I35E Cayuga Interchange
Column Supported Embankments
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

- **30 ft. fill**
- **5-10 ft. Sand – urban fill**
- **55 ft. Highly Organic Silty Soils and Peat “Weight of Hammer”**
- **Sand and gravel**

- **ramp/loop**
- **Sensitive wetland**
Bridge

Sensitive wetland
Buried Organic Layers – medium fill heights

- **Sensitive wetland**
- **5-15 ft. fill**
- **5-10 ft. Sand – urban fill**
- **5-20 ft. Highly Organic Silty Soils with Peat**
- **Sand and gravel**
EPS - Geofoam

15-15 ft.
Buried Organics – Tall Fills and Walls

- Mainline 35E
- 25 ft. fill
- MSE Walls
- 20-30 ft. very loose to loose Sand
- 5-15 ft. Partially Compressed Highly Organic Silty Soils with Peat
- Medium dense to dense Sand and gravel
Column Supported Embankment (CSE)
3 CSE Areas

1. CSE Mainline South
2. CSE Mainline North
3. CSE NW Ramp
Mainline South

MSE Walls

25 ft.

12 ft.
Mainline North
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
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.)
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

<table>
<thead>
<tr>
<th>Data collected</th>
<th>Gages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strain along length of column</td>
<td>Sister bar strain gages</td>
</tr>
<tr>
<td>Ground settlement (between columns)</td>
<td>Shape-Accel-Array</td>
</tr>
<tr>
<td>Pore pressure development</td>
<td>VW Piezos</td>
</tr>
<tr>
<td>Applied pressure induced</td>
<td>Earth Pressure Cells</td>
</tr>
</tbody>
</table>
Letting Nov. 2012

• Bids for Column Supported Embankment
  – $435 / SY
  – $470 / SY
  – $660 / SY

• Subcontractor:

[menARD logo]

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

Uniform Load (building/embankment)

Load Transfer by Arching

5 to 30% of load on soil

Load Transfer by skin friction

Limited settlement

70 to 95% of load in CMC

Load Transfer by skin friction

Load Transfer by Arching

Controlled Modulus Columns

Load Transfer Platform
Value Engineering Proposal

- Redesign of Column Supported Embankments
- Menard would become Geotech Engineer of Record
- Benefits
  - More economical design
  - Additional areas covered
# VE Summary

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

VERTICAL SETTLEMENT
Total Settlement: 1.51"
Settlement at bottom of CSES: 1.0"
Settlement at top of bearing layer: 0.3"
Settlement in Compressible Soil: 0.3"

Total displacements $u_z$
Maximum value = 0.08200 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 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

Sites

AET - Cayuga - A - VW
AET - Cayuga - B1 - VW
AET - Cayuga - B2 - VW
AET - Cayuga - C - VW
AET - Cayuga - D - Logger 229
AET - Cayuga - D - VW
AET - Cayuga - Loggers
Earth Pressure Cells

On top of column

In between columns

<table>
<thead>
<tr>
<th>Plot</th>
<th>Latest</th>
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<tbody>
<tr>
<td>D-HEPC-1_571_Pressure: AET - Cayuga - D - VW</td>
<td>33.59</td>
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<tr>
<td>D-HEPC-2_596_Pressure: AET - Cayuga - D - VW</td>
<td>176.0</td>
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<tr>
<td>D-HEPC-3_621_Pressure: AET - Cayuga - D - VW</td>
<td>171.5</td>
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<td>D-LEPC-1_Pressure: AET - Cayuga - D - VW</td>
<td>17.62</td>
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<td>D-LEPC-2_Pressure: AET - Cayuga - D - VW</td>
<td>13.06</td>
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<tr>
<td>D-LEPC-3_Pressure: AET - Cayuga - D - VW</td>
<td>8.622</td>
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</tbody>
</table>
Earth Pressure Cells

**FEM Model**
(drained condition)

- 300 psi  
  \( P = 58 \text{ kips} \)

Midway between columns

**Measured**
(undrained to drained with time)

- 180 psi  
  \( P = 36-40 \text{ kips} \)

Midway between columns

- 15 psi
- 5-15 psi
Load Cell Data

AET - Cayuga - D - VW: Load Cells

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

<table>
<thead>
<tr>
<th>Plot</th>
<th>Latest Value</th>
<th>Unit</th>
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<tbody>
<tr>
<td>D-LC-1-572_Load: AET - Cayuga - D - VW</td>
<td>10116</td>
<td>Pounds</td>
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<tr>
<td>D-LC-2-597_Load: AET - Cayuga - D - VW</td>
<td>35883</td>
<td>Pounds</td>
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<tr>
<td>D-LC-3-622_Load: AET - Cayuga - D - VW</td>
<td>36198</td>
<td>Pounds</td>
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</table>

Graph showing load cell data over time, with readings in pounds.
Strain Gages in Columns

AET - Cayuga - D - VW: Load Cells

SB-597 Strain (Microstrain)

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

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<tr>
<td>D-SB-1-597_Microstrain: AET - Cayuga - D - VW</td>
<td>-92.51</td>
<td>Microstrain</td>
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<tr>
<td>D-SB-2-597_Microstrain: AET - Cayuga - D - VW</td>
<td>-205.5</td>
<td>Microstrain</td>
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<tr>
<td>D-SB-3-597_Microstrain: AET - Cayuga - D - VW</td>
<td>-288.3</td>
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<td>D-SB-4-597_Microstrain: AET - Cayuga - D - VW</td>
<td>-174.5</td>
<td>Microstrain</td>
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</tbody>
</table>

Graph showing strain measurements at different heights:
- 4 ft.
- 10 ft.
- 18 ft.
- 34 ft.

Dates:
- 9/28/2016
- 12/4/2015
- 9/29/2015
- 7:00:00 PM
- 12:00:00 AM
Settlement
Vertical SAA

AET – CayugaD – SAAX (vertical)

10 mm
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

They thought it was a camera