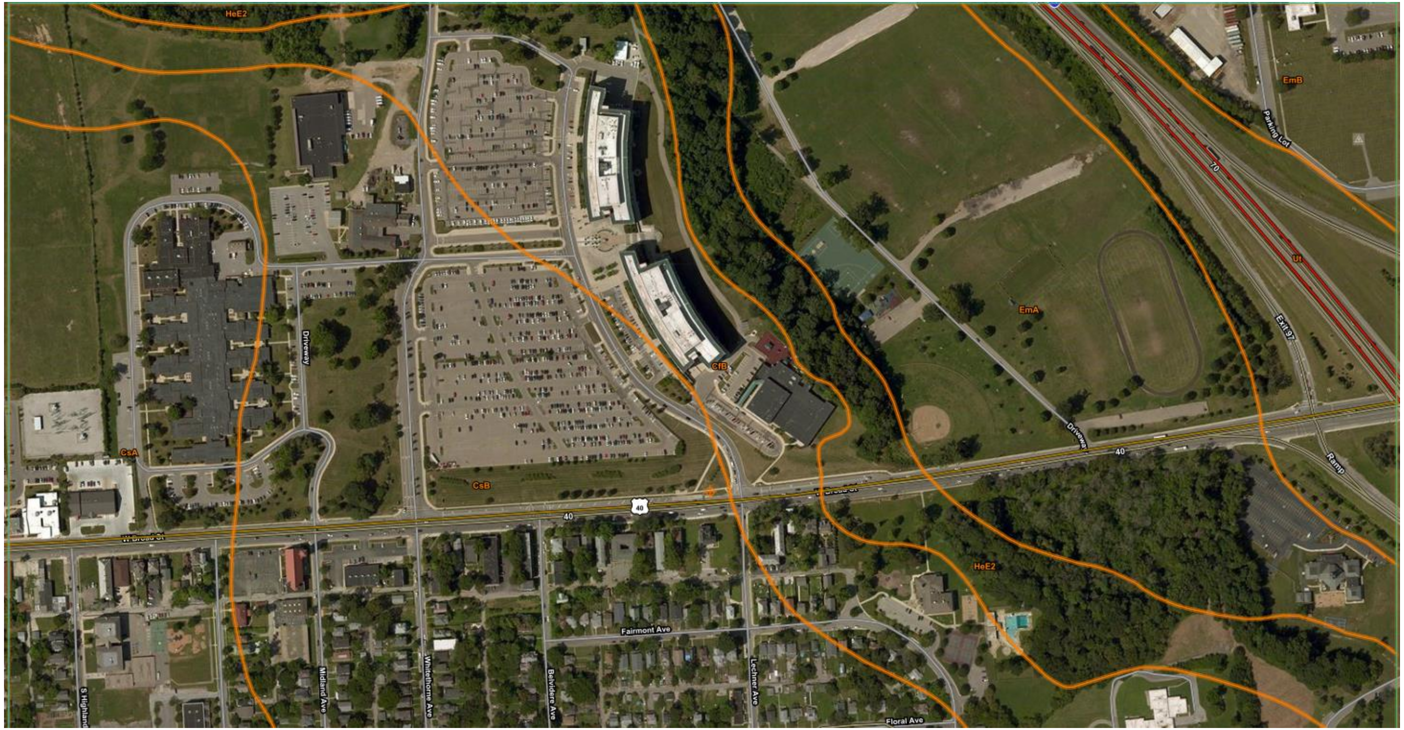
- Ground Improvement options
- Selecting the best Ground Improvement option for your project
- Subsurface exploration
- Ground Improvement Specifications
  - method-based
  - performance-based
- Acceptance testing
- Performance Monitoring during and after construction

SAFETY


STATE OF OHIO • DEPARTMENT OF NATURAL RESOURCES • DIVISION OF GEOLOGICAL SURVEY
PHYSIOGRAPHIC REGIONS OF OHIO
PROVINCES & SECTIONS
INTERIOR LOW PLATEAU
Bluegrass Section
0 10 20 30 40 miles
0 10 20 30 40 50 kilometers
Till Plains
1. Steuben Till Plain
2. Central Ohio Clayey Till Plain
2.1. Berea Headlands of the Till Plain
3. Southern Ohio Loamy Till Plain
3.1. Union City-Bloomer Transitional Terrain
3.2. Whitewater Interlobate Plain
3.3. Bellefontaine Upland
3.4. Mad River Interlobate Plain
3.5. Darby Plain
3.6. Columbus Lowland
4. Illinoian Till Plain
5. Dissected Illinoian Till Plain
6. Galion Glaciated Low Plateau
Transitional boundary
Lake basin/deposits outside Huron-Erie Lake Plains
Huron-Erie Lake Plains
7. Maumee Lake Plains
7.1. Paulding Clay Basin
7.2. Maumee Sand Plains
7.3. Woodville Lake-Plain Reefs
7.4. Findlay Embayment
7.5. Fostoria Lake-Plain Shoals
7.6a and 7.6b. Bellevue-Castalia Karst Plain
8. Erie Lake Plain
8.1. Berea Headlands of the Erie Lake Plain
Bluegrass Section
9. Outer Bluegrass Region
Glaciated Allegheny Plateaus
10. Killbuck-Glaciated Pittsburgh Plateau
11. Akron-Canton Interlobate Plateau
12. Illinoian Glaciated Allegheny Plateau
13. Grand River Low Plateau
13.1 Grand River Finger-Lake Plain
Allegheny Plateaus
14. Muskingum-Pittsburgh Plateau
15. Shawnee-Mississippian Plateau
16. Ironton Plateau
17. Marietta Plateau
17.1. Little Switzerland Plateau
4/98


STATE OF OHIO • DEPARTMENT OF NATURAL RESOURCES • DIVISION OF GEOLOGICAL SURVEY
GLACIAL MAP OF OHIO
N
0 10 20 30 40 miles
0 10 20 30 40 50 kilometers
WISCONSINAN
(14,000 to 24,000 years old)
Ground moraine
Wave-planed ground moraine
Ridge moraine
ILLINOIAN
(130,000 to 300,000 years old)
Ground moraine
Dissected ground moraine
Hummocky moraine
PRE-ILLINOIAN
(older than 300,000 years)
Ground moraine
Dissected ground moraine
Kames and eskers
Outwash
Lake deposits
Peat
Colluvium

Right here…
US 40 crosses 5 soil units between N Wheatland and I-70



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Different structures
Different locations

- The answers to these questions should help define your exploration and testing programs:
  - How many borings/soundings?
  - What type?
  - How deep?
  - Sampling type and interval?
  - Install monitoring instruments?

Project Overview and Objectives

- What types of construction or structures are planned
- New construction or rebuilding / renovating
- How will the planned construction change the loading on the soil
- What is known about the soil properties
- What soil properties can be determined
- How and when will additional information become available

Specific Geotechnical Information

- Depth to rock or other dense and strong layer
- Depth of groundwater table
- Identification of soil stratigraphy
- Properties of each layer
  - Unit weight
  - Relative density
  - Plasticity limits
  - Natural water content
  - Strength
  - Compressibility
  - Permeability

Geotechnical Considerations

- Loading conditions
  - Applied bearing pressure
  - Size of the area being loaded
- Stress increase versus depth
- Bearing capacity
- Slope stability
- Global stability
- Total settlement
- Differential settlement
- Subsurface voids (sinkholes, karst, abandoned mines, abandoned utilities, etc.)

Performance Expectations

- Strength related – are factors of safety adequate
  - bearing capacity, sliding, overturning, global stability, slope stability, short term conditions, long term conditions, etc.
- Serviceability – are settlements and/or lateral deformations acceptable
  - Total settlement
  - Differential settlement
  - Rate of settlement
- Is groundwater a concern (level, contamination, flow rates, etc.)

What's Next

- Can the problem be solved with more or better geotechnical data?
  - Additional exploration and testing
- Can ground improvement methods be used to overcome the problem?
  - Is additional geotechnical information needed
  - Preliminary selection of ground improvement method(s)
  - Evaluation of ground improvement options
  - Recommended ground improvement method(s)

Geotechnical Evaluation – do we have enough information?

- Can How do you expect the soil to behave with your project on it?

- How do you need your project to perform?
  - What has to change to meet project expectations?

Planning Geotechnical Explorations

- What are the risks associated with not obtaining additional geotechnical data?
- What information is needed?
- What questions will be answered with the information?
- What is the potential cost savings?
- How many borings/soundings?
- What type?
- How deep?
- Sampling type and interval?
- Install monitoring instruments?

U.S. Department of Transportation

Publication No. FHWA NHI-16-072
April 2017

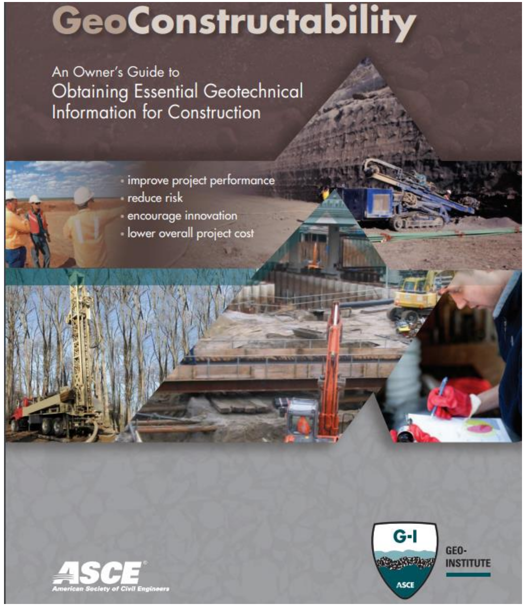
NHI Course No. 132031

Geotechnical Engineering Circular No.5

Geotechnical Site Characterization

NATIONAL HIGHWAY INSTITUTE
Training Solutions for Transportation Excellence

- ***GeoConstructability – An Owner's Guide to Obtaining Essential Geotechnical Information for Construction,*** Report of the Geotechnical Constructability Task Force, Geo-Institute of ASCE, American Society of Civil Engineers, 2011. [especially Appendices Nos. 1 and 7]



Objectives of Ground Improvement

- Reduce total & differential static settlement
- Increase allowable bearing pressure
- Change seismic site classification
- Reduce risk of liquefaction
- Improve slope stability or global stability
- Reduce sinkhole or subsidence risk

What will Ground Improvement do?

- Increase the strength
- Decrease the compressibility
- Reduce the hydraulic conductivity

Ground Improvement Methods

- Apply surcharge load and wait
- Insert elements (wick drains) to accelerate drainage
- Applying energy to densify the soil
- Reinforcing the soil with granular or cemented elements
- Combine the soil with a cementitious binder
- Filling void space with injected materials

Options and Selection: Suggested References

- FHWA-NHI-16-027 / FHWA GEC 013 / NHI Course No. 132034
  Ground Modification Methods Reference Manual – Vol. I, April 2017

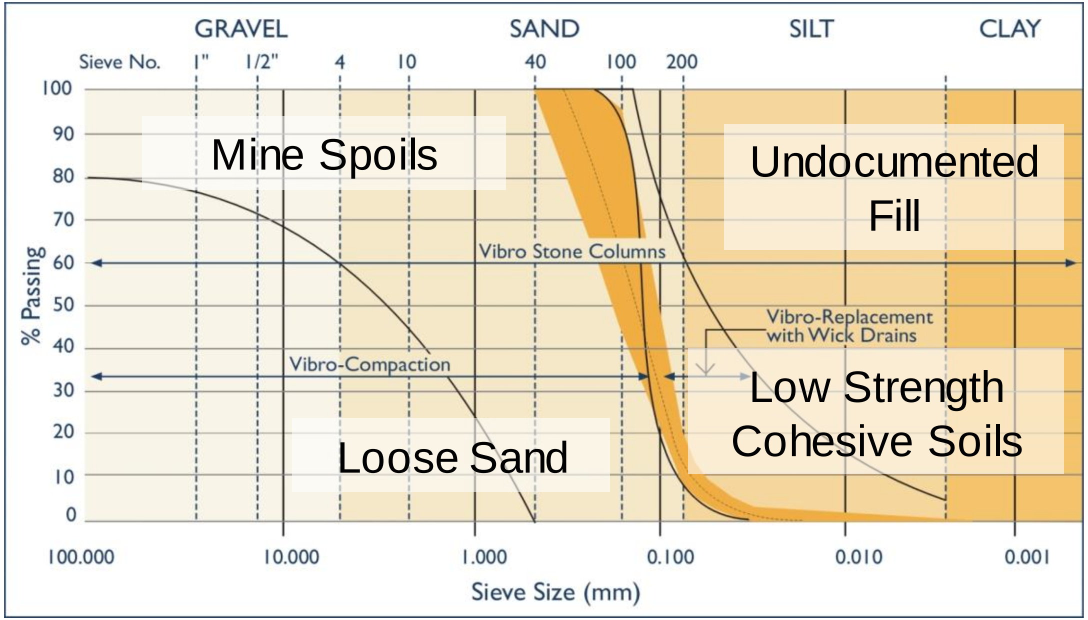
- FHWA-NHI-16-028 / FHWA GEC 013 / NHI Course No. 132034
  Ground Modification Methods Reference Manual – Vol. II, April 2017

- **https://geotechtools.org**

  Developed for the second Strategic Highway Research Program Project Number R02 (SHRP 2 R02) *Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform* + *http://www.trb.org/SHRP2*

Selection of Ground Improvement Techniques – The Engineers Challenge

Soil Type Governs the Ground Improvement Technique



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Wick Drains

- Prefabricated Vertical Drains (PV drains, PVD's)
- Wick Drains
- Synthetic drains
- Band Drains
- Strip Drains

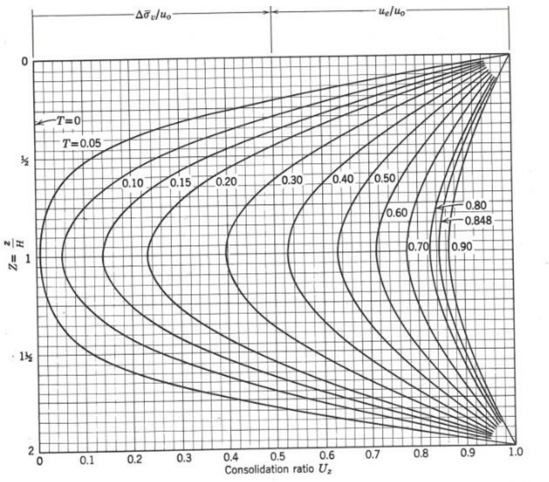
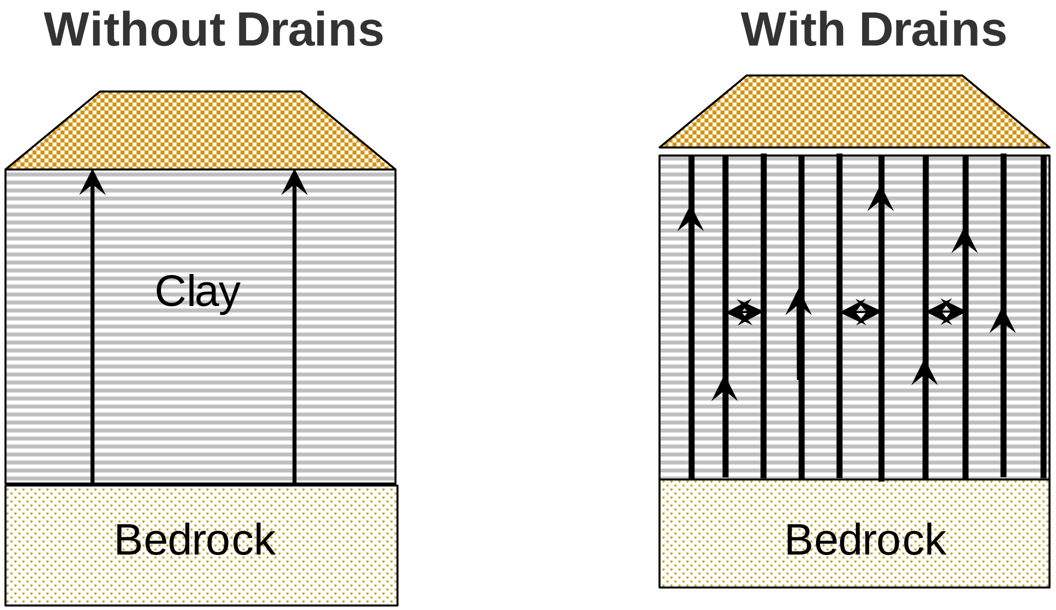


Fig. 27.2 Consolidation ratio as function of depth and time factor: uniform initial excess pore pressure.

Wick Drains – The General Idea



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Consolidation – key parameters

- Length of the drainage path, H
- Time, t
- Required average degree of consolidation, U_{avg}
- Fill availability/cost
- Coefficient of consolidation, c_v and c_h
  - Neither are easy to determine
  - c_h tends to be greater than c_v due to clay deposition and layered stratigraphy
    - Are there sand layers that can speed up consolidation?
    - Factor in disturbance/smear if factoring up.

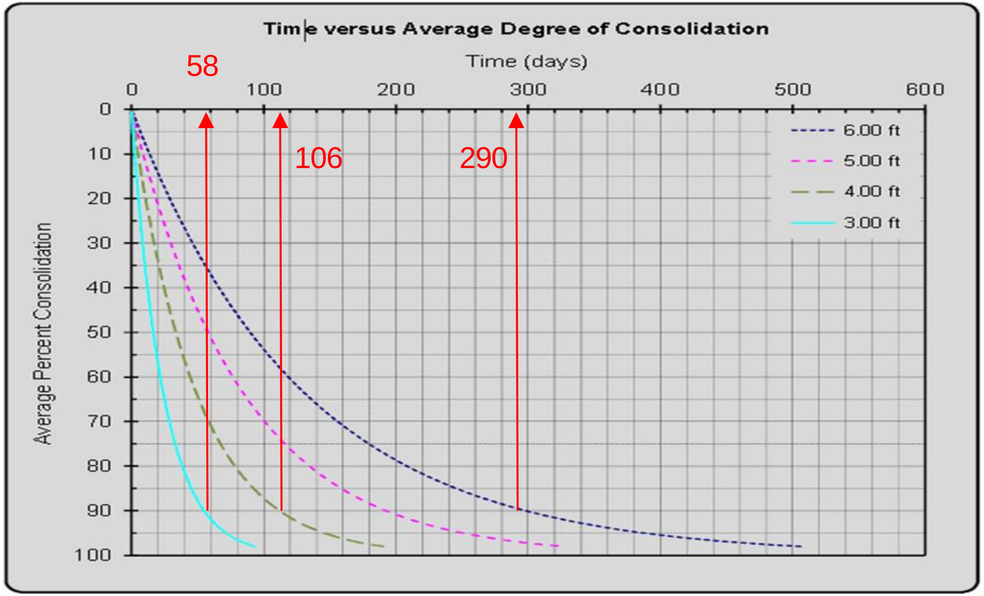
Dissipation Curves

HBWick Drains
A Division of Hayward Baker

ASSUMPTIONS:
1. Radial drainage only
2. Uniform soil deposit
3. No backpressure from horizontal drainage
4. Soil parameters constant in time and position
5. No drain resistance considered
6. No disturbance considered

	Input		Consolidation Time (days)
c_h =	0.1	ft^2/day	
U_{avg} =	95	%	
Spacing 1 =	6.00	ft	388
Spacing 2 =	5.00	ft	251
Spacing 3 =	4.00	ft	146
Spacing 4 =	3.00	ft	72
Wick Drain Pattern =	Triangular		
Equivalent Drain Diameter =	0.22	ft	

(Recommend Value = 0.22 ft)



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THINK SAFE

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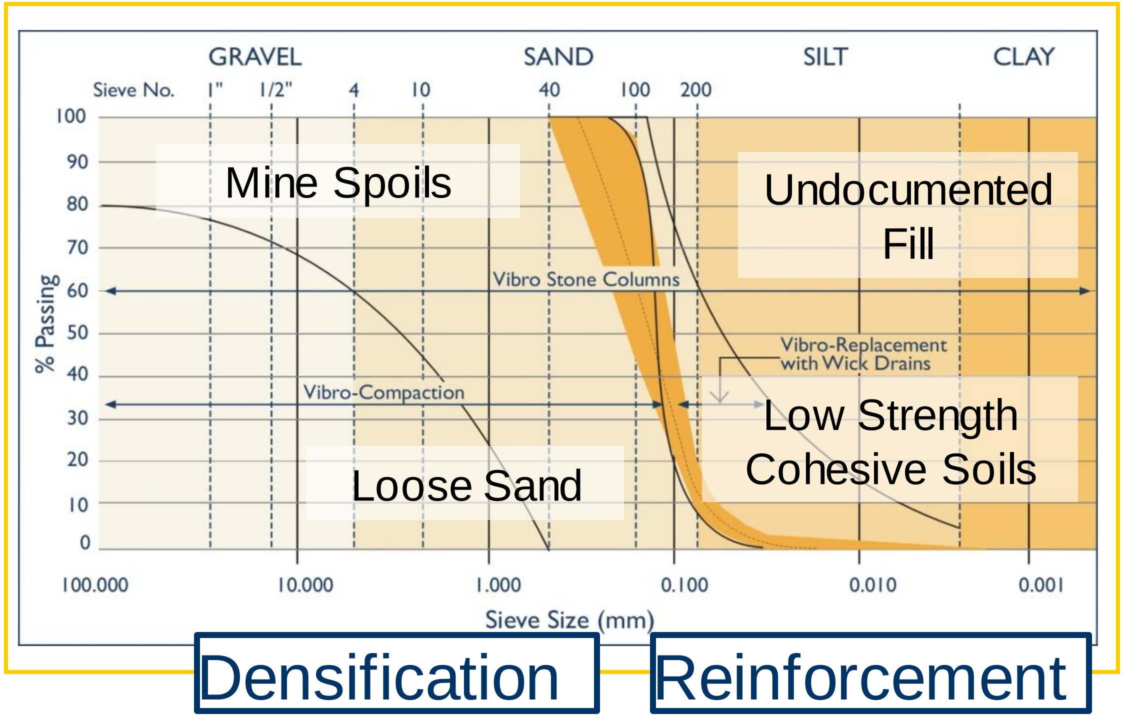
Selection of Ground Improvement Techniques – The Engineers Challenge

Soil Type Governs the Ground Improvement Technique



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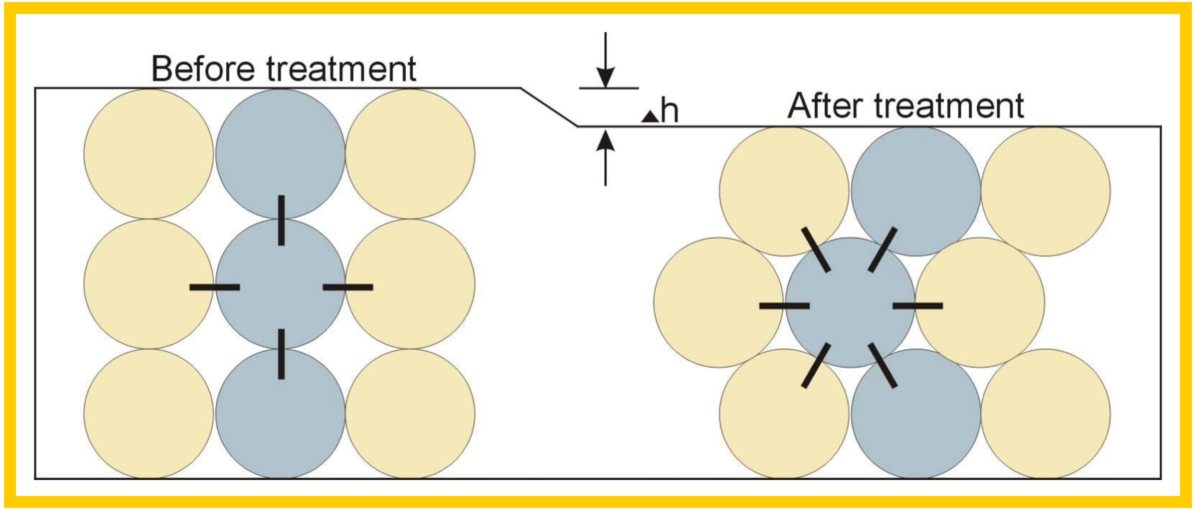
Densification techniques rearrange particles -- decreasing void space, increasing grain to grain contact



Note: This is only possible if there are no fines in the soil matrix

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Densification: Dynamic Compaction

- INDOT: I-69, White River Segments
  - Vibro Stone Columns and Dynamic Compaction

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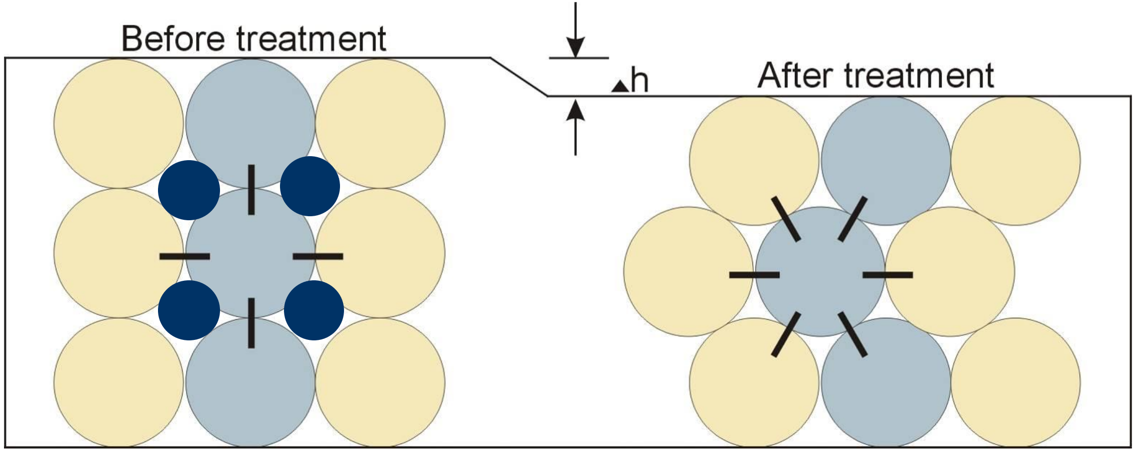
Densification: Vibro Compaction

Gunderson Lutheran Hospital Parking Deck, La Cross, WI

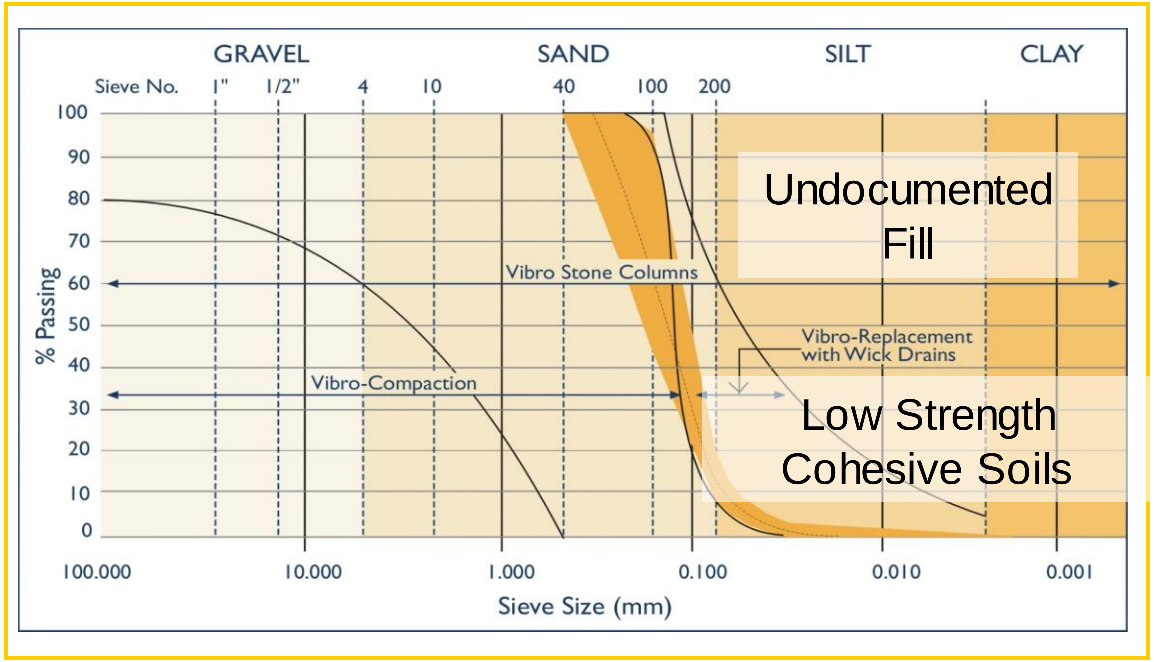
What happens when we introduce fines into the soil matrix?



We now must move from Densification to Reinforcement

Selection of Ground Improvement Techniques

Soil Type Governs the Ground Improvement Technique



Aggregate Piers/Stone Columns

- Piers or columns of dense aggregate installed as foundation elements to support light to medium loads.
- Often referred to as an intermediate foundation system, i.e. not shallow but also not deep.
- Usually about 24 to 36 inches in diameter and about 10 to 40 feet deep.

Aggregate Piers – When to use them?

- Usually used to reduce expected settlements for Retaining Walls/Embankments (also have a wicking effect).
- May be used to increase bearing capacity.
- Used to increase FS against Global Stability Failure
- Installed in cohesive and cohesionless soils.
- Installed above and below the groundwater table.

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Case Studies: Aggregate Pier/Stone Column Installations

INDOT I-69 CSX to
White River
Washington, IN

I90/94 - I290 "Circle"
Interchange
Chicago, IL

Case Studies: Aggregate Pier/Stone Column Installations

Ohio River Bridges
Louisville, KY

Aggregate Pier/Stone Column Nomenclature

Trade Names:

- Geopiers
- Vibro Piers
- VSC (Vibro Stone Columns)
- Terra Piers

Install Methods:

- "Rammed" Aggregate Piers
- Vibro Replacement
- Vibro Displacment
- Top Feed/Bottom Feed
- Impact Piers/Rampact Piers

Aggregate Pier/Stone Column Nomenclature

Neutral Terms are **"Aggregate Columns"**, **"Aggregate Piers", "Stone Columns", etc.**

Any term that doesn't include an install method or trade name

Coke and Pepsi = Cola

Kleenex and Puffs = Tissues

Aggregate Pier Design Methodology

Design references:

Elastic Settlement Relationships:

- Ground Improvement Design and Construction of Stone Columns, Volume 1+2 1983 FHWA-RD-83-026 PB84-190024

Cylindrical Cavity Expansion + Vertical Deformation:

- Priebe, The Design of Vibroreplacement (1995).

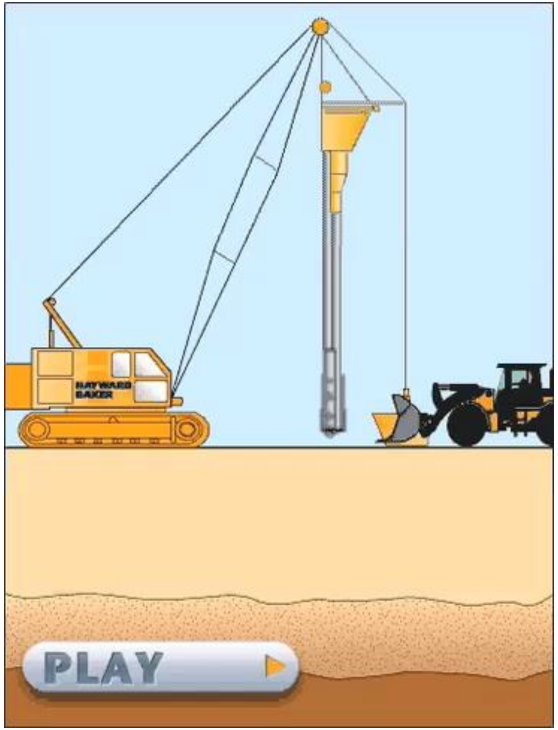
Equivalent Spring Deformation Methods:

- Sehn and Blackburn, Lawton and Fox, others.

Full-scale load tests with published papers.

Thousands of successful installations.

Construction Process



Limitations

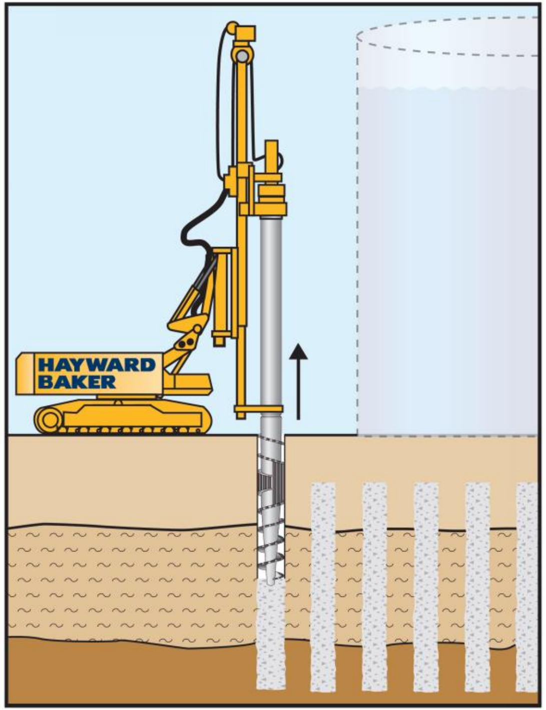
- Requires soil that can provide adequate lateral support (confinement) of the aggregate pier.
  - for cohesive soils, usually want average N > 4.
- Can be expected to reduce settlements by a factor of 2 to 4 (high treatment ratio).
- Soft clays, peats, organic soils thicker than about 2 to 3 feet (Enter Rigid Inclusions, Soil Mixing).
- Upper bound to the load carrying capacity of the Aggregate Pier/Soil Matrix system – very heavy loads may not be appropriate. ~100 kips per Pier…

What are Rigid Inclusions (RI)?

- High modulus grout columns
- Typical grout strength is 2,500 to 4,000 psi
- Typical diameters 12” to 18”
- Works in conjunction with a load transfer platform (LTP)

Why Rigid Inclusions?

- Geotechnical
  - Reduce Settlement
  - Increase Bearing Capacity
- Structural
  - Shallow Spread Footing
  - Slab-on-grade replaces structural slab
- Environmental
  - Little to no spoil (contamination)
  - Quiet compared to pile driving

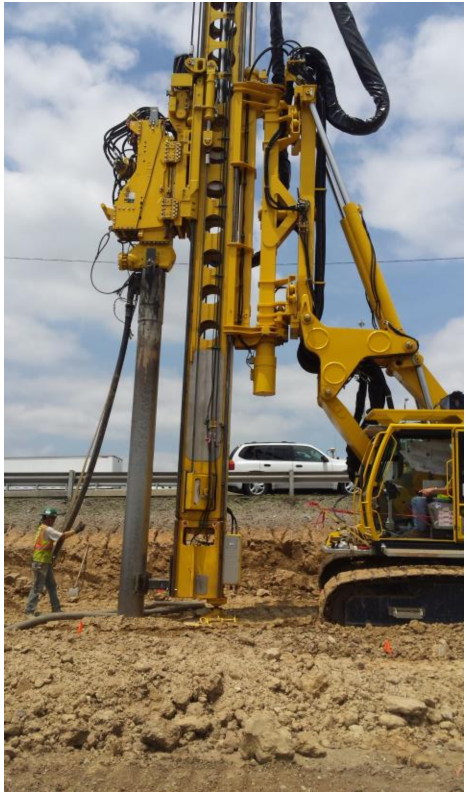


Benefits

- Cost: Shallow spread foundations and slab-on-grade vs. pile caps and structural slab
- Schedule: Gain time compared to surcharge or surcharge with wick drains
- Reduce settlement more than aggregate piers
- Minimizes spoil created at ground surface
- Quality verification through data acquisition and testing

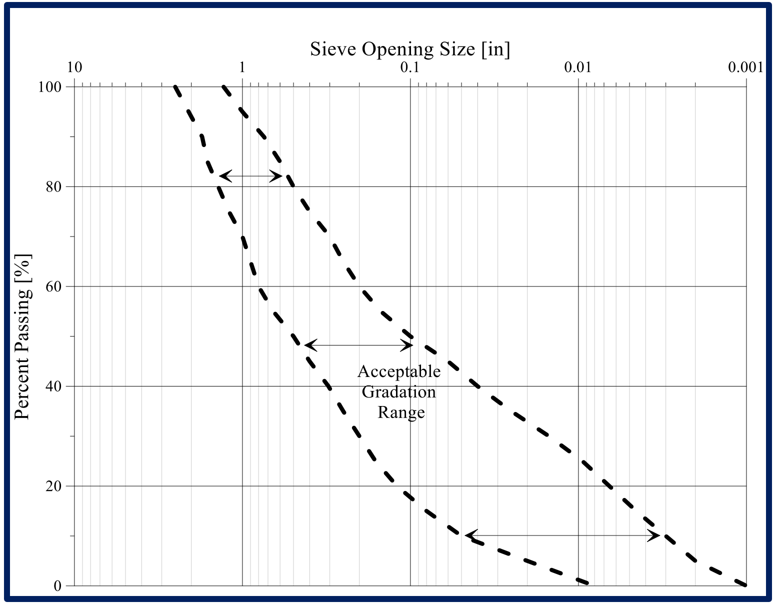
Rigid Inclusions for Transportation

- Iowa DOT -
- Ohio River Bridge – Louisville, KY
  - Embankment Support next to active roads
- I-64 High Rise Bridge – Norfolk, VA
  - Embankment Support next to Sheet Pile wall
- SD River Bridge Double Track – San Diego, CA
  - MSE wall support for new commercial railroad tracks
- Hopkinton Department of Public Works – Boston, MA
  - Foundation and slab-on-grade support
  - Moncrief-Dinsmore Rd Bridge – Jacksonville, FL
  - Box culvert support
- SR 713 Kings Highway – Fort Pierce, FL
  - Utility Support

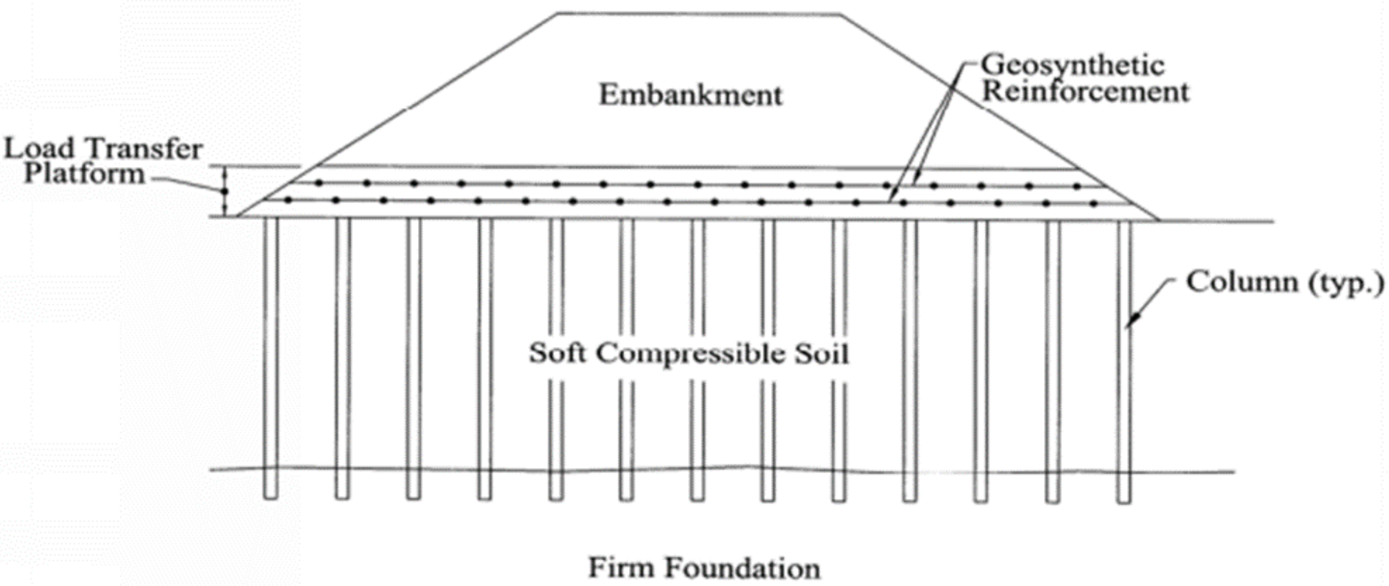


Load Transfer Platform

- A load transfer platform (LTP) is used to transfer load from the structure to the Rigid Inclusions
- Structural Fill – Granular soil (DGAB)
- LTPs may include 1 to 4 layers of embedded geogrid or steel mesh (or none at all…)

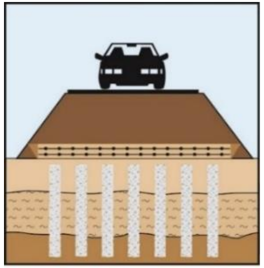


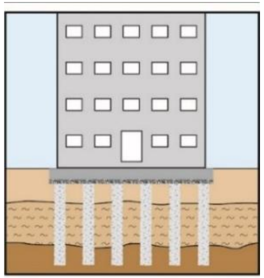
Load Transfer Platform



Rigid Inclusions - Applications

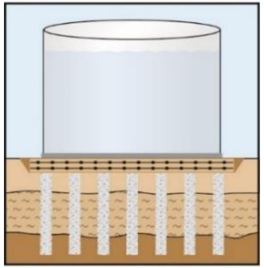
Ohio River Bridge
Louisville, KY

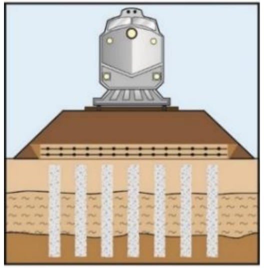




Albany, NY

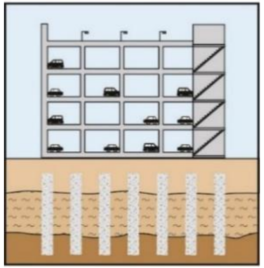
Harrisburg, PA

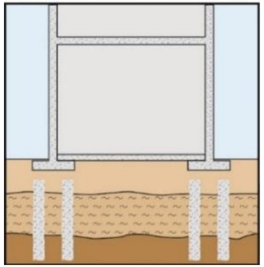




SD River Bridge
Double Track
San Diego, CA

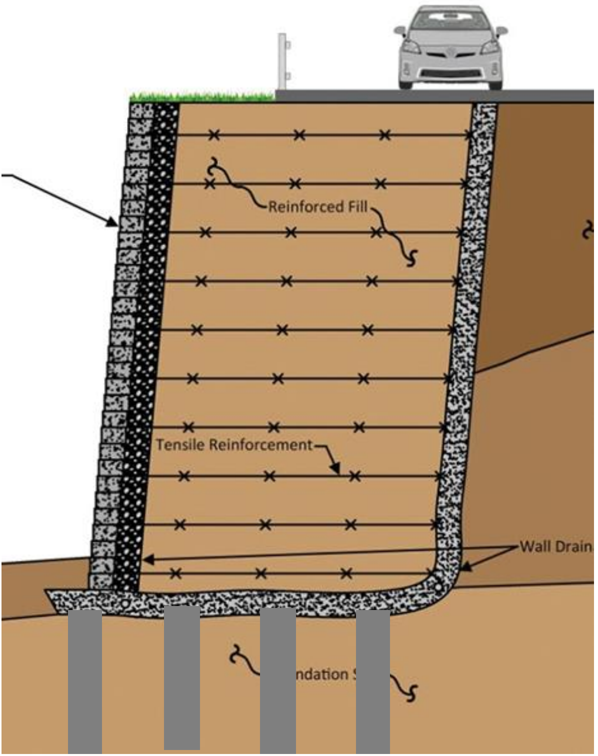
Norfolk, VA



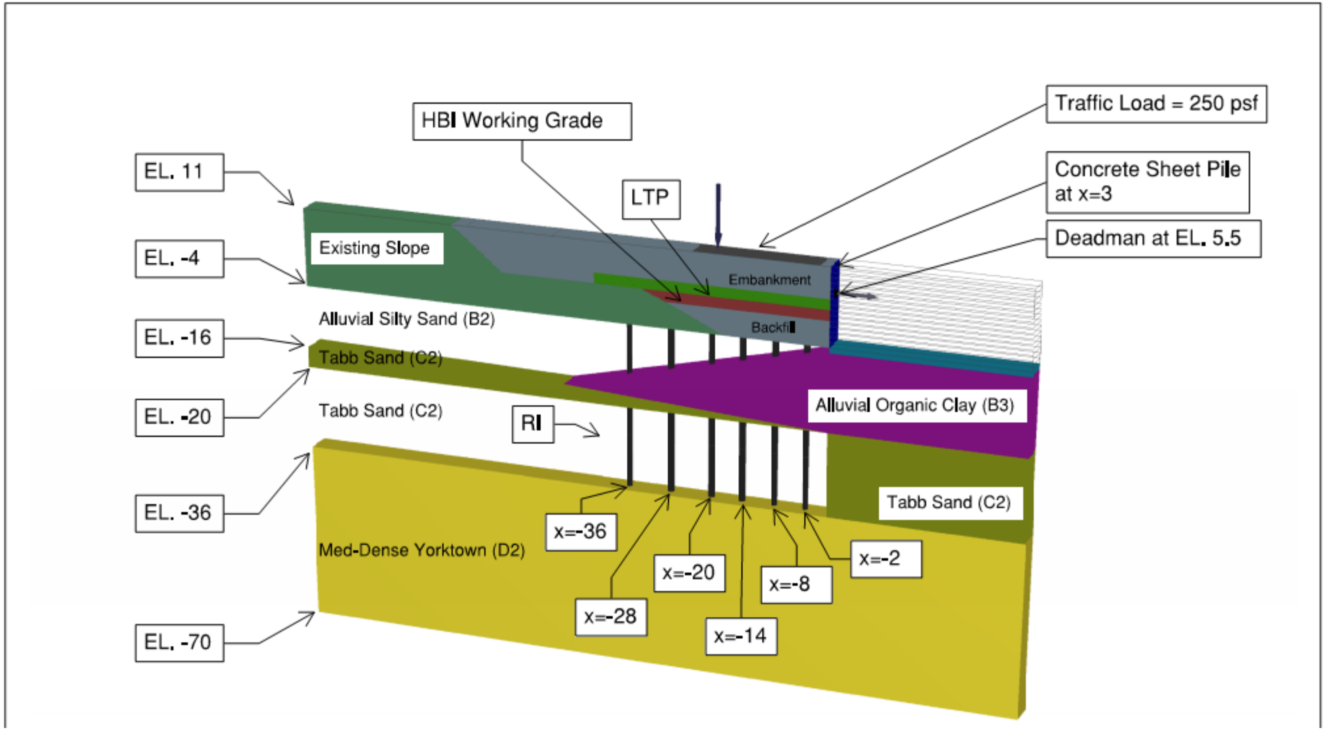


Ithaca, NY

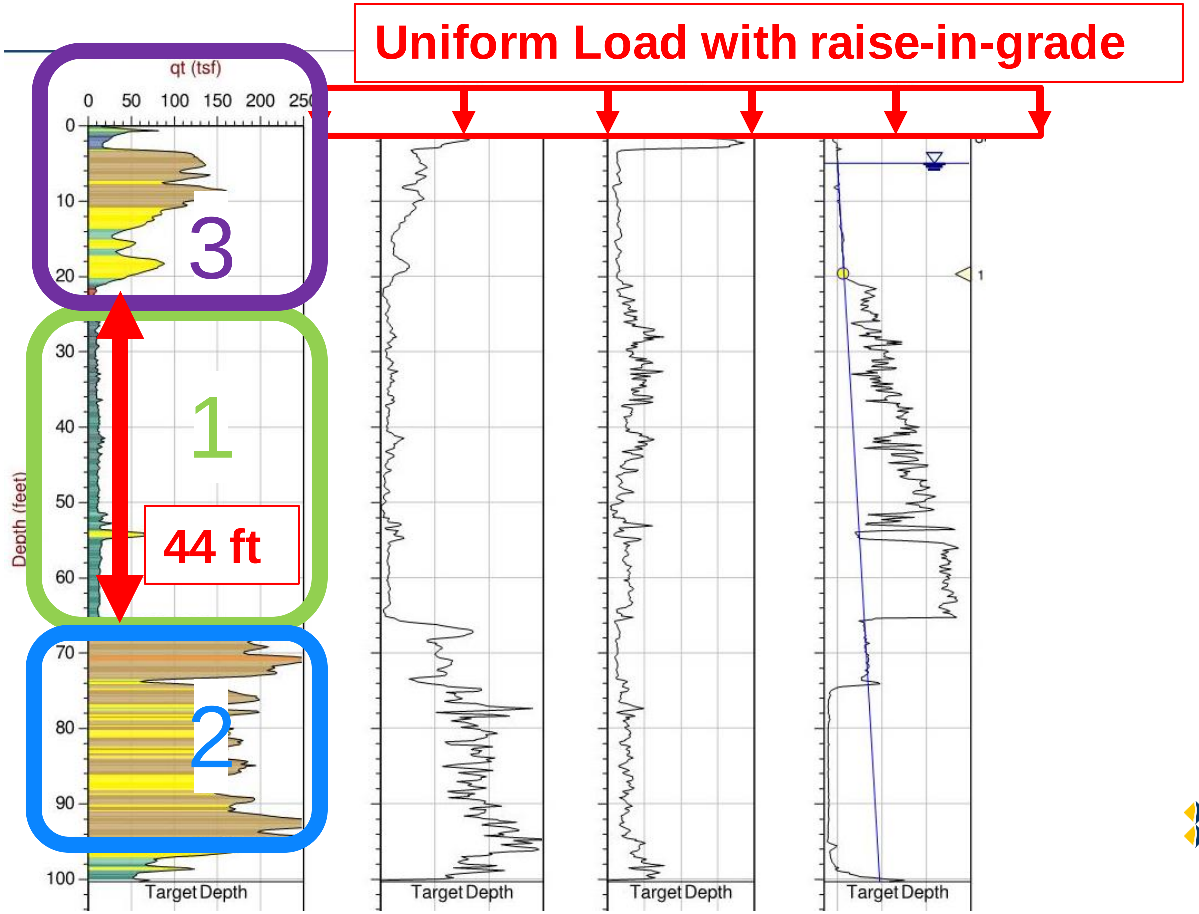
Applications: MSE Walls / Retaining Walls



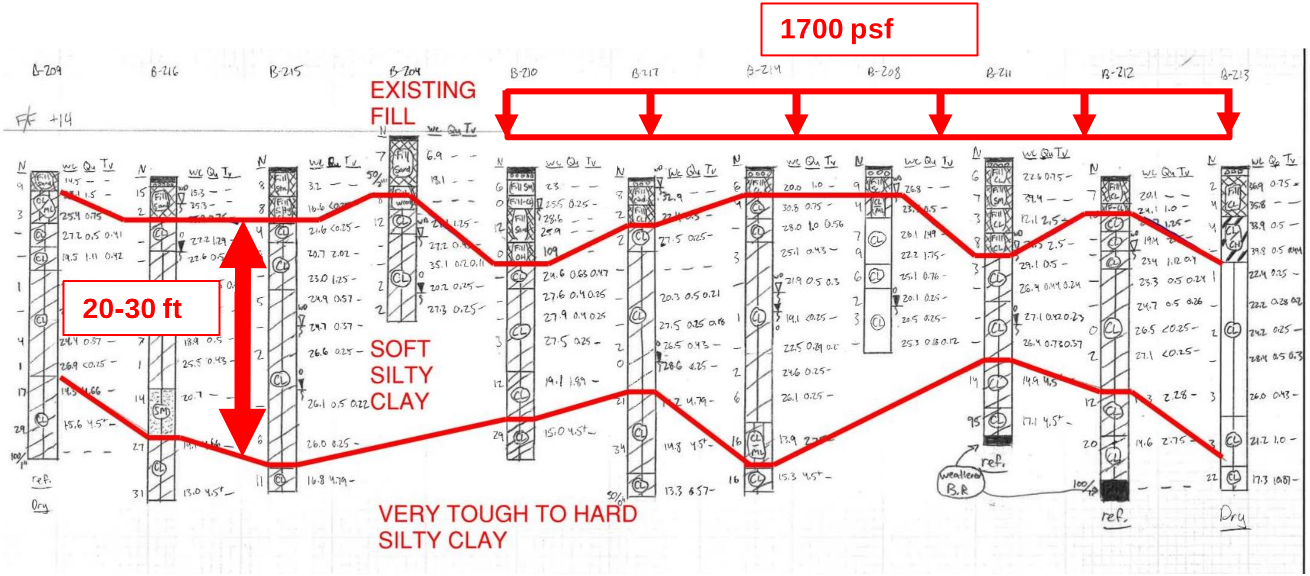
PLAXIS 3D Version 2017.1.0.0



Typical Soil Profile for Rigid Inclusions



RI Design – Settlement Reduction

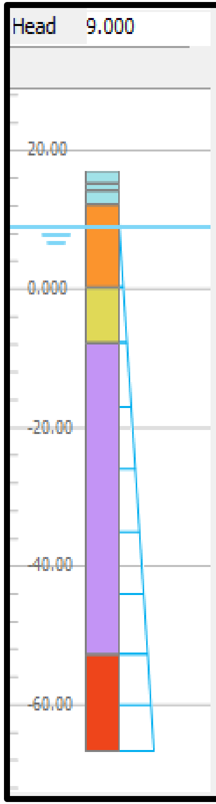


Estimated settlement without ground improvement – 6 inches
Estimated settlement with aggregate piers – 1.5 to 3 inches
Estimated settlement with rigid inclusions – less than 1 inch

RI Design - Finite Element Analysis

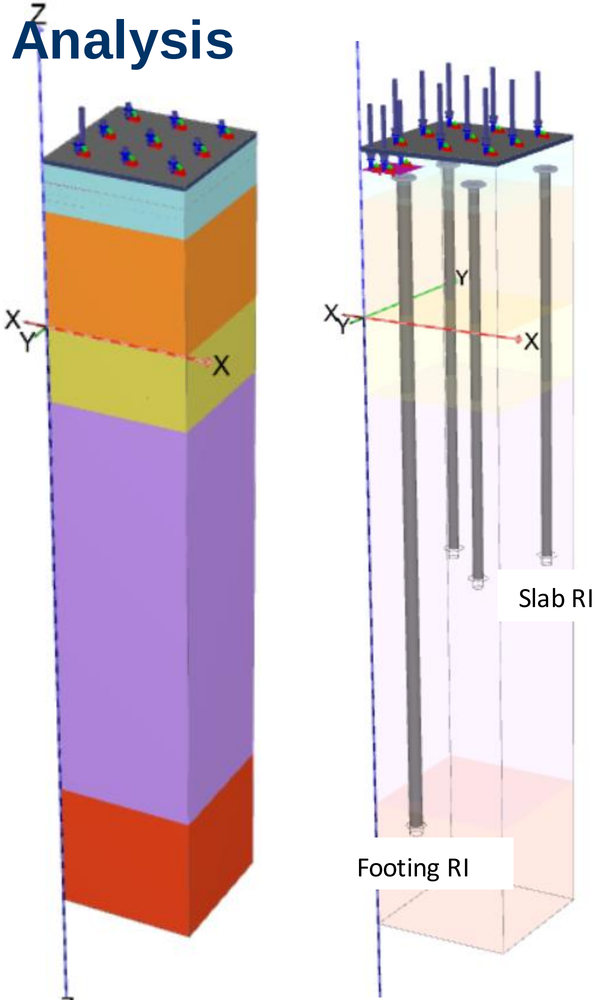
- Axisymmetric and Plain Strain (2D models)
- 3D models for difficult geometry and refined analysis
- What Level of Analysis is Appropriate?
  - Constitutive Models (governs soil behavior)
  - Soil-Structure Interaction (governs interaction with dissimilar materials)

RI Design - Finite Element – 3D Analysis



Soil layers | Water | Initial conditions | Preconsolidation | Fi

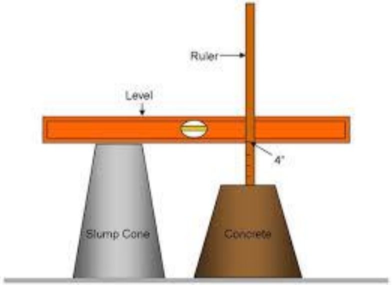
Layers		Borehole_1	
#	Material	Top	Bottom
1	Structural Fill	16.83	15.00
2	Structural Fill	15.00	14.00
3	Structural Fill	14.00	12.00
4	Med. Dense Sand	12.00	0.000
5	Loose Sand	0.000	-8.000
6	Sandy Clay	-8.000	-53.00
7	Yorktown - Dense Sand	-53.00	-67.00



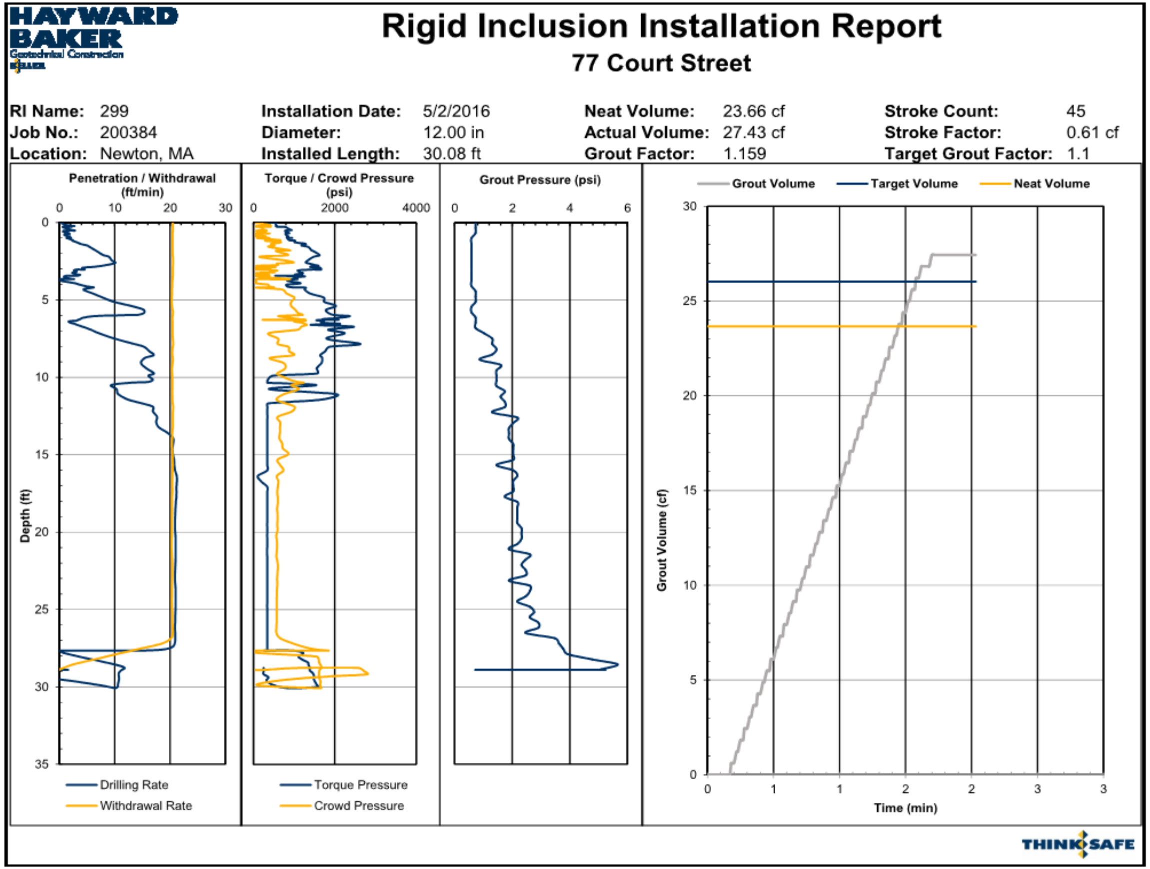
Quality Control: Grout Mix Design

Pumpable Strength

Compressive



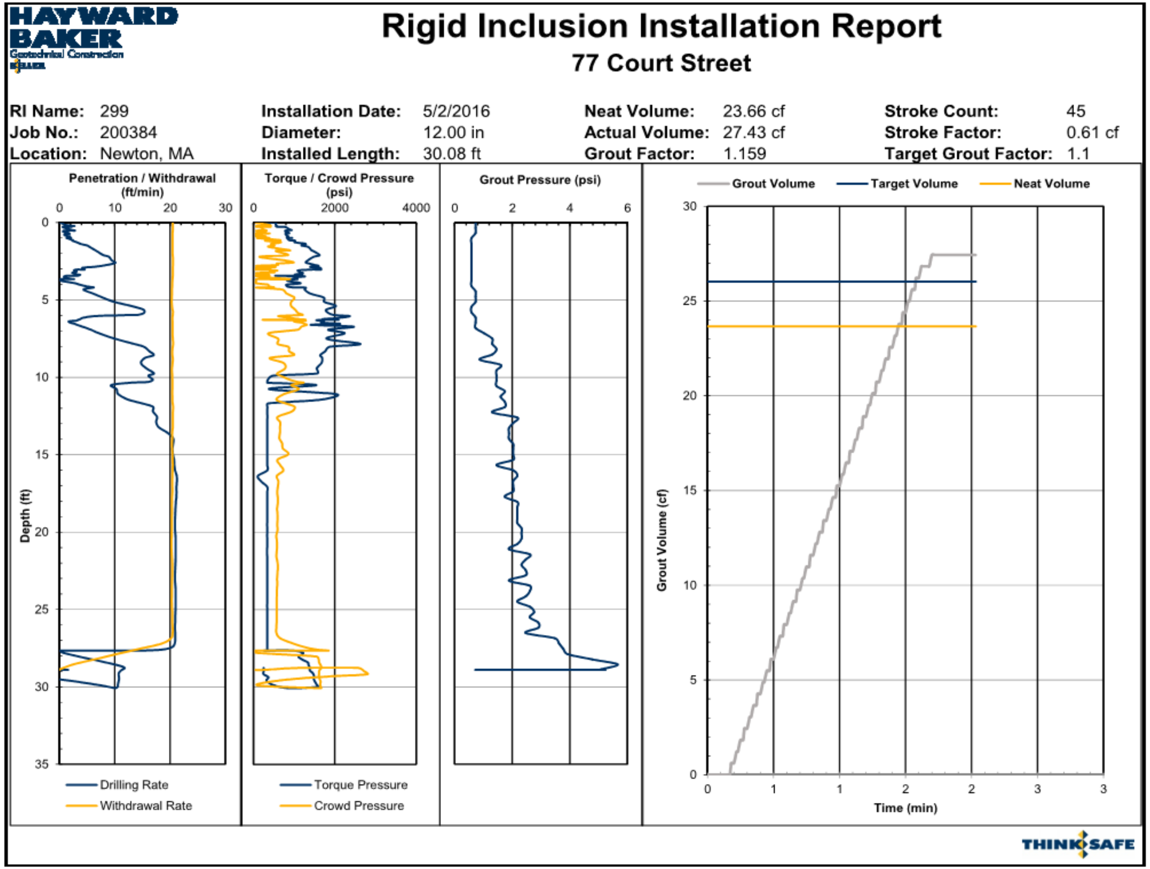
RI Quality Control - DAQ


HAYWARD BAKER
Geotechnical Construction
KELLER

Rigid Inclusion Installation Report
77 Court Street

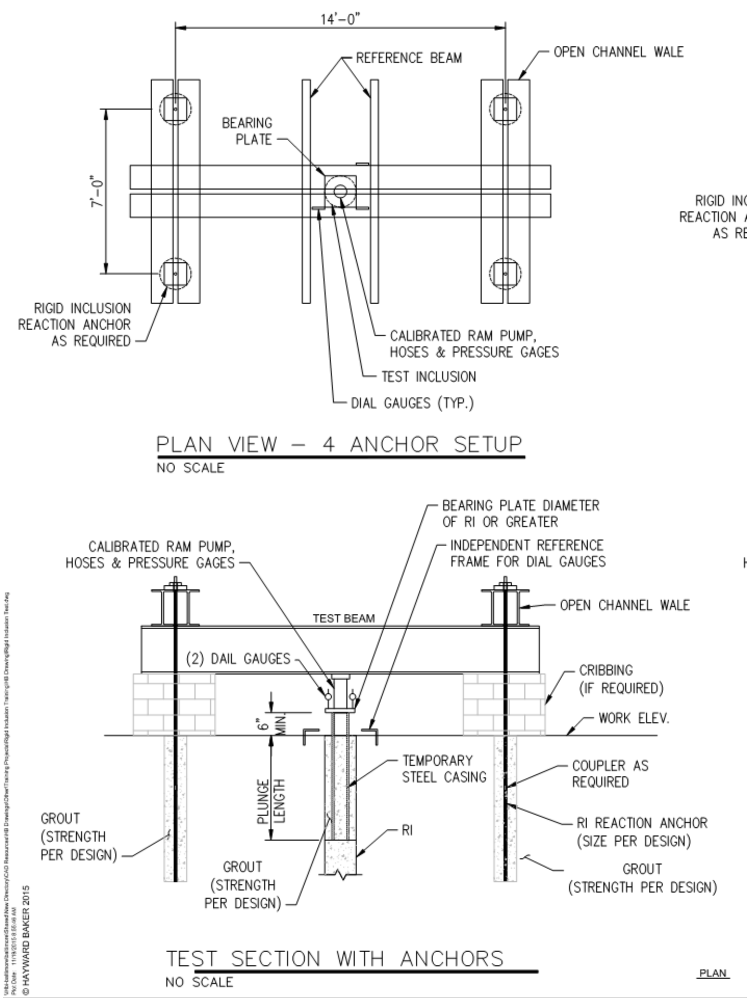
RI Name:	299	Installation Date:	5/2/2016	Neat Volume:	23.66 cf	Stroke Count:	45
Job No.:	200384	Diameter:	12.00 in	Actual Volume:	27.43 cf	Stroke Factor:	0.61 cf
Location:	Newton, MA	Installed Length:	30.08 ft	Grout Factor:	1.159	Target Grout Factor:	1.1

RI Quality Control - DAQ

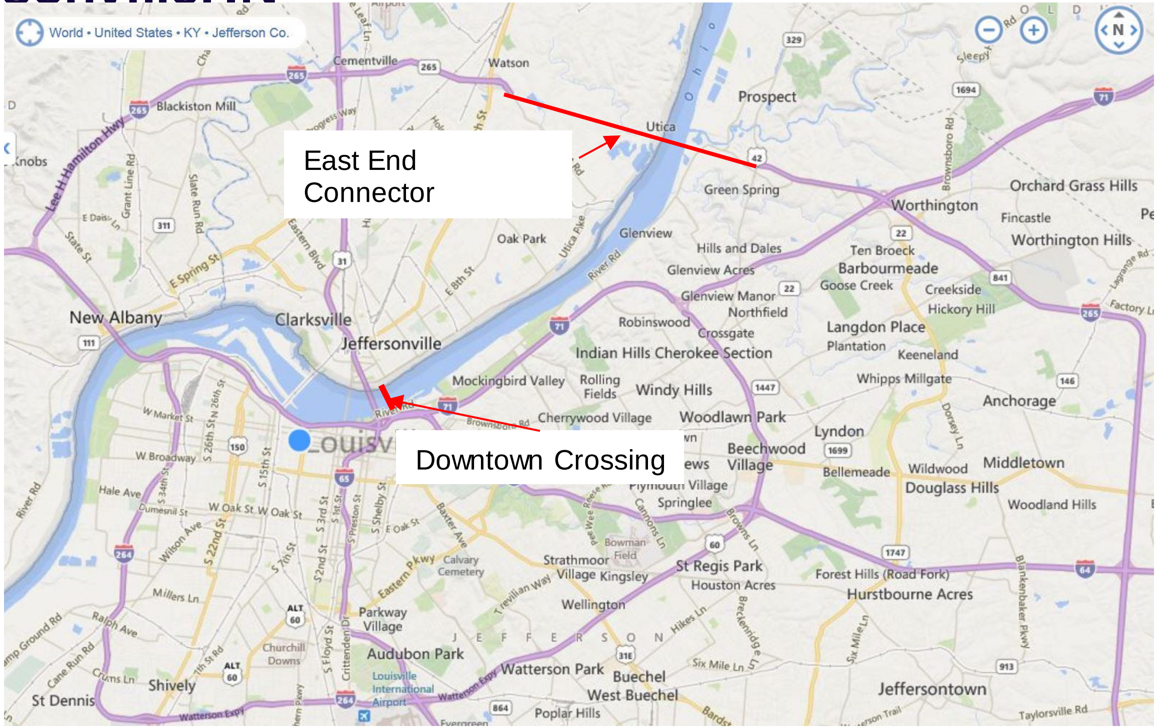


RI Quality Control - Load Testing

- Static Load Testing
- 150% to 200% Design Load
- Design Load from FE Analysis



CASE STUDY: Ohio River Bridges, Louisville, KY/Jeffersonville, IN



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Downtown Crossing

THINK SAFE

The Downtown Pursuit Interchange Reconstruction – 41 Embankments, Ramps, MSE Walls

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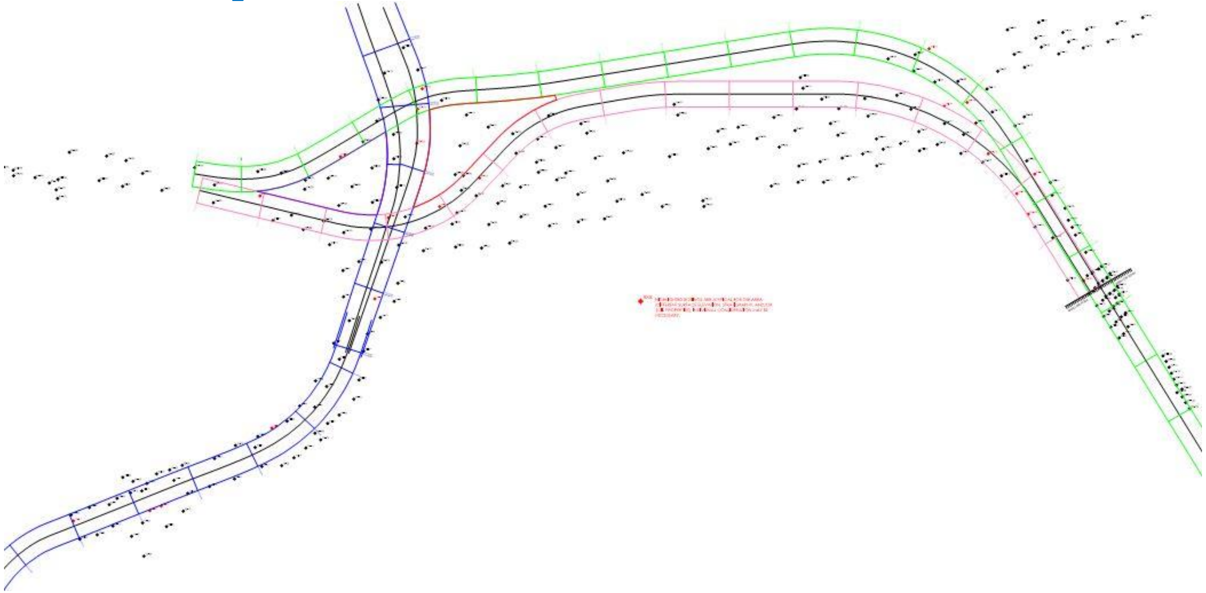
HBI PRE-BID EFFORT

- HBI reduced available geotechnical data into average subsurface profiles for every 500 feet of roadway.



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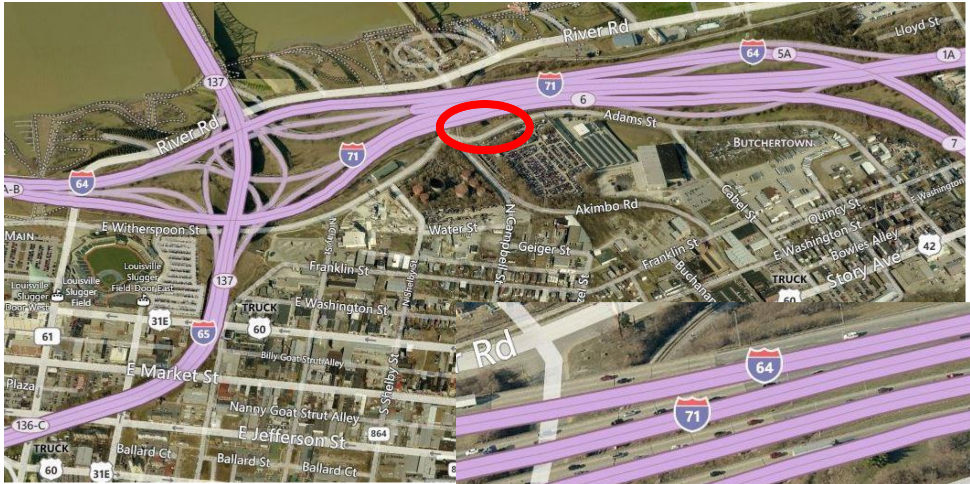
TEST EMBANKMENT - LOCATION



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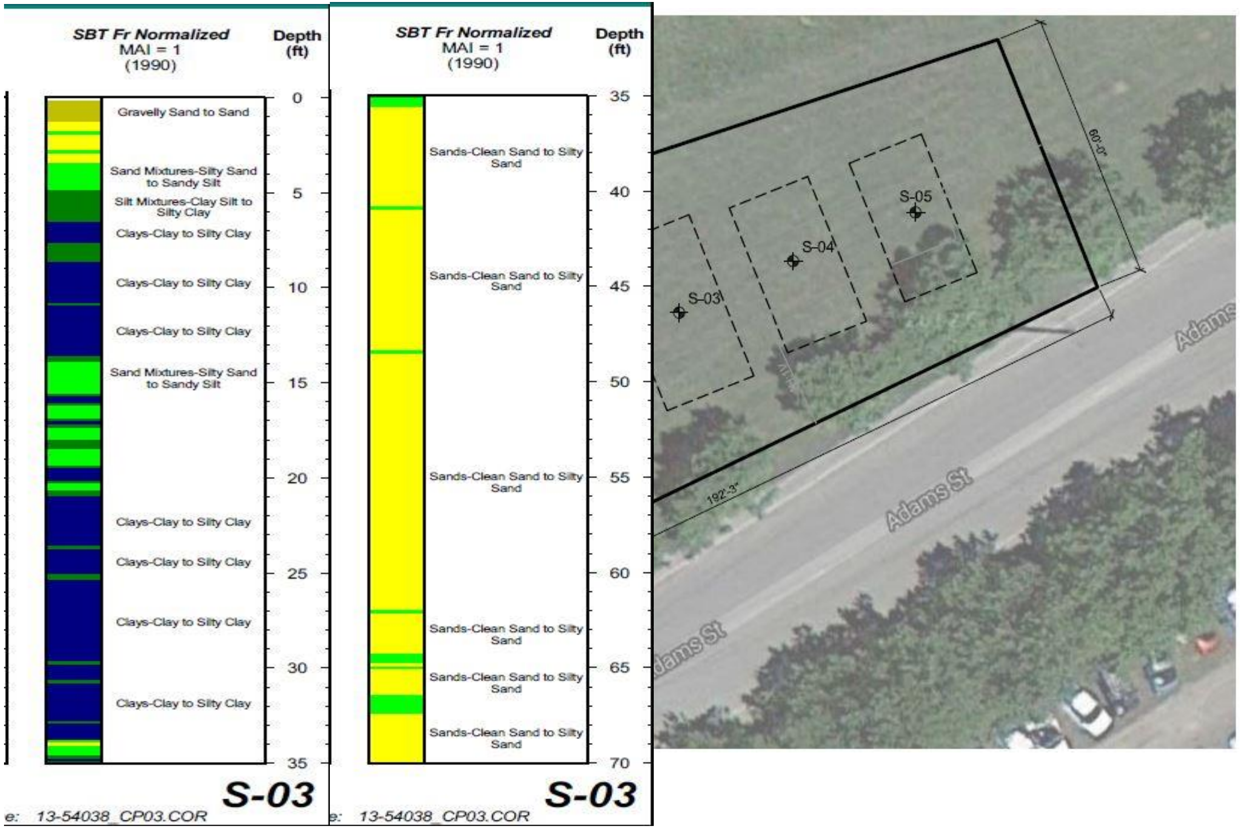
TEST EMBANKMENT CPTU PLAN



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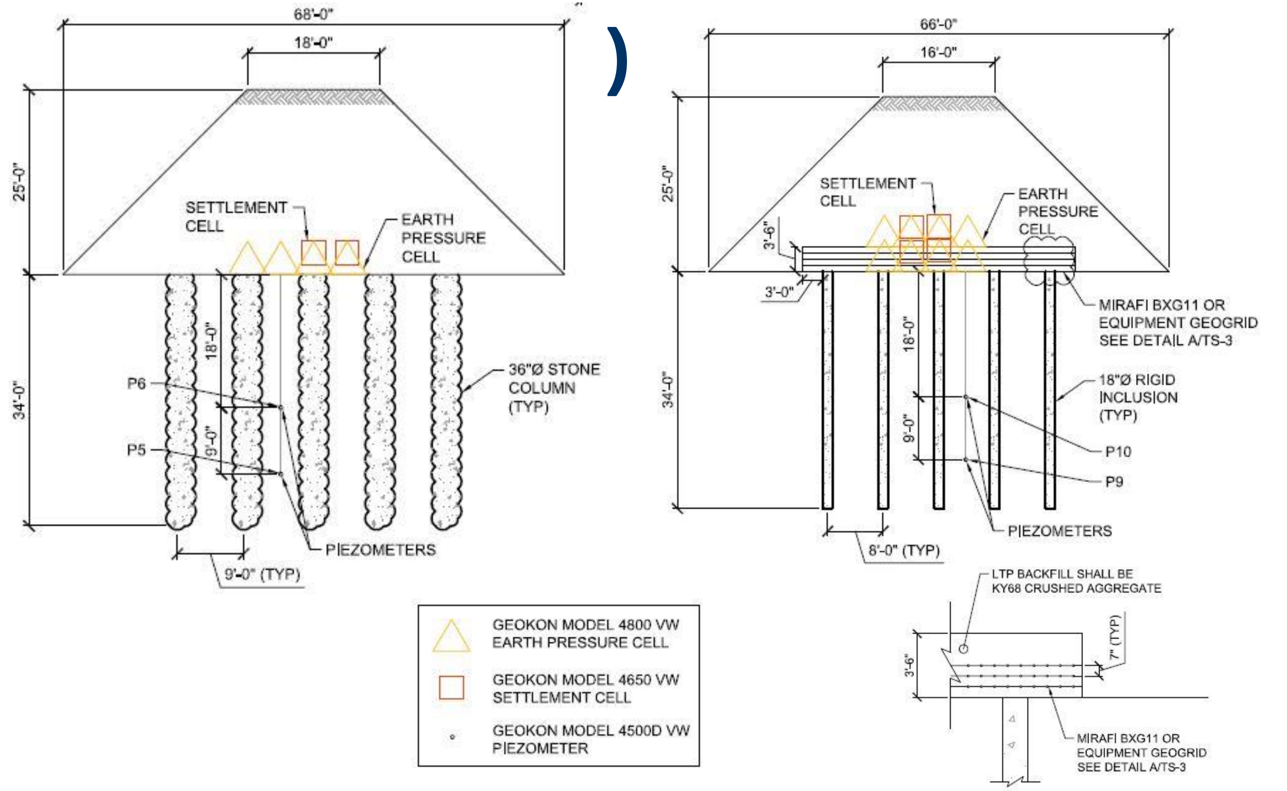
TEST EMBANKMENT AND SELECTION OF INSTRU)



TEST EMBANKMENT – LAYOUT

LEGEND

- EARTH PRESSURE CELLS
- SETTLEMENT CELL
- PIEZOMETERS (2PER LOCATION)
- 36"Ø STONE COLUMNS
- 18"Ø RIGID INCLUSIONS

EP21 - EP24 LOCATED ABOVE PLATFORM

20–0 0 20–0 40

1" = 20'–0"

TEST EMBANKMENT – IMPLEMENTATION

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TEST EMBANKMENT – IMPLEMENTATION

TEST EMBANKMENT – IMPLEMENTATION

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DATA COLLECTION BOX

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BUILDING THE EMBANKMENT

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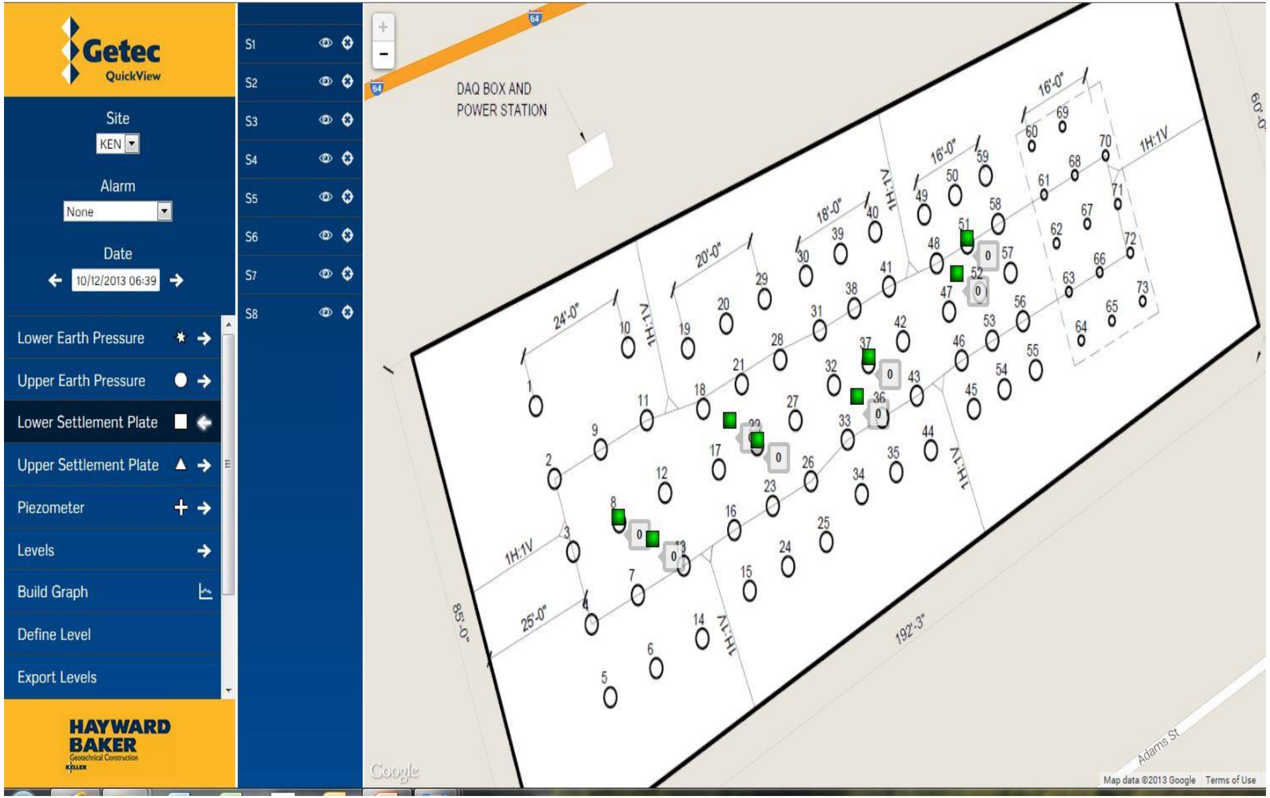
TEST EMBANKMENT COMPETE!!

TEST EMBANKMENT – MONITORING WEBSITE



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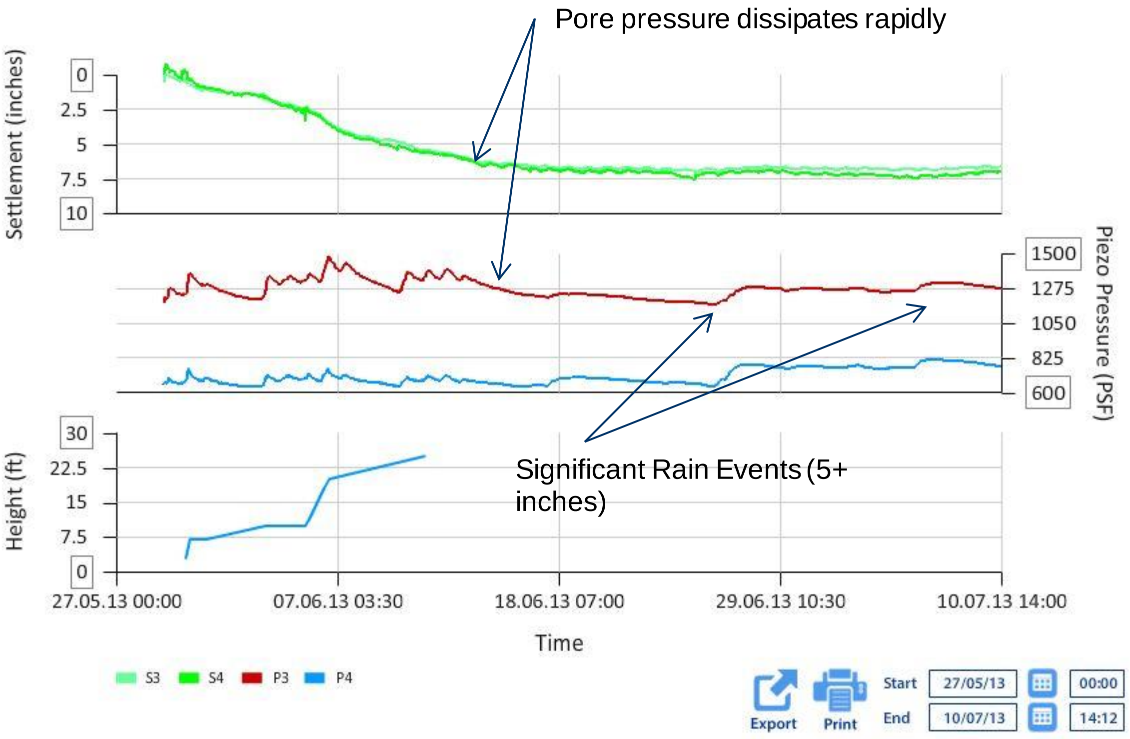
KEY FINDINGS



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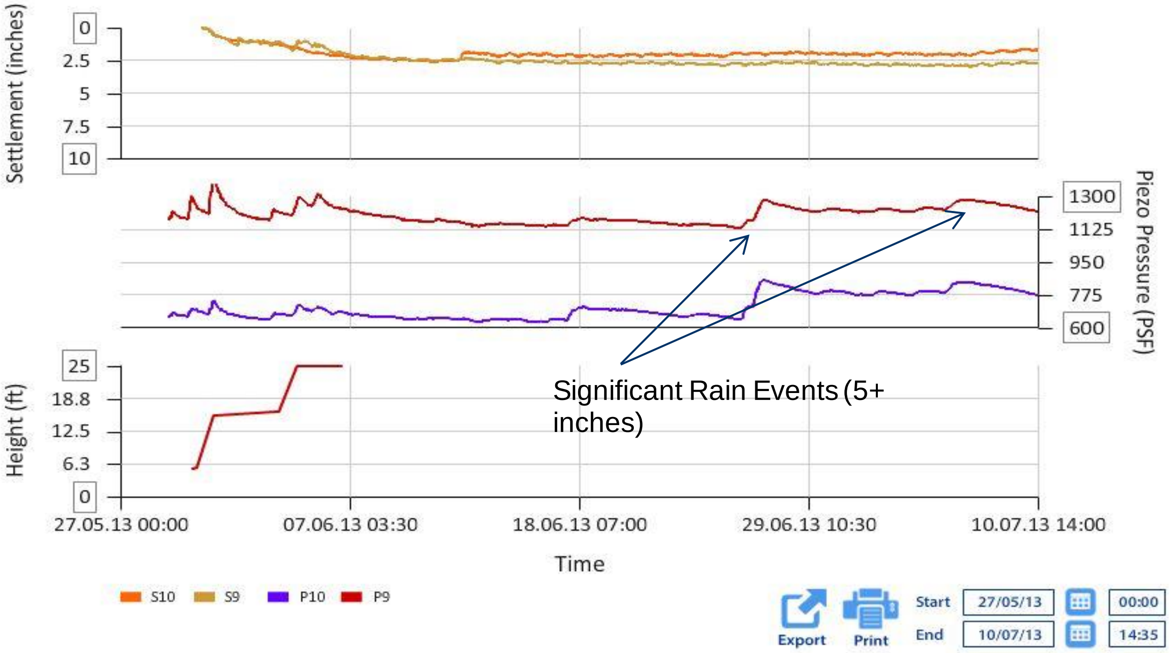
KEY FINDINGS



RI's effective at limiting total settlement

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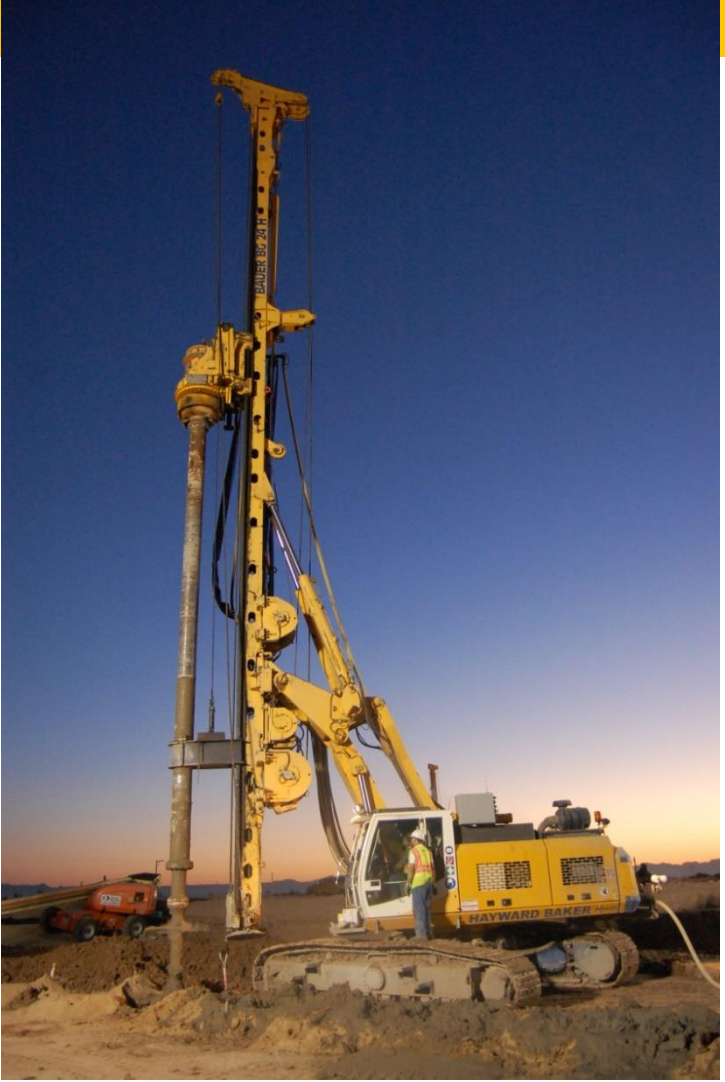
KEY FINDINGS

Cell	Element Spacing	Predicted Pre-Treatment Settlement	Predicted Post-Treatment Settlement	Observed Settlement from Instruments	% Diff Predicted/Observed
12 x 12 SC	12' Square	9.32"	6.88"	6.13"	-11%
10 x 10 SC	10' Square	9.56"	6.56"	6.97"	+6%
9 x 9 SC	9' Square	11.99"	7.02"	5.99"	-14%
8 x 8 SC	8' Square	10.71"	5.91"	6.93"	+17%
8 x 8 RI	8' Square	11.80"	2.26"	2.40"	+6%



Soil Mixing methods can use a Wet process when dryer stiffer soils need to be mixed

Wet mixing process combines the binders with water and the binder is injected as a slurry during the mixing

Top down soil mixing process

The use of higher strength material in the design is possible with the wet installation process

Dry Soil mixing methods are utilized in wetter softer soils or where spoil is a problem

Dry binder materials are pneumatically injected into the soil during the dry mixing process

Bottom up method of soil mixing

There must be adequate soil moisture for the binders to fully hydrate often limiting design strengths

Batching/Delivery equipment setup at the project sites can be compact

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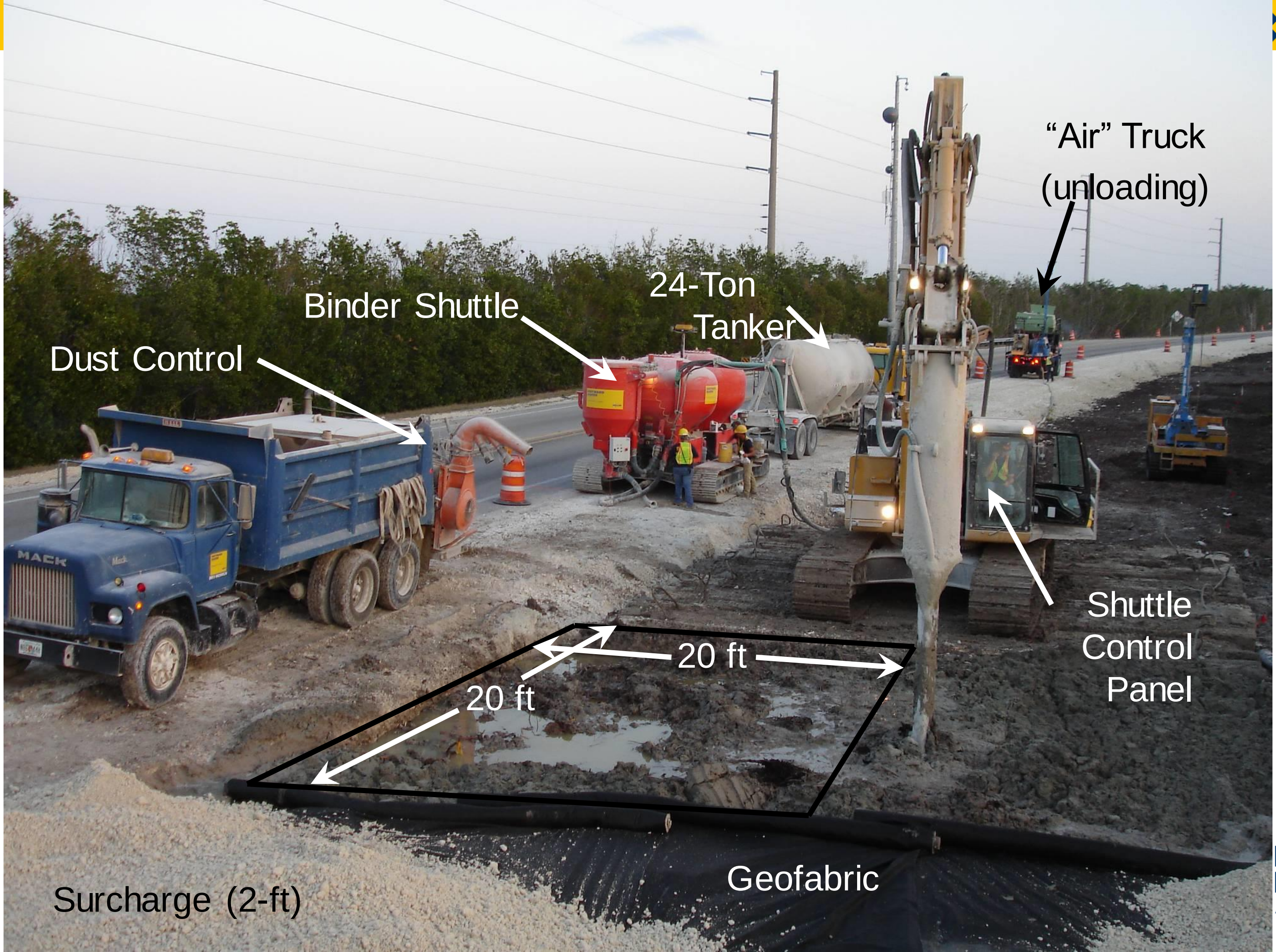
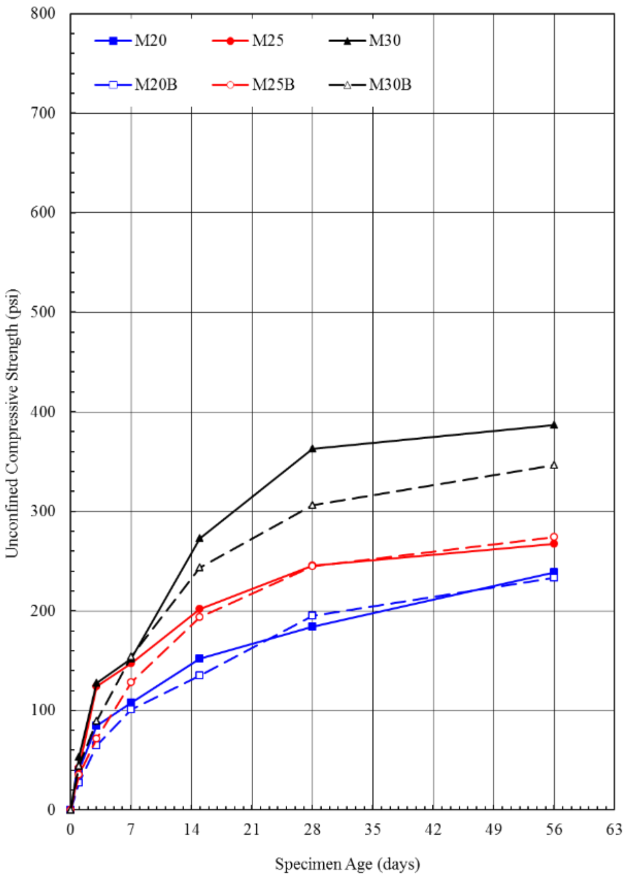
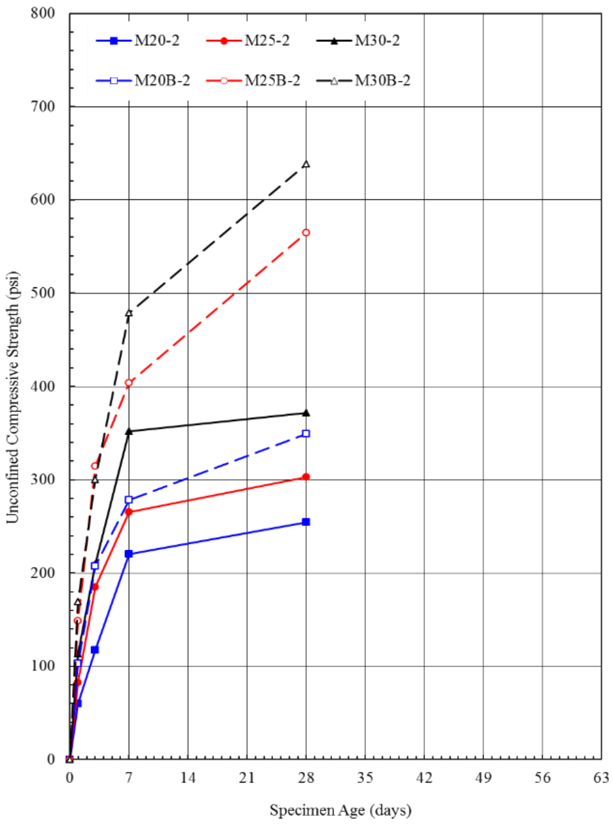

"Air" Truck
(unloading)
24-Ton
Tanker
Binder Shuttle
Dust Control
MACK
20 ft
20 ft
Shuttle
Control
Panel
Geofabric
Surcharge (2-ft)

Bench Scale Test Reporting





Preparing Specifications and Plans

- *“Discussion of how to write specifications (method based, performance based, etc.) while avoiding proprietary aspects…”*

Contracting Framework =

Design – Bid – Build

Preparing Specifications and Plans

- Avoid the use of “method” specifications
  - Unlikely to accommodate available tools and approaches offered by the various specialist contractors
  - May preclude certain methods that might otherwise provide desired performance more economically

- Performance is the ultimate goal

Do's and Don'ts: Suggested References

- **Guidance for Drafting Specifications for Ground Improvement**

  Deep Foundations Magazine, April 2016

Performance Expectations and Requirements

- Regardless of **Design-Bid**-Build or **Design-Build**,
  - Understand the performance requirements for the new construction
  - Communicate them clearly, and completely, in the contract documents
  - Anticipate natural variability and appropriate means of compensation
    - Unit price by “area” units is unlikely to fairly share risk

Performance Expectations and Requirements

- Specify, not only the required behavior, but also the *acceptable design/analysis methods* to be used by the specialist Ground Improvement engineer

- Define review and acceptance responsibilities among the parties

Information to be provided in contract documents

- Complete geotechnical report
  - Not just logs and test result tables
- Existing and planned grades
- Existing and planned utilities
- Groundwater regime and planned surface drainage features
- Information regarding site history, reported past activities
- Known contamination
- Planned construction sequence

Applied Bearing Pressures and Loading

- How is design bearing pressure to be computed?
  - FS against bearing capacity failure or serviceability/settlement?
  - At what location is the target bearing pressure to be computed?
    - Average across structure or extreme edges?
- Are there different requirements for different structure elements?

Settlement

- Define acceptable magnitude of vertical displacement during construction and post-construction
  - Static, service dynamic, and seismic
  - Specify for which structure type each criterion applies, e.g., embankment fill, MSE wall facing, etc.
- Conditions under which settlement is to be computed
  - Provide and describe DL, Sustained LL, Transient LL and Extreme Service Loads
  - Define the necessary design loading combinations

Settlement

- Define acceptable displacements with regard to magnitude and time
  - Immediate/during construction
  - Primary consolidation settlement
  - Secondary compression/creep settlement
- Define where and how settlement is to be measured
  - Devices, precision, reference baseline
- Define when monitoring is to occur and by whom

- Define acceptable corrective actions

Slope Stabilization

- Acceptable analysis methods
- Appropriate soil strength parameters
- Required static and seismic FS against instability
- Any allowable temporary FS
- Monitoring method
- Monitoring frequency
- Acceptable corrective actions

Special Circumstances and Considerations

- Explicitly define operational constraints
  - Work hours
  - Staged construction
  - Noise, dust, vibration limits, etc.
  - Access
  - Water sources and disposal
  - Spoil management

Special Circumstances and Considerations

- Anticipate/report the presence of obstructions
- Anticipate/report flowing and/or artesian water condition
- Anticipate/report presence or potential presence of hazardous materials or gases
- Locale-specific considerations
  - Weight restrictions
  - Frost laws
  - Available or restricted local materials
  - Labor agreements/rules

The recurring expectation…

- Provide **clarity**
  - For the specialist engineer and construction team
  - For the reviewer(s)
  - For the Owner

Verification Methods

- Select the tools based on the means used to provide improvement:
  - **Drainage**
    - Observe and measure
      - Settlement monitors
      - Piezometers
  - **Densification**
    - Test program: verify adequacy of pattern(s) – adjust compensation
    - Volume change
      - Settlement monitors
    - Pre- and post-improvement penetration resistance or PMT/DMT modulus assessments

Verification Methods

- **Reinforcement**
  - System “analysis” <u>and</u> element behavior and quality
    - Single elements versus groups?
  - Observe and measure
    - Settlement monitors
    - Piezometers
    - Pressure cells
- Consider Purpose
  - Quality Control
  - Quality Assurance

Verification Methods

- Be sensible with respect to scope and schedule of verification testing
  - Do X# "tests" manage risk better than Y# "tests"?
  - Remember "review period" costs money…
    - Specialty contractor resources don't sit idle for free

When considering Ground Improvement …

- Evaluate project setting and risks
- Have the end in mind
- Don’t forget the fundamental soil mechanics

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