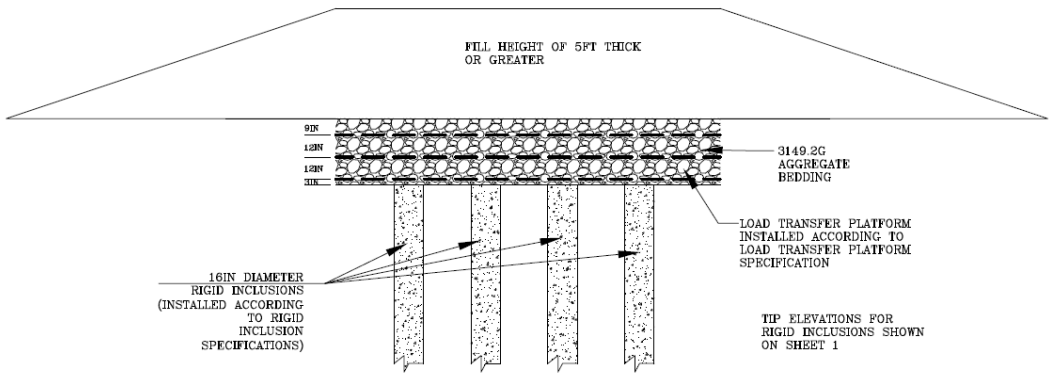
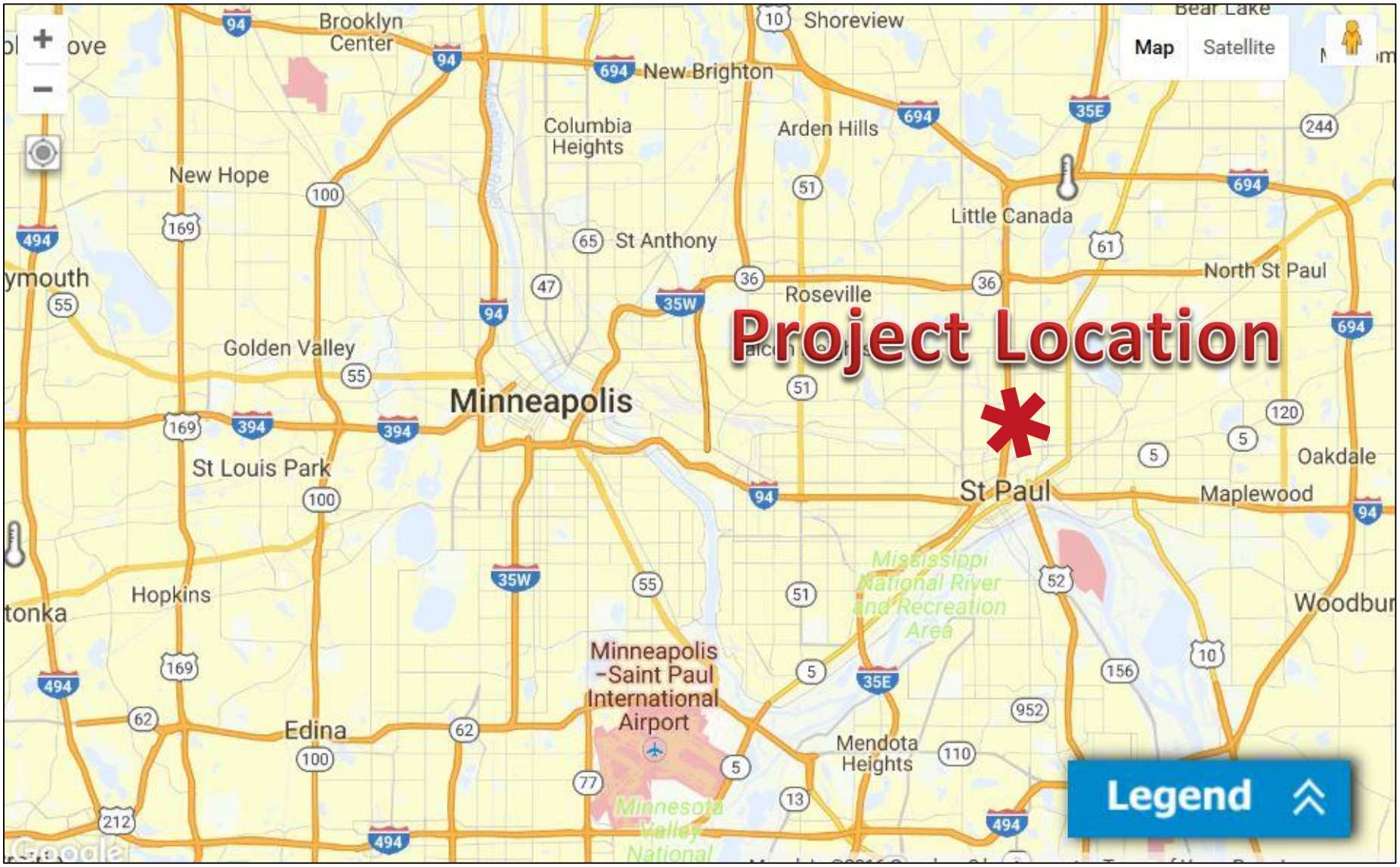
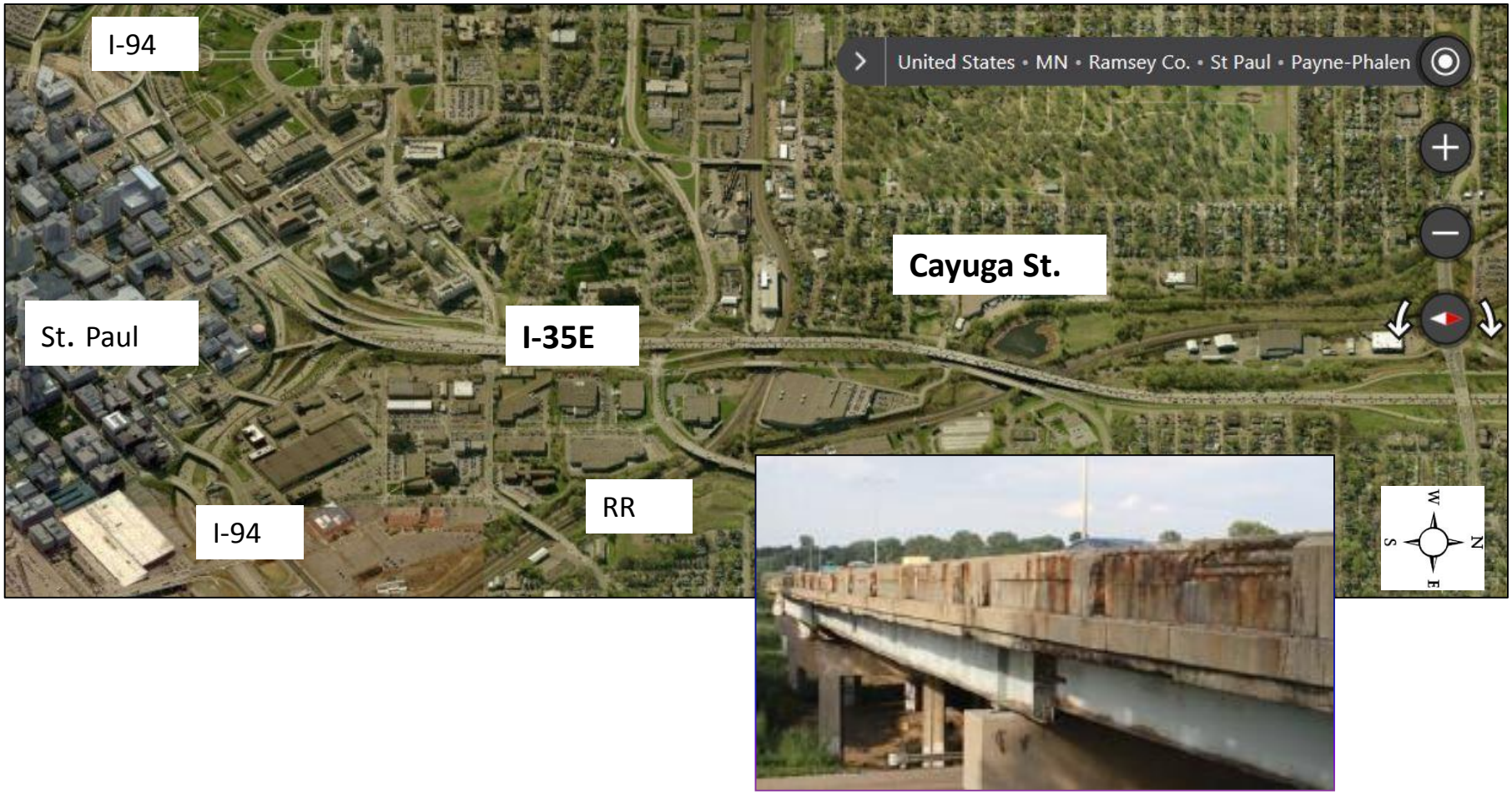
I35E Cayuga Interchange Column Supported Embankments



TYPICAL SECTION (FILL SECTION)
NOT TO SCALE

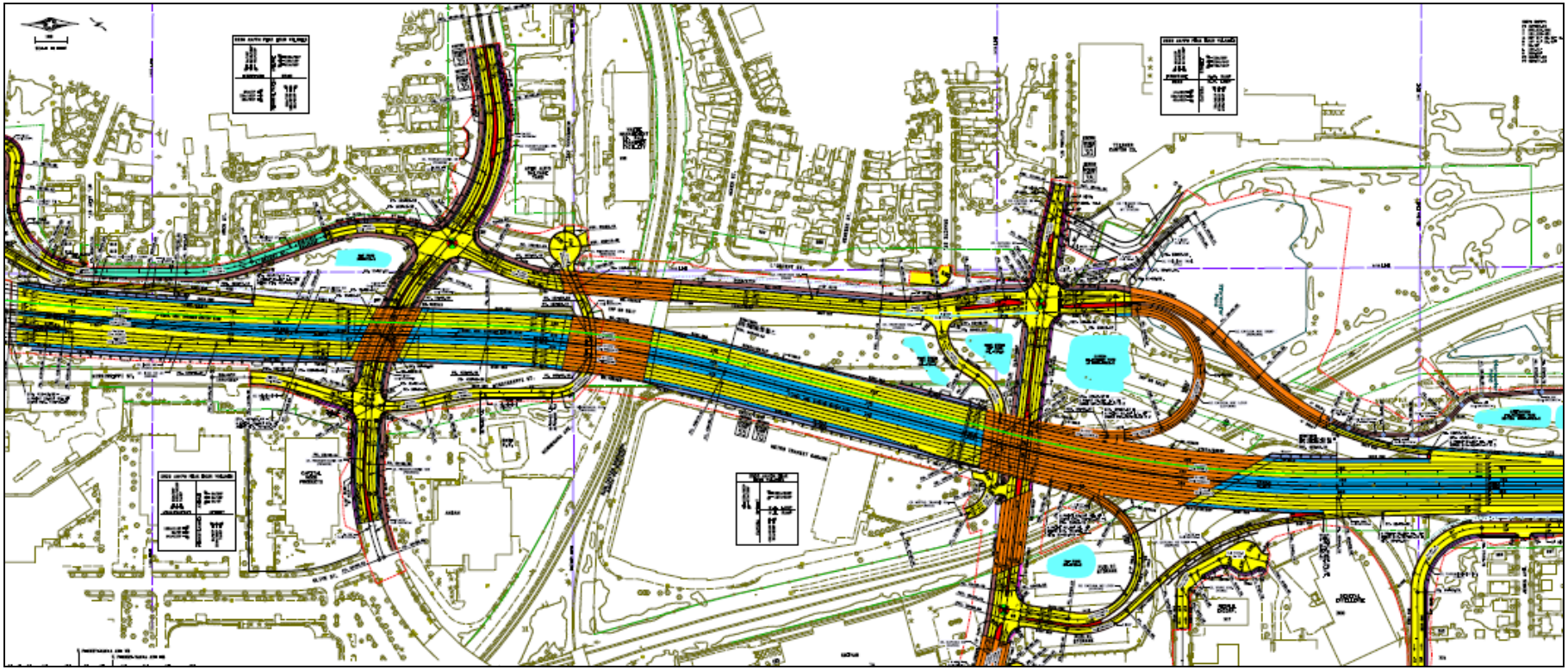

Project Location
Map
Satellite
Legend
Brooklyn Center
Shoreview
New Brighton
Columbia Heights
Arden Hills
New Hope
Little Canada
St Anthony
North St Paul
Roseville
Golden Valley
Minneapolis
St Louis Park
St Paul
Oakdale
Maplewood
Hopkins
Mississippi National River and Recreation Area
Minneapolis -Saint Paul International Airport
Edina
Mendota Heights
Minnesota Valley National

I35E Cayuga Interchange

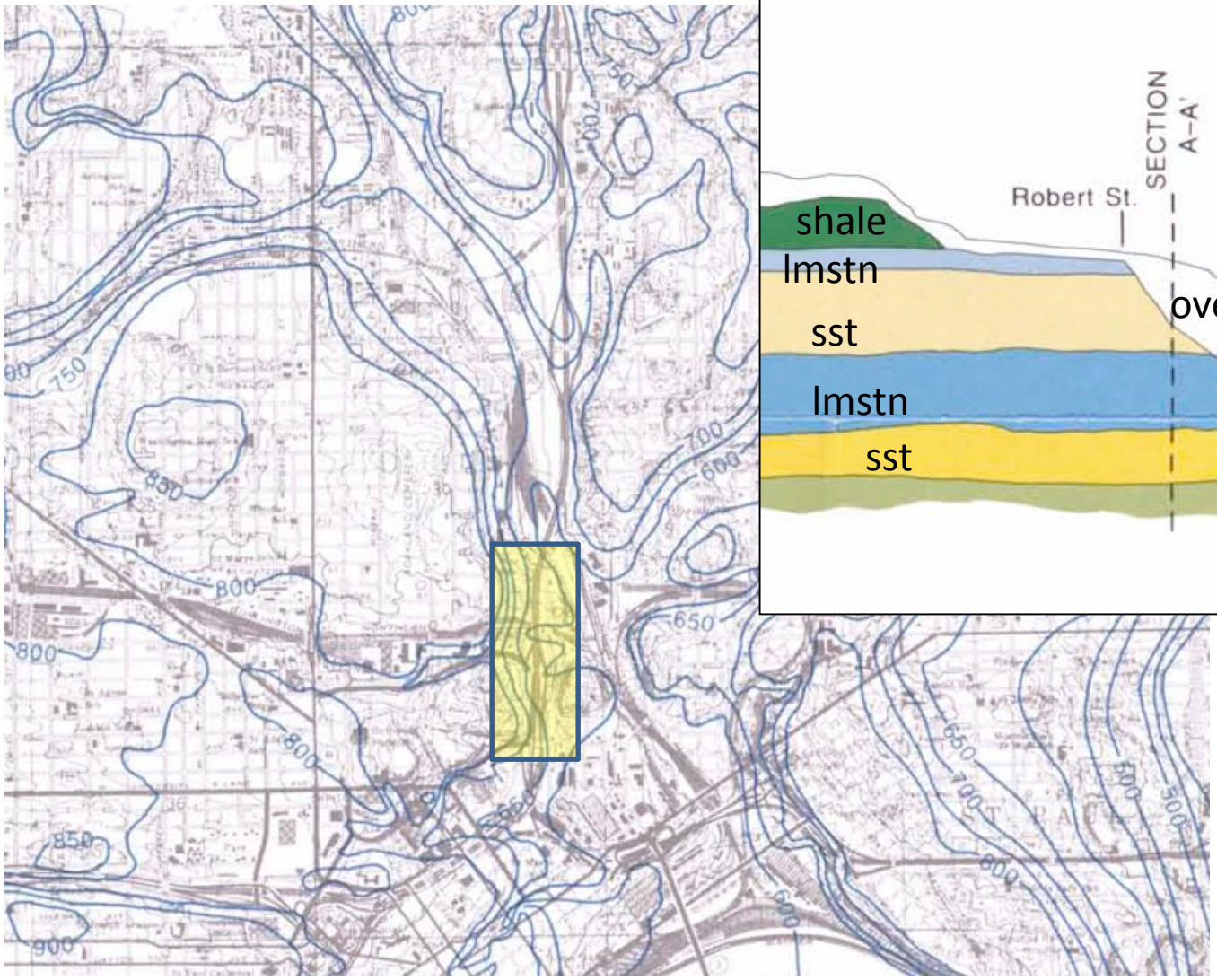


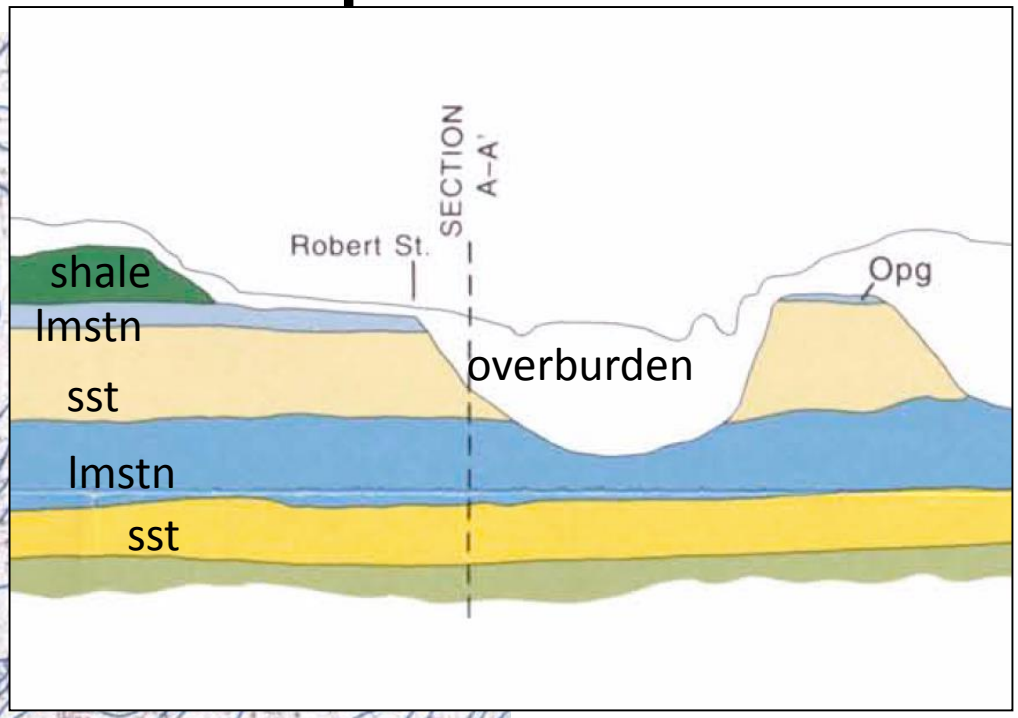
Cayuga Interchange

- $115 Million Dollar Project (1 mile)
- 10 Bridges, new alignment, poor soils, big fills, RR



Bedrock Maps

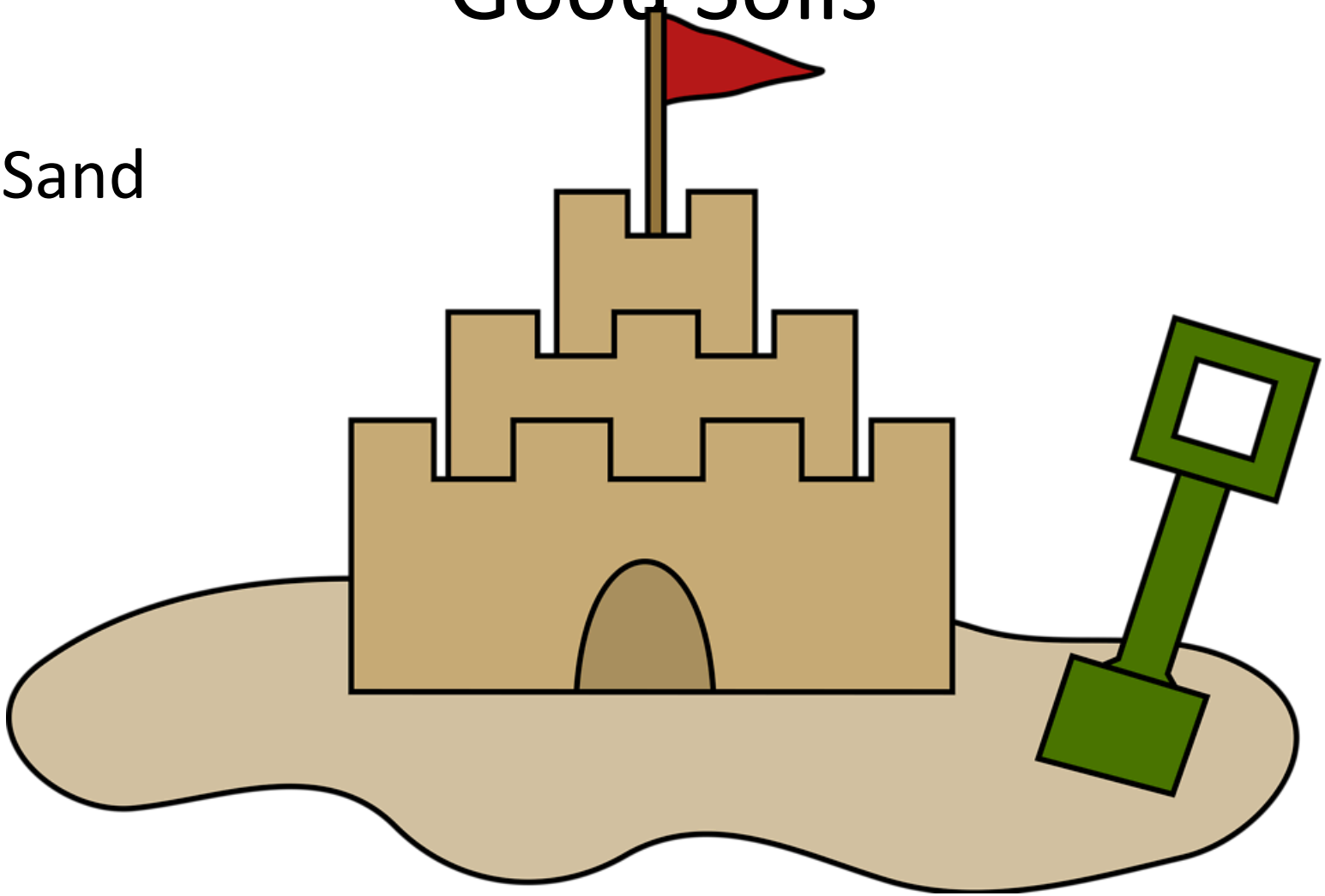




Two main soil types

Good Soils

- Sand



Poor Soils

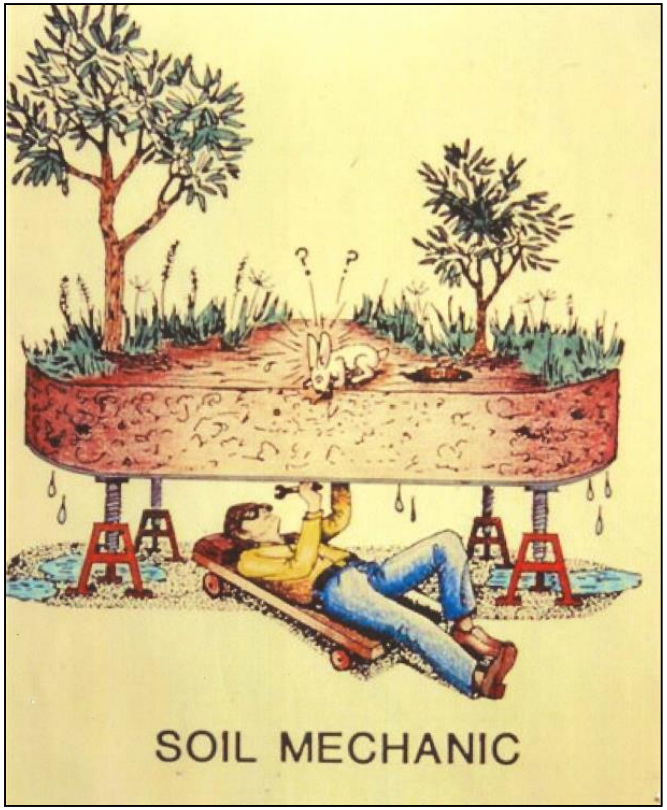
- *”Mixed, semi-fibrous, spongy, marly, highly organic, partially-decomposed, woody, black, Peat, silt, swamp deposits, trace shells, very soft”*
- Organic contents up to 60%, moisture contents up to 350%
- SPT blow counts WH to 10
- Highly Variable depths and layer thickness

Subsurface Investigations

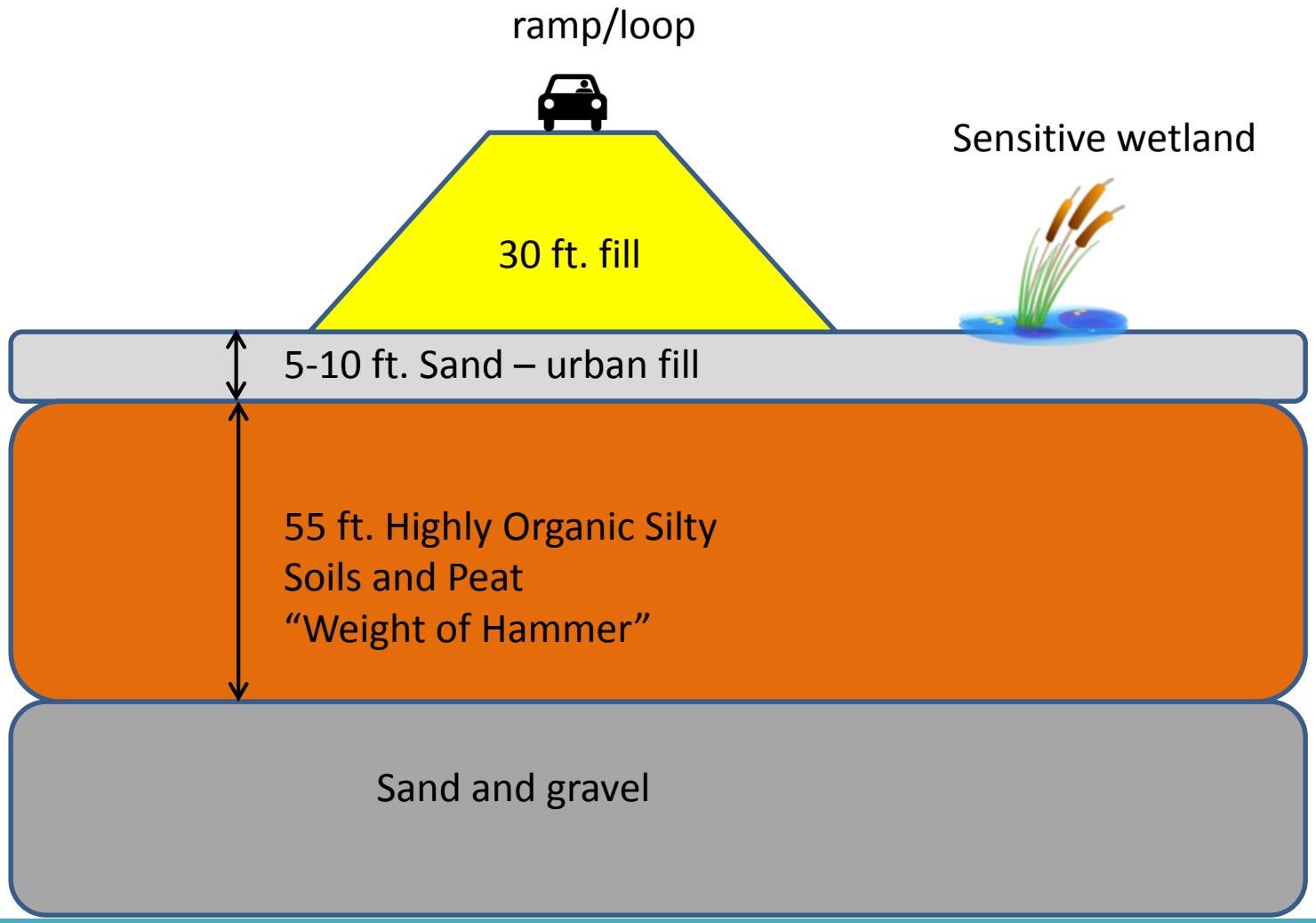
- 350 CPT Soundings
- 150 SPT Borings
- 30 1-D Consol. Tests

Ground Improvement Methods used on project

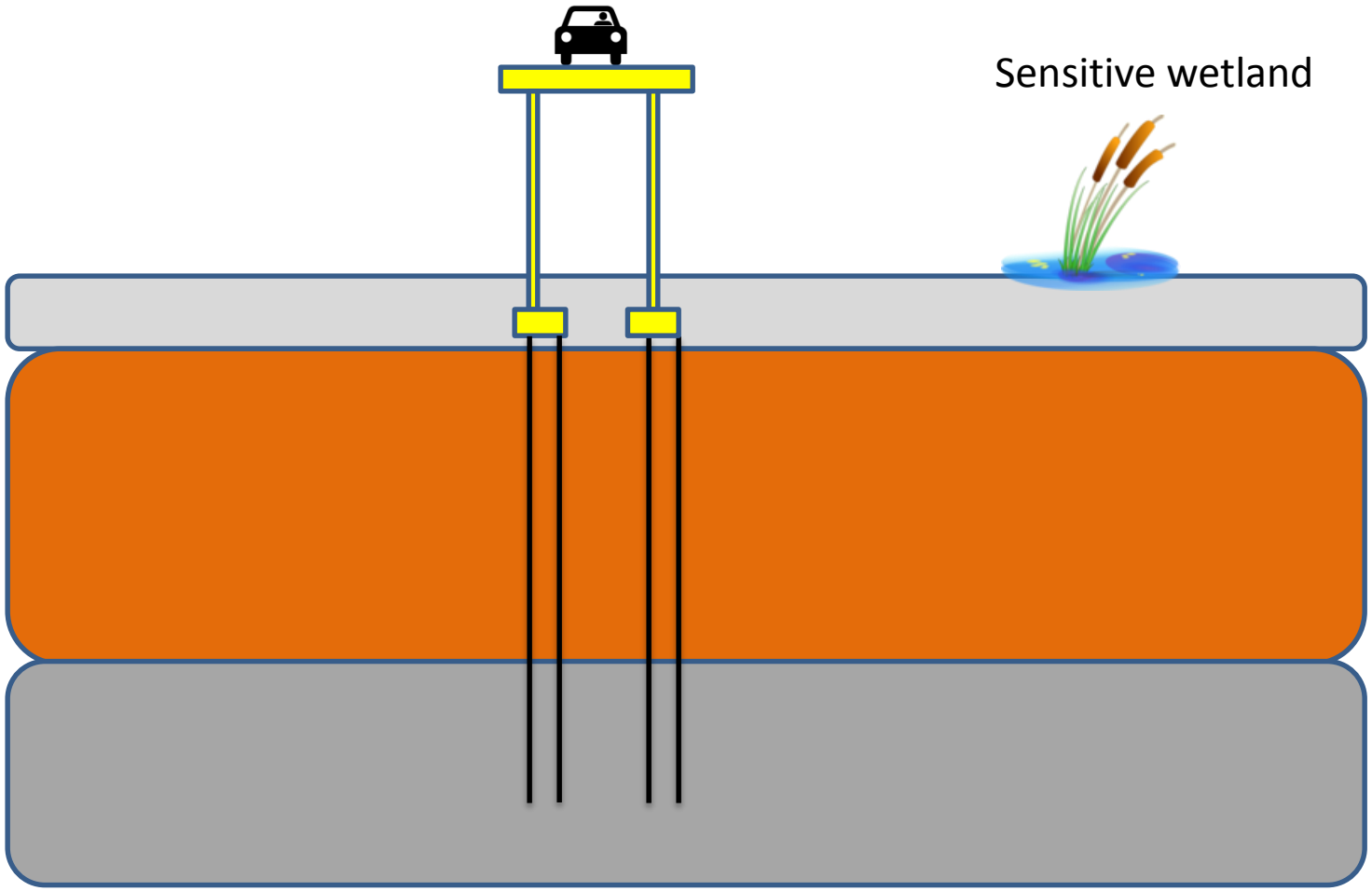
- Excavation/replace
- Bridges
- Geofoam
- Column Supported Embankments



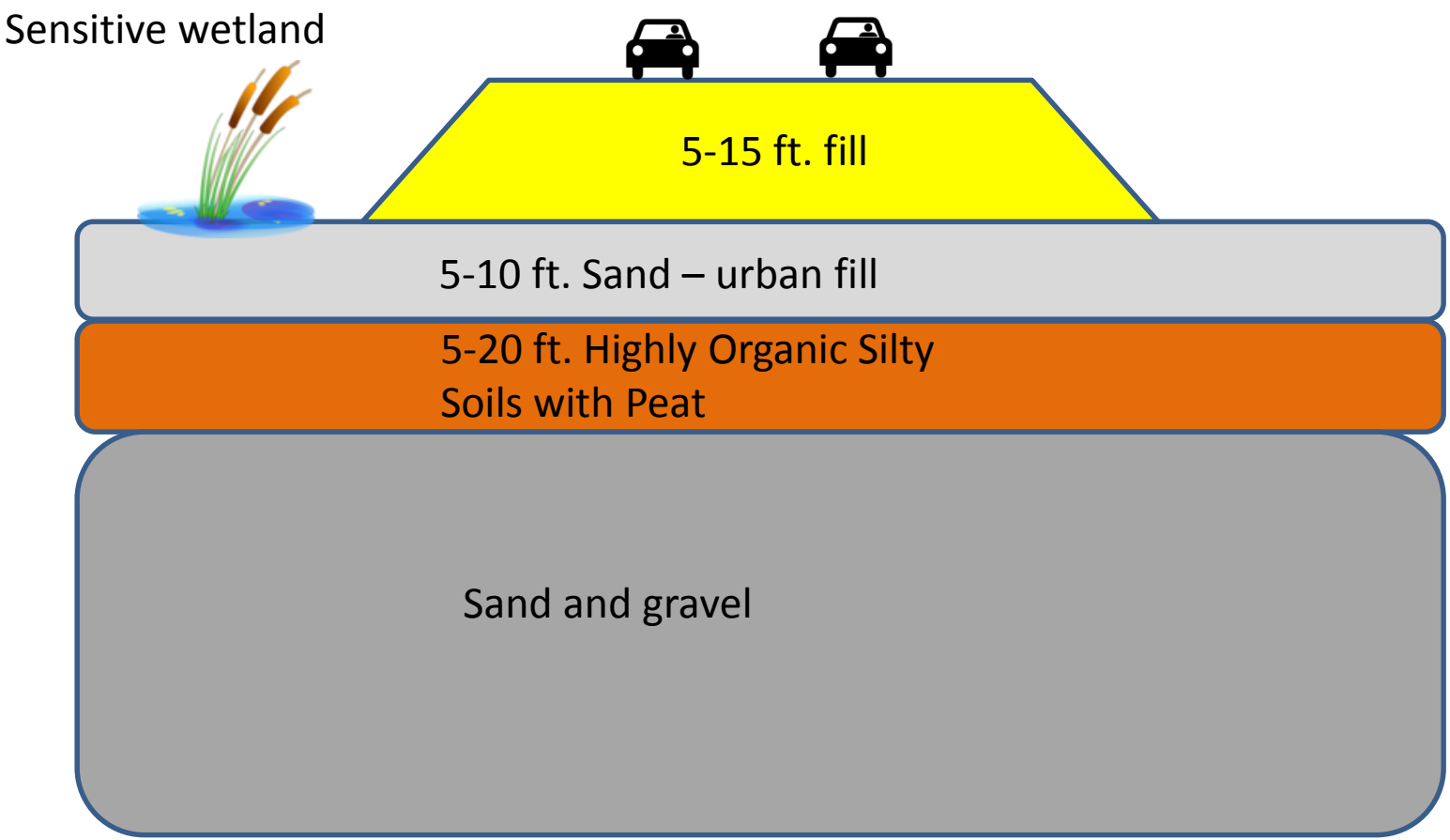
Deep organic deposits – tall fills



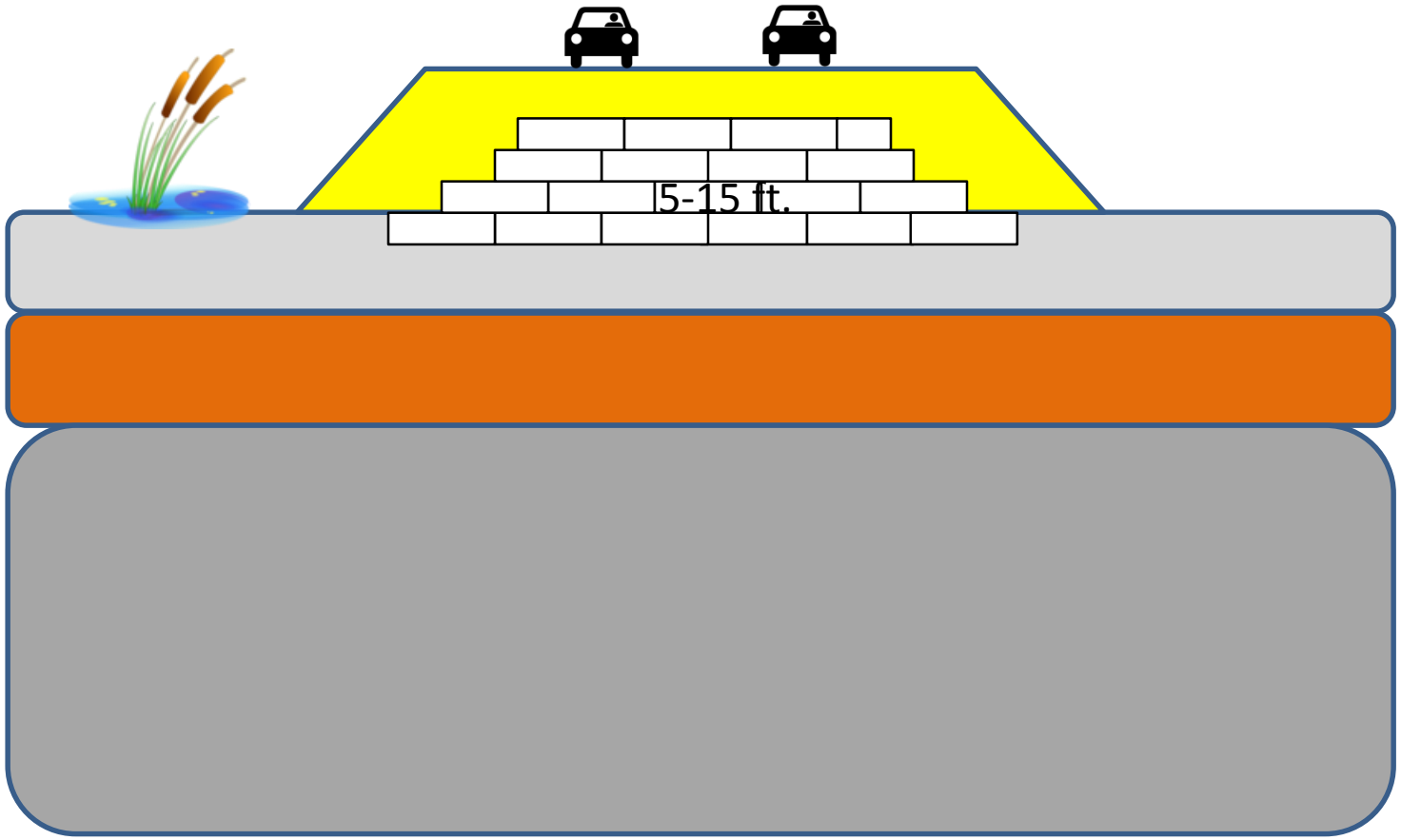
Bridge



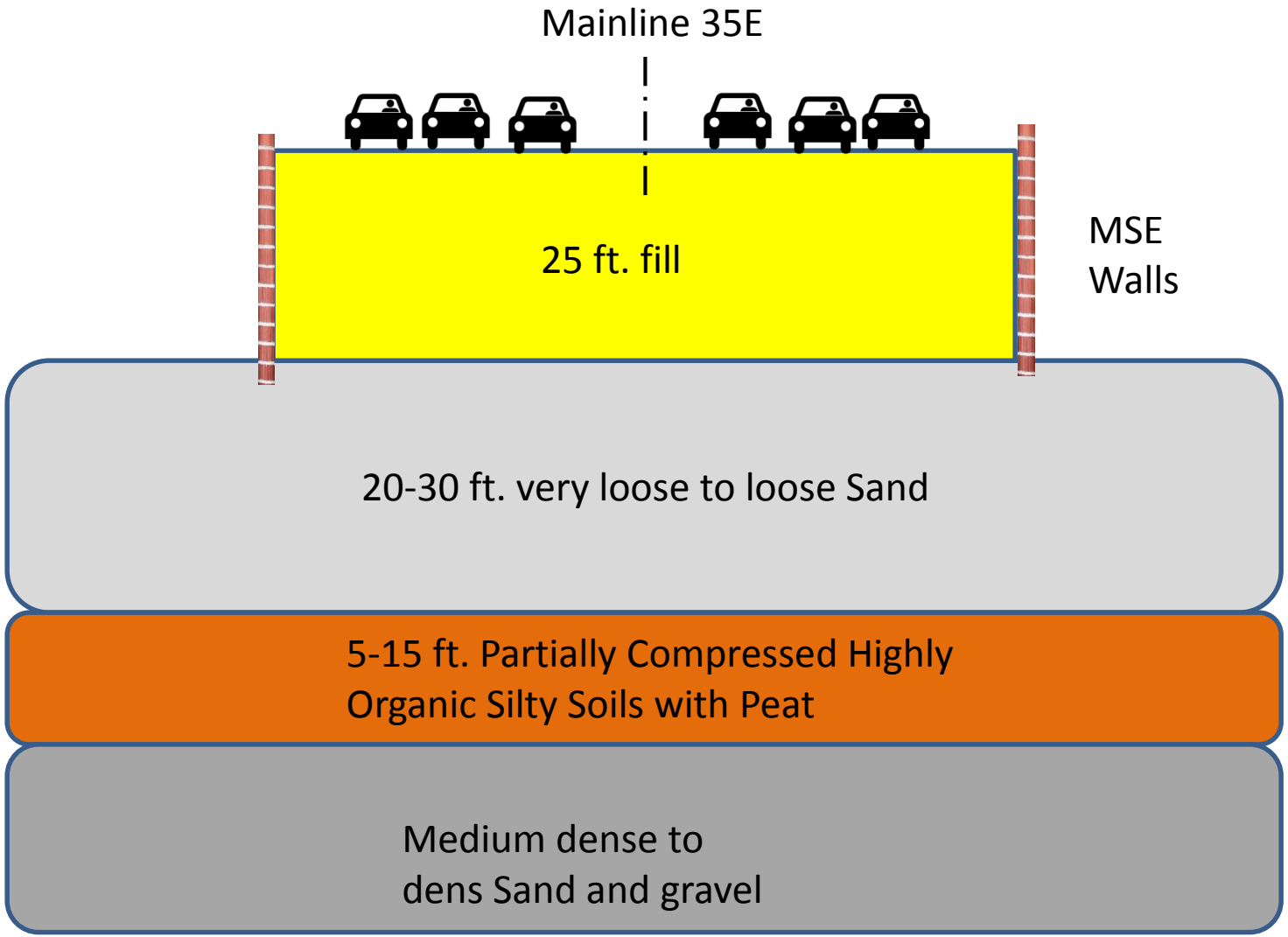
Buried Organic Layers – medium fill heights



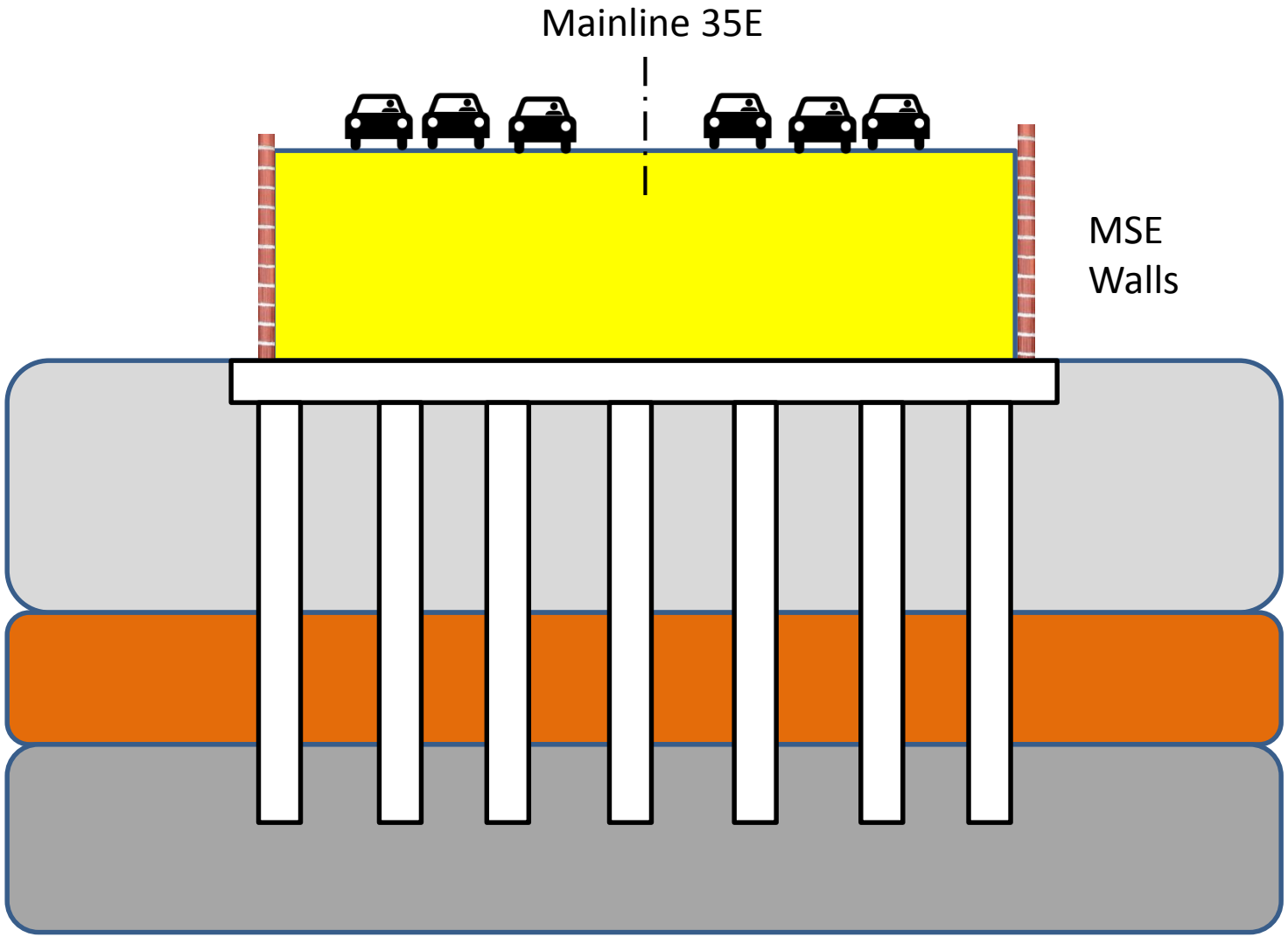
EPS - Geofoam



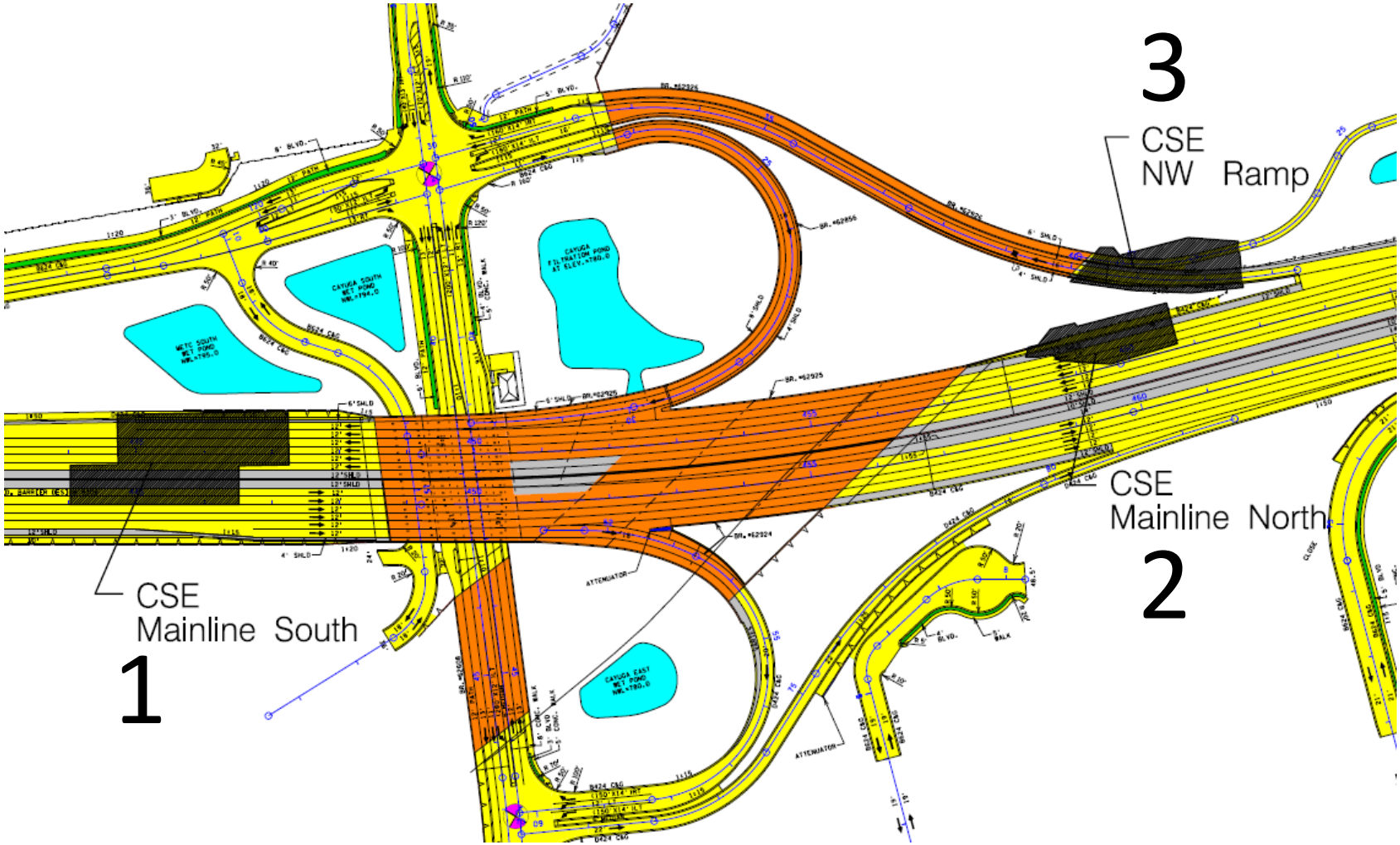
Buried Organics – Tall Fills and Walls



Column Supported Embankment (CSE)



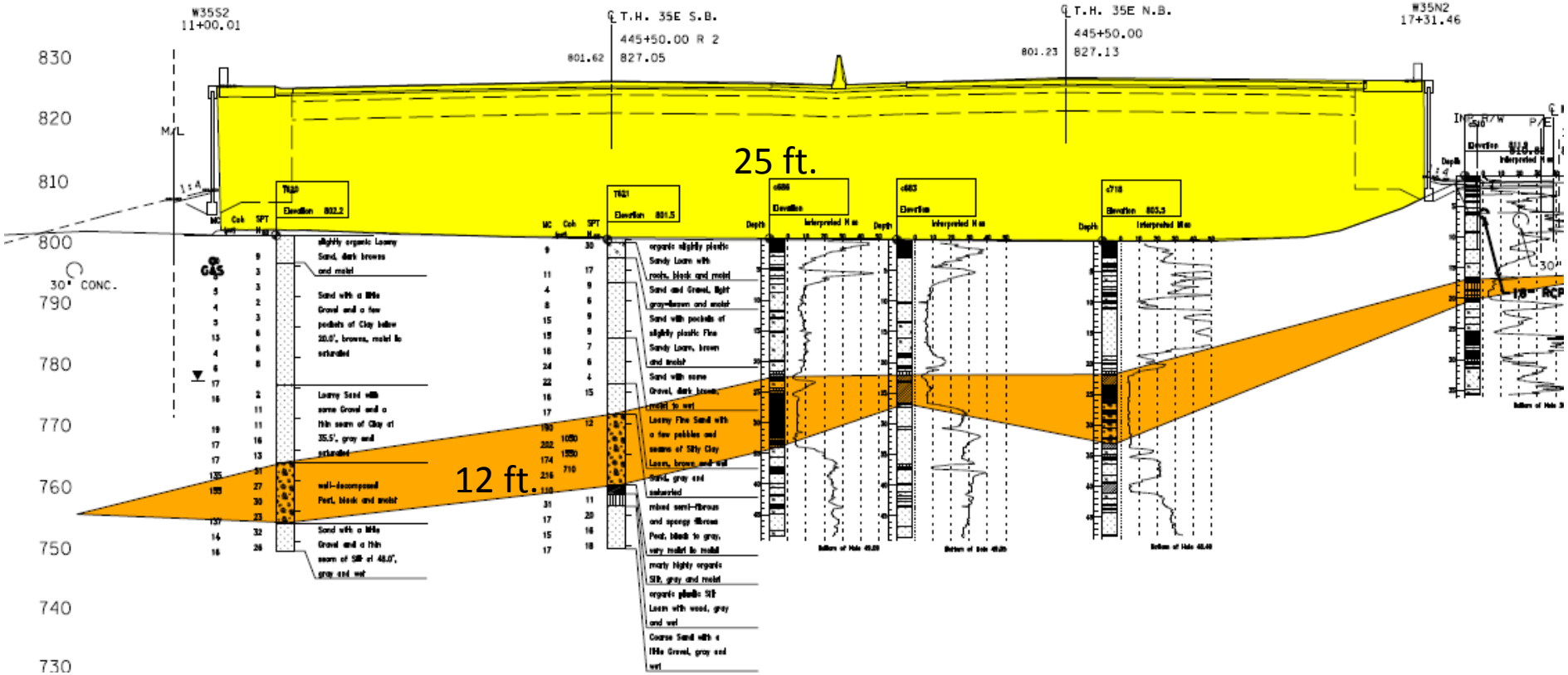
3 CSE Areas



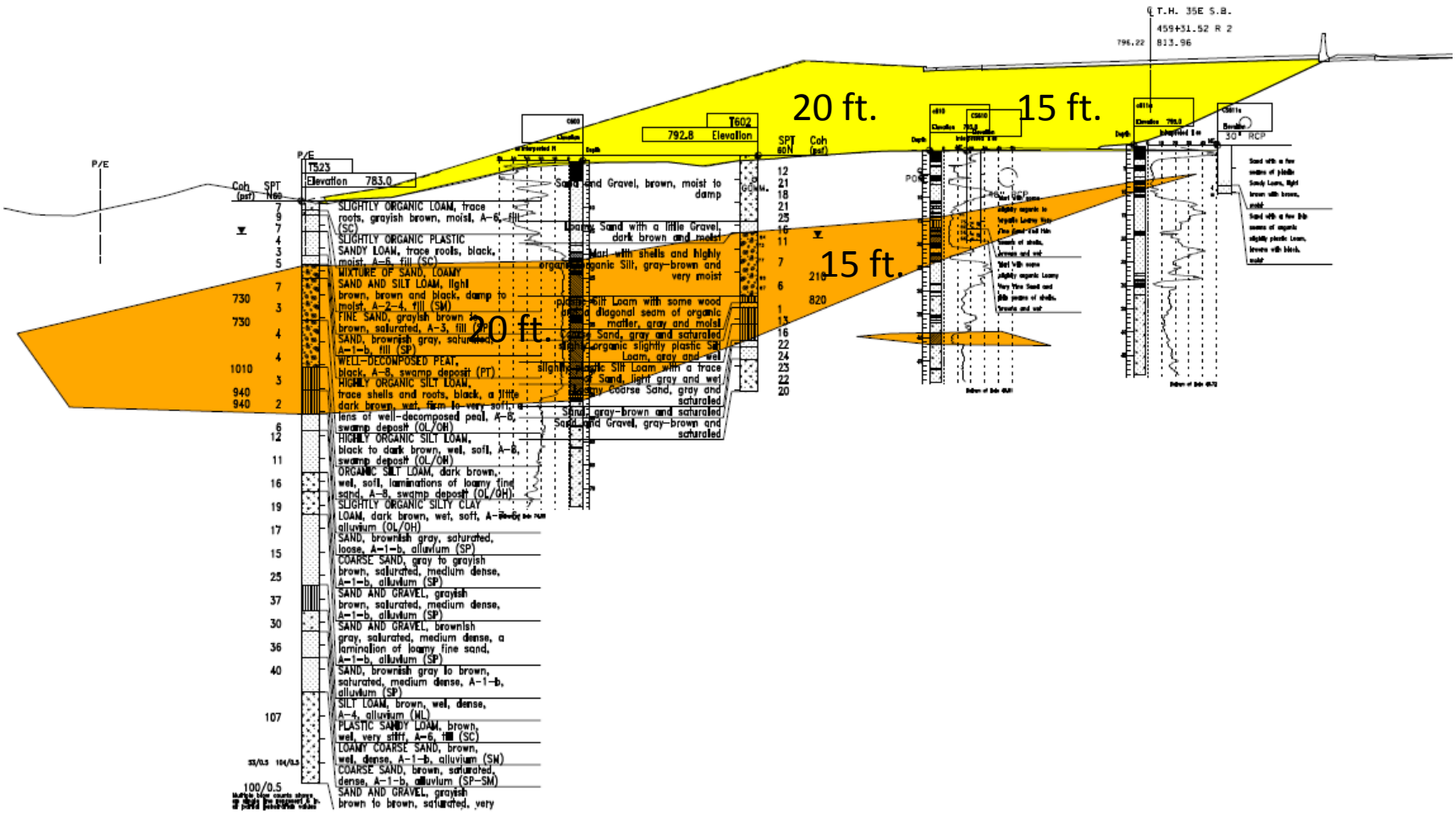
Mainline South

MSE Walls

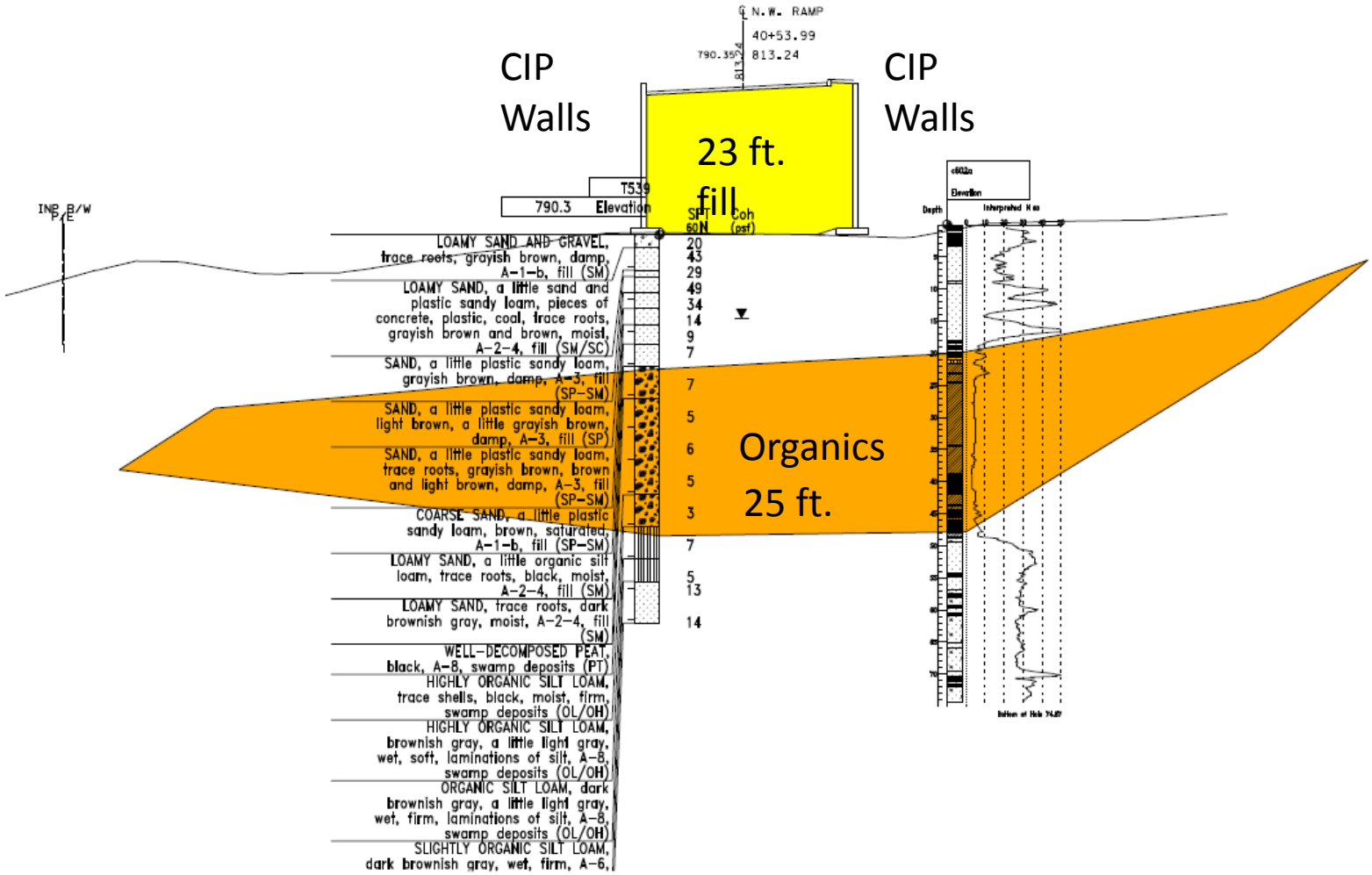
MSE Walls



Mainline North



NW Ramp


CIP Walls
CIP Walls
23 ft. fill
Organics 25 ft.
℄ N.W. RAMP
40+53.99
790.35
813.24
T539
790.3 Elevation
SPT 60N
Coh (psf)
LOAMY SAND AND GRAVEL, trace roots, grayish brown, damp, A-1-b, fill (SM)
LOAMY SAND, a little sand and plastic sandy loam, pieces of concrete, plastic, coal, trace roots, grayish brown and brown, moist, A-2-4, fill (SM/SC)
SAND, a little plastic sandy loam, grayish brown, damp, A-3, fill (SP-SM)
SAND, a little plastic sandy loam, light brown, a little grayish brown, damp, A-3, fill (SP)
SAND, a little plastic sandy loam, trace roots, grayish brown, brown and light brown, damp, A-3, fill (SP-SM)
COARSE SAND, a little plastic sandy loam, brown, saturated, A-1-b, fill (SP-SM)
LOAMY SAND, a little organic silt loam, trace roots, black, moist, A-2-4, fill (SM)
LOAMY SAND, trace roots, dark brownish gray, moist, A-2-4, fill (SM)
WELL-DECOMPOSED PEAT, black, A-8, swamp deposits (PT)
HIGHLY ORGANIC SILT LOAM, trace shells, black, moist, firm, swamp deposits (OL/OH)
HIGHLY ORGANIC SILT LOAM, brownish gray, a little light gray, wet, soft, laminations of silt, A-8, swamp deposits (OL/OH)
ORGANIC SILT LOAM, dark brownish gray, a little light gray, wet, firm, laminations of silt, A-8, swamp deposits (OL/OH)
SLIGHTLY ORGANIC SILT LOAM, dark brownish gray, wet, firm, A-6,
Depth
Elevation
Interpreted N so

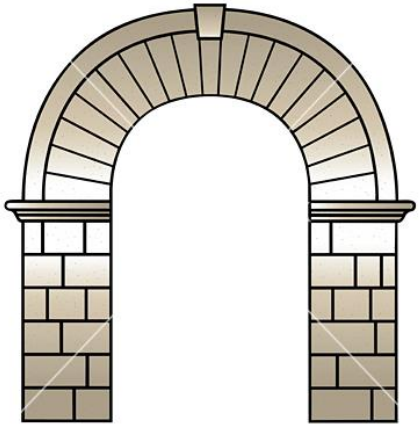
CSE Design

- Consultant – Dan Brown & Associates
- Contract value: $172,000
  - Geotech Reports, plans and specifications (including instrumentation)
- Performance requirements
  - Slope Stability F.S. =1.5
  - Long term settlement less than 1 inch

DAN BROWN AND ASSOCIATES

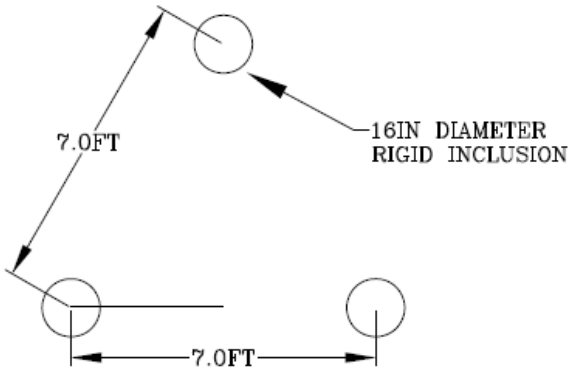
CSE Design - Approach

- All of the embankment load is distributed through load transfer platform and into the rigid columns
- No significant load between columns



Rigid Inclusion Design

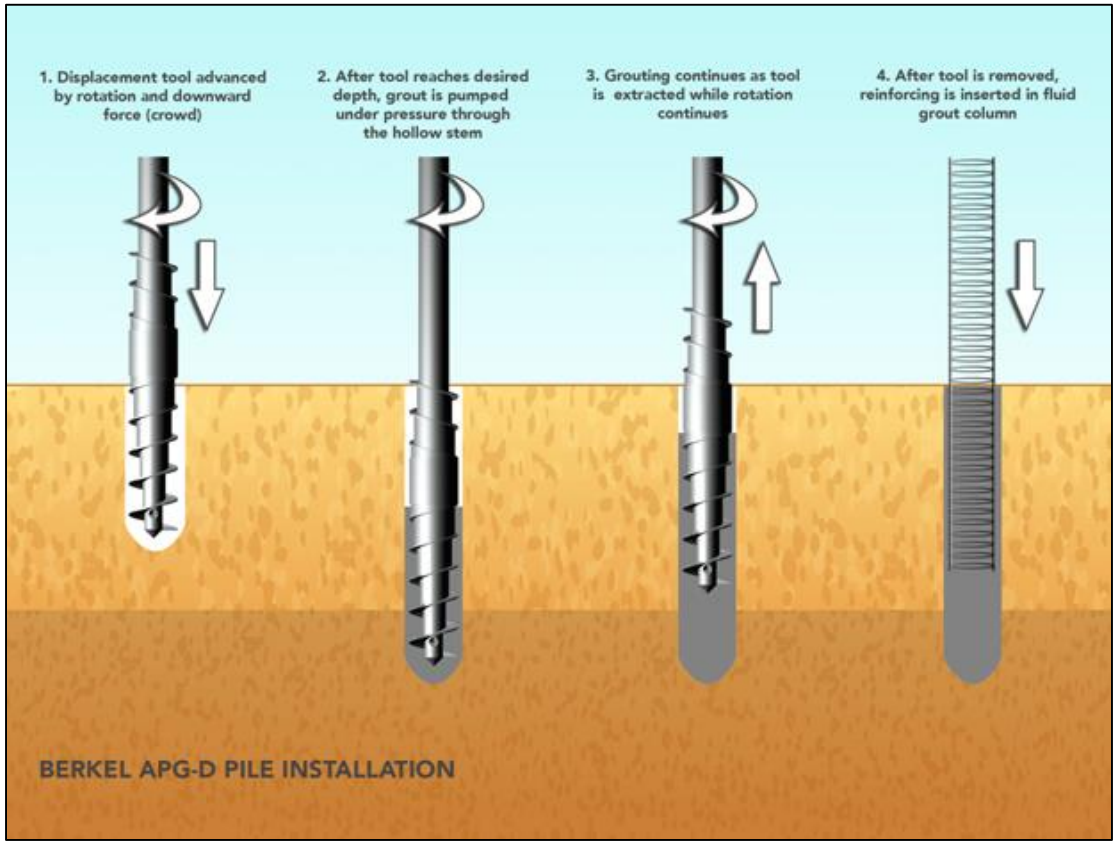
- 16 in. diameter cast-in-place grout columns installed with “drilled displacement” tooling
- 7 ft. center-to-center spacing
- Installed to depths of 5-10 ft. below poor soils (40-62 ft.)



RIGID INCLUSION
LAYOUT (TYP.)
NOT TO SCALE

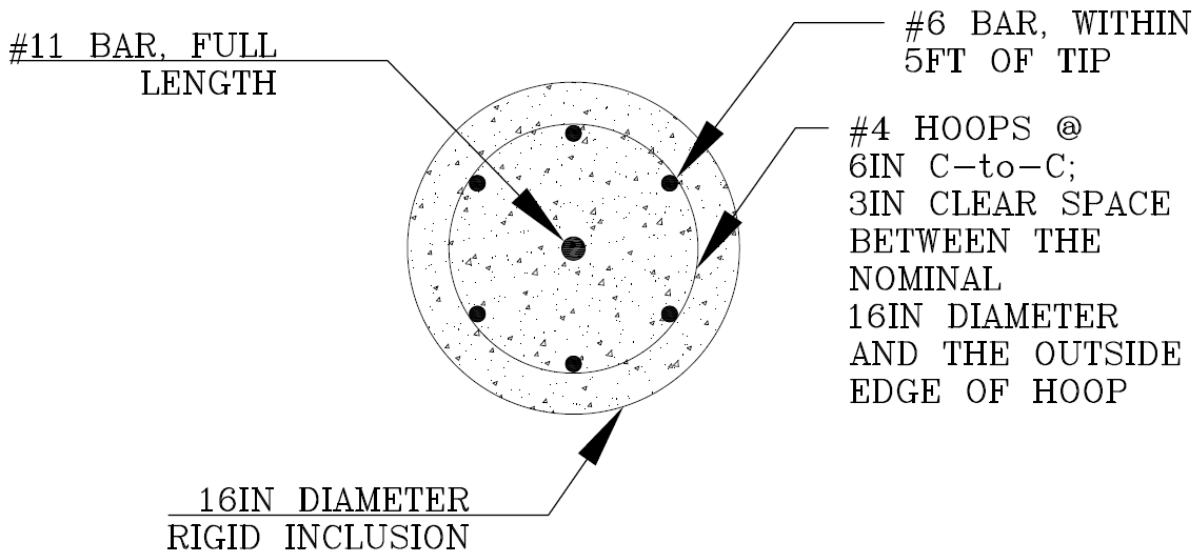
Drilled Displacement Piles

- Berkel uses "unique" displacement tool
- Displacement increases shaft friction



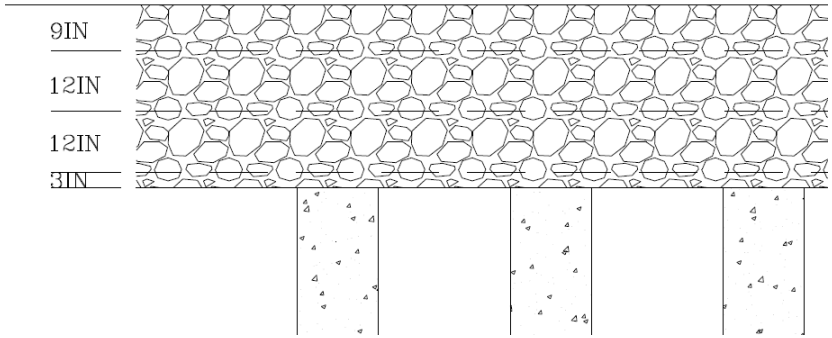
Shaft Design

- Grout – 4,000 psi
- Steel reinforcement for perimeter piles
- Design load = 40-80 tons
- ~$20/LF



Load Transfer Platform Design

- Beam Method
  - Select well graded granular fill (94-98% compaction)
  - Minimum of three horizontal biaxial geosynthetic reinforcement layers with vertical spacing of 8-18 in.
  - 34 in. LTP thickness (½ the clear span between columns)



Instrumentation Plan

- Goals: Evaluate load development, evaluate performance of LTP and measure settlement between columns

Data collected	Gages
Compressive strain along length of column	Sister bar strain gages
Ground settlement (between columns)	Shape-Accel-Array
Pore pressure development	VW Piezos
Applied pressure induced	Earth Pressure Cells

Letting Nov. 2012

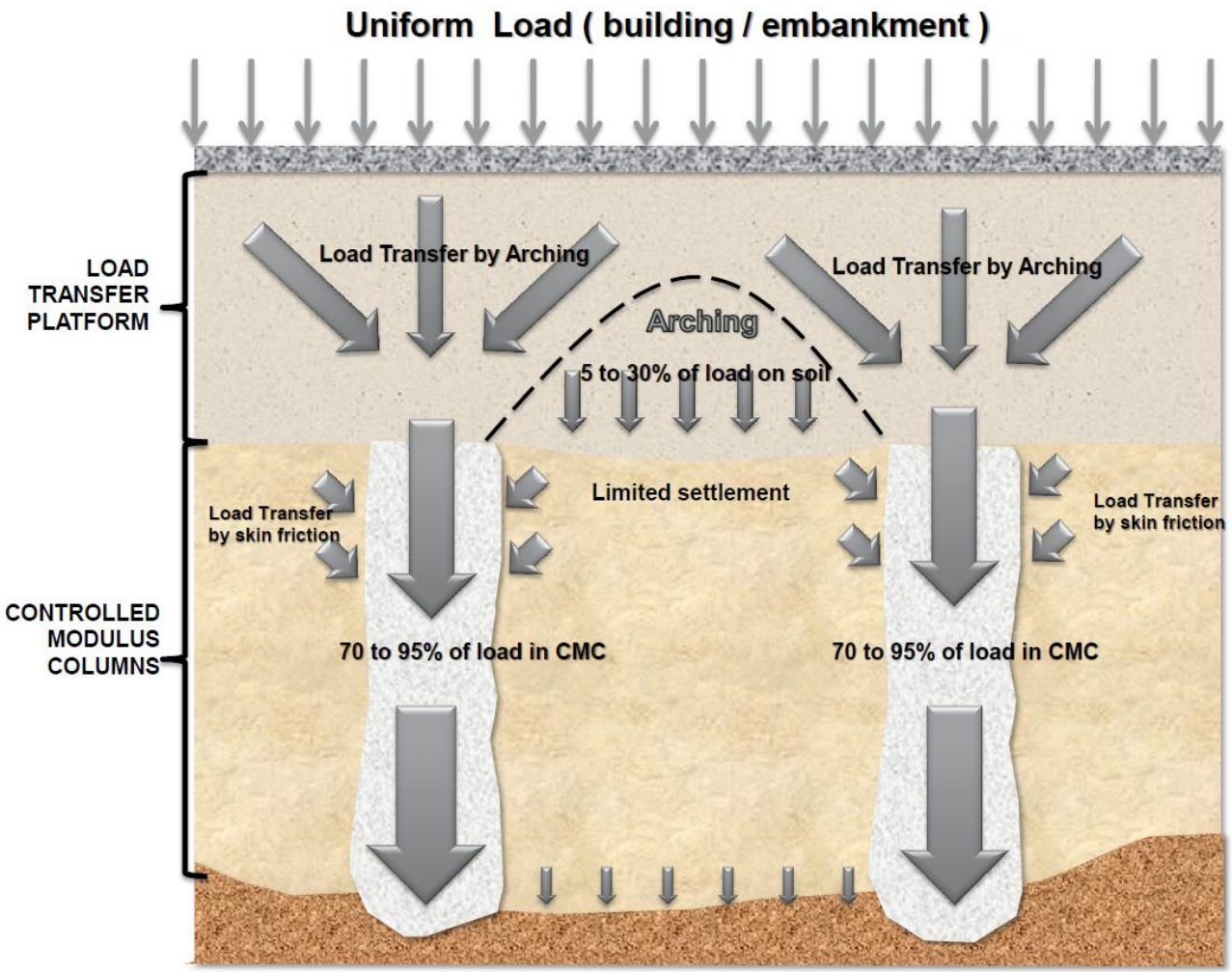
- Bids for Column Supported Embankment
  - $435 / SY
  - $470 / SY
  - $660 / SY
- Subcontractor:

menard
Ground Improvement Specialists

Controlled Modulus Columns (CMC)

- Type of rigid inclusion – in family of auger cast piles
- High torque and down thrust along with special reverse flight augers displaces soil laterally
- Pressure grouted
- Results in composite ground improvement solution

Soil Arching



Value Engineering Proposal

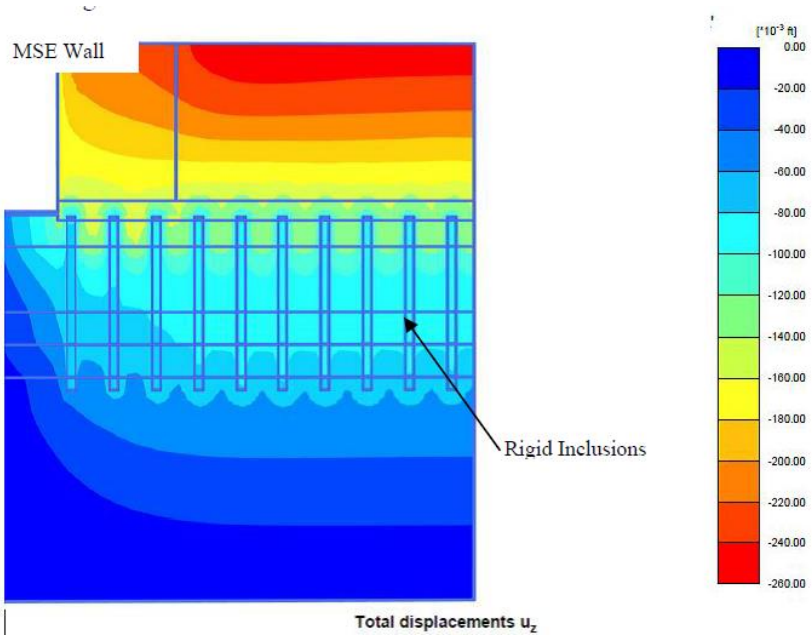
- Redesign of Column Supported Embankments
- Menard would become Geotech Engineeer of Record
- Benefits
  - More economical design
  - Additional areas covered

VE Summary

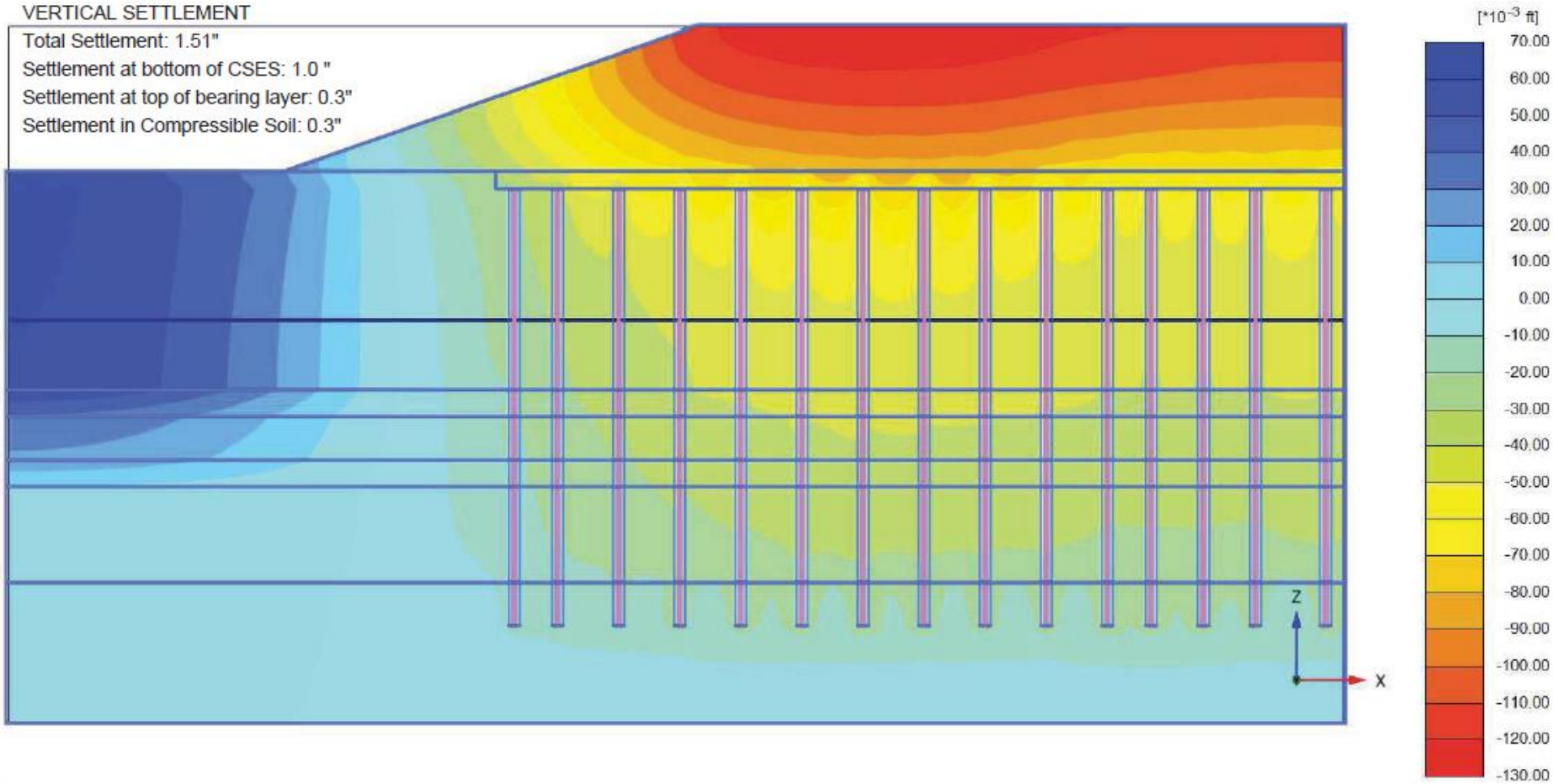
	Base Design	V.E. Proposal
Diameter	16 inch	15.5 inch
Quantity	1,481	1,597
* Depth	40-62 ft.	20-60 ft.
Improved Area	63,700 sq. ft.	77,100 sq. ft.
* LTP / Reinforcement	3 ft. thick with 3 layers biaxial	2 ft. thick – no reinforcement
Column Reinforcement – perimeter columns	Single bars and full depth cages	Single bars
Design Methodology	Beam Method - FHWA guidance manual	Plaxis Software
Instrumentation		More gages

Revised CSE Design

- Finite element analysis with PLAXIS
- Vertical and horizontal stress/deformation
- Model showed small horizontal displacements that reduced or eliminated steel reinforcement in outside columns



Vertical Deformations

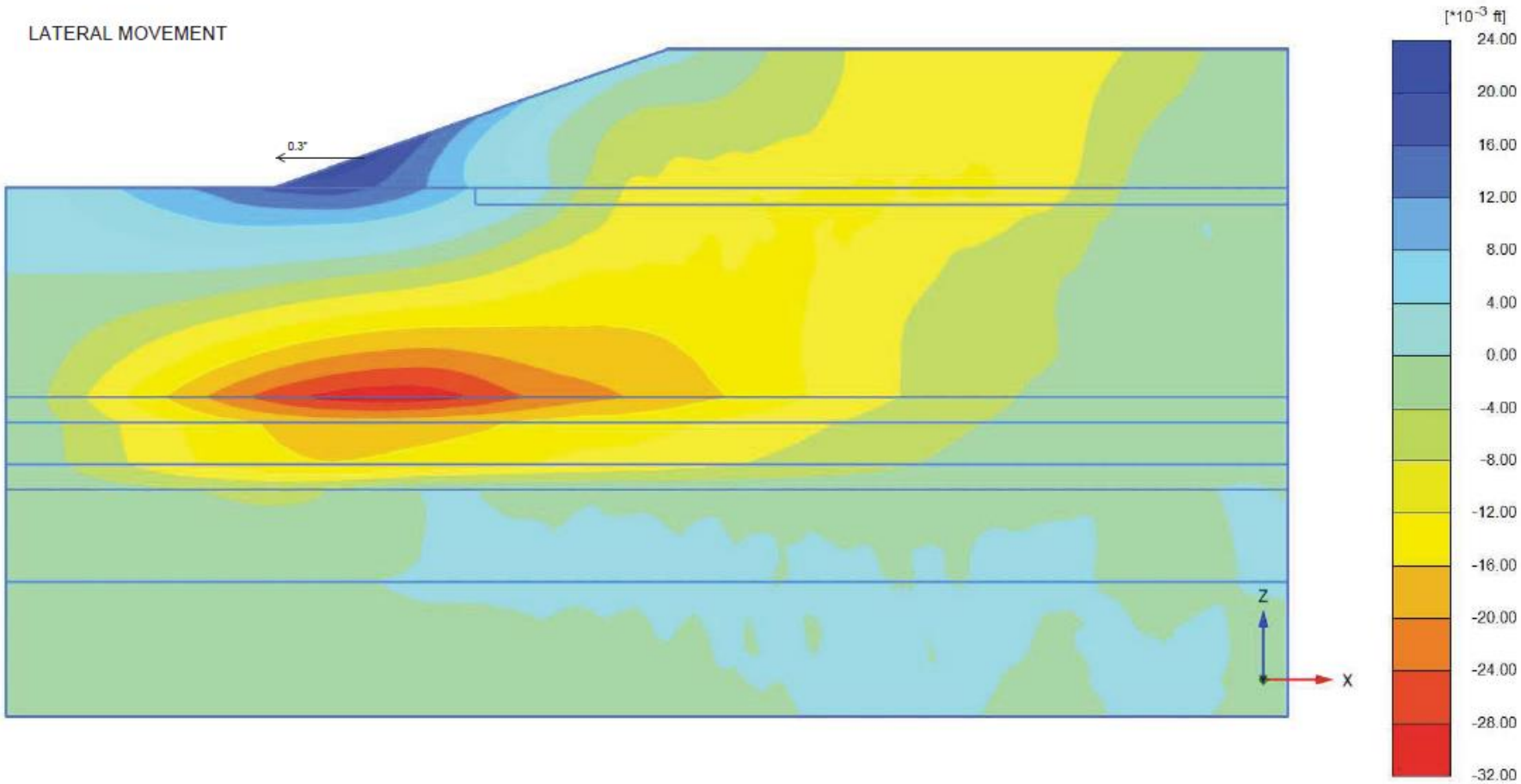


Total displacements u_z

Maximum value = 0.06200 ft

Minimum value = -0.1259 ft

Horizontal Deformations

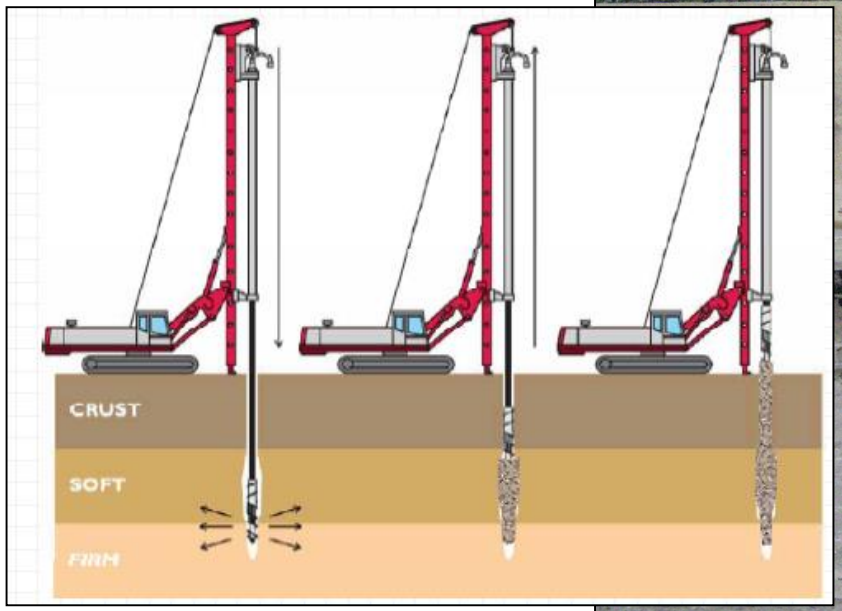


Total displacements u_x

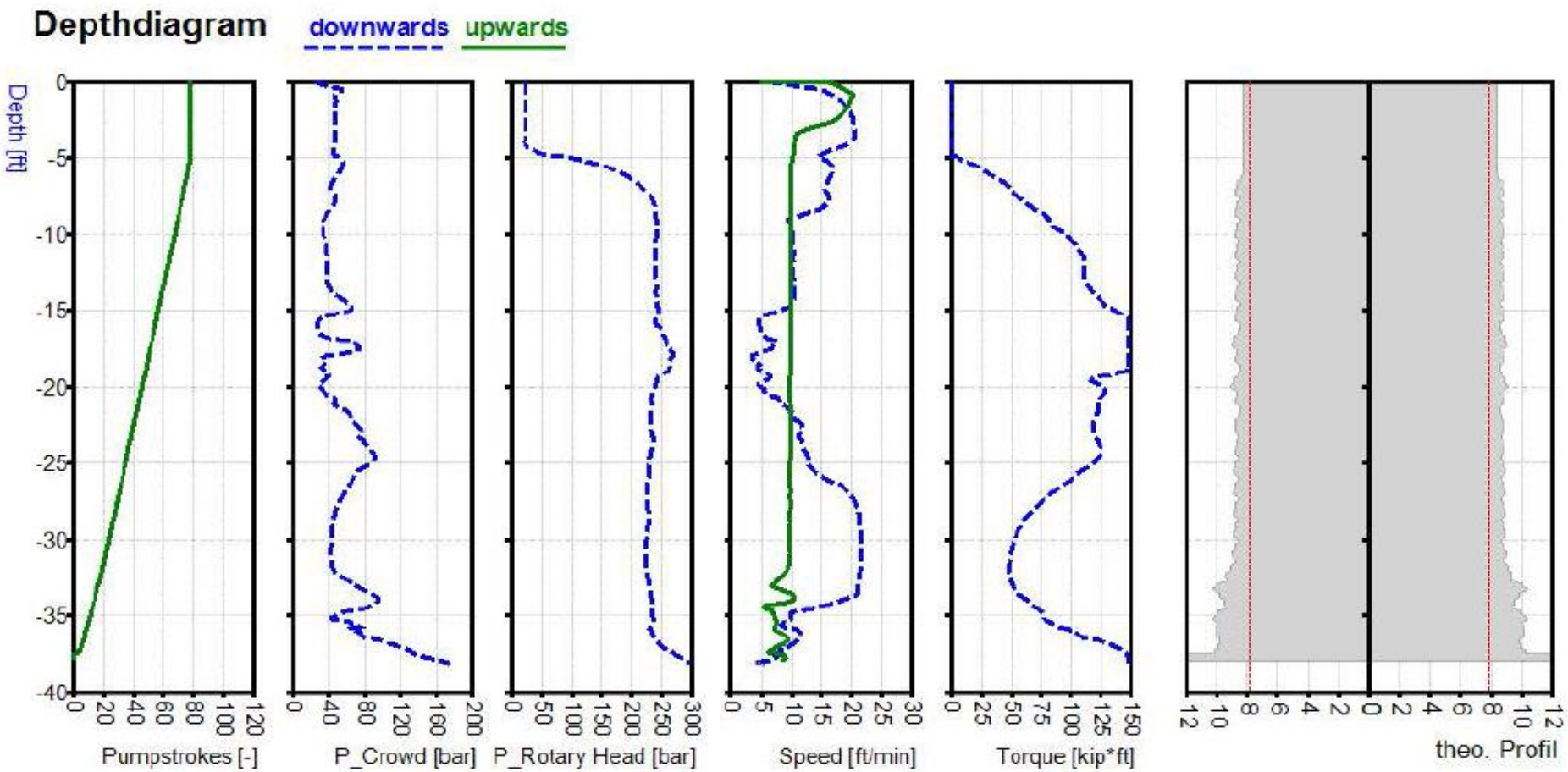
Maximum value = 0.02212 ft (Element 99 at Node 79119)

Minimum value = -0.03061 ft (Element 10904 at Node 93142)

CMC Construction



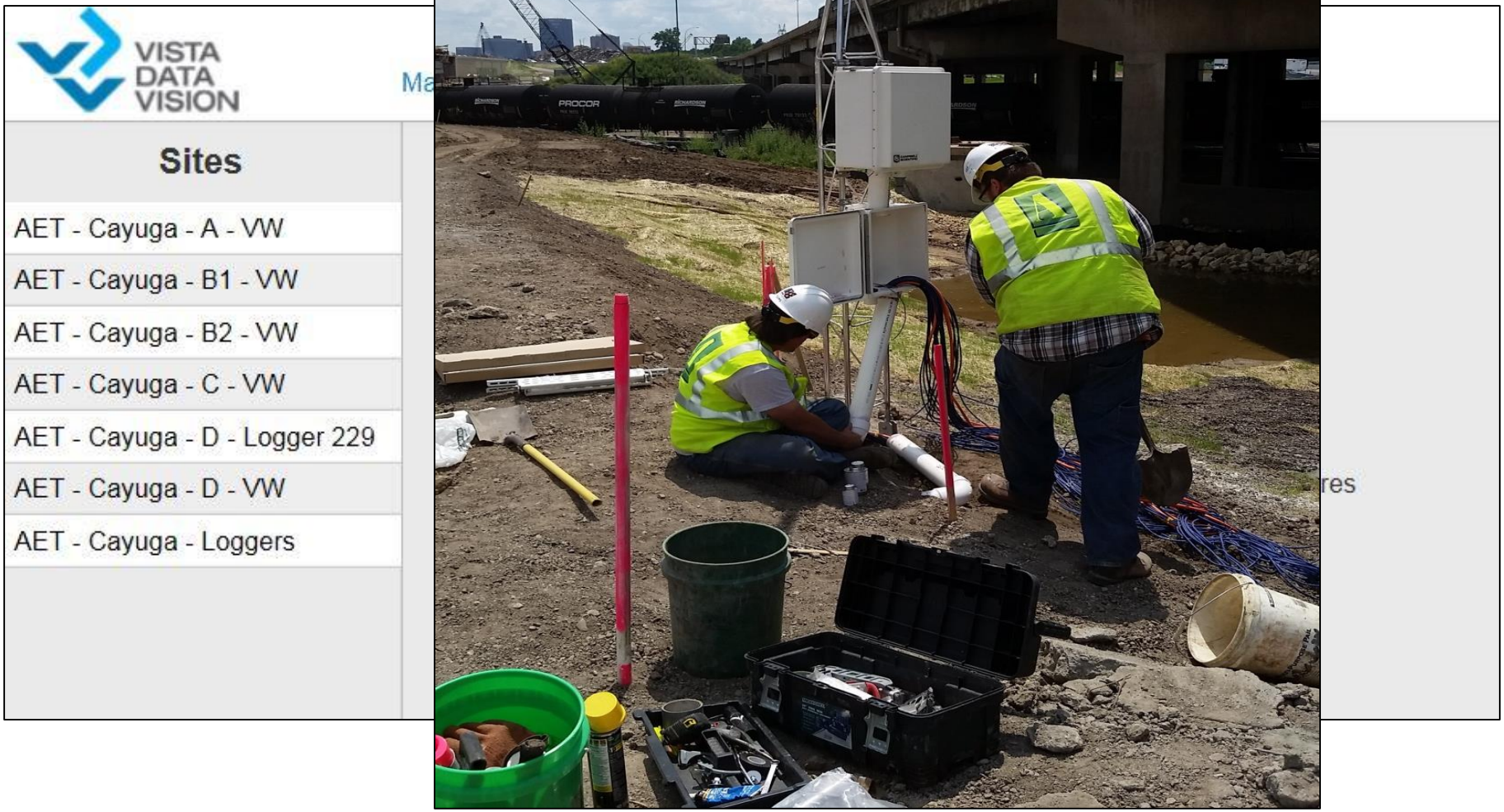
CMC Quality Control

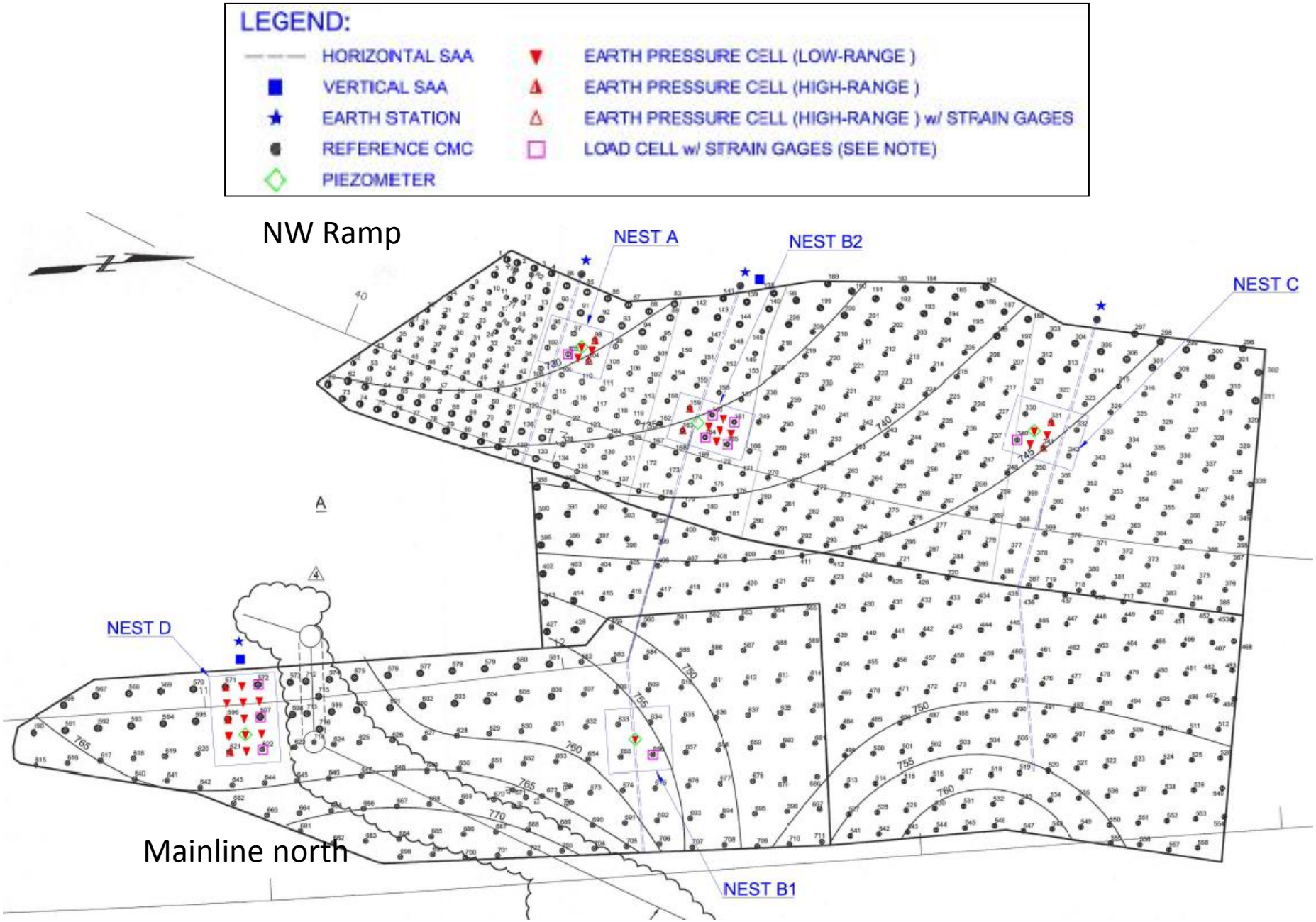


CMC Load Tests

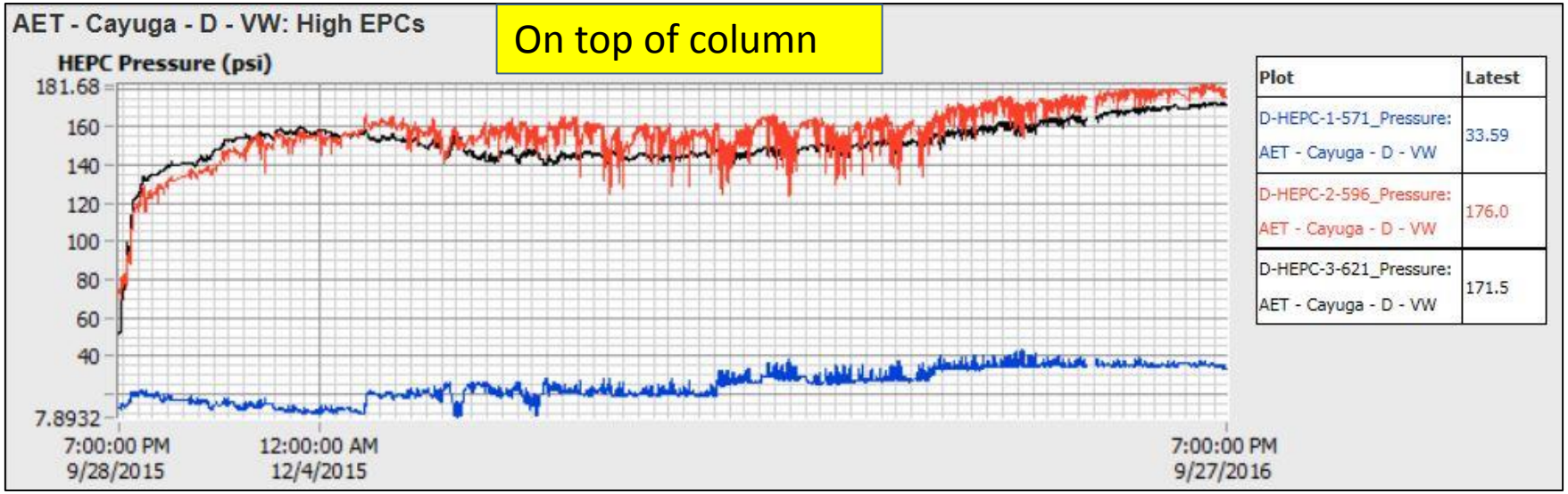
- 4 full scale load tests (sacrificial)
- ASTM D-1143 “Quick Test”
- 150% of design load
- All tests showed less than ¼ in. of deflection

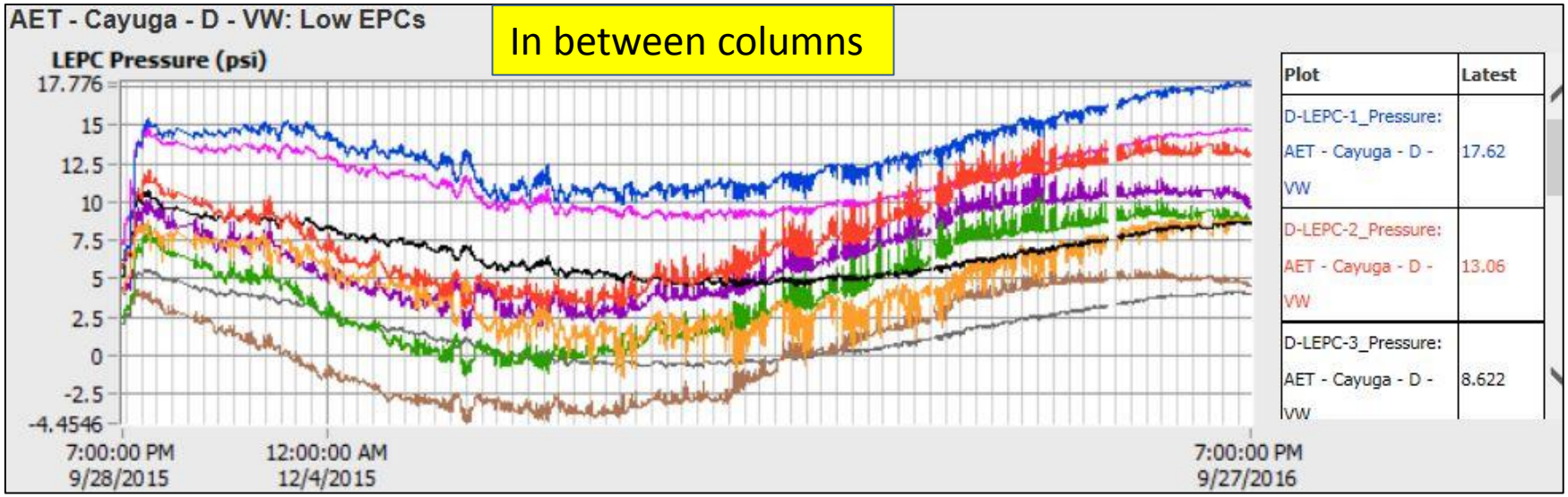
Instrumentation




LEGEND:
HORIZONTAL SAA
VERTICAL SAA
EARTH STATION
REFERENCE CMC
PIEZOMETER
EARTH PRESSURE CELL (LOW-RANGE)
EARTH PRESSURE CELL (HIGH-RANGE)
EARTH PRESSURE CELL (HIGH-RANGE) w/ STRAIN GAGES
LOAD CELL w/ STRAIN GAGES (SEE NOTE)
NW Ramp
NEST A
NEST B2
NEST C
NEST D
NEST B1
Mainline north

Earth Pressure Cells

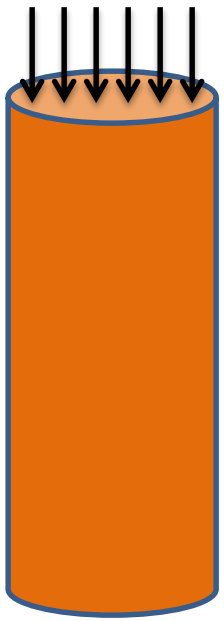




Earth Pressure Cells

FEM Model
(drained condition)

300 psi
P=58 kips

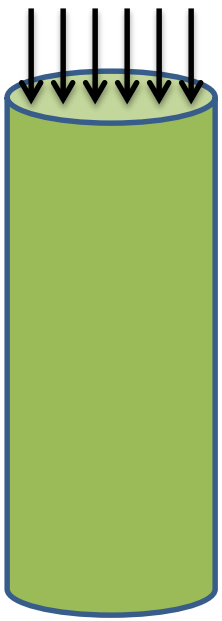


15 psi

Midway between columns

Measured
(undrained to drained with time)

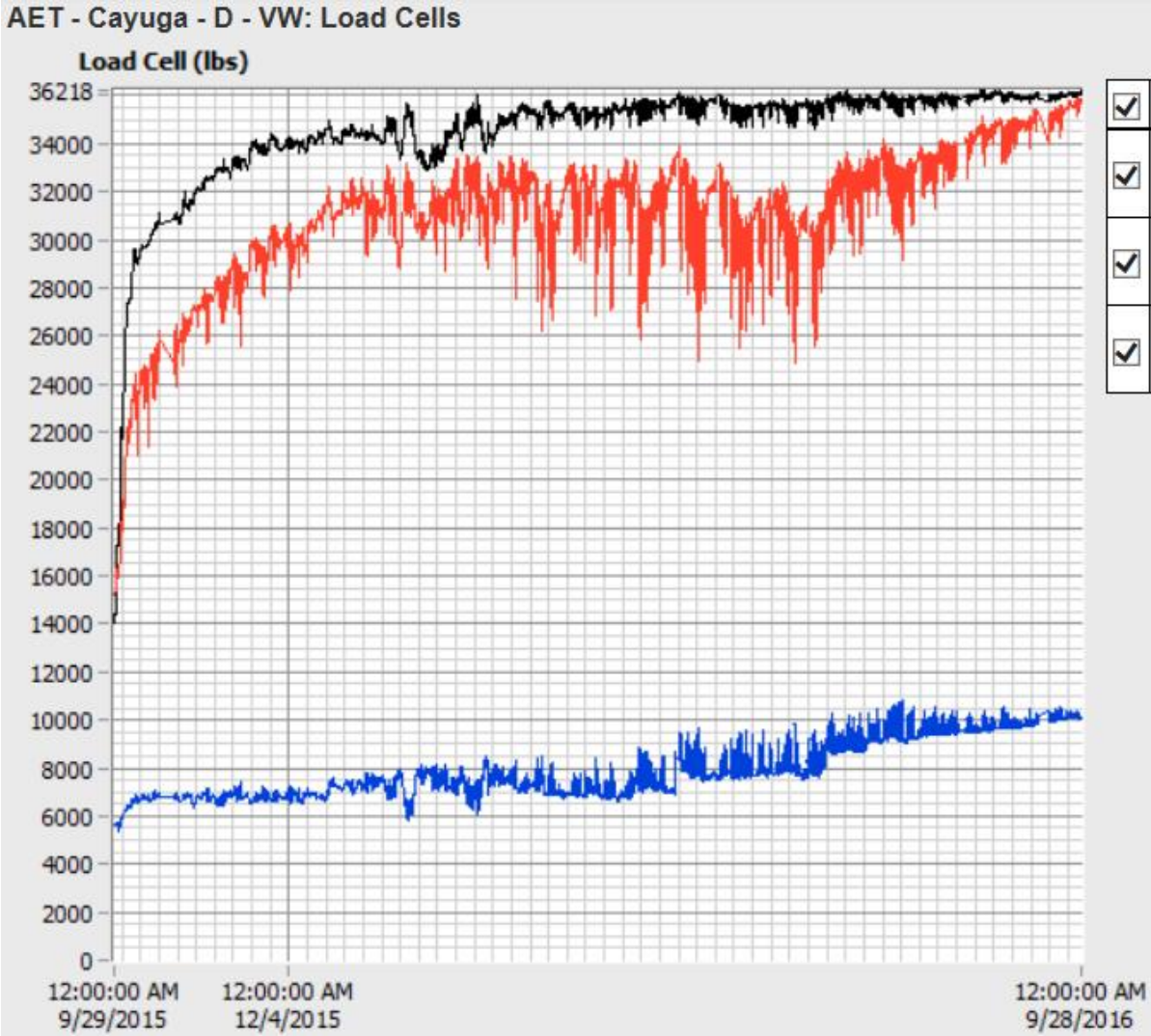
180 psi
P=36-40 kips



5-15 psi

Midway between columns

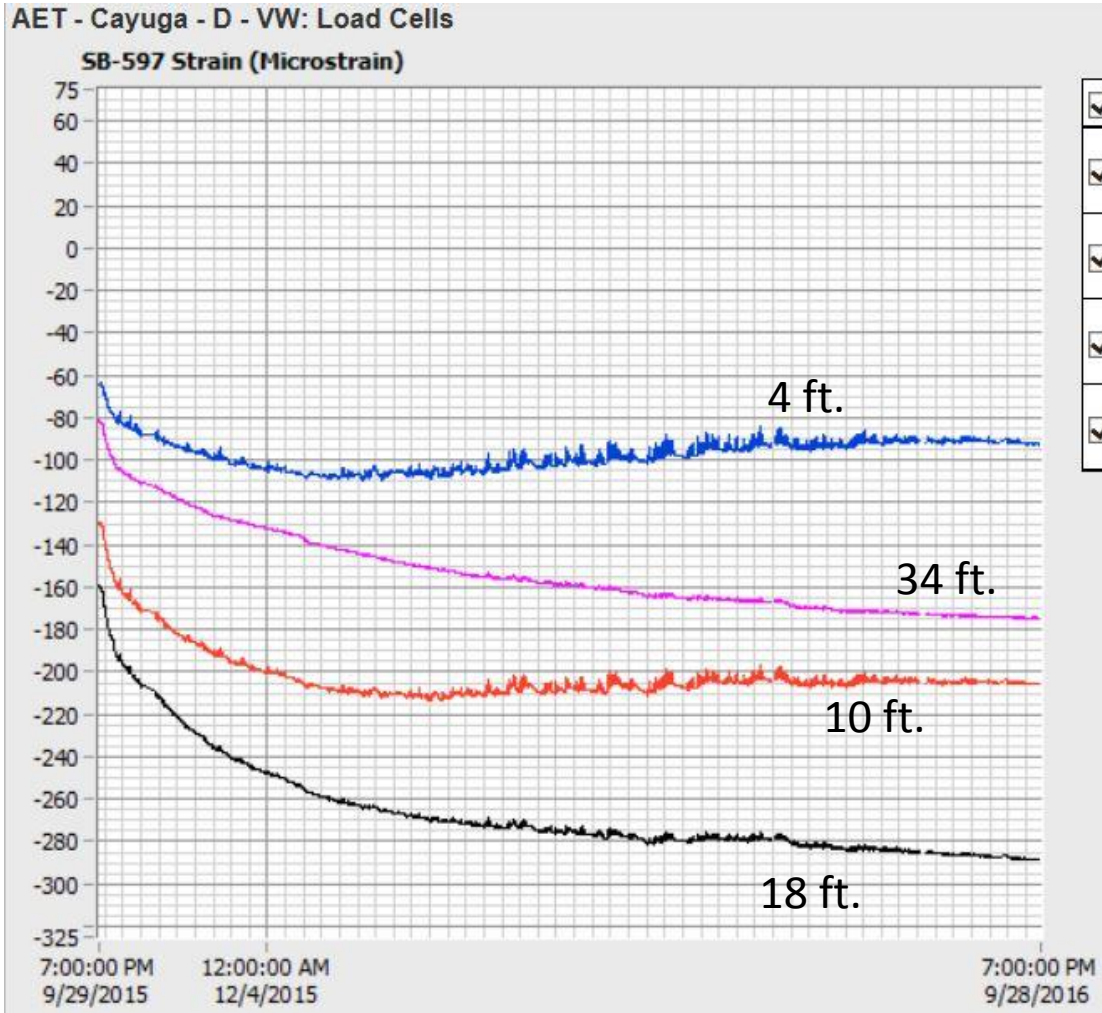
Load Cell Data



Latest Time: 11:00:00 PM 9/27/2016

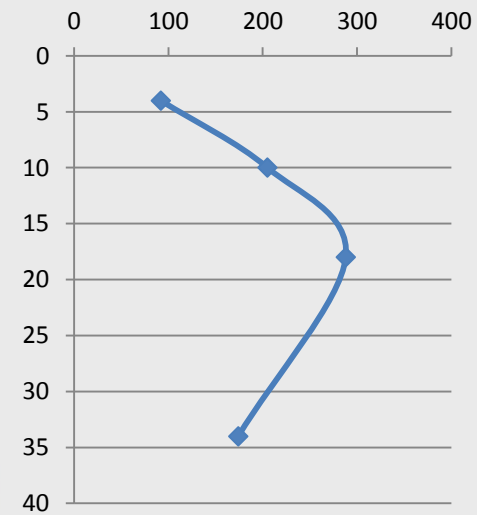
☑	Plot	Latest	Unit
☑	D-LC-1-572_Load: AET - Cayuga - D - VW	10116	Pounds
☑	D-LC-2-597_Load: AET - Cayuga - D - VW	35883	Pounds
☑	D-LC-3-622_Load: AET - Cayuga - D - VW	36198	Pounds

Strain Gages in Columns

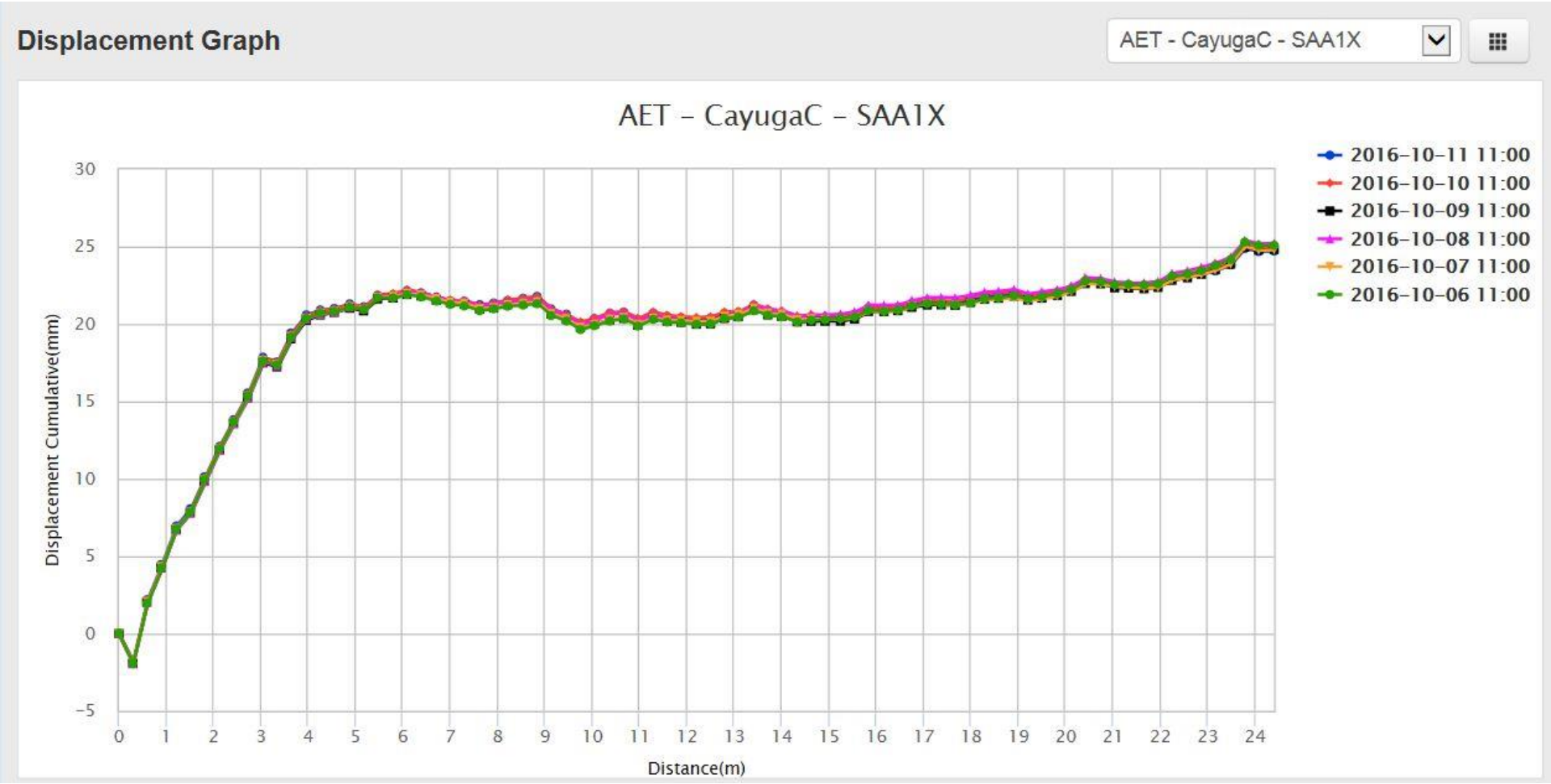


Latest Time: 11:00:00 PM 9/27/2016

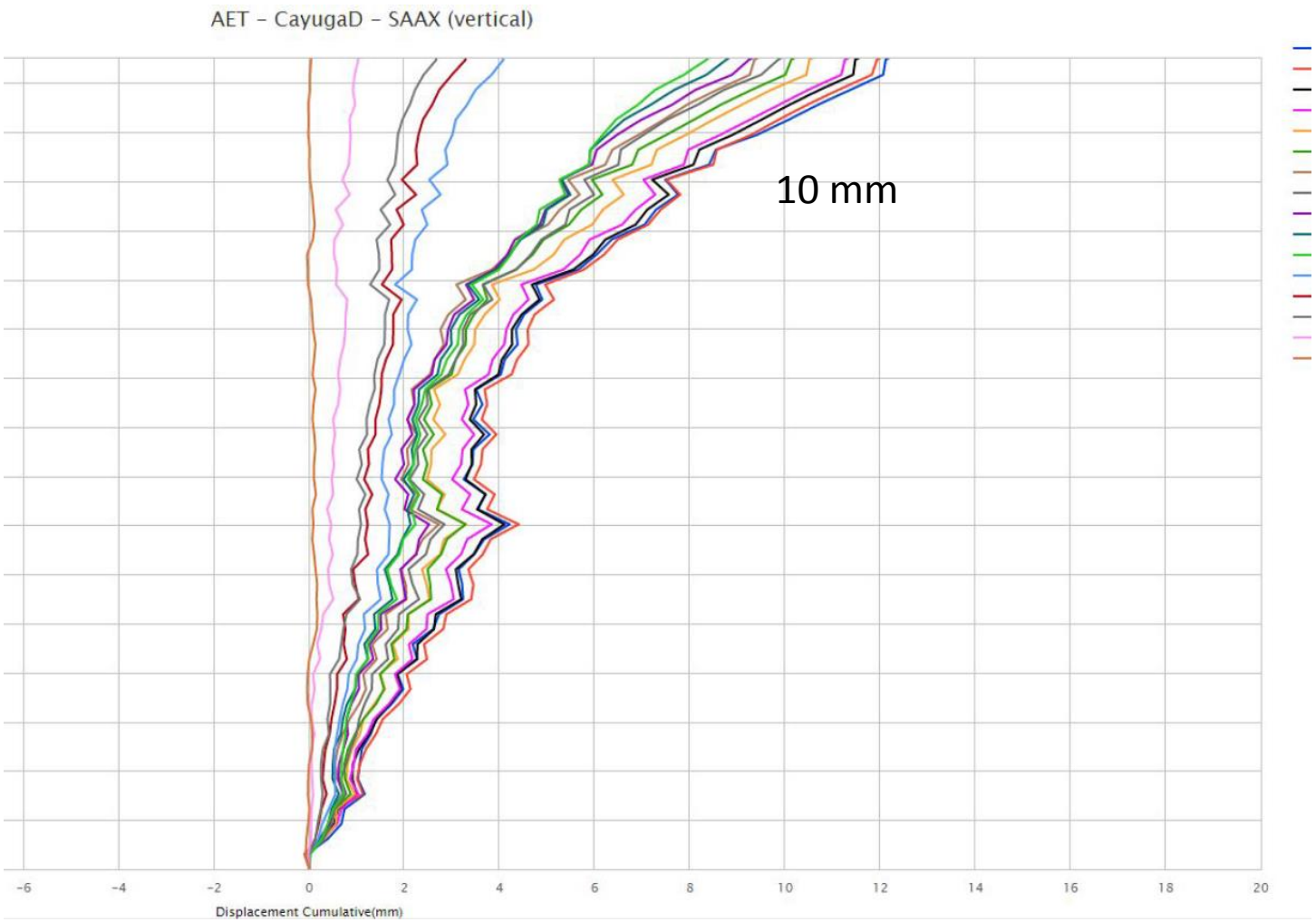
☑	Plot	Latest	Unit
☑	D-SB-1-597_Microstrain: AET - Cayuga - D - VW	-92.51	Microstrain
☑	D-SB-2-597_Microstrain: AET - Cayuga - D - VW	-205.5	Microstrain
☑	D-SB-3-597_Microstrain: AET - Cayuga - D - VW	-288.3	Microstrain
☑	D-SB-4-597_Microstrain: AET - Cayuga - D - VW	-174.5	Microstrain



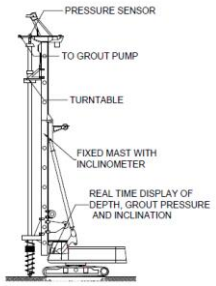
Settlement


Displacement Graph
AET - CayugaC - SAA1X
AET – CayugaC – SAA1X
2016-10-11 11:00
2016-10-10 11:00
2016-10-09 11:00
2016-10-08 11:00
2016-10-07 11:00
2016-10-06 11:00
Displacement Cumulative(mm)
30
25
20
15
10
5
0
-5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Distance(m)

Vertical SAA



Summary



- Successful construction of three CSE areas
- Over 1,600 Controlled Modulus Columns installed
- Instrumentation validated design
- Bid cost $48/sq. ft. was about 1/3 the cost of bridging poor soil areas
  - CSE total cost ~3.5 M
  - Equivalent area on bridge~9-10 M

Thank You