Deep Soil Mixing Design
Minnick Road Section 14 Project

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Introduction

The Minnick Road Section 14 Emergency Streambank Protection Project, located in the Town of Lockport, NY, exemplifies the application of deep soil mixing to stabilize a highway embankment along Tonawanda Creek, a tributary of the Niagara River

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Location

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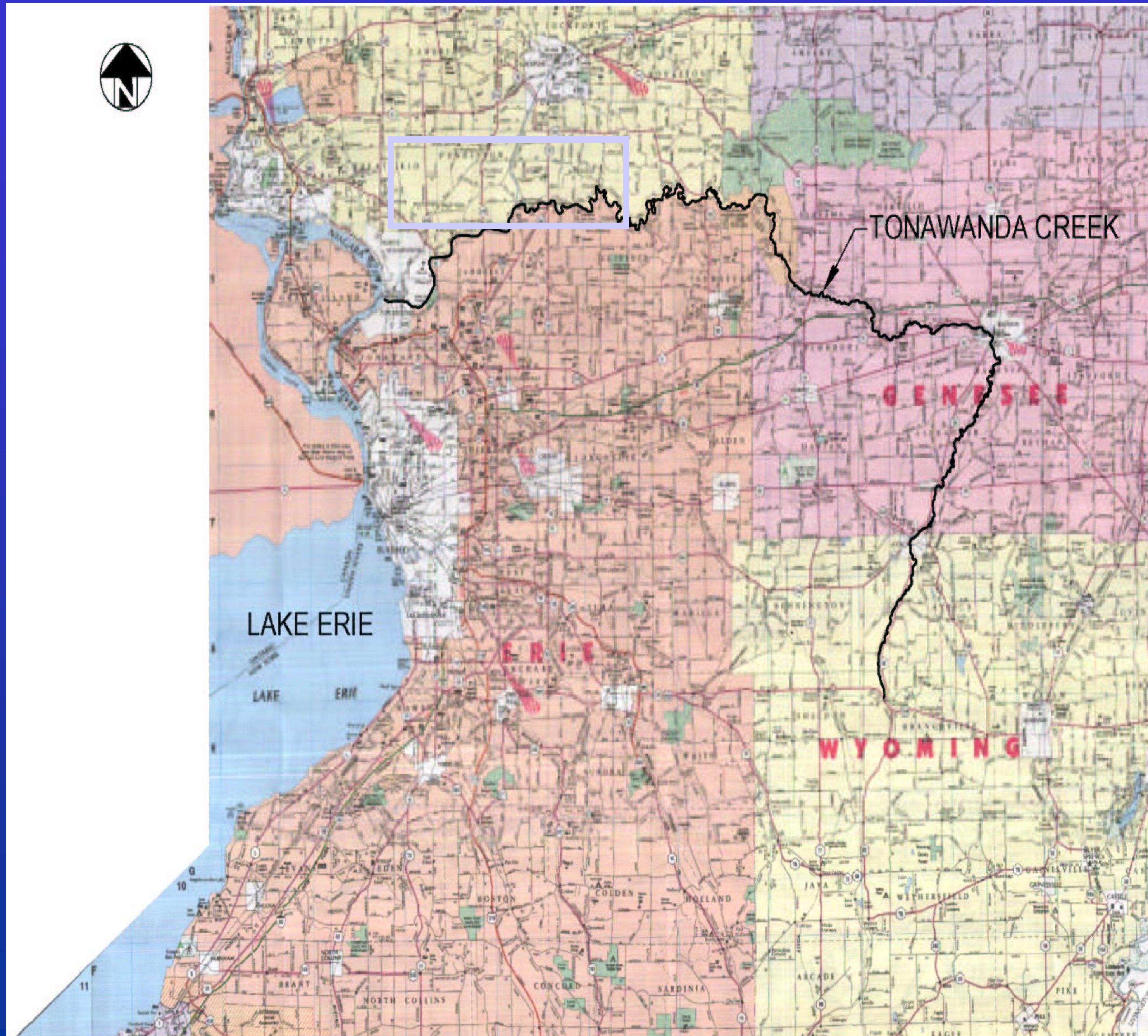

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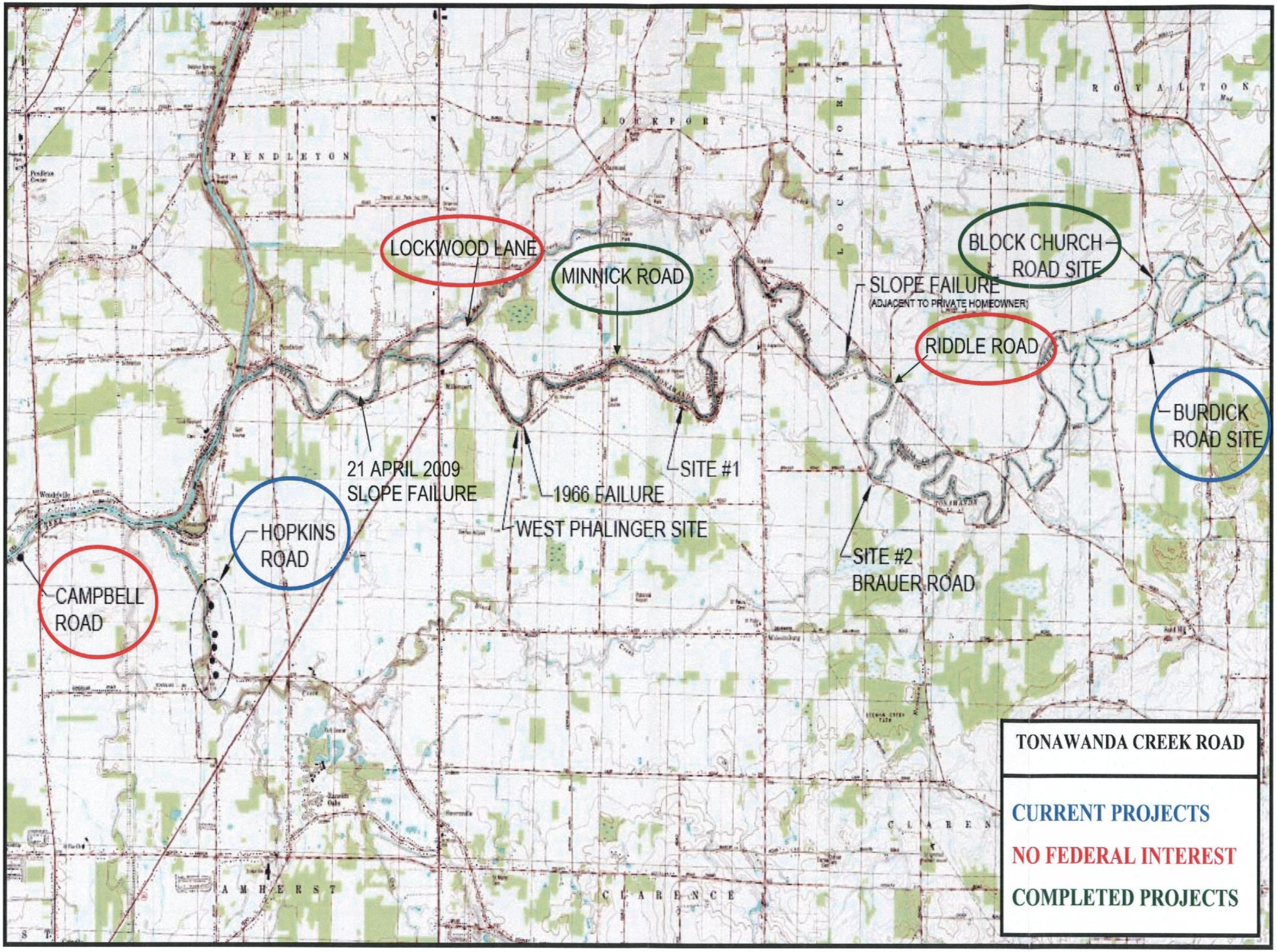
Past Failures


LOCKPORT
PENDLETON
ROYALTON
LOCKWOOD LANE
MINNICK ROAD
BLOCK CHURCH
ROAD SITE
SLOPE FAILURE
(ADJACENT TO PRIVATE HOMEOWNER)
RIDDLE ROAD
BURDICK
ROAD SITE
21 APRIL 2009
SLOPE FAILURE
SITE #1
1966 FAILURE
WEST PHALINGER SITE
HOPKINS
ROAD
CAMPBELL
ROAD
SITE #2
BRAUER ROAD
AMHERST
CLARENCE
TONAWANDA CREEK ROAD
CURRENT PROJECTS
NO FEDERAL INTEREST
COMPLETED PROJECTS

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Westphalinger Road Slide

House Lost to Erosion Downstream of the Minnick Road Site

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Minnick Road Site (Pre-Project)

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Project History

- Problems first noted in the early 1990's
- Approved as a Section 14 project in 1999
- PCA executed in 2006
- Construction started in 2007
- Completed in 2008

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Project Site Info

- Length 190 LF
- Bank height 25 feet
- 2 lane road
- Culvert through center of project with chronic seepage issues
- Settlement of guide rail and road on creek side (subtle progressive bank failure)

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Local Geology

- Glacial deposits (Lake Tonawanda)
- Sand/silt layer overlies a thick (25+ feet) soft lacustrine clay layer
- Tonawanda Creek cuts through these layers
- Glacial till and bedrock underlie the soft clay layer
- The soft lacustrine clay layer is 30 to 50 feet below grade and governs slope stability in this region

Typical Stratification

Sand/Silt

Soft Clay

Glacial Till

Bedrock

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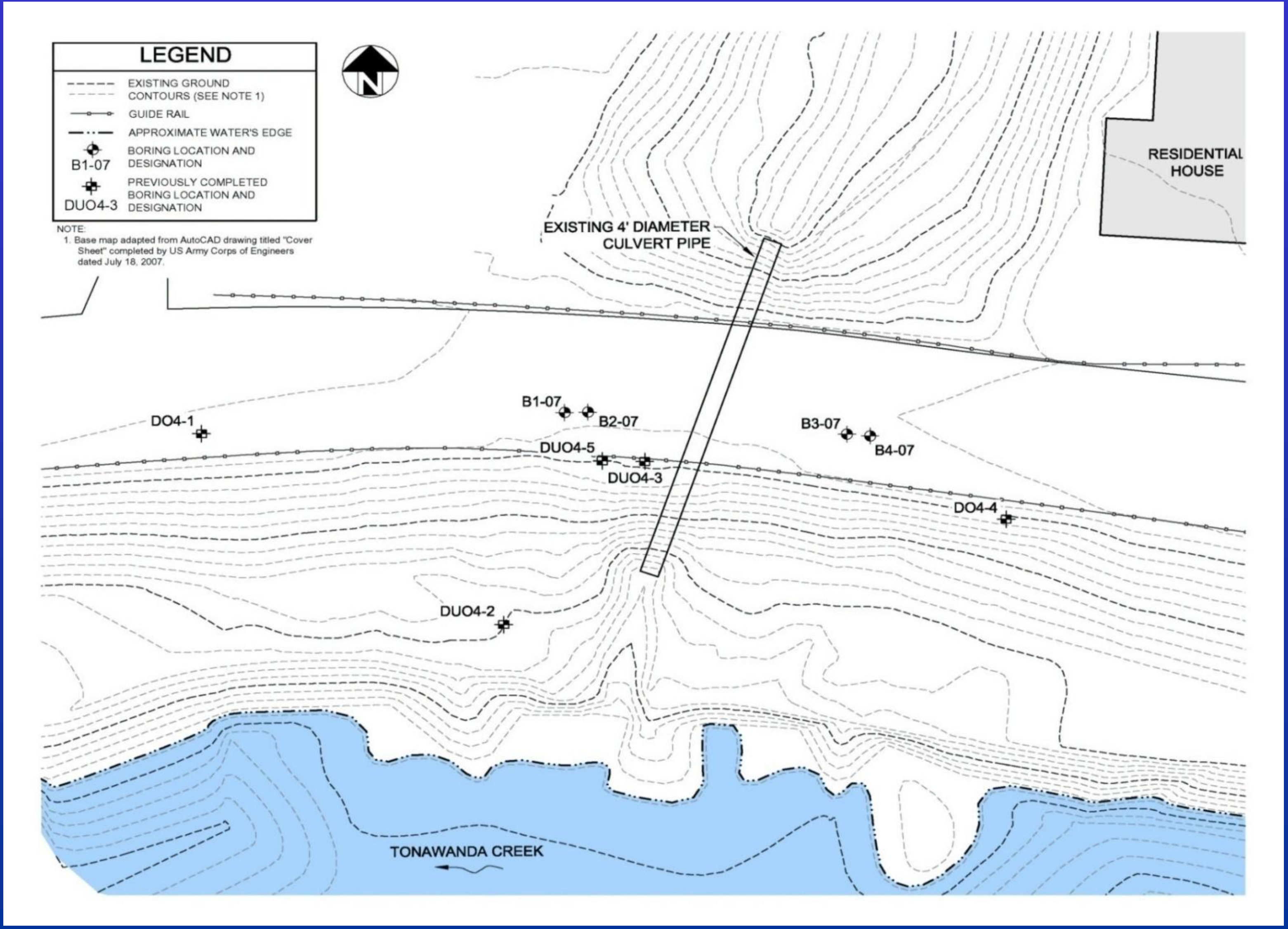
Subsurface Explorations

- 1999 – 2 standard split spoon sample borings
- 2004 - 2 standard split spoon sample borings and 3 standard split spoon-undisturbed sample borings
- 2007 - 2 continuous standard split spoon sample borings and 2 continuous standard split spoon - undisturbed sample borings with field vane shear tests

Plan of Borings



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Laboratory Soils Testing

- Natural moisture content
- Atterberg limits
- Grain size distribution
- UU triaxial
- CU triaxial
- UC and CU triaxial tests on soft clay mixed with cement (7, 14 and 28 day)

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Geotechnical Parameters (Soft Clay)

- USCS classification: CL
- LL=42, PL=22, PI=20
- Natural moisture content 44%
- Average peak vane shear strength 255 psf
- Average remolded shear strength 66 psf
- Sensitivity 2.1 (moderately sensitive)

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Soft Lacustrine Clay

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Design

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Remedial Design Options

- Modify the slope geometry
- Provide or improve surface and or subsurface drainage
- Provide internal slope strengthening/reinforcement
- Construct a retaining structure

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Original Design – Steel Sheet Pile

- Steel sheet pile wall
- Front wall driven into glacial till
- Back wall shorter sheets
- Anchors in bedrock (about 60 feet below ground surface)
- Relatively disruptive to subsurface during construction

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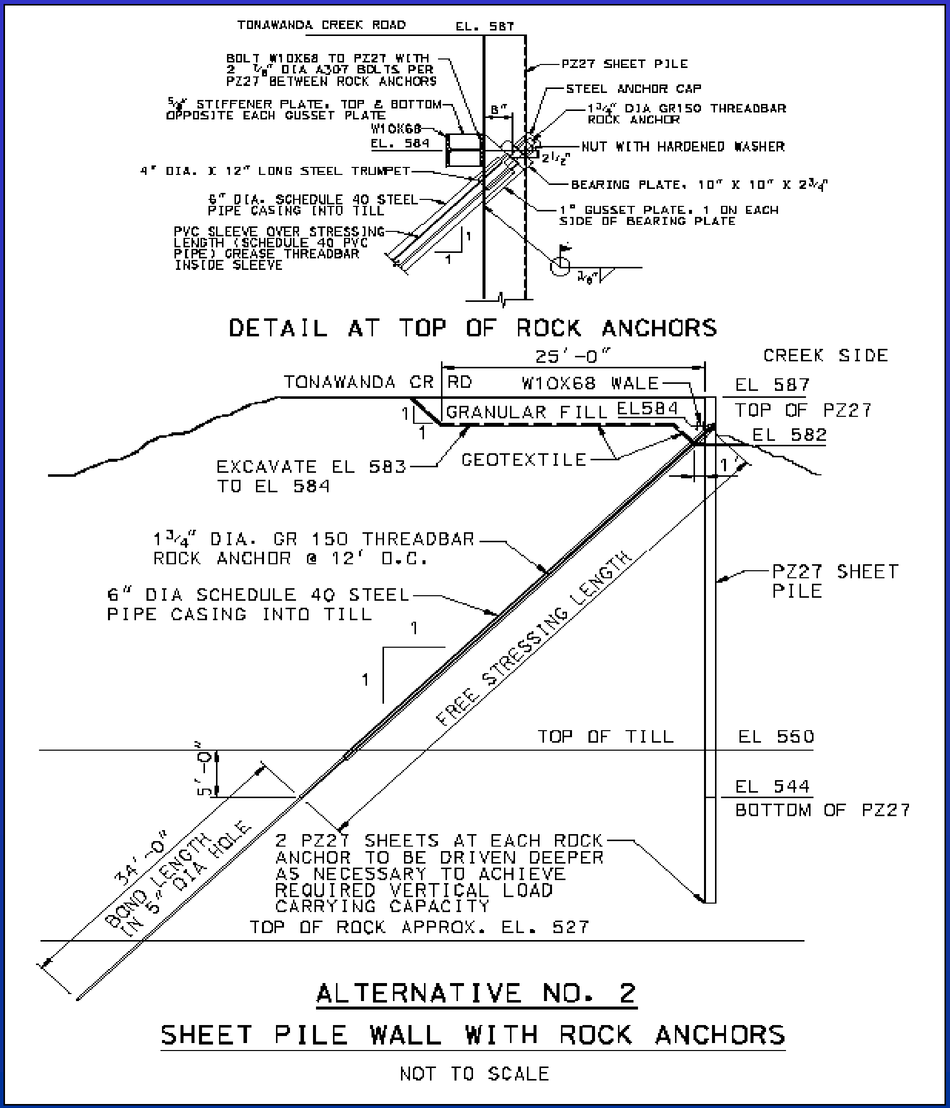
Initial Design Section – Anchored Sheet Pile Wall



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Rationale for Design Change

- Vibrations from driving steel sheet pile wall might adversely affect existing utilities and several existing nearby houses on the opposite side of the road
- Vibrations could induce slope failure
- A/E firm had prior soil mixing design experience at a nearby slide site
- More cost effective than sheet pile wall

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What is Dry Soil Mixing?

- 2 to 3 foot diameter columns
- Depths to 60 feet
- Suitable Soils:

  Clayey Silt, Silty Clay, Clay, Sensitive Clay, Marine Clay, Organic Clay, Peat
- Soil mix column strength typically 10 to 50 times stronger and much stiffer than native soil

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Soil Mixing Design

- Dry mix method
- 30 foot penetration of upper sands and lower soft clays into glacial till
- Soil-cement columns 30 inches in diameter
- 651 columns total, arranged into rows
- Average soil strength increased tenfold
- Slope stability FOS increased from 1.0 (existing case) to 1.5

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Soil-Cement Mix Proportions

- 3 different mixes prepared and tested
- Type I Portland cement
- Cement content varied from 2.7% to 4% to 7.8% (8-10 94-lb bags per 30-foot column)
- Average 7 day compressive strength varied from 34 psi to 115 psi
- Average 14 day compressive strength varied from 49.5 psi to 140 psi

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Dry Soil Mixing Procedure

- Mixing blade advanced through the entire thickness of the sand/silt and soft clay layers
- Cement injected under pressure as the blade is advanced back up
- High pore pressures induced (temporary)
- Rows of soil mixing holes alternated to minimize the effect of the high pore pressures
- Vibrating wire piezometers used on other nearby project to monitor pore pressures during mixing

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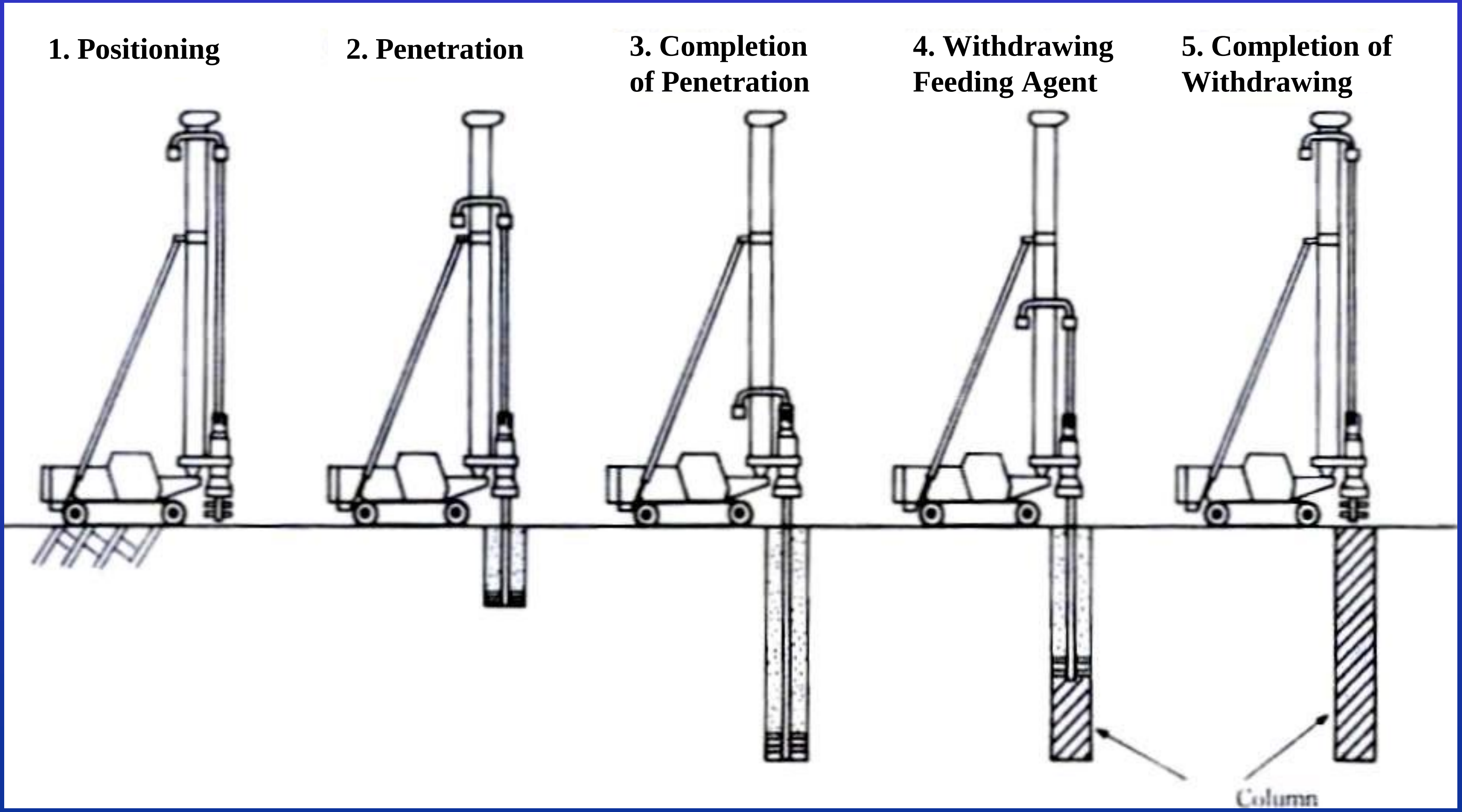
Dry Soil Mixing



Column Plan and Dry Mix Process

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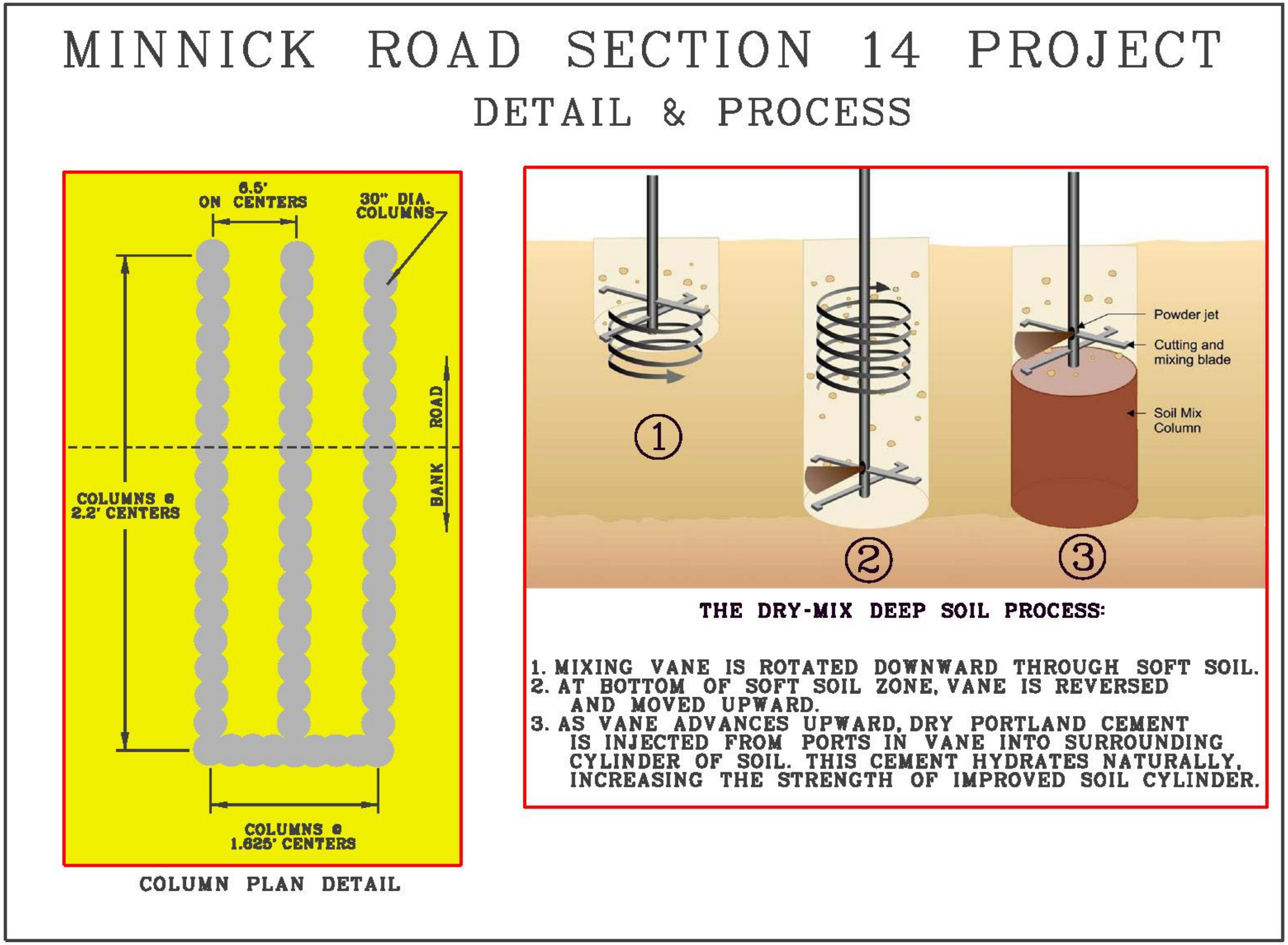

Figure 3

Minnick Road Plan and Section

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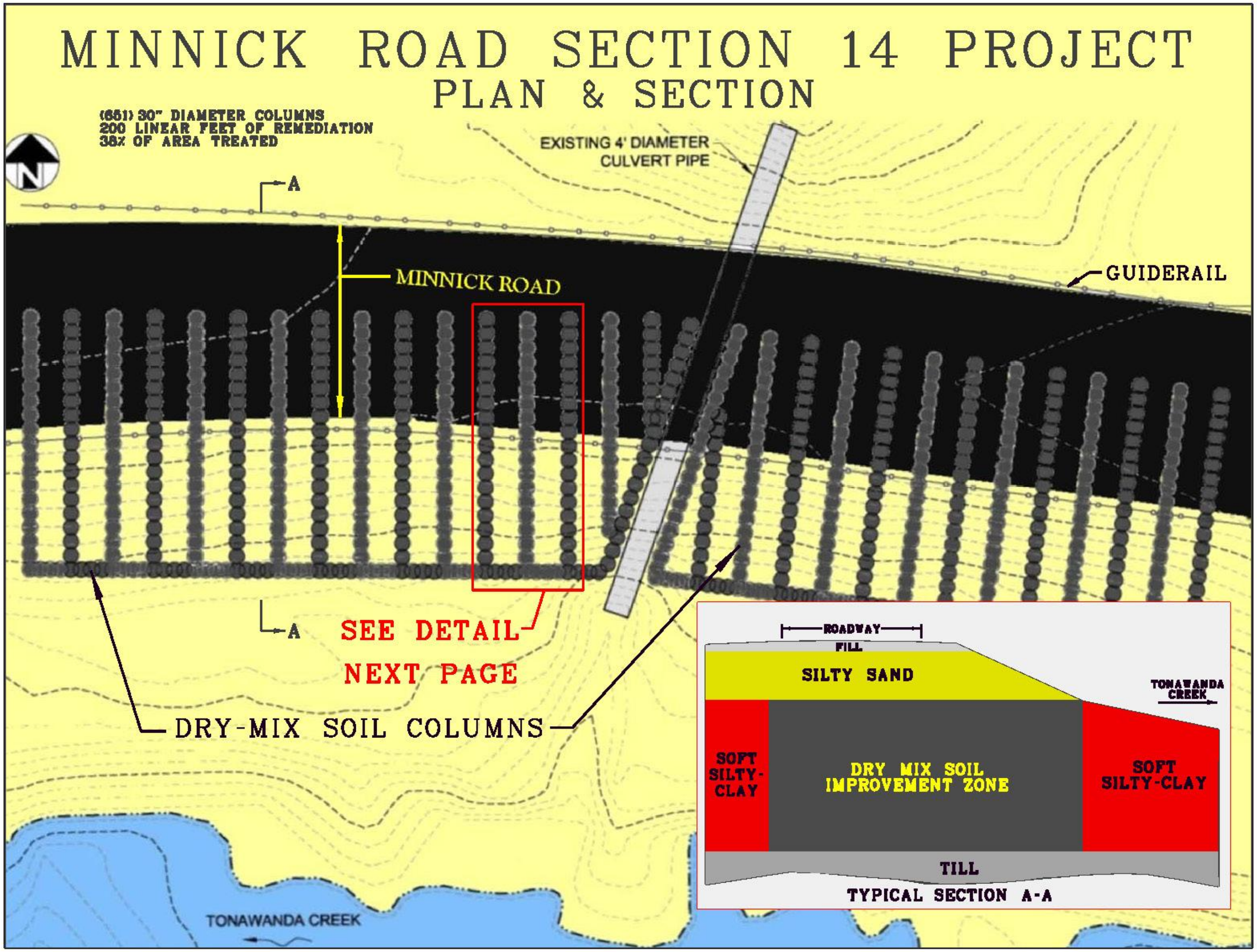
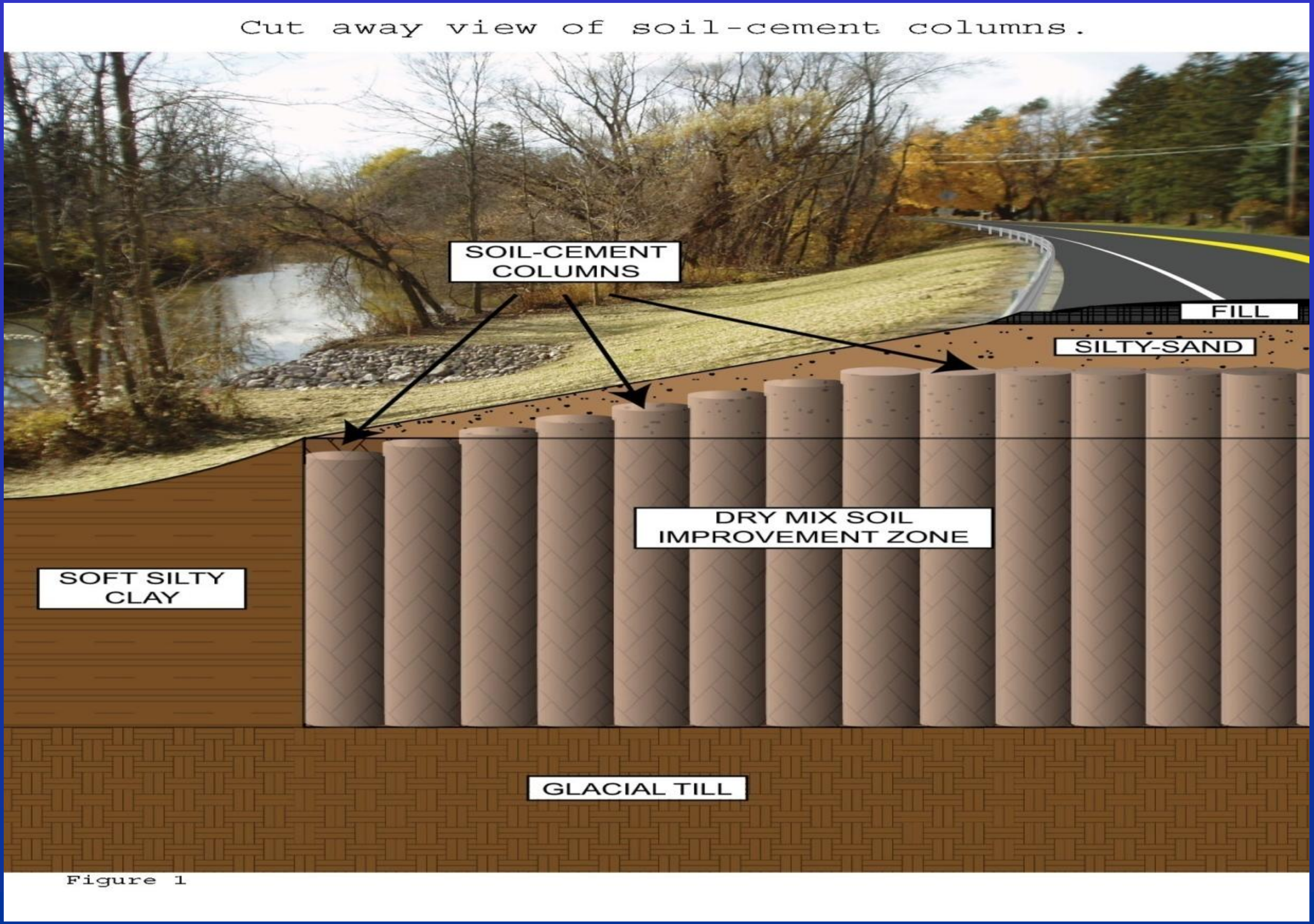


Figure 2

Cut Away View



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Placing the Construction Pad

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Casagrande B-135 Soil Mixing Rig

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Cement Hopper

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Soil Mixing Vane

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Preparing to Advance the Vane

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Vane Below Ground Surface

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Performance Monitoring

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3 Different QA Methods

- Shelby Tubes – dismissed due to difficulty and variability in results
- Continuous SPT Testing
- Vane Extraction Testing

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Shelby Tube Sampling

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SPT Sampling

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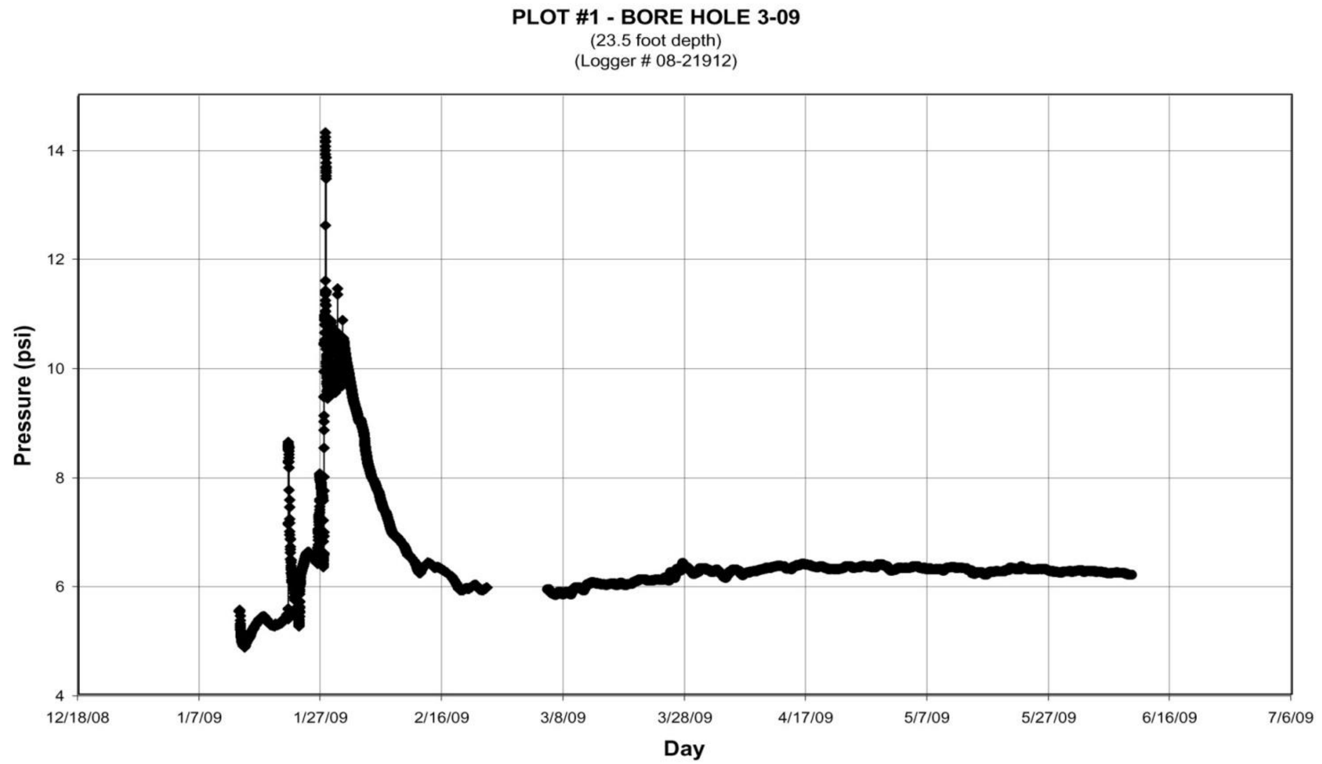
Induced Pore Pressures



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Extraction Vane Assembly

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Insertion of Extraction Vane

Uncovered Extraction Vane

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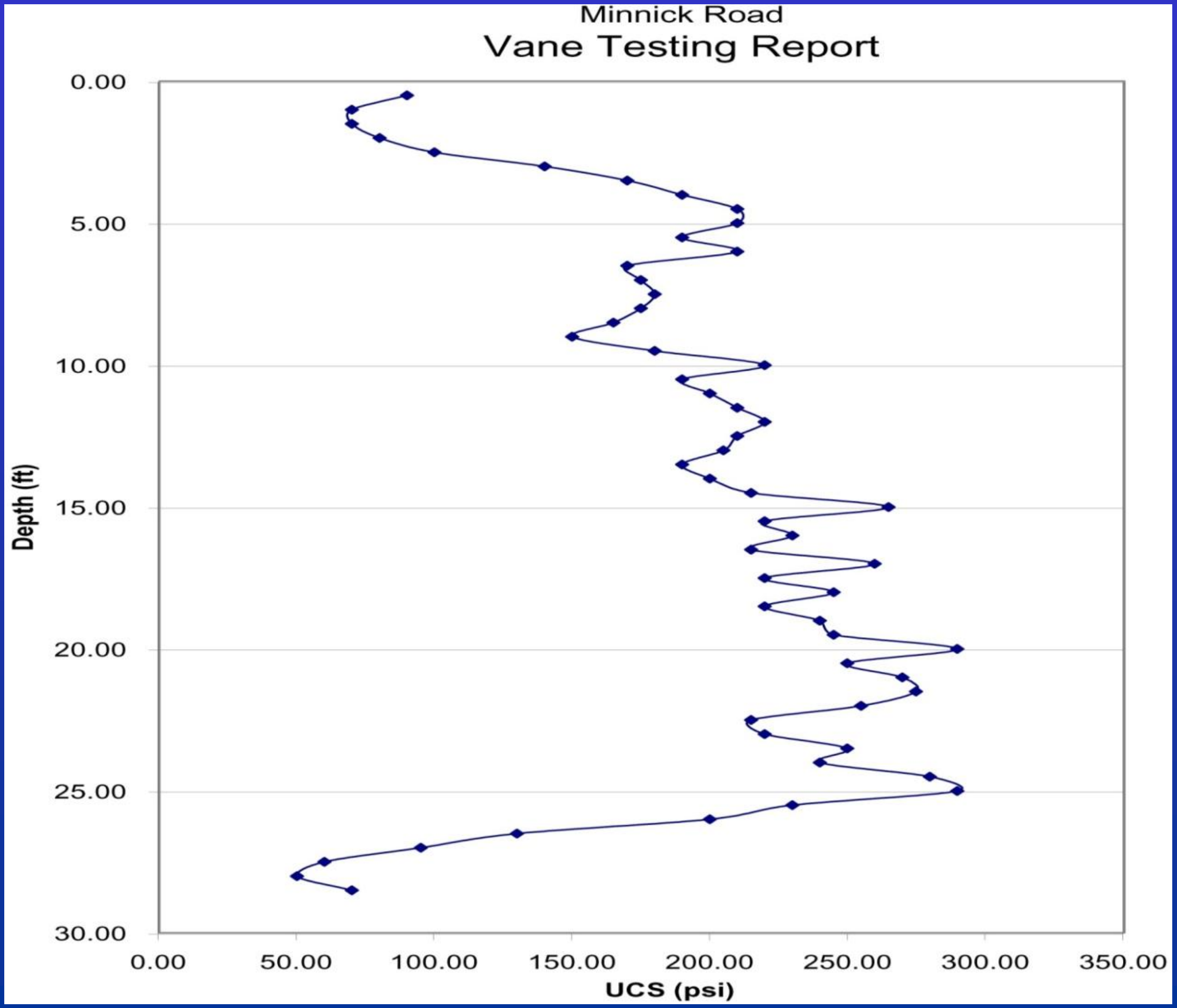
Extraction Vane Results



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Soil Improvement

- Initial Conditions (soft clay):
  Shear strength = 100 to 300 psf
  N-values (SPT) = Weight of Hammer

- Final Conditions (soil-cement columns):
  Shear strength (design) 2000-3000 psf
  Shear strength (vane extraction) 10,000 psf
  N-values (SPT) = minimum 25 blows/ft

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Time Line

- Project started in December 2007
- Completed in October 2008
- Equipment included Casagrande B-135

  hydraulic piling rig – top 4 feet removed to compensate for this 40 ton live load
- Peak productivity 30 columns per work day under optimal conditions
- Productivity affected by obstructions in soil

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Project Statistics

- The soil mixing volume measured 190 feet long by 40 feet wide by 26 feet deep (7320 CY)
- 651 30-inch diameter soil mix columns
- 38% of total volume was treated by mixing
- Minimum compressive strength of the completed columns 70 psi
- Total cost $1.15 million

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Selected Cost Information

- Anchored Sheet Pile Wall ~ $2,100/LF
  Estimated Total Cost = $420,000 - $440,000

- Dry Soil Mixing - $15/LF of column
  Total Cost = $431,000

- Wet Soil Mixing - $25-30/LF of column (w/o spoils removal)

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Some Interesting Facts

- By miscalculation, twice the dosage of cement was used on this project than was planned, which turned out to be a blessing
- Large (2 feet) movements of the lower slope on the creek side occurred, due to the high induced pore pressures
- Obstructions along the culvert in the middle of the project, including boulders and concrete debris, forced a change in construction from soil mixing

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Movement on the Creek Side

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Obstructions Near Culvert

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Damaged Mixing Vane

Some Unexpected Excitement

The job was shut down for one day mid-project when survey measurements indicated movement (several inches) along the other side of the road, where the utilities are located.

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Survey Point that Moved

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Problem Resolution

This turned out to be a survey bust as a result of a lawn mower hitting a survey stake. Everything returned to normal, but this sure caught a lot of attention for one day!

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Completed Project

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Completed Project

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Acknowledgements

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- Dave Pastor, Nichols, Long and Moore Construction

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Recognition

- Recipient of the 2008 Great Lakes and Ohio River Division Engineering Excellence Award for engineering excellence and technical innovation

- Nominated to the 2010 USACE Chief's Design and Environmental Awards

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Lessons Learned

- Successful application of soil mixing to this small streambank protection project
- Likely applications to future nearby projects
- Soil mixing method dependent upon favorable subsurface conditions (soft clay, minimal obstructions, sufficient moisture for hydration of the cement)

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Lessons Learned (Continued)

- When you try something new, you may have to overcome some old attitudes
- The best indicator of success came from a resident, who no longer felt the rumble of trucks driving past her house
- Teamwork led to success

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Questions?