The National Academies of
SCIENCES · ENGINEERING · MEDICINE

TRANSPORTATION RESEARCH BOARD

Design and Construction of Mechanically Stabilized Earth Structures

Thursday, October 10, 2019
2:00-3:30 PM ET

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

Purpose

Provide an overview of Mechanically Stabilized Earth (MSE) walls and ground improvement methods

Learning Objectives

At the end of this webinar, you will be able to:

- Describe the performance of Mechanically Stabilized Earth (MSE) walls on sites with significant settlement
- Describe various techniques to mitigate settlement (lightweight fills, phased construction, ground improvement)

Design and Construction of MSE Structures on Compressible Soils

Peter L. Anderson, P.E.

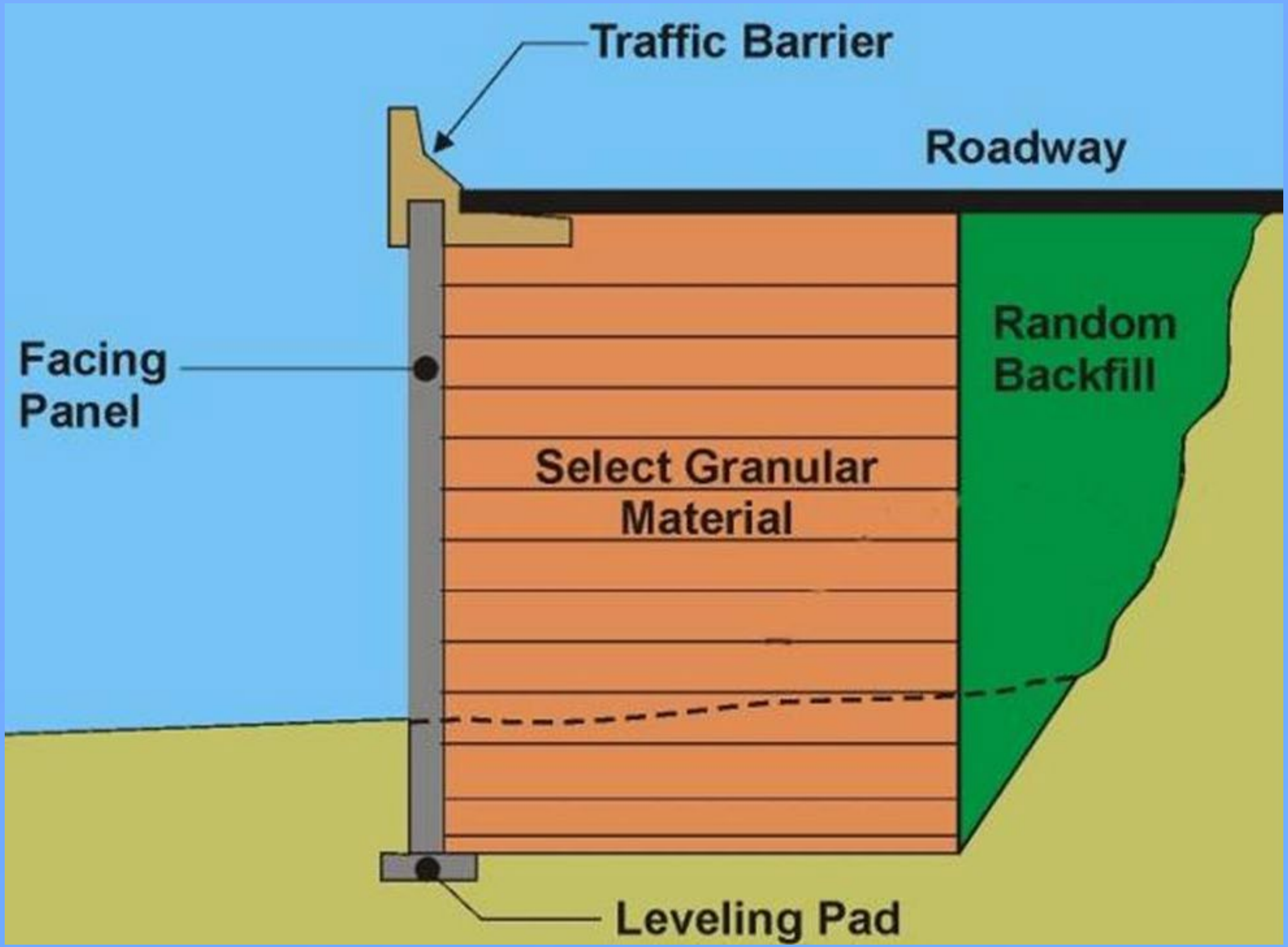
Vice President, Technical Development & Northeast Regional Manager

The Reinforced Earth Company

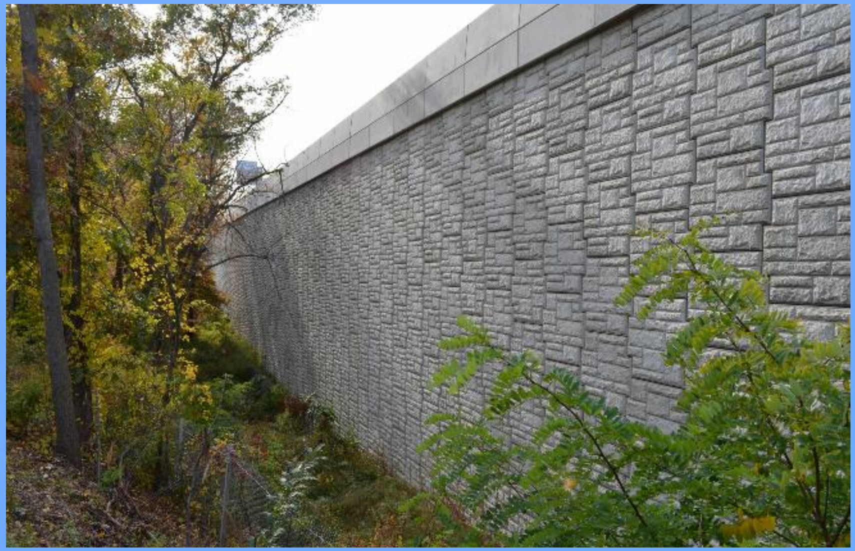
Transportation Research Board

October 10, 2019

Typical Section of MSE Retaining Wall



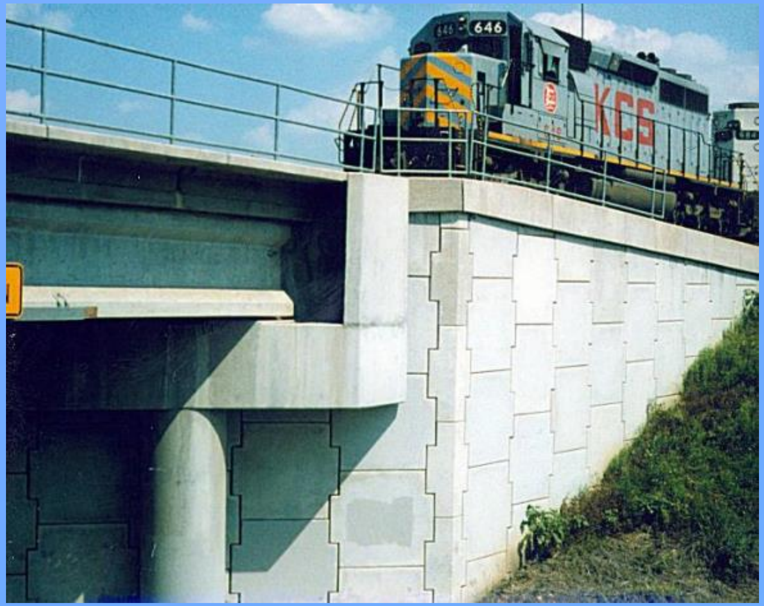
MSE Retaining Walls



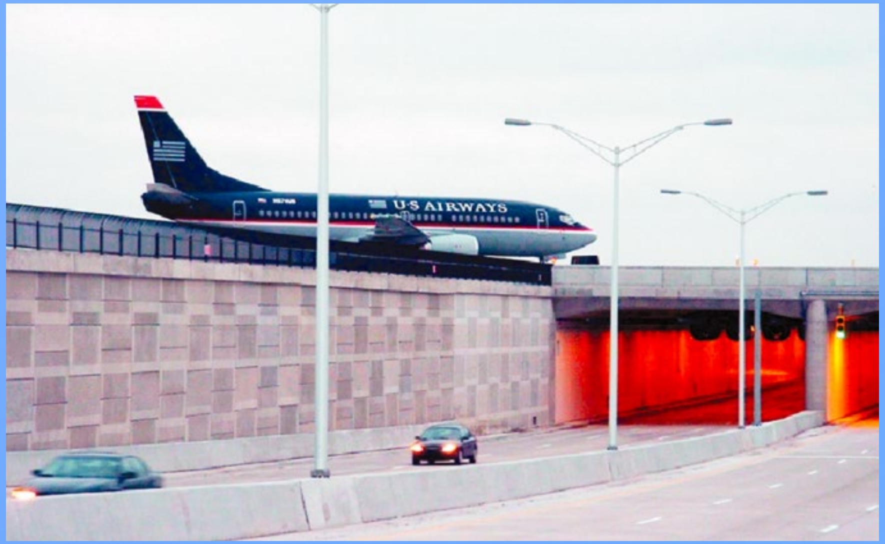
MSE Bridge Abutments

Rapid Transit

Commuter & Heavy Railway



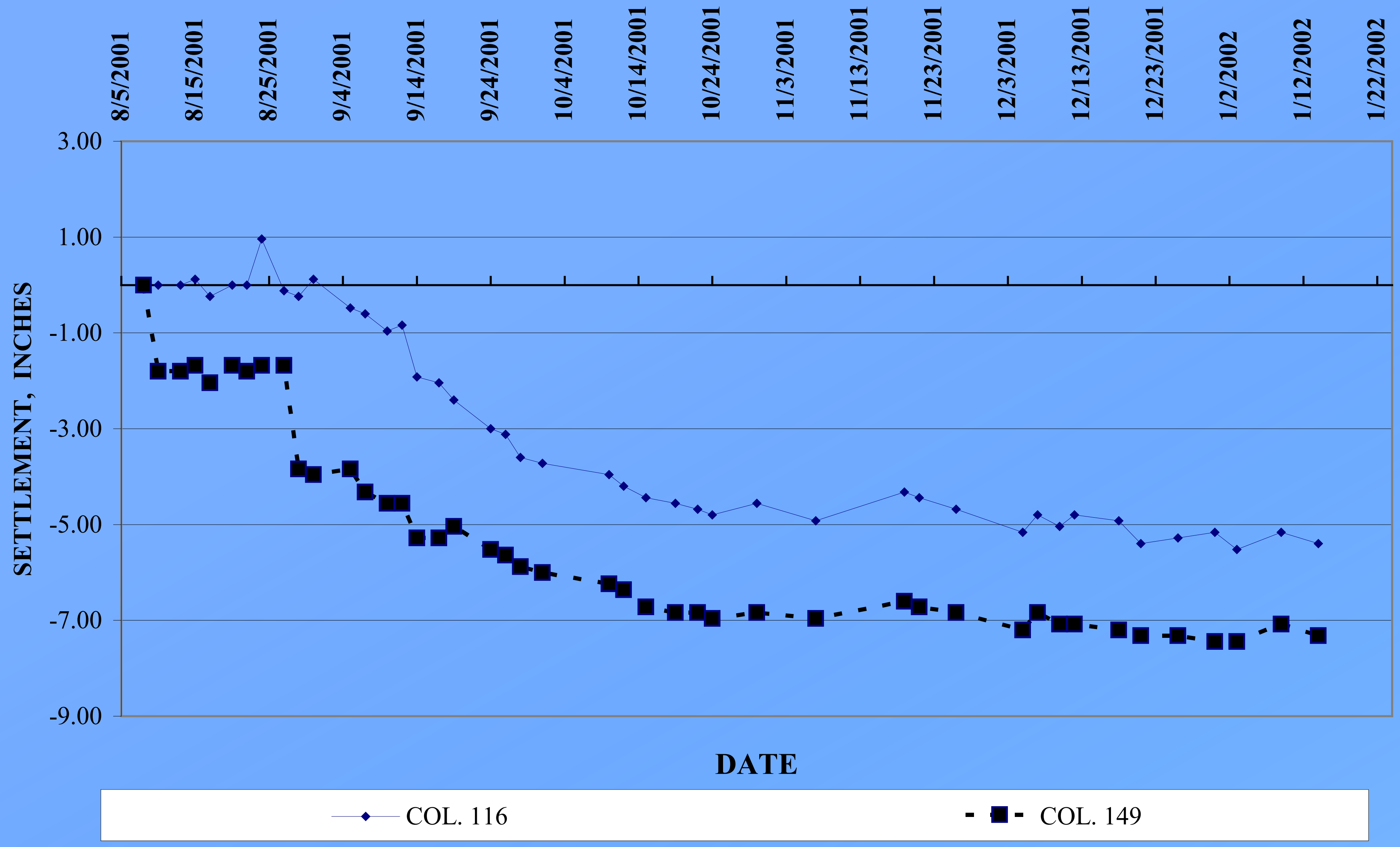
Taxiway and Runway Support



MSE Structures Can Be Constructed on Compressible Foundation Soils

WMATA, Branch Ave, MD - 2001

WMATA - BRANCH AVENUE STORAGE YARD - MSE WALL
SETTLEMNT PLATES ON MSE WALL FACE



Settlement: 7.5”

Differential 2” in 165 ft. or 0.1%

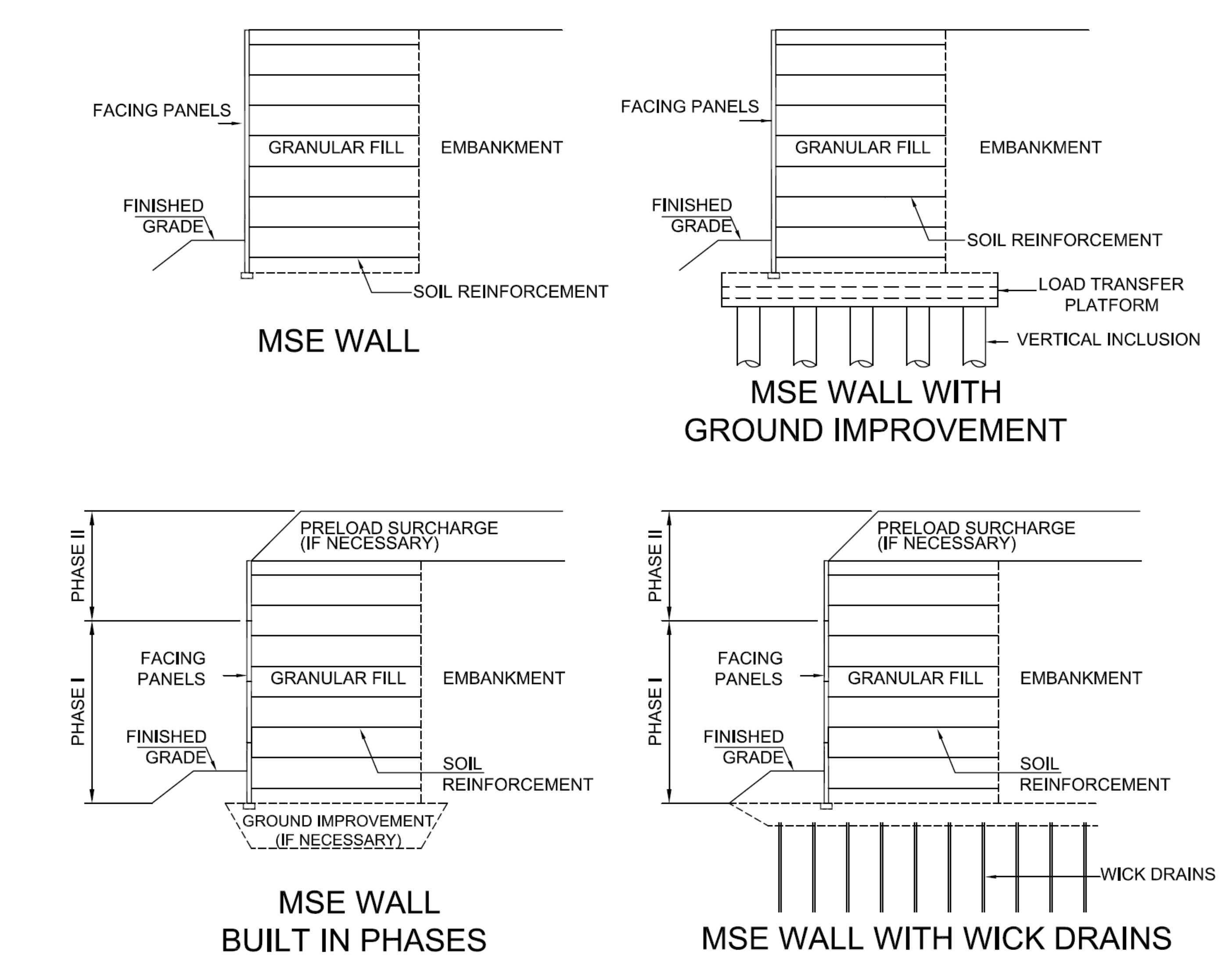
Total and Differential Settlement

- MSE walls are flexible gravity structures
- No limit on total settlement for wall performance
- Differential settlement: 1 ft. in 100 ft. (5’x5’ Panels)
- Differential settlement: 1 ft. in 200 ft. (5’x10’ Panels)

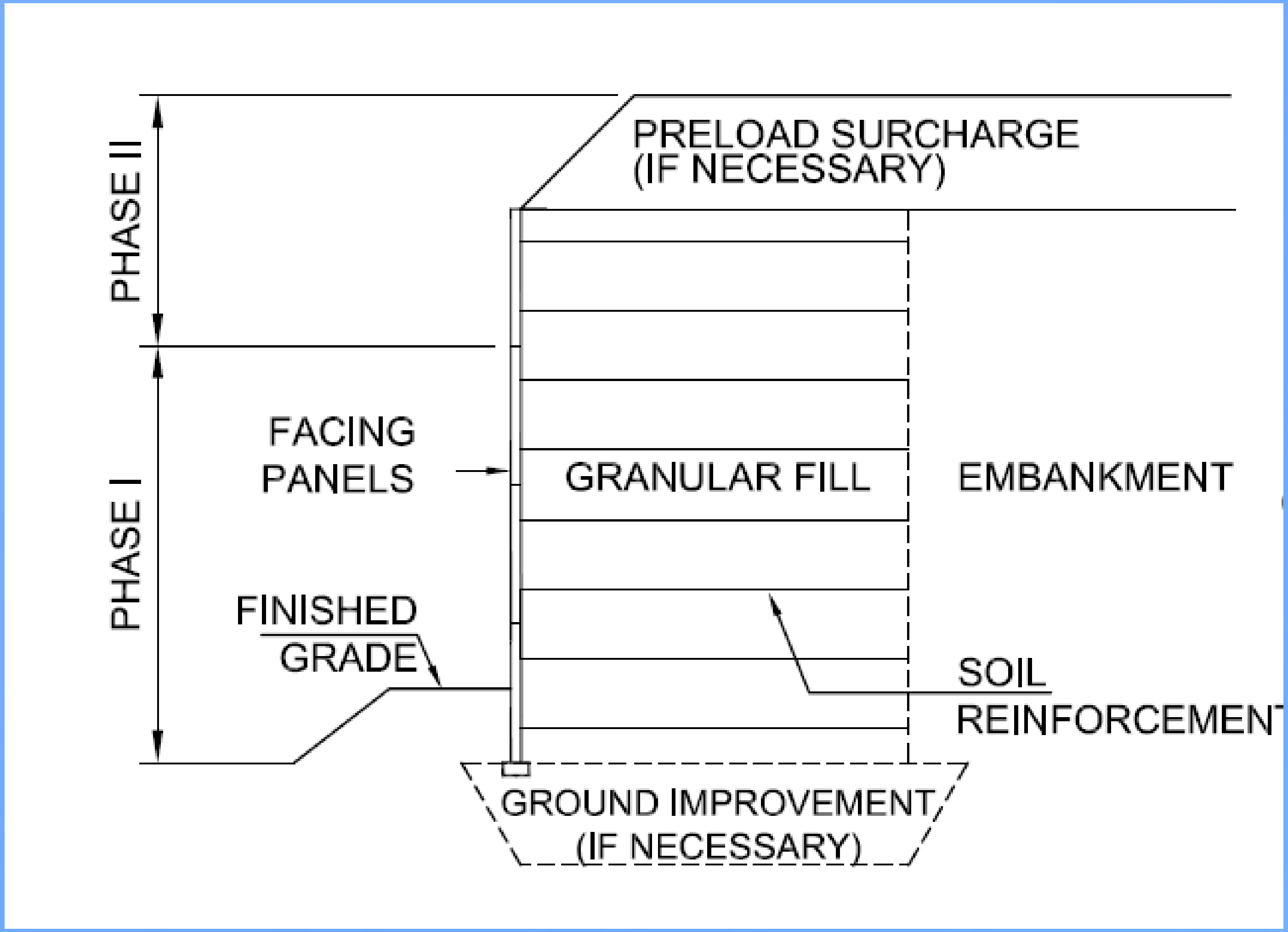
MSE Structures with Significant Settlement

Location	Year Built	Height of Wall (m)	Wall or Abutment	Total Settlement (mm)	Differential Settlement %	Facing Shape
Route 39, CA	1972	16.8	Wall	1070	N/R	Elliptical
Sprain Brook Pkwy, NY	1978	15.5	Mixed Abut	890	2	Cruciform
Wells, ME	1980	9.8	True Abutment	380	< 1	Cruciform
McNeil Station, VT	1984	8.5	True Abutment	400	< 1	Cruciform
Julesburg, CO	1988	12.2	Wall	275	0.2	Cruciform
Marcy Utica Deerfield, NY	1990	9.1	Wall	750	1	Cruciform
Lakeland, FL	1997	9	Wall	780	1.2	Cruciform
Atlanta Airport, GA	2006	21	Wall	600	<1	Square

Options to Address Bearing Capacity and Settlement



MSE Wall Construction Built in Phases

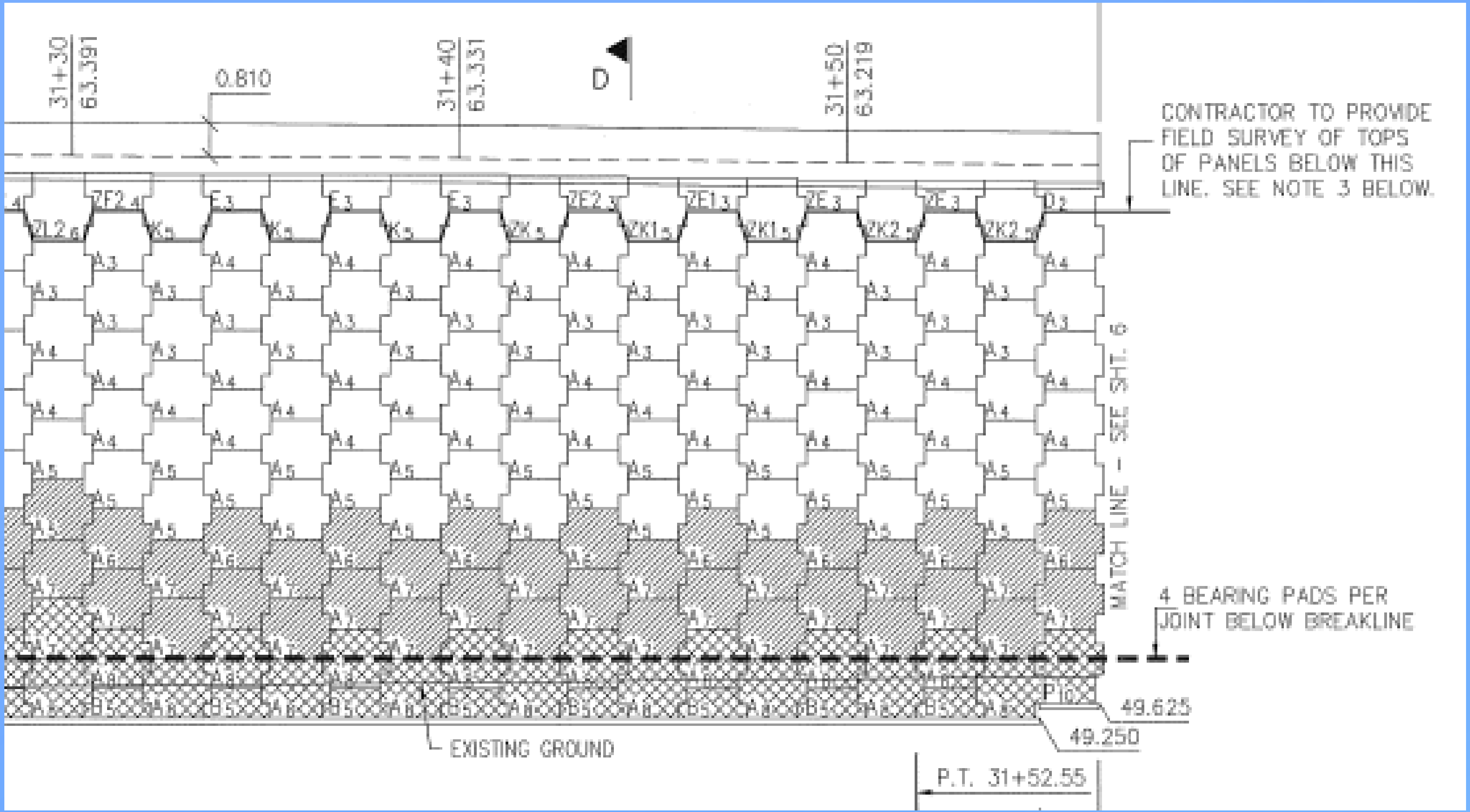


MSE Wall Construction Built in Phases

- Wall constructed without top panels
- Wall surcharged to force settlement
- Settlement monitored until meets criteria
- Survey top of wall after settlement
- Design top panels to achieve required top of wall
- Fabricate top panels and remove surcharge
- Install top panels
- Install traffic barrier and roadway

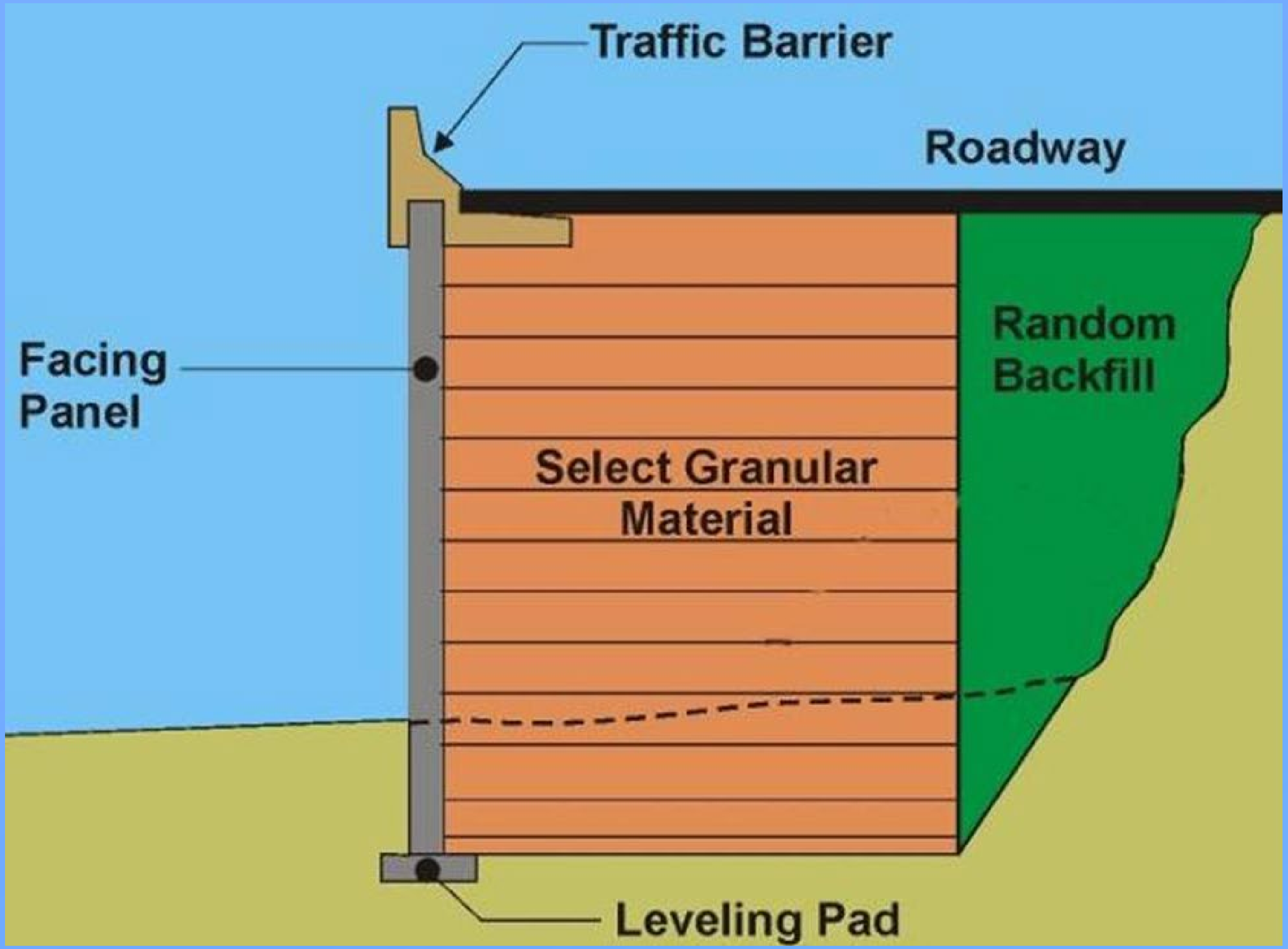
Richmond Airport – Completion of Phase I

Survey Tops of Installed Panels

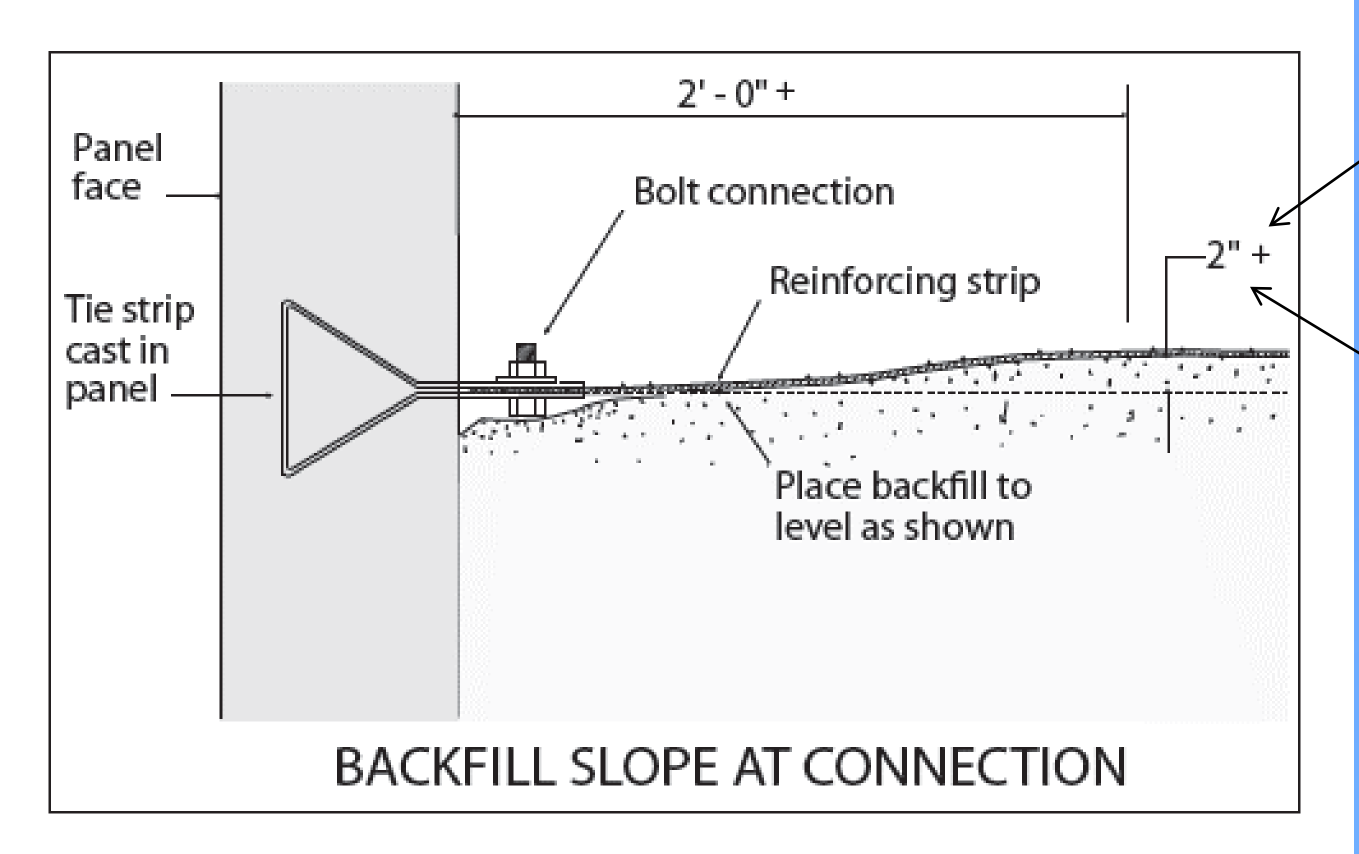


Richmond Airport – Completion of Phase II

Differential Settlement Perpendicular to Wall Face



Accommodating Differential Settlement Perpendicular to Wall Face



2" Typical for Normal Construction

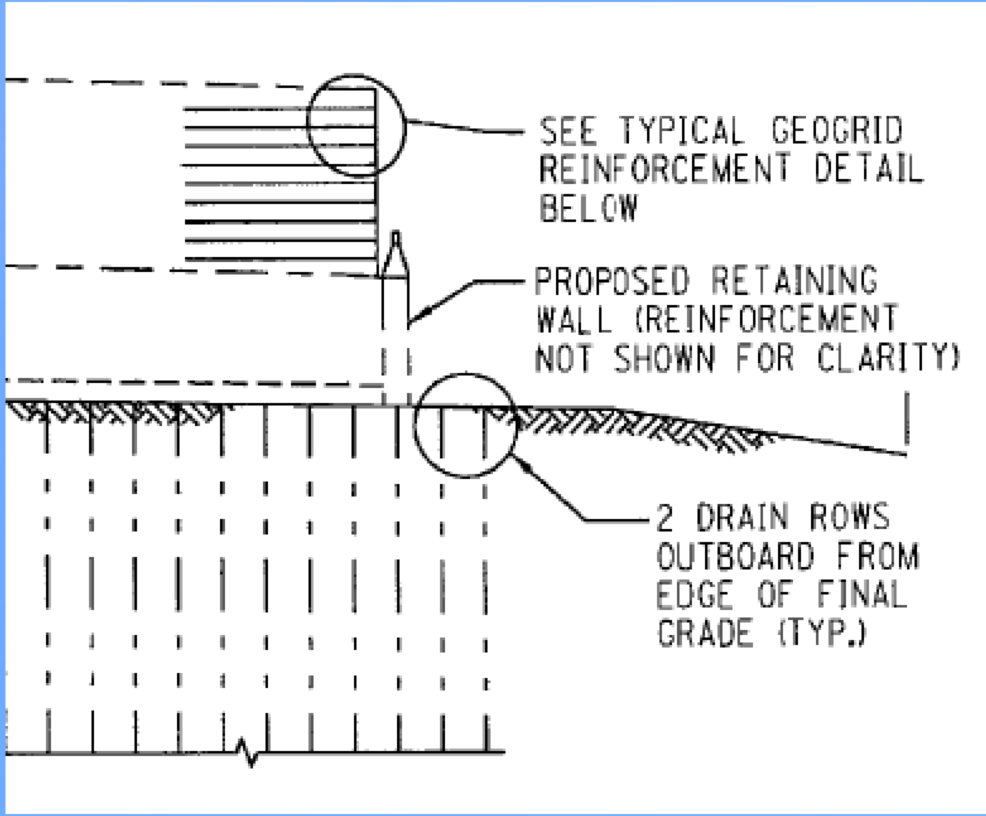
4" to 6" if expect large settlement

Belt Parkway over Mill Basin, Brooklyn, NY

- Two-stage construction recommended in contract documents
- Height of surcharge and anticipated settlement specified
- Settlement in excess of 18” anticipated
- Conventional MSE wall construction proposed
- Walls constructed atop wick drains, leaving out top panels
- Walls surcharged with wire faced MSE walls
- Top panels installed after settlement complete

Surcharge Specified in Contract Drawings

SURCHARGE TABLE			
STATION		SURCHARGE HEIGHT ABOVE FINAL GRADE (M)	ESTIMATED TOTAL SETTLEMENT (M)
NORTH EMBANKMENT	4+957 TO 5+000	4.60	0.31 TO 0.46
	5+020	3.70	0.29 TO 0.37
	5+040	3.40	0.26 TO 0.33
	5+060	3.00	0.23 TO 0.29
	5+080	3.00	0.21 TO 0.27
	5+100 TO 5+400	2.40	0.18 TO 0.24
	5+400 TO 5+700	1.50	0.02 TO 0.03
SOUTH EMBANKMENT	4+080 TO 4+150	4.60	0.21 TO 0.29
	3+750 TO 3+850	2.40	0.05 TO 0.06

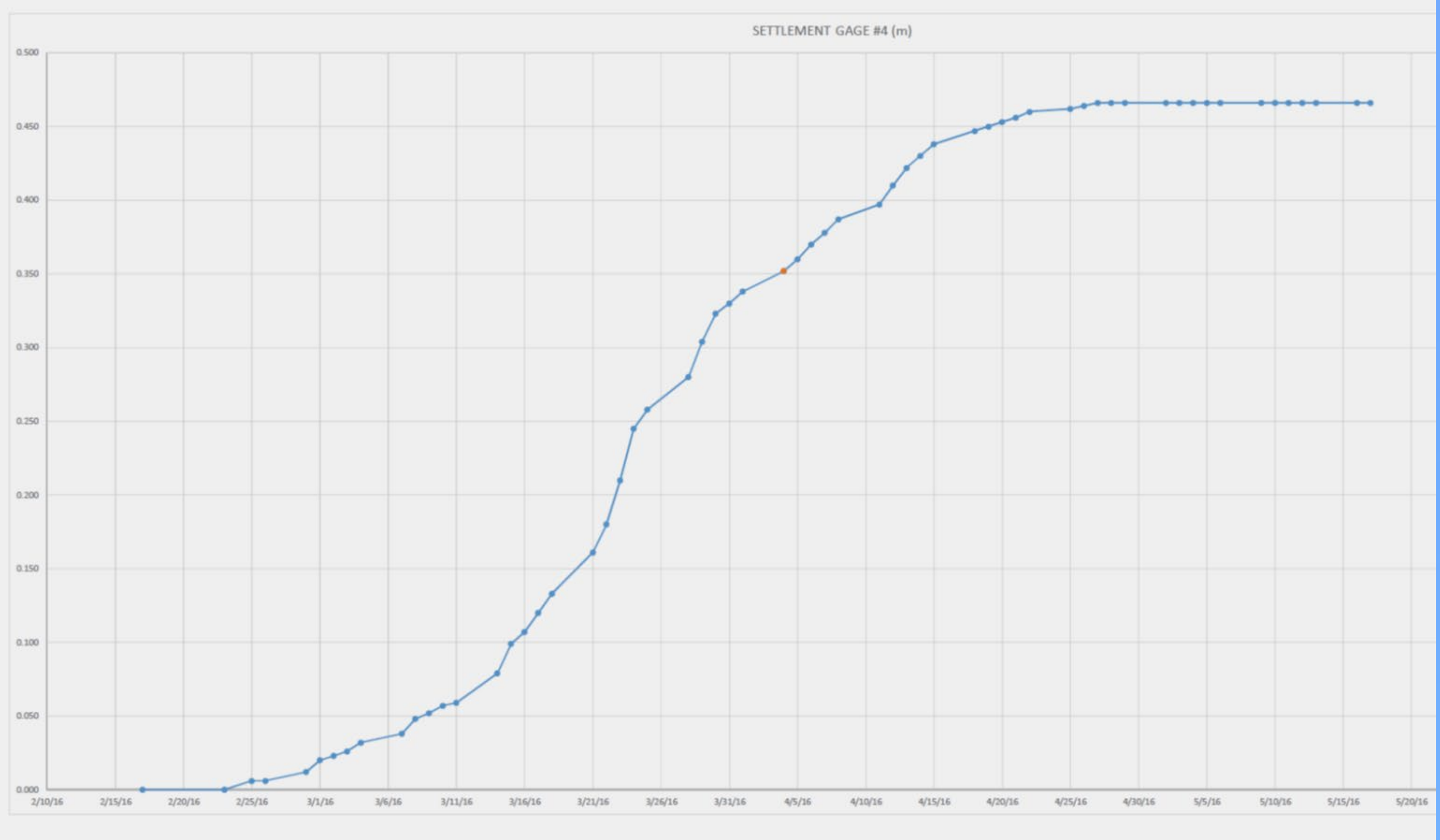


Wire Faced MSE Wall Behind Abutment

Precast Panel Faced Approach MSE Walls

Approach Walls With Temp MSE Surcharge

Belt Parkway over Mill Basin – Settlement Data

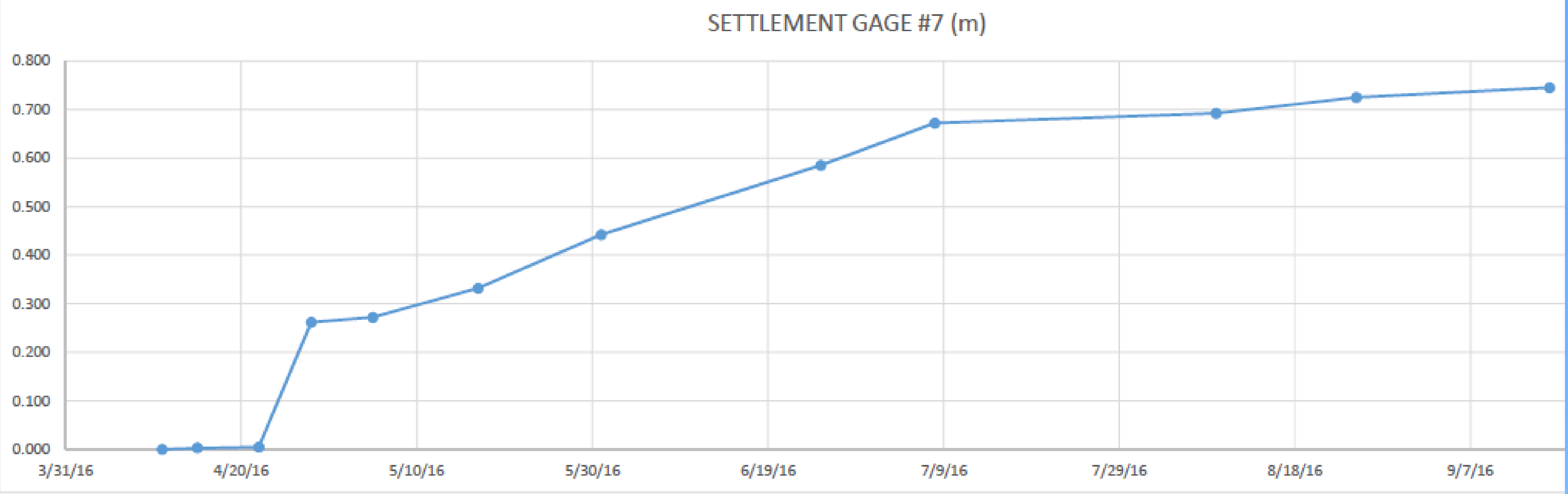


More than 0.45m (18”) of Settlement at wall face in three months

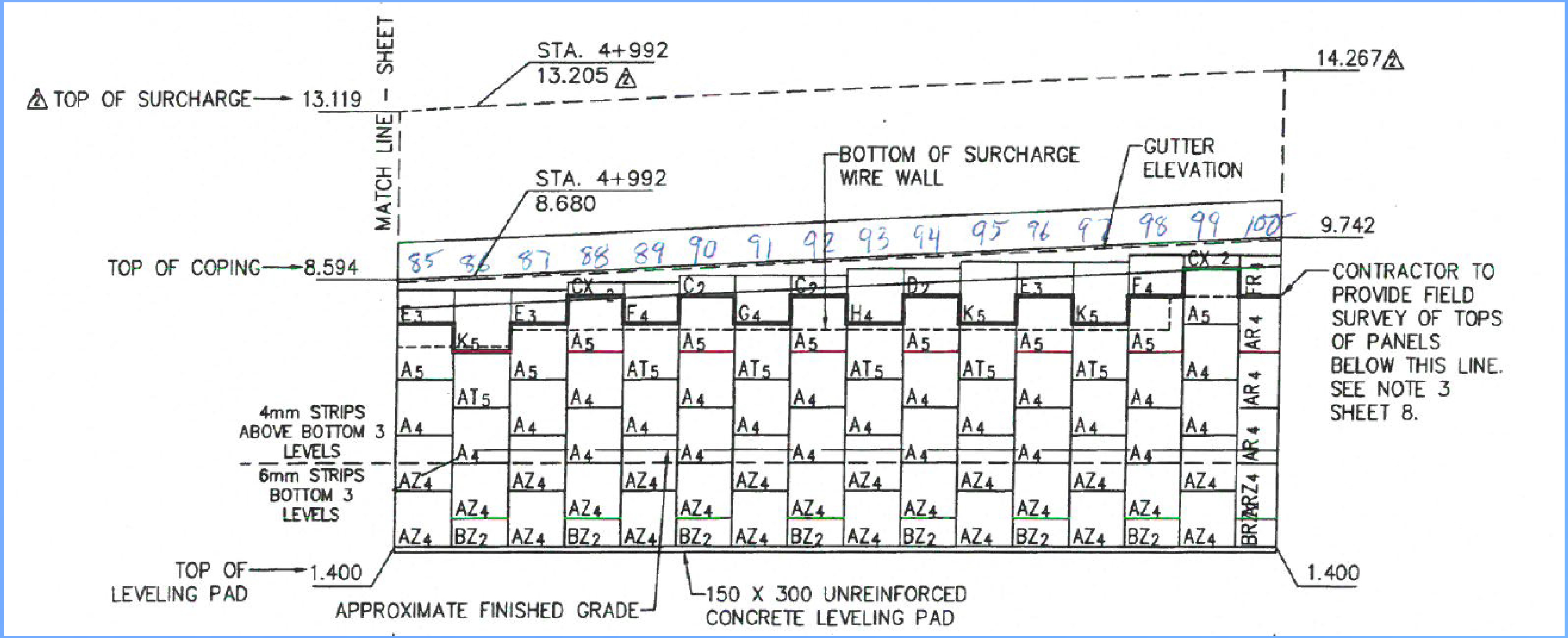
0.75m (30”) Settlement (Center of Embankment)

SETTLEMENT GAGE #7 NORTH ABUTMENT

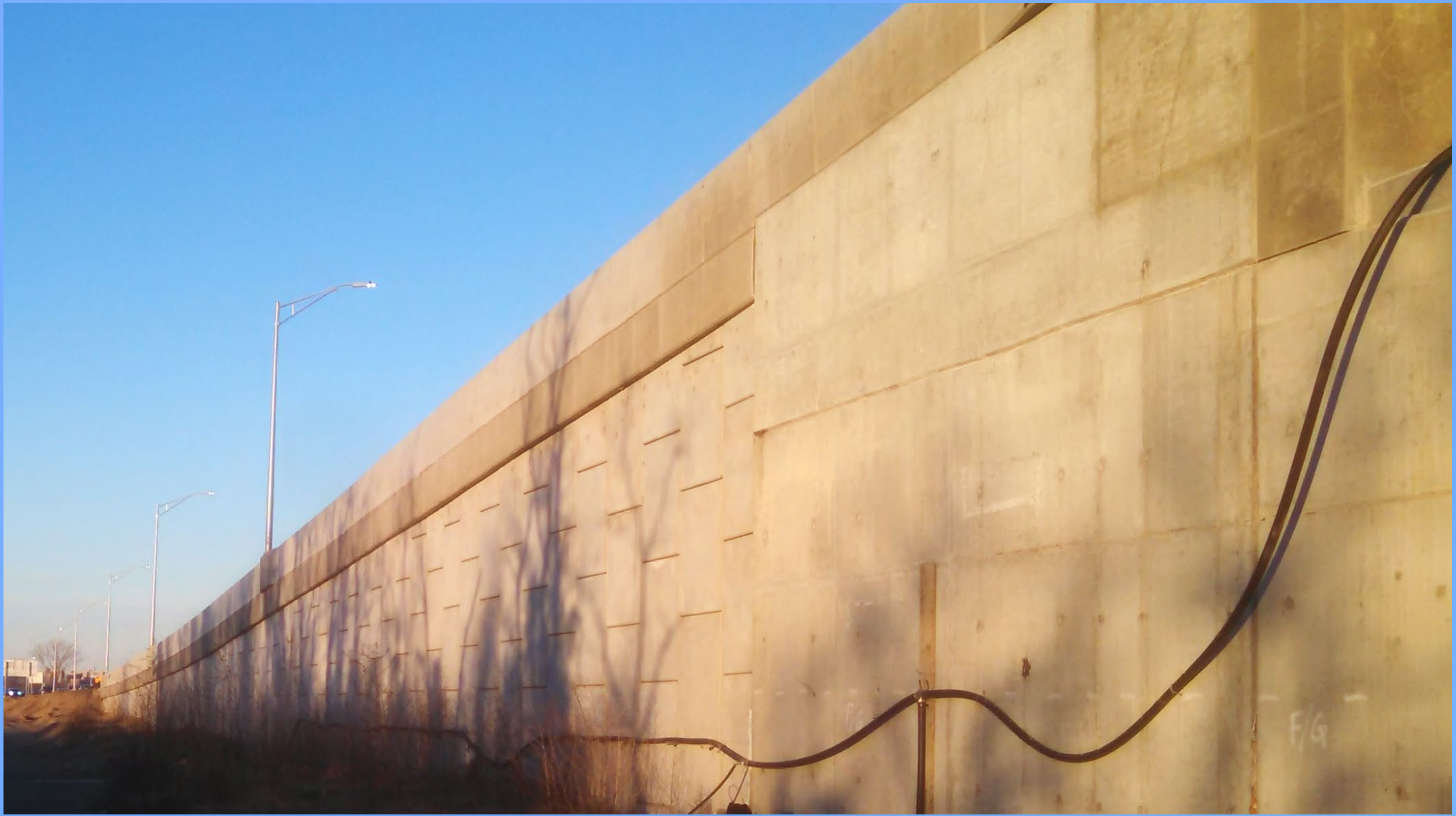
DATE	4/11/2016	4/15/2016	4/22/2016	4/28/2016	5/5/2016	5/17/2016	5/31/2016	6/25/2016	7/8/2016	8/9/2016	8/25/2016	9/16/2016
FILL HEIGHT (m)	0	2.800	3.200	5.700	7.000	7.500	10.600	14.800	14.800	14.800	14.800	14.800
BASE ELEVATION (m)	1.725	1.722	1.720	1.463	1.453	1.393	1.283	1.140	1.053	1.033	1.000	0.980
SETTLEMENT (m)	0.000	0.003	0.005	0.262	0.272	0.332	0.442	0.585	0.672	0.692	0.725	0.745



Top Panels and Traffic Barrier Installed After Settlement

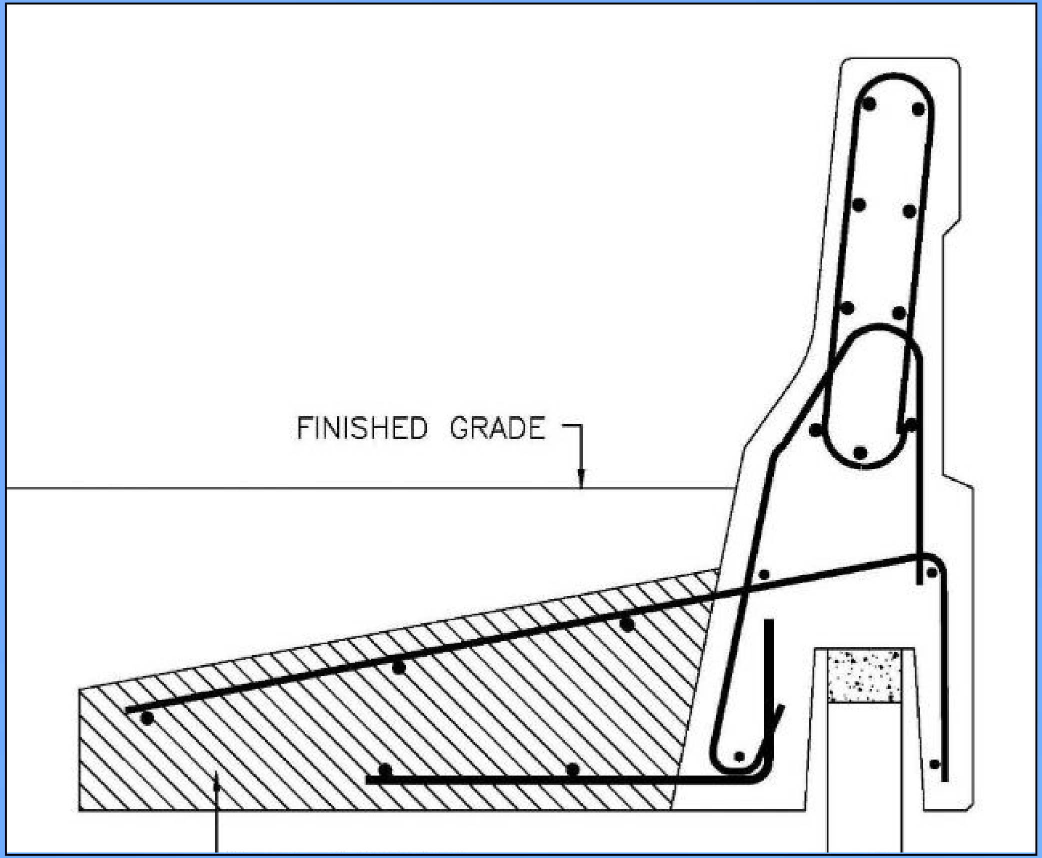


Completed Structure



Completed Structure

Typical Precast Traffic Barrier Detail



Important: Coping Lip Required

Pre-Construction Meeting

- **Attendance**
  - Resident, Geotech, Inspector, Contractor, Ground improvement rep, MSE wall rep
- **Presentations by MSE and Ground Improvement Reps**
  - Detailed MSE wall construction procedures
  - Ground improvement installation
  - Project specific details – monitoring, drainage, expected settlement, etc
- **Inspection**
  - What to look for, what will be required
  - Who’s doing the monitoring, and what to do with the data
- **General discussion**
  - Discuss what's important to: Resident, Inspector, Geotech, Contractor

In Summary

MSE Walls:

- Are flexible gravity structures
- Can tolerate significant total and differential settlement
- Can accommodate large settlements by phasing wall construction
- Can use ground improvement to enhance performance

Thanks for Listening!

Wick Drains and Rigid Inclusions

Transportation Research Board Webinar

Design and Construction of MSE Structures on Compressible Soils

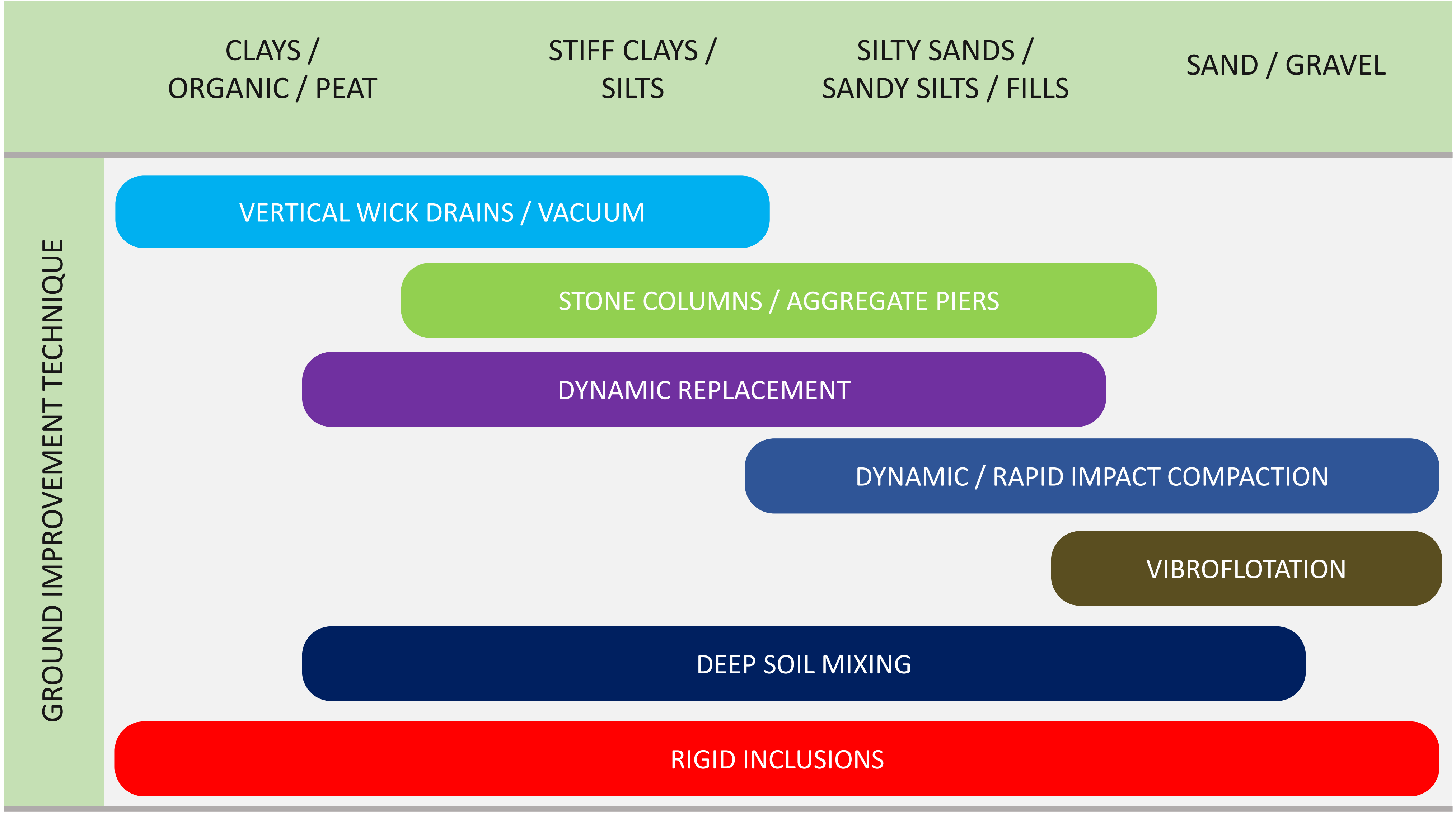
Sonia Sorabella Swift, PE

October 10, 2019

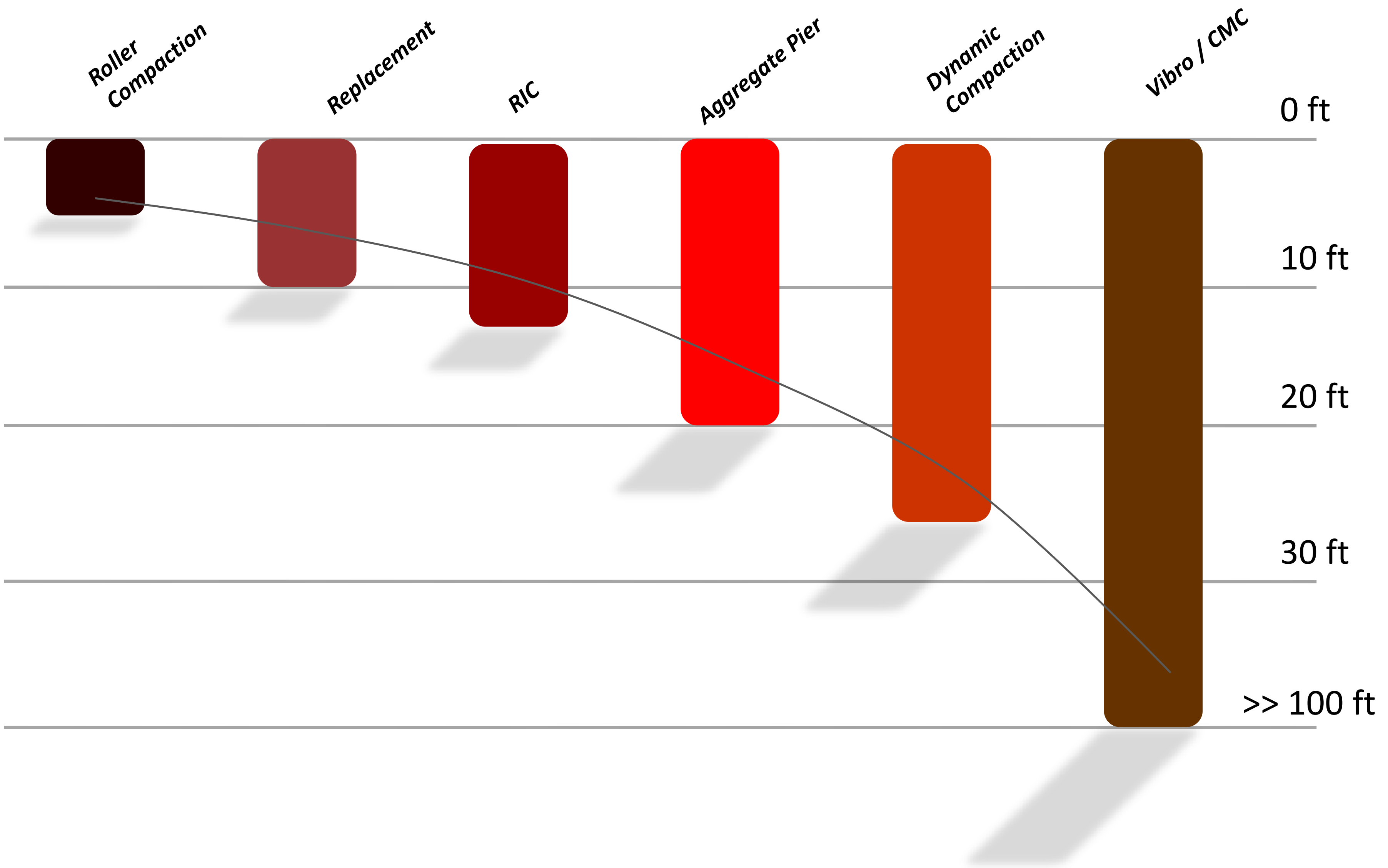
Foundation Requirements for MSE Structures

- Control Settlement
  - Short-term (during construction)
  - Long-term
- Bearing Capacity
- Lateral Stability (sliding)
- Overturning Stability
- Global Stability
- Seismic Considerations

Types of Ground Improvement



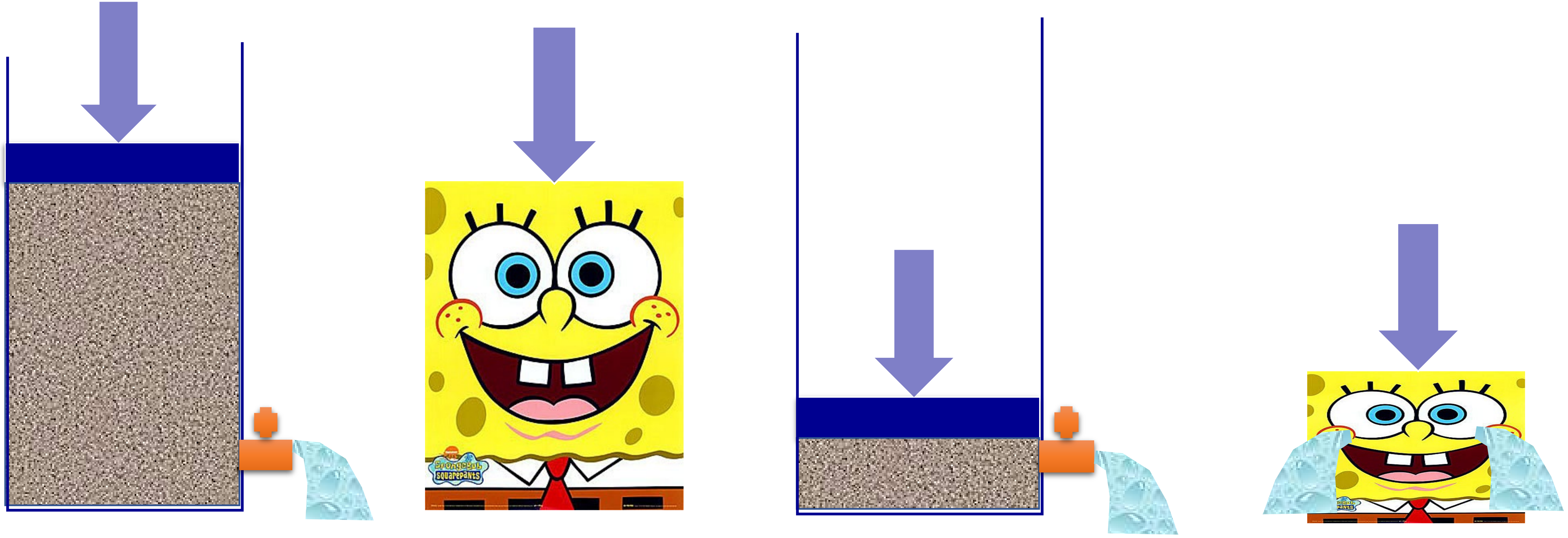
Optimized Depth of Ground Improvement



Vertical Wick Drains

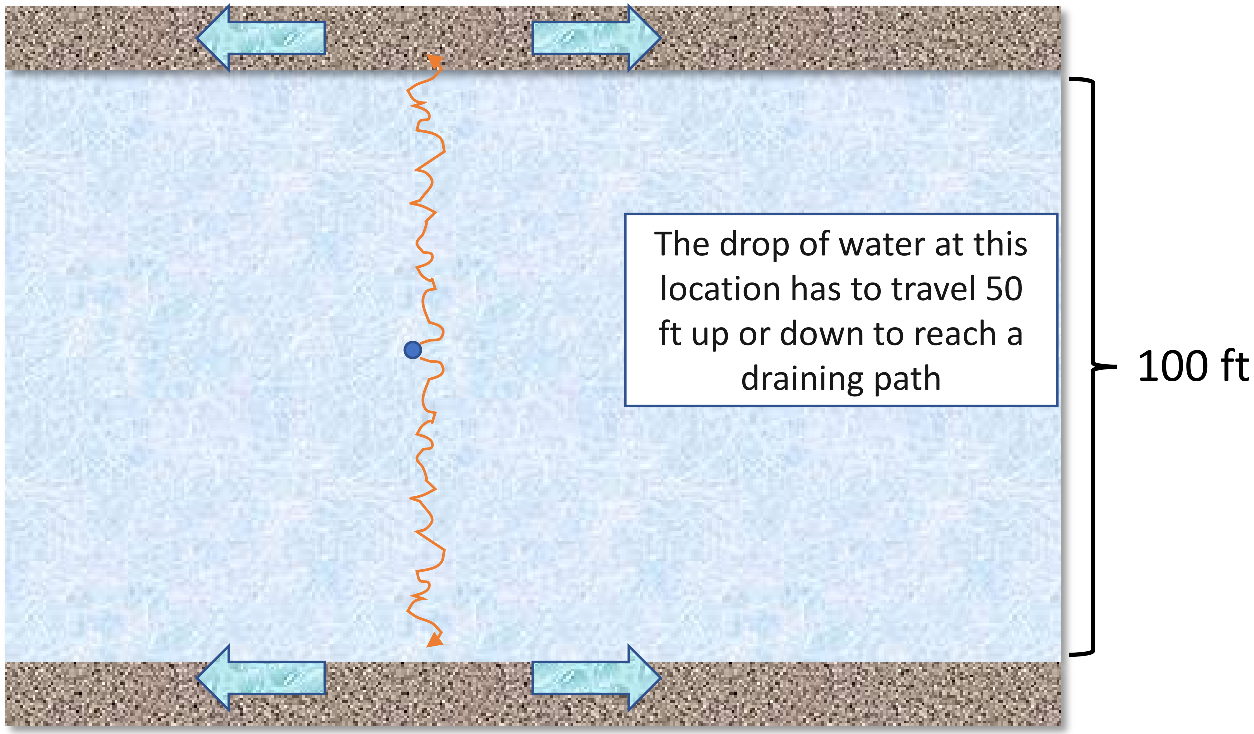
Wick Drains – Basic Principles

When load is applied to soft saturated soils, the pore pressures increase. Over time, those pore pressures dissipate, which reduces the volume of the soil mass (settlement).

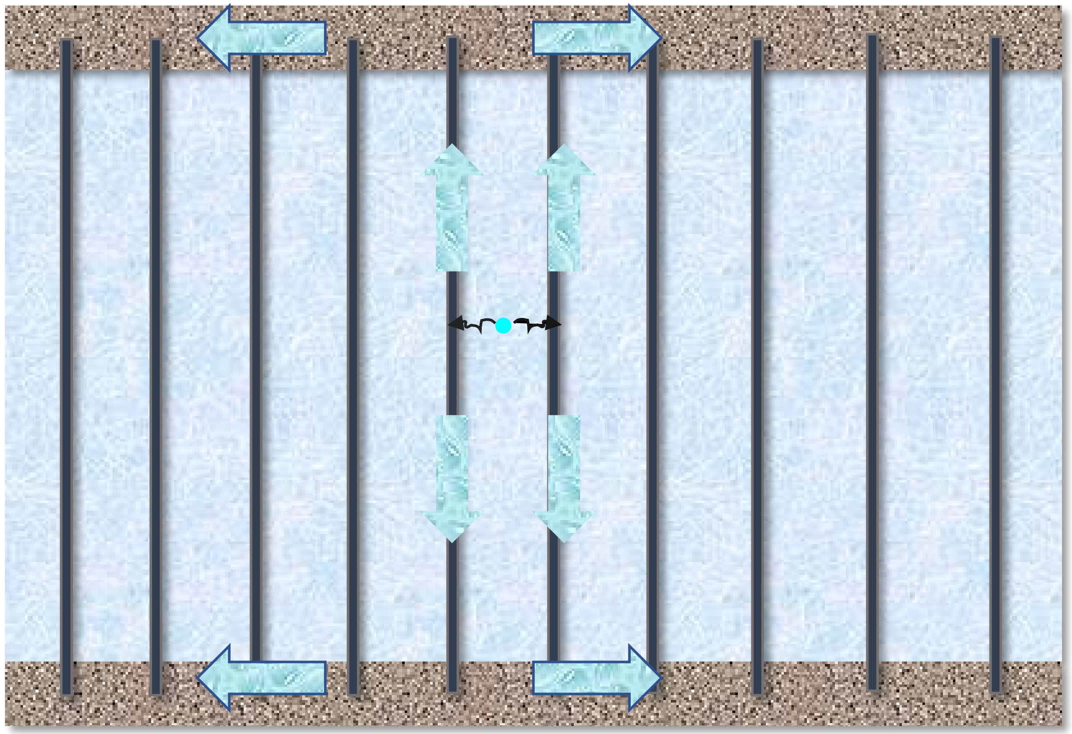


Wick Drains – Basic Principles

- Soft cohesive soils tend to have very low permeability, so it takes the water a long time to travel through the soil.
- Wick drains reduce the length of the path the water has to travel to reach a more permeable layer.

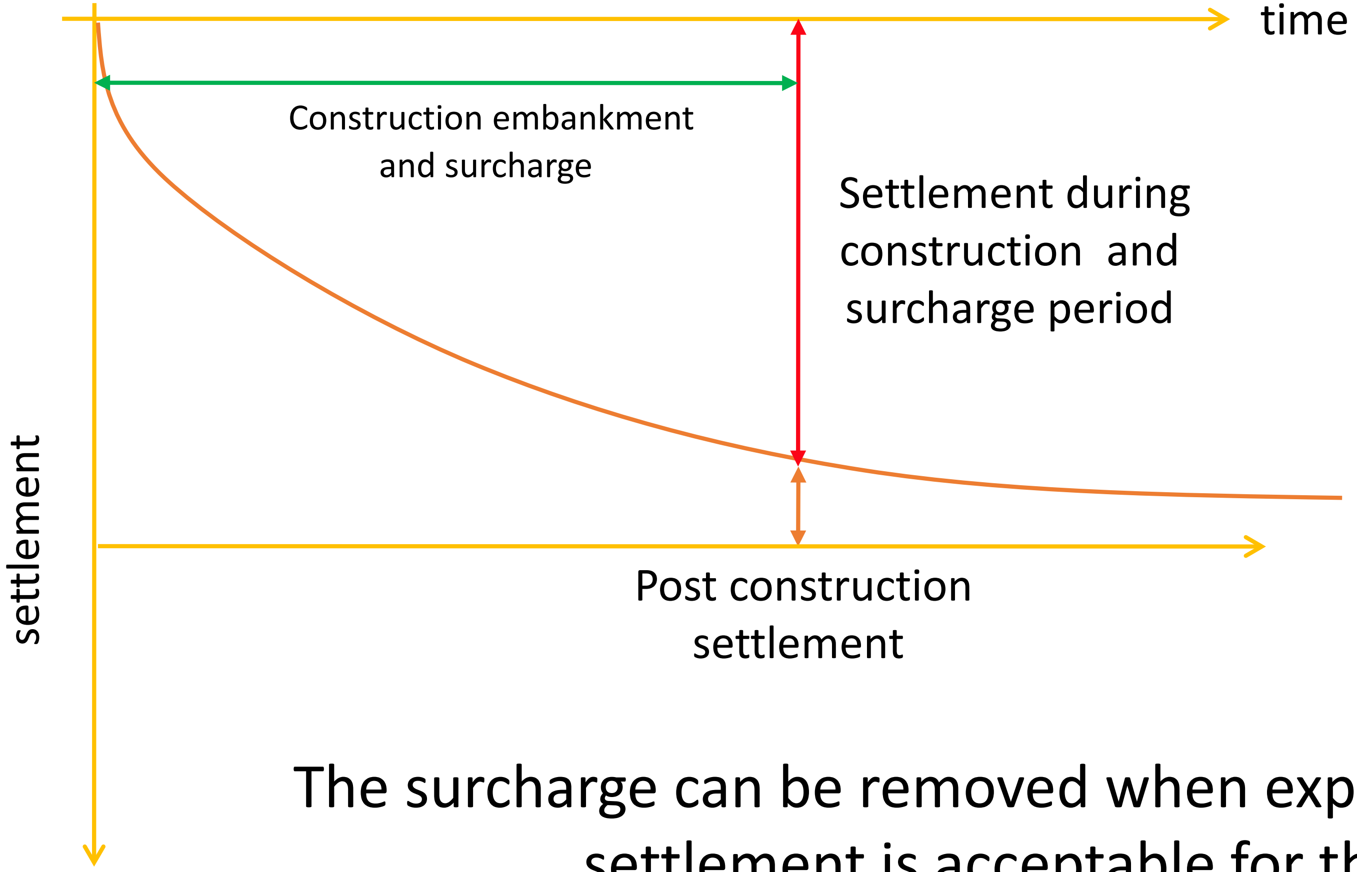


Without Wick Drains



With Wick Drains

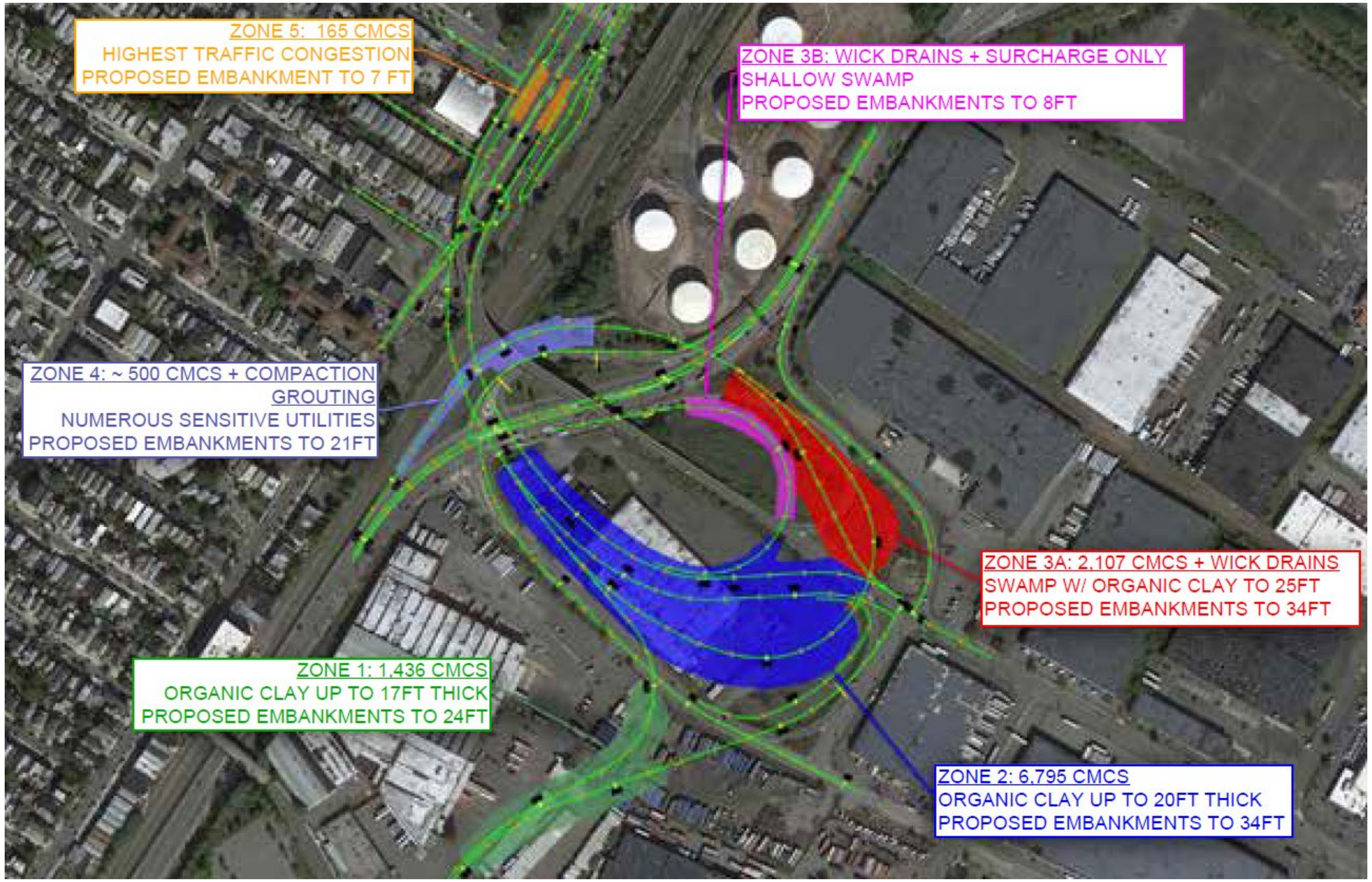
Surcharging with Wick Drains



The surcharge can be removed when expected post-construction settlement is acceptable for the structure.

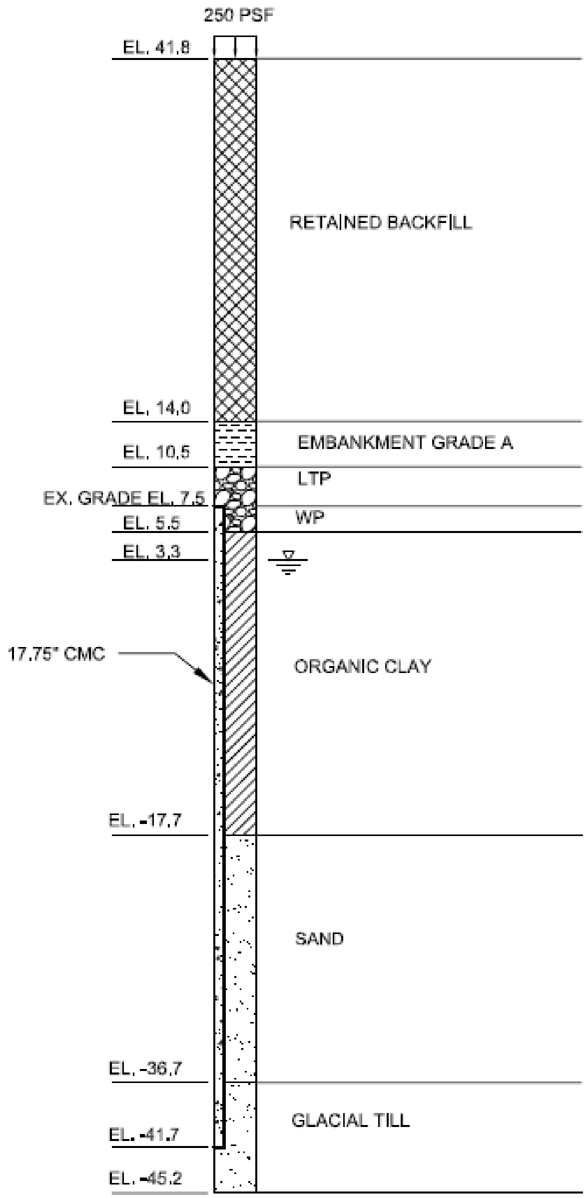
Wick Installation Video

NJTA 14A Interchange



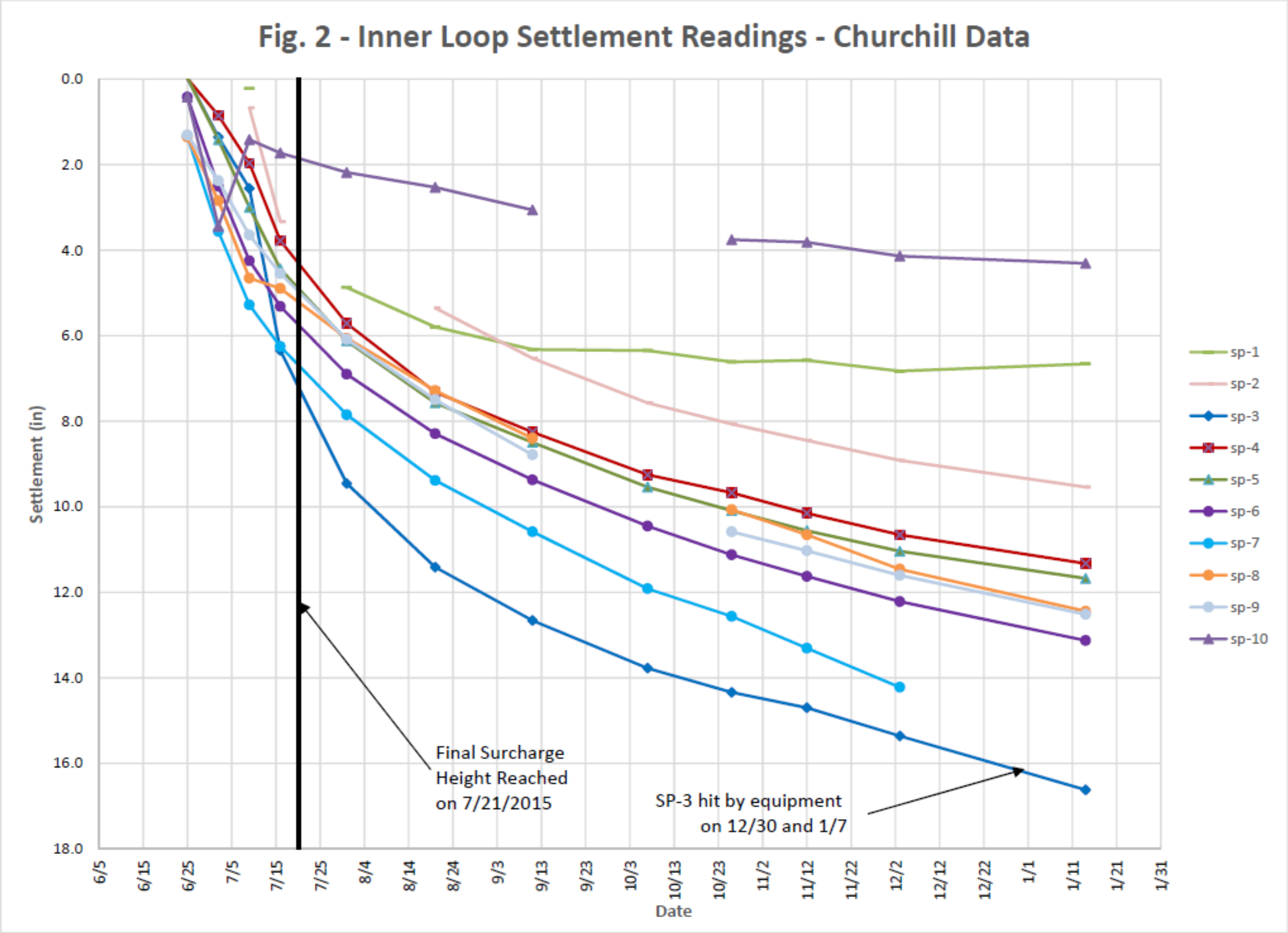
- Part of $160 million improvement project in the cities of Bayonne and Jersey City, New Jersey
- Up to 96 inches (2.4 meters) of unimproved settlement estimated
- Over 11,000 CMCs
- Approximately 80,000 linear feet (24,384 meters) of wick drain
- Complex existing and proposed utilities were supported or protected

The need for wicks



- 20+ feet (6 meters) of saturated clay
- Embankment height of 35+ feet (11 m)
- Clay located right at the ground surface
- Wick drains were used with a surcharge to reduce long-term settlement to acceptable values.

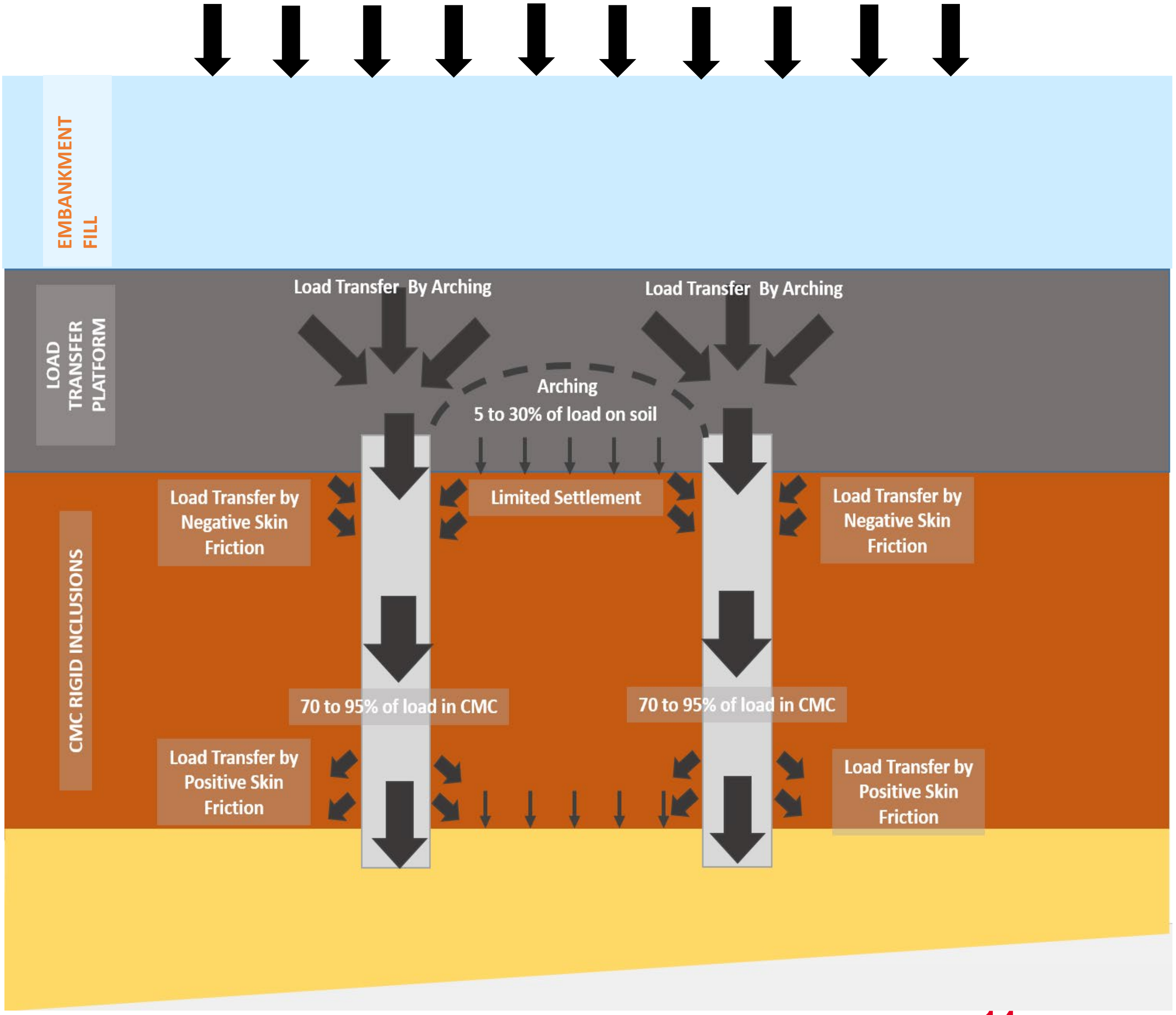
Settlement Readings during Consolidation



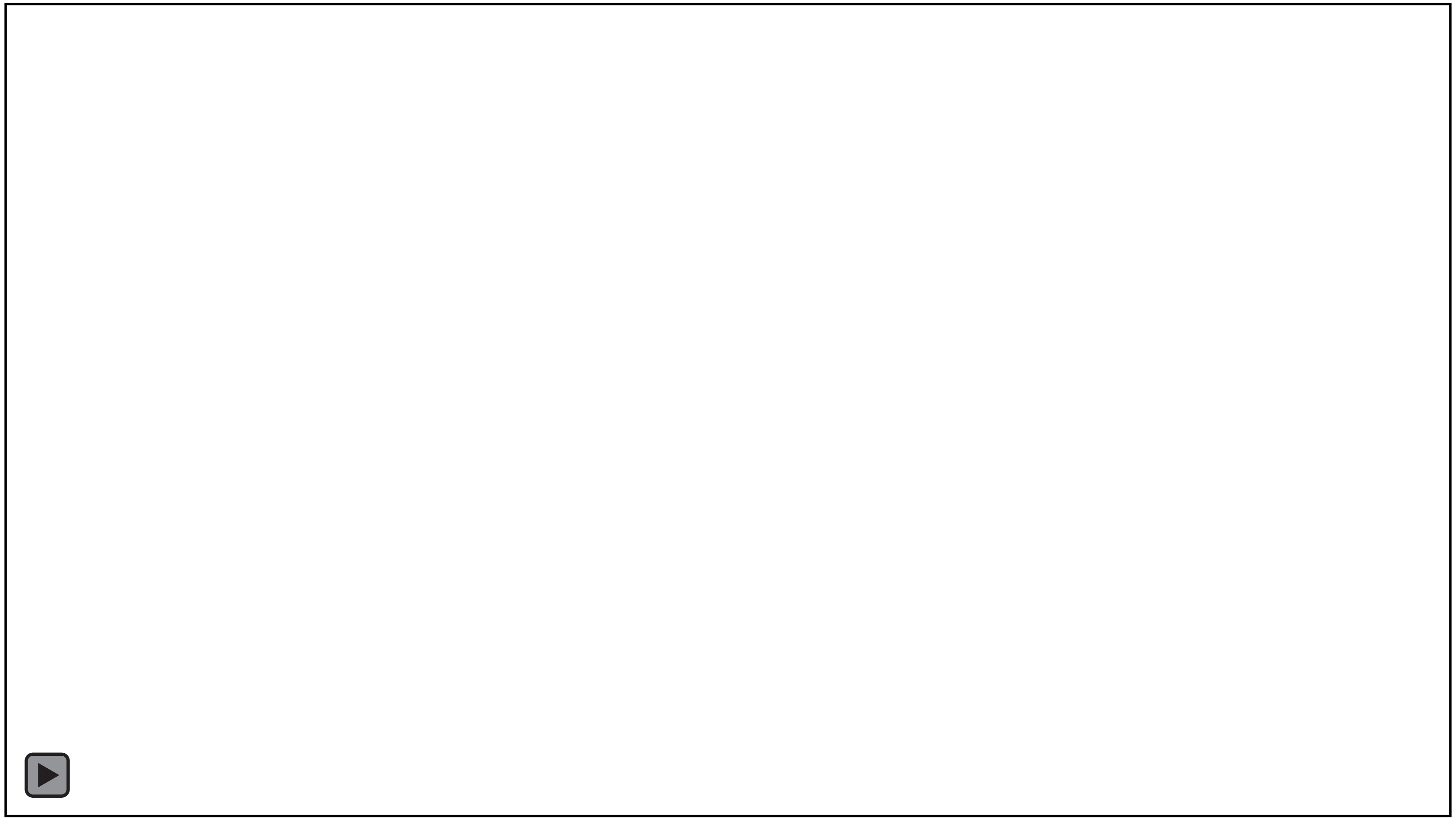
Rigid Inclusions

Rigid Inclusion and LTP

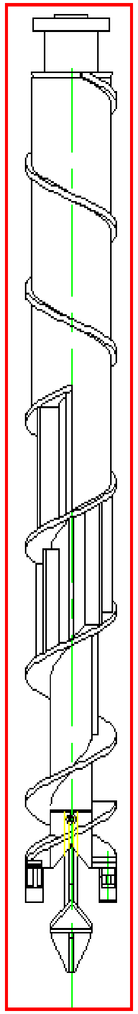
- Rigid inclusions (RIs) are similar to augered cast-in-place piles but are not physically connected to the structure they support.
- RIs are designed to a performance specification – the diameter and spacing of the inclusion varies to achieve the performance requirements.
- Load Transfer Platforms (LTP) are a well-compacted layer of granular soil placed above the RIs to transfer load into the RIs.
- RIs and LTPs are designed together to control the amount of load that is transferred into the RI and soil.

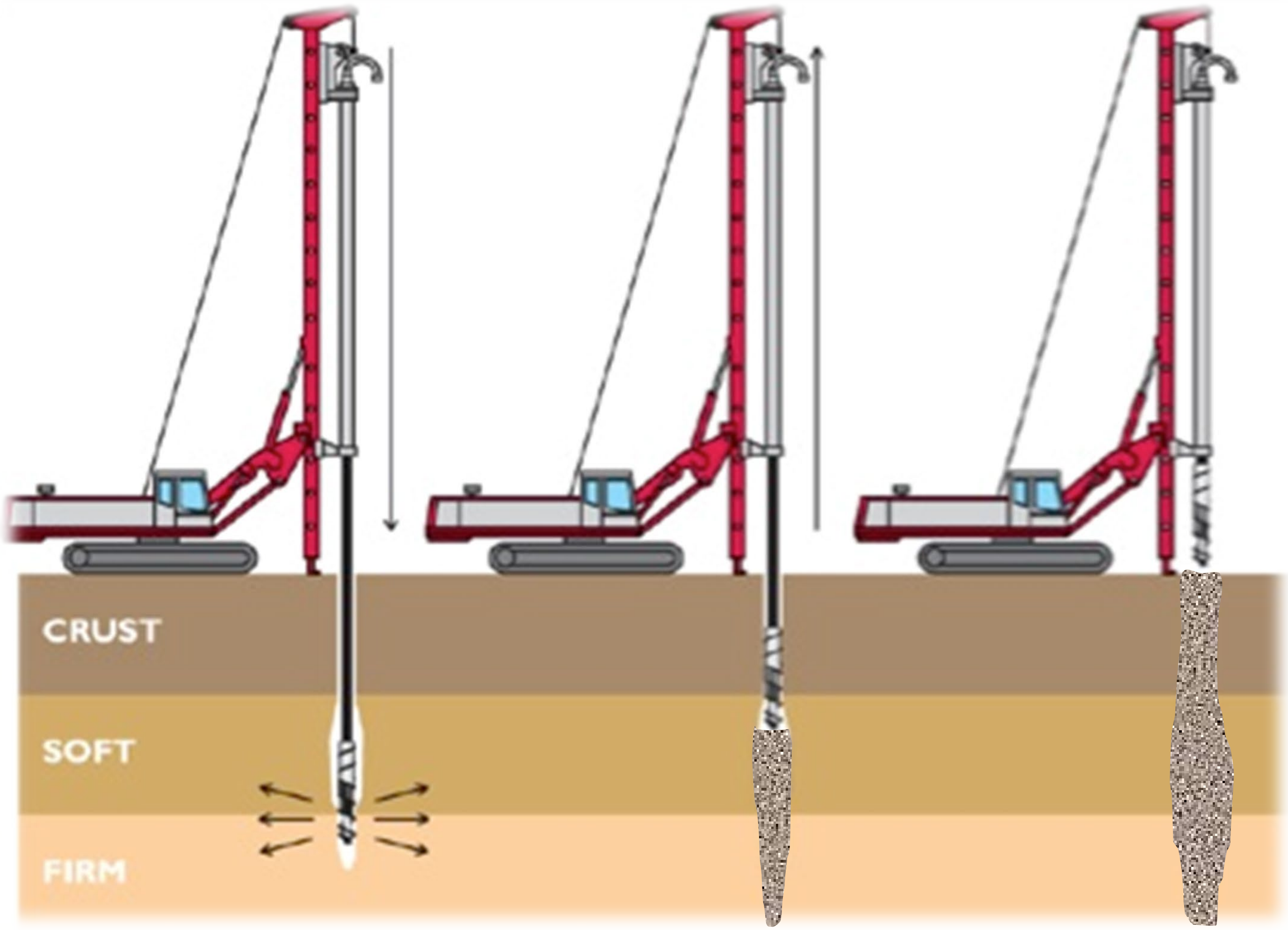


Rigid Inclusion Installation



Typical Installation Sequence



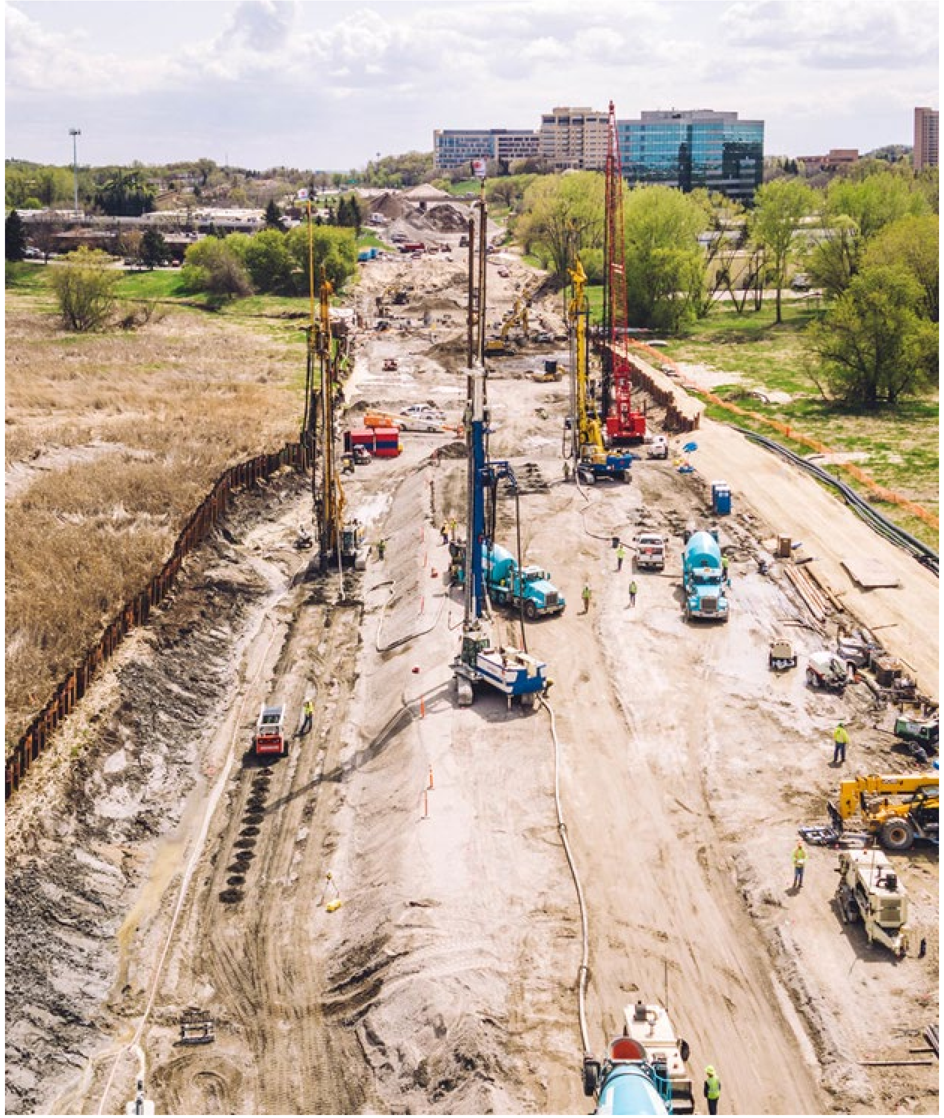


Why Rigid Inclusions?

- Schedule doesn’t allow for wick and surcharge program or wick solution is undesirable due to cost, wick spacing, etc.
- Thick layers of soft compressible soils exist that make stone columns susceptible to bulging.
- Soils are highly heterogeneous leading to large differential settlement.
- Soft soils resulting in large lateral movements exist – by controlling vertical settlement, lateral movement is inherently controlled.

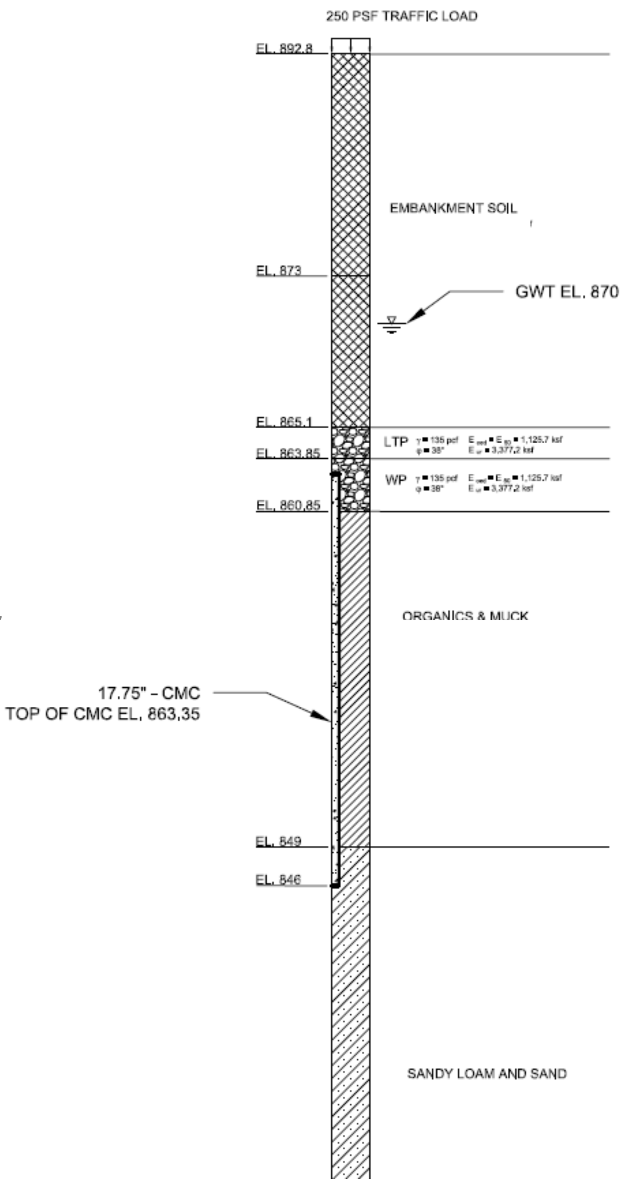
TH 169 – Nine Mile Creek – Hopkins, Minnesota

- Existing bridge over Nine Mile Creek wetlands was about 2/3 mile (1 km) long
- Bridge was to be replaced and roadway widened – soil conditions varied across proposed final roadway
- Design–build letting in 2016, to be completed in 2017
- Wall heights up to 30 feet (9 meters) high



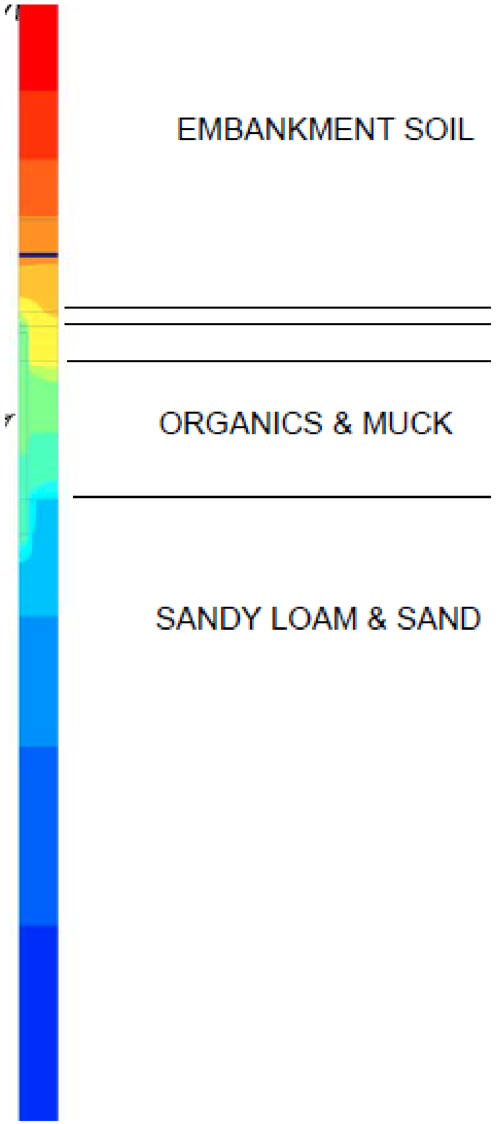
Design Approach – Finite Element Modeling

- Used PLAXIS 2D to perform unit cell (axisymmetric) models to optimize CMC rigid inclusion design based on soil conditions, wall height, existing grades, and structures present (culverts).
- This approach is valid for estimating total settlement, local differential settlement (dimpling), and checking stress in CMC near center of embankments
- Not valid for analyzing edge effects, lateral deformations, and the forces caused by such deformations



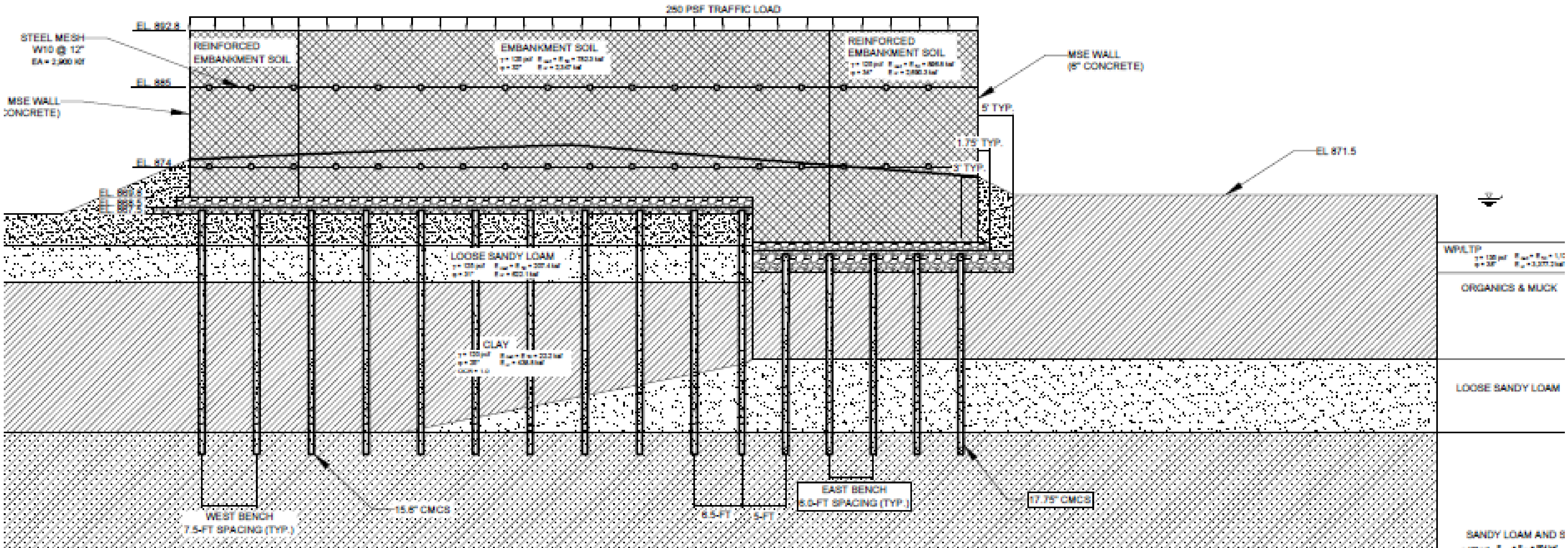
CONSTRUCTION STAGING :

1. INITIAL STAGE. EXISTING GROUND SURFACE EL. 873.
2. EXCAVATE AND PLACE WP.
3. INSTALL CMC.
4. PLACE LTP.
5. FILL TO EL. 892.8.
6. CONSOLIDATE.
7. APPLY 250 PSF TRAFFIC LOAD.



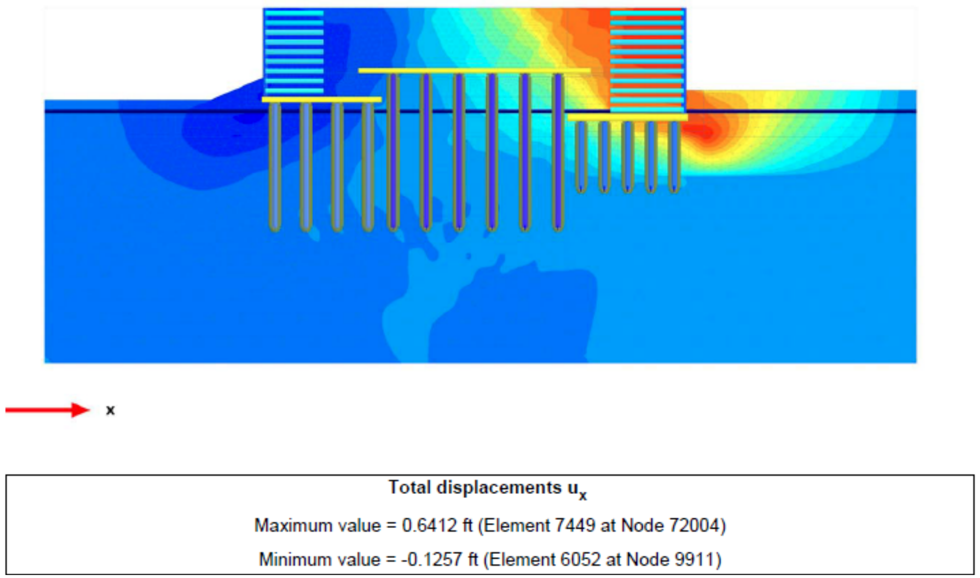
Nine Mile Creek Design Challenges

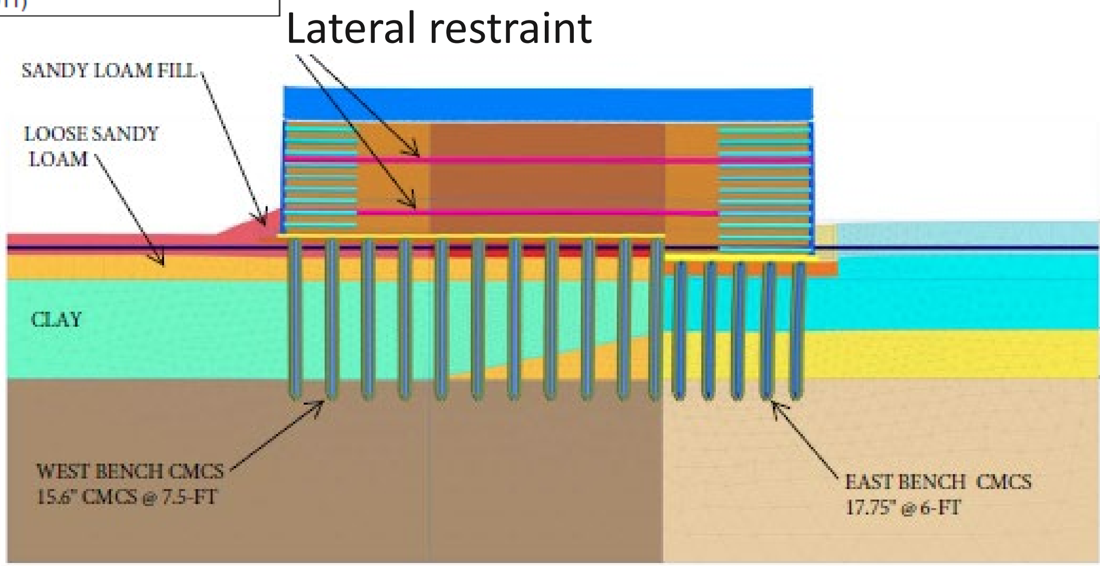
- Large lateral movements observed in 2D and 3D Plaxis finite element models
- MNDOT hired a 3rd party consultant to perform an independent FLAC model, which confirmed the settlement and lateral movements observed



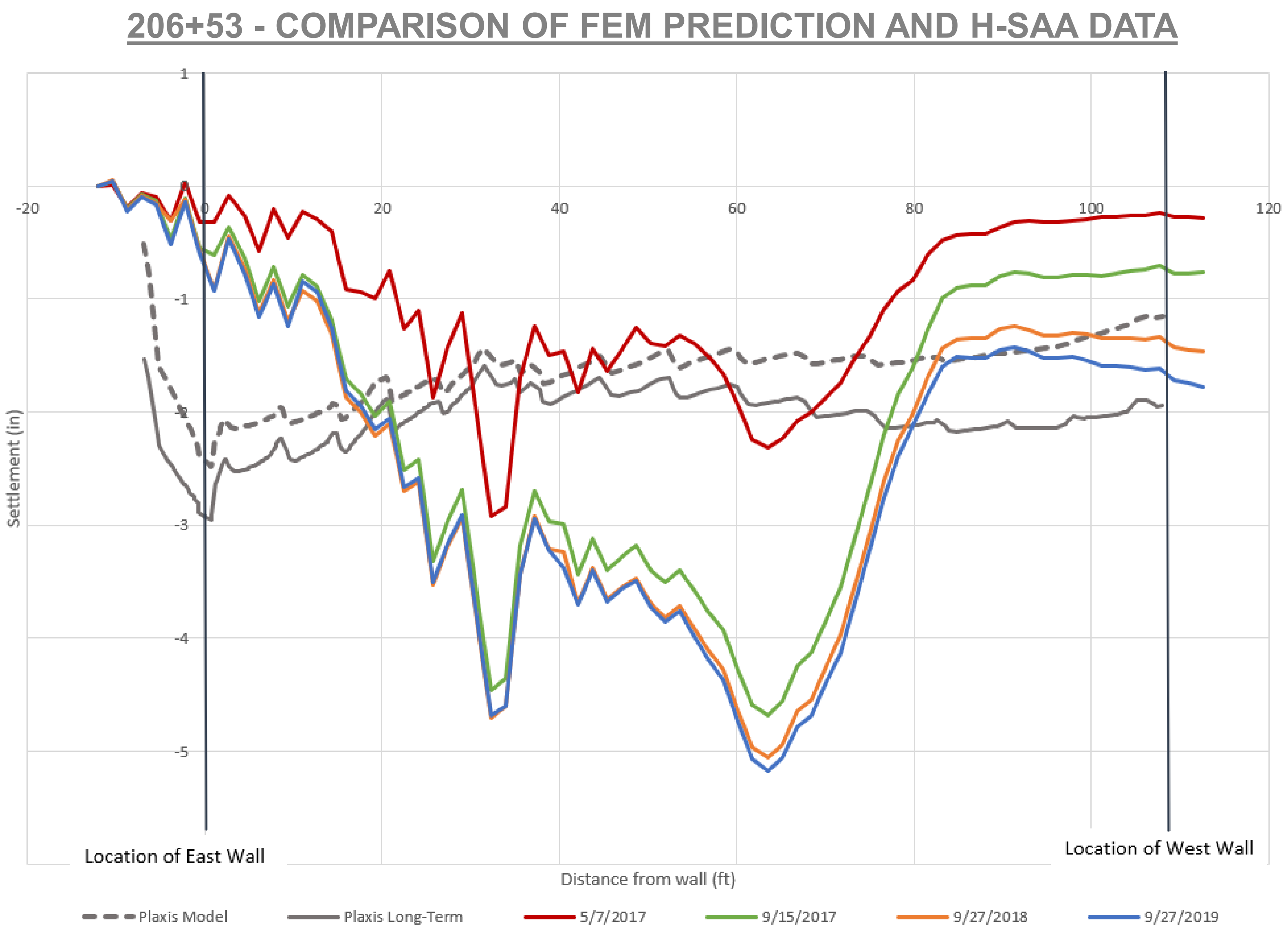
Design Challenges – Lateral Spread

- Models indicated a tendency for the walls to spread apart, especially on the east
- Excessive wall movement and CMCs required heavy reinforcement due to high bending moments
- Predicted lateral deflection was reduced from early estimates of nearly 8 inches (20 cm) down to ~3 inch (8 cm) max
- The stiffness required couldn't be provided by geotextiles so we used steel rebar anchored at the ends with steel plates

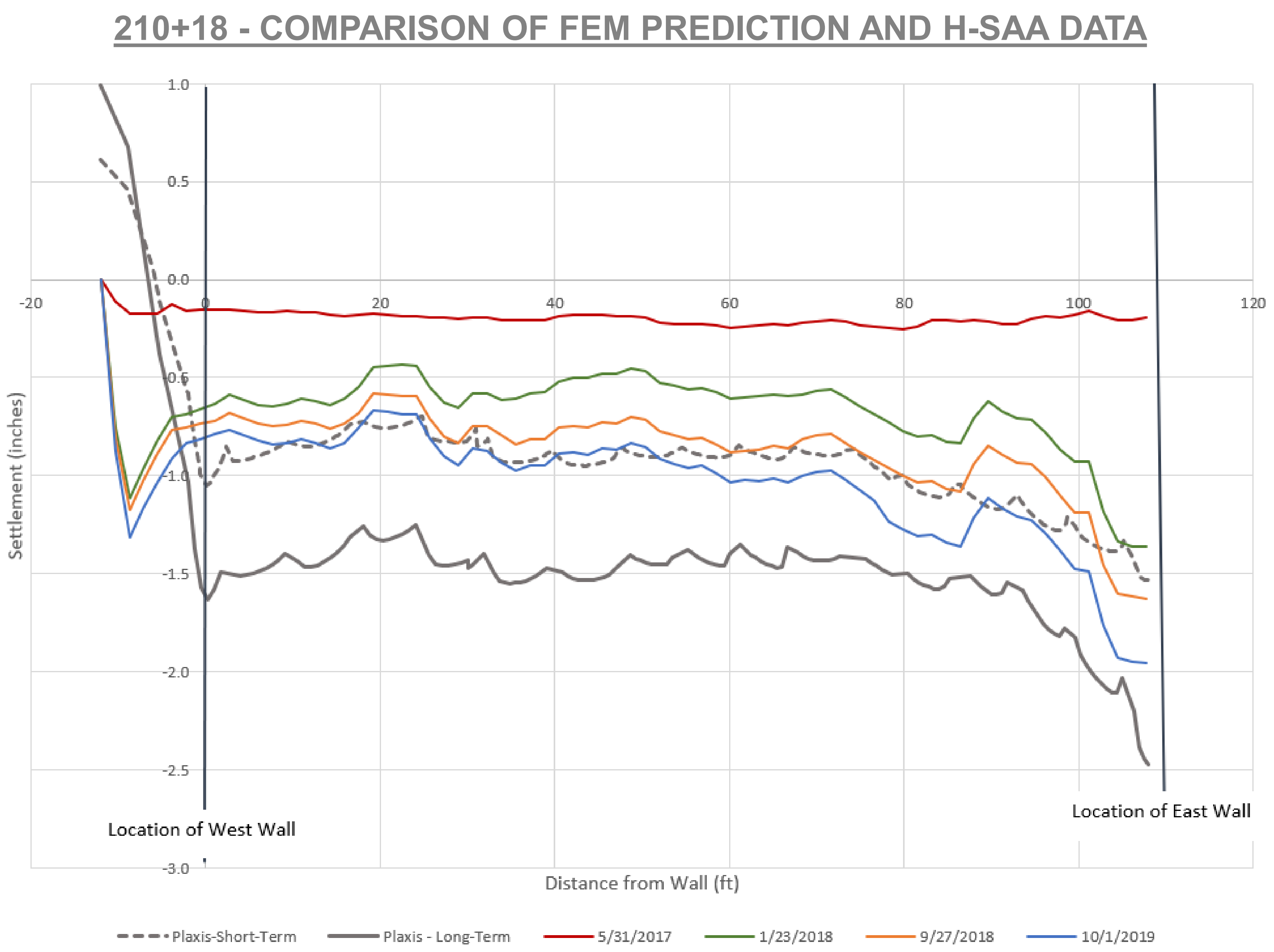




Instrumentation Results - Settlement

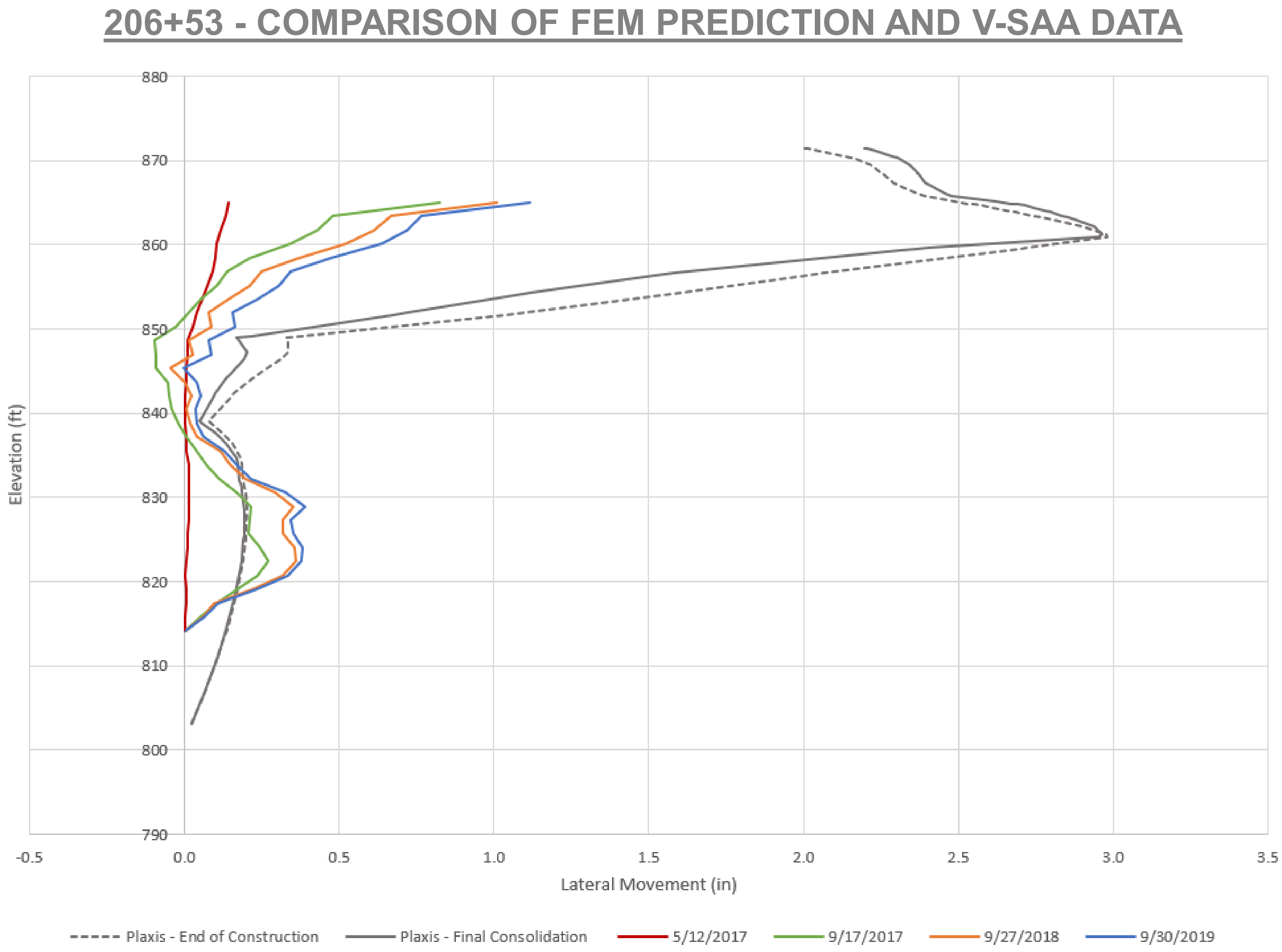


Instrumentation Results - Settlement



Instrumentation Results – Lateral Movement

- Recorded lateral deflection directly in front of MSE wall is significantly less than predicted in design
  - Also instrumented restraint rebar and it did engage somewhat but less than predicted
- Past projects have shown similar over-prediction, even without using a lateral restraint system
  - Being studied currently



Project Completion

Road was paved ahead of schedule in fall of 2017. Photos are shortly before final completion.

Design and Construction of MSE Structures on Compressible Soils

Peter Anderson, Sonia Swift, and Allen Sehn

Aggregate Piers and Soil Mixing

Al Sehn, Ph.D., P.E.
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Transportation Research Board
October 10, 2019

Dealing with Soft Soils Beneath MSE Structures

- Staged loading
- Wick drains and staged loading
- Densify in situ
- Wick drains and preloading, and possibly surcharge loading
- Excavate and replace
- Aggregate piers, stone columns, cemented stone columns
- Rigid inclusions
- Soil mixing methods
- Piled raft system

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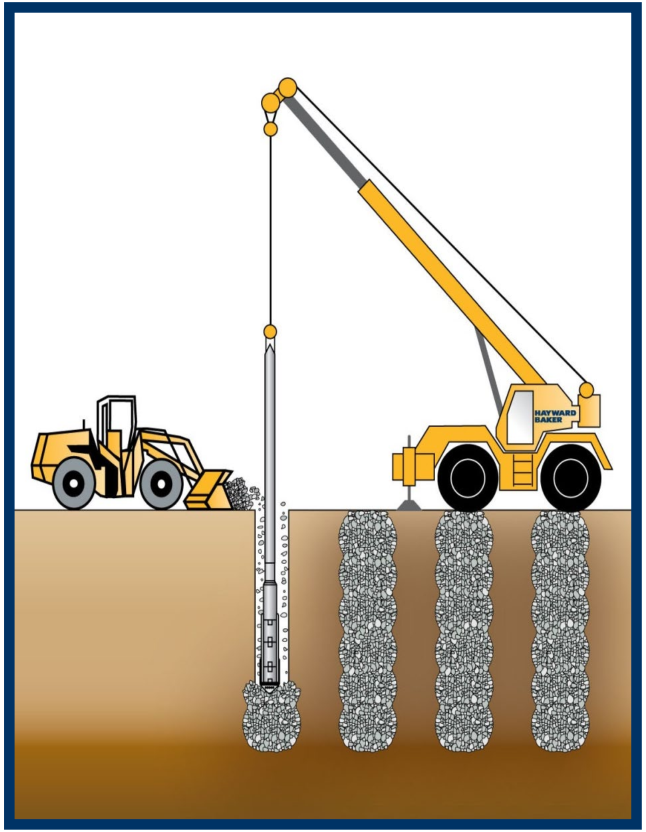
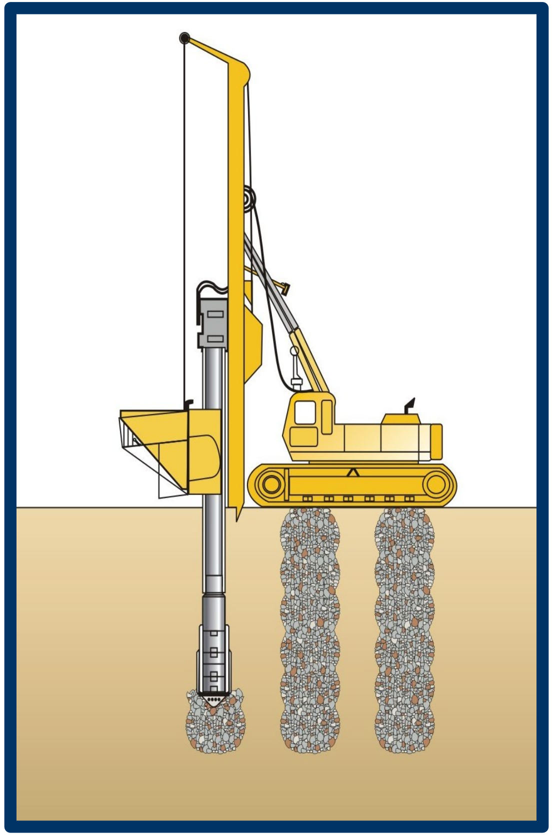
Aggregate Piers

- What are they?
  - piers or columns of dense aggregate installed as foundation elements
  - often referred to as an intermediate foundation system
  - usually about 30 to 42 inches in diameter and about 10 to 20 feet deep
- How do they work?
  - aggregate piers form a composite system with the surrounding soil
  - the pier material is cohesionless
  - the pier must have lateral support from the surrounding soil
  - when confined laterally, the aggregate pier is much stronger and stiffer than the surrounding soil

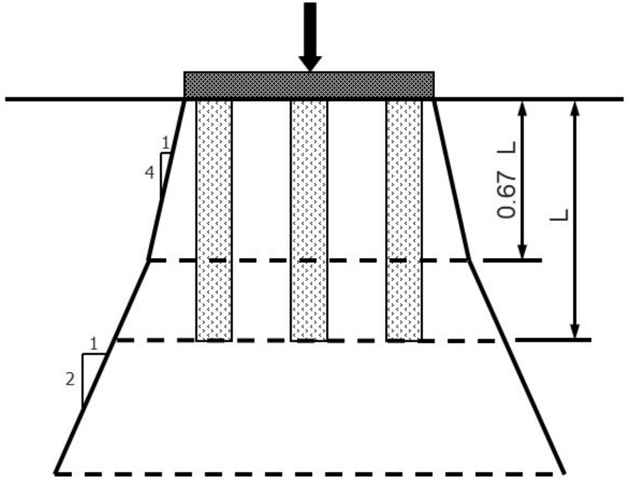
Aggregate Pier Construction

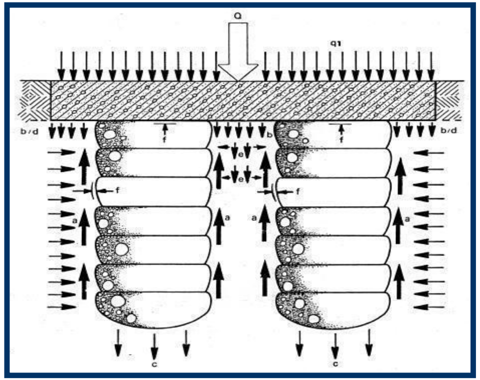


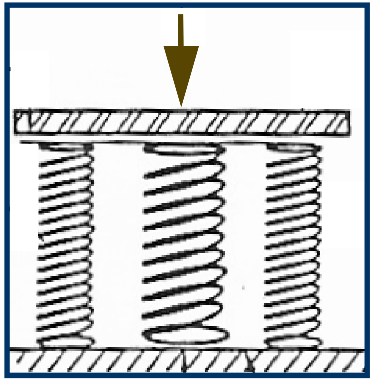


Aggregate Pier Design

- Design based on spring analogy:
  - rigid footing: aggregate pier deflection equals matrix soil deflection.
  - stiff spring (aggregate pier) takes more load than the soft spring (matrix soil).
- Must consider settlement from the aggregate pier zone plus the settlement from below the aggregate piers







Aggregate Pier Design

$$q_p = \frac{q\left(\dfrac{K_p}{K_s}\right)}{\left(\dfrac{A_p}{A}\dfrac{K_p}{K_s} - \dfrac{A_p}{A} + 1\right)}$$

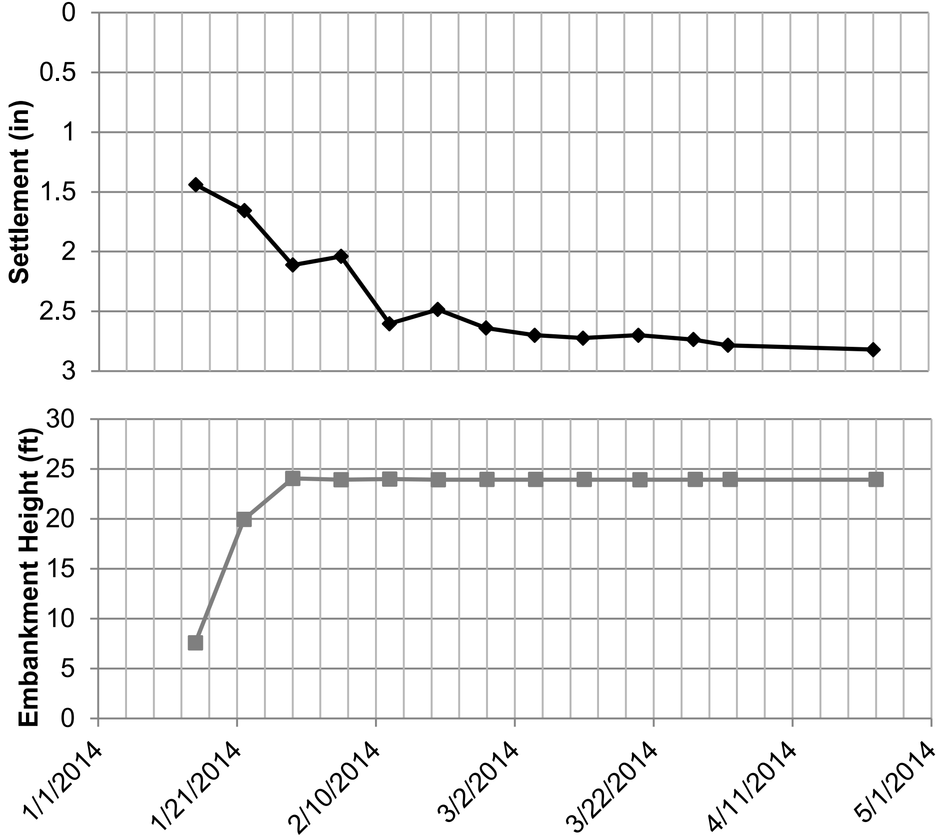
1. Select area replacement ratio
2. Select stiffness values for soil and aggregate pier based on soil type
3. Calculate the design stress in the column
4. Calculate footing settlement
5. Perform load test to verify aggregate pier stiffness

Ohio River Bridges, Louisville, KY

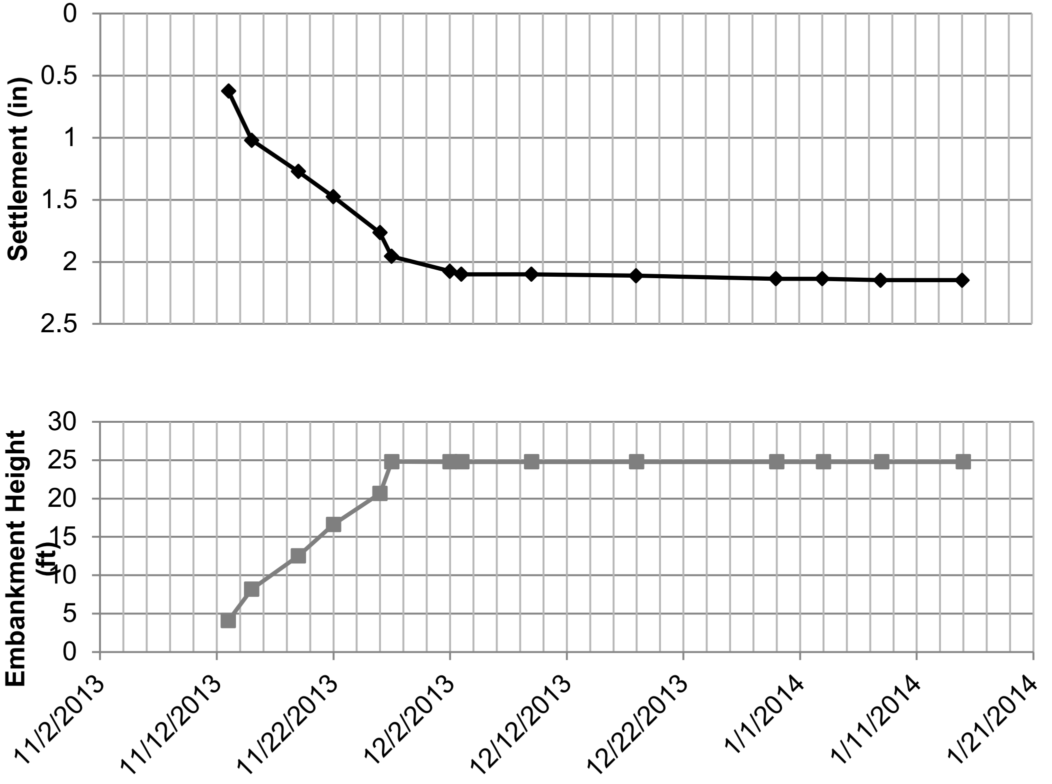
aggregate piers, grouted aggregate piers, wick drains, rigid inclusions

- Design-build ground improvement for more than 40 retaining walls and embankments
- 1.0 inch = total allowable settlement after paving
- 1:500 allowable differential settlement of pavement
- 25-foot-high “test embankment” used to evaluate different methods and spacing

ORB – Wall 10 Performance aggregate piers



ORB – Wall 24 Performance aggregate piers



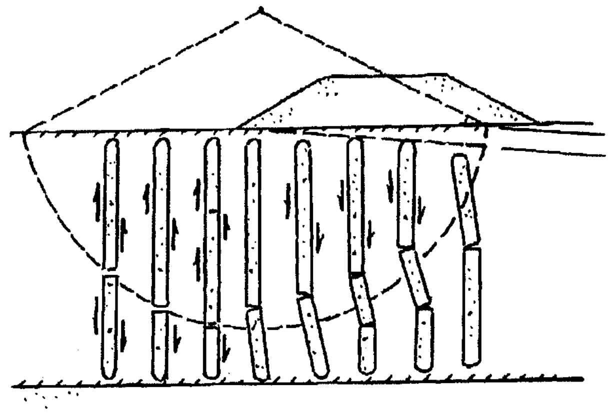
Soil Mixing – many methods

- **Wet Soil Mixing** – uses a cement-water slurry to add the cement
  - Single-axis cement deep soil mixing, up to 9-ft diameter
  - Multi-axis cement deep soil mixing, up to 6-axis, usually 2 to 4 ft in diameter
  - Mass mixing, up to about 20 ft deep
- **Dry Soil Mixing** – dry cement powder is added to the soil
  - Cement is conveyed pneumatically to the mixing tool
  - Single column, high rotation speed, typically 1-m diameter or less
  - Mass mixing, up to about 20 ft deep
    - Rotary mixing tools
    - Bucket mixing

Soil Mixing Design Considerations

- Soilcrete is a stiff and brittle material
  - soilcrete will attract most or all of the load
  - use shear panels for slope stability applications
  - for vertical support applications, must consider settlement and bearing capacity at the base of the soilcrete
- Soilcrete is variable in strength
  - need comprehensive knowledge of the subsurface conditions
  - use 2.0 to 2.5 x the required design strength, depending on expected variability

Soil Mix Columns for Embankment Support



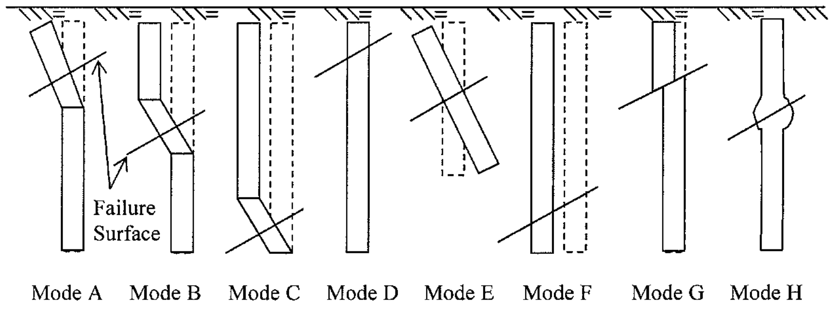
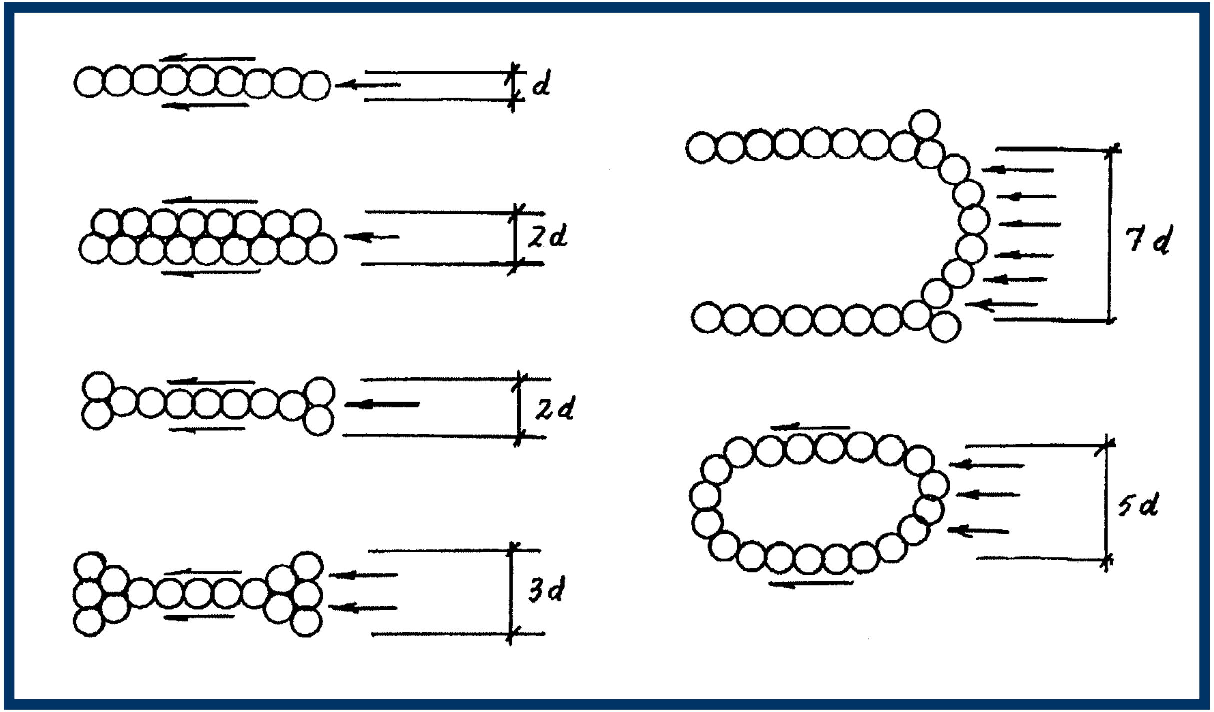


Figure 2. Failure mechanisms for DMM columns (after Kivelo and Broms 1999)

Ref.: Broms, 1999

Column Patterns to Resist Shear



Ref.: Broms, 1999

Dry Soil Mix Columns – Strength Expectations

Predicted design shear strength

- Peat 30 - 100 kPa
- Mud 50 - 100 kPa
- Organic clay 50 - 150 kPa
- Clay 100 - 250 kPa
- Silty clay, clayey silt 100 - 300 kPa
- US practice, 50 - 800 kPa (slag and cement)

100 kPa = 14.5 psi ≈ 1 tsf

Mixing Energy

$$\text{BRN} = \text{Blade Rotation Number}$$

$$\text{BRN} = \frac{\text{Number of blades}}{\text{Retrieval rate}}$$

$$\text{BRN} = \frac{6}{0.02} = 300$$

Typical Values for Dry Soil Mixing

Number of blades = 4 - 8

Retrieval rate = 0.01 - 0.03 m/rev

Rotation speed = 100 - 200 rpm

- Recommended mixing energy in different soils
  - Organic soils, peat: BRN > 400
  - Mud, organic clay, sandy clays: BRN > 300
  - Clay, quick clay, silty clay: BRN > 200

Basic Design Concepts

- Axial loading
  - columns usually designed to carry all of the load
- Shear loading
  - within the treatment zone, use shear panels and discount or neglect any contribution from the soil between the shear panels
  - depth and length of shear panels is determined from slope stability calculations

QA / QC (Pre-Production)

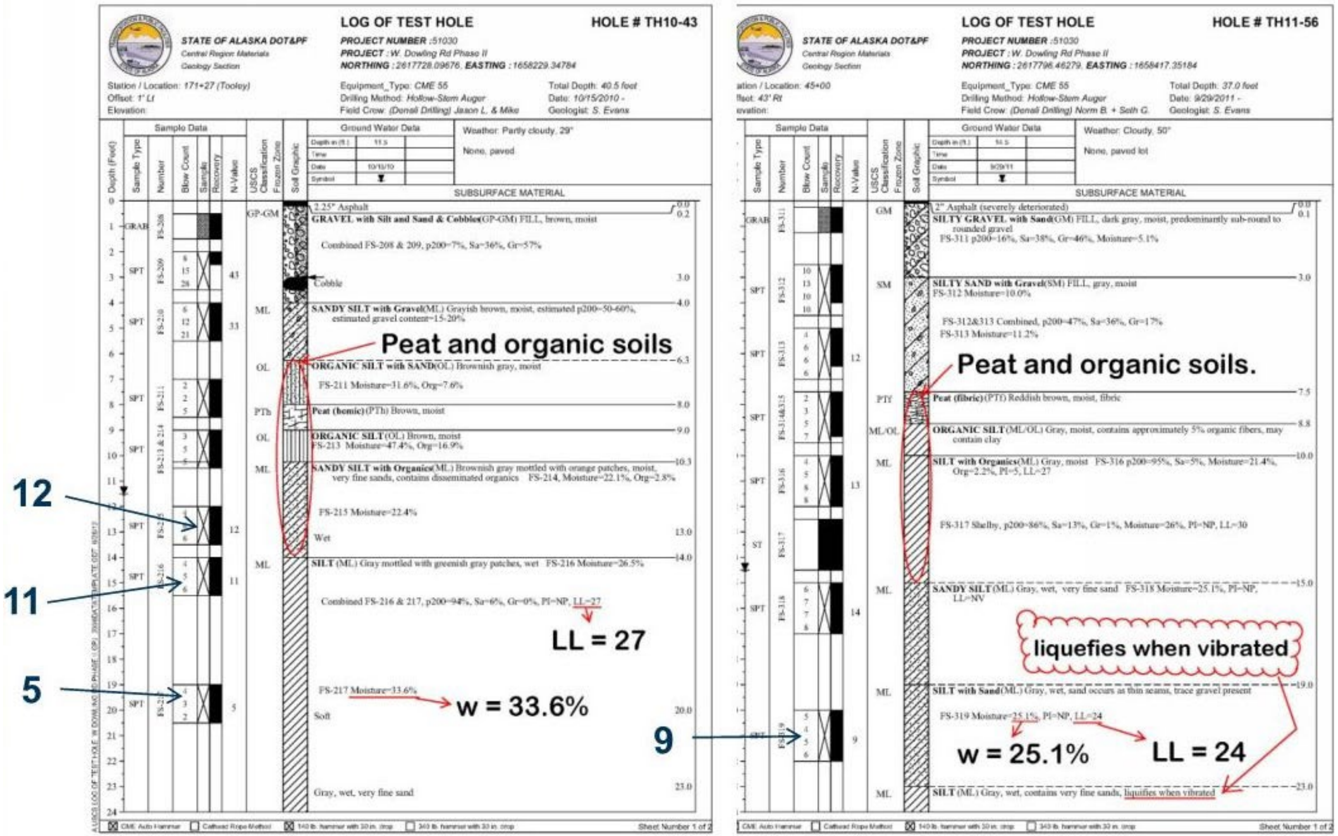
- Mixing
  - Gather representative soil samples
  - Mix with predetermined mixing energy
  - Use predetermined binder mix and dosage
- Lab Testing
  - Test for parameters of design concern
    - Permeability
    - Unconfined Compressive Strength
    - Shear Strength (confined)

Technical Resources

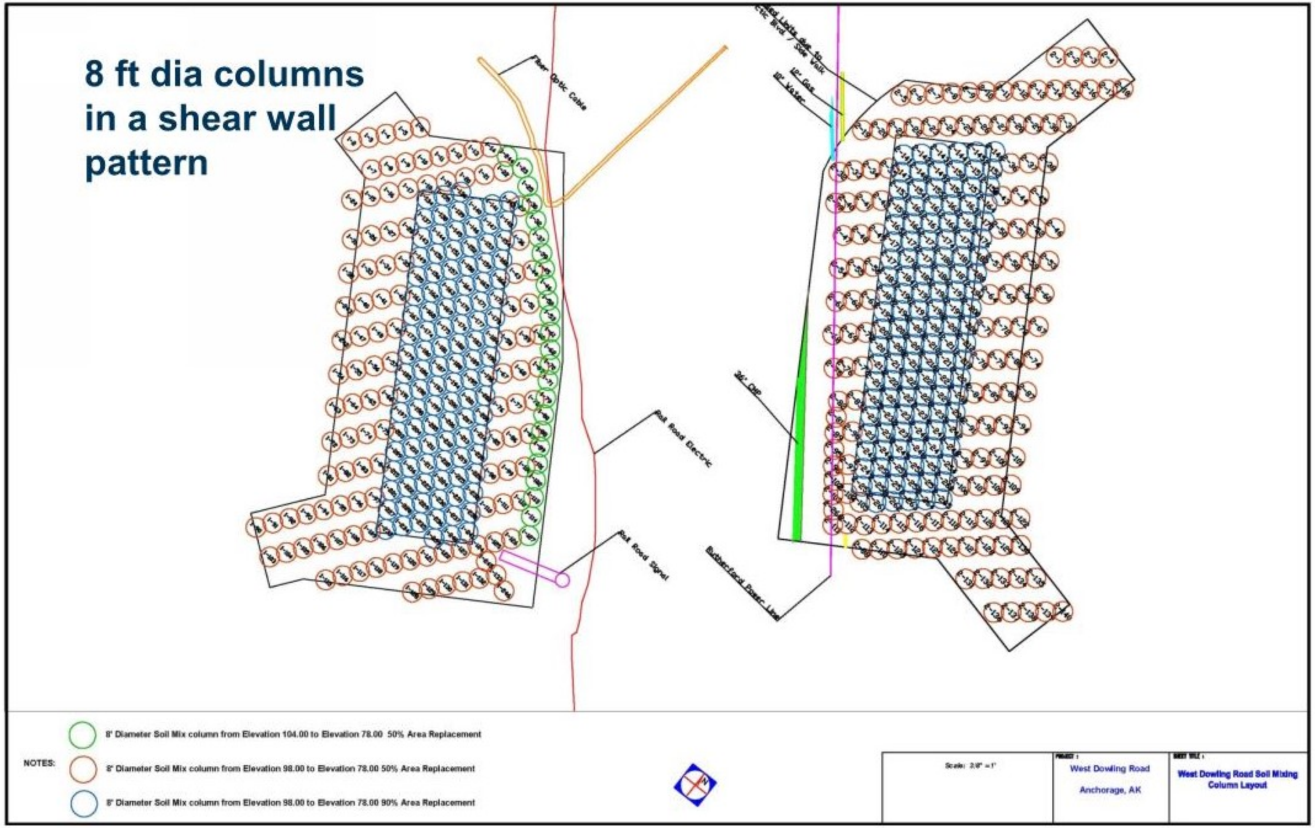
- FHWA GEC No 13 – Ground Modification Methods Reference Manual, 2017, Chapter 7, Deep Mixing and Mass Mixing
- GeoTechTools, www.GeoTechTools.org
- FHWA Design Manual: Deep Mixing for Embankment and Foundation Support, FHWA-HRT-13-146, October 2013


April 4, 2015

Problem Soils – Anchorage, Alaska Bridge Site



Ground Improvement Plan – Wet Soil Mixing



Wet Soil Mixing Operation

2018 Anchorage, Alaska Earthquake

- November 30, 2018
- 14 km NNW of Anchorage
- M = 7.0
- Roadway embankment failure located 0.8 miles from the bridge site
  - No ground improvement
- Geotechnical Extreme Event Reconnaissance
  - December 10 and 12
  - 3-person team of inspectors
  - Very light damage noted
  - Small permanent deformation
  - No loss of serviceability to bridge


Thank you!
Questions?
HAYWARD BAKER

Today’s Participants

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Panelists Presentations

http://onlinepubs.trb.org/onlinepubs/webinars/191010.pdf

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