Construction and Long-Term Performance of Innovative Geotechnologies

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Approx. 100,000 cubic meters of geofoam was placed.
I-15 Reconstruction - Quick Facts

- Single Largest Design-Build Highway Contract in U.S.
- 17 Miles of Urban Interstate
- $1.5 Billion (Project Cost)
- Wasatch Constructors (Prime Contractor)
- 4 Year Construction Duration (1997 - 2001)
- 144 Bridges/Overpass Structures
- 160 Retaining Walls (mostly MSE Walls)
- $350 K Embankment Study
Geotechnical Issues

• Large Primary Consolidation Settlement (1 to 1.5 m)
• Time Rate of Consolidation (2 years to end of primary)
• Creep Settlement (Bump at Bridge)
• Foundation Stability (Large Embankments on Soft Soils)
• Schedule Constraints (two 2-year projects)
• Maintenance of Traffic (Had to be maintained)
• New Technologies and Development of Specifications
Subsurface Profile in Salt Lake Valley

Upper Bonneville Clay

Interbeds

Lower Bonneville Clay
Settlement of Soft Clays in Salt Lake Valley

Approximate 2 years of primary settlement
I-15 Embankment Construction
2-stage MSE wall with surcharge
Prefabricated Vertical Drains

PV Drain Spacing 1.5 to 2.5 m triangular spacing

Placement of anchor bar

PV drain pushed into ground
2-Stage MSE Walls

Right-of-way constraints required many slopes to be built vertically.

Beginning of 2-stage MSE Wall
2-Stage MSE Wall Connections

Attachment of Panels with threaded rod

Female threaded rod coupler

Concrete Fascia Panel
## 2-Stage MSE Wall with Prefabricated Vertical Drains

### Cost and Schedule Comparison

<table>
<thead>
<tr>
<th>Two-Stage MSE Wall</th>
<th>Description</th>
<th>Total Cost</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Embankment Removal ($6/m^3)</td>
<td>$9,500</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Bedding Sand ($7/ton, 1 crew 2 days)</td>
<td>$2,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PV Drain Installation (1.5 m triangular spacing)</td>
<td>$14,000</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>($1.5/m without pre-drilling, $3/m with pre-drilling)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wall/Embankment Construction and Settlement Time</td>
<td>$54,000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>($300/m^2 wall face, $9/m^3 embankment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3-stage Embankment Construction, Surcharging, Settlement Time, and Removal</td>
<td>$20,000</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>(Placement - $9/m^3, Removal - $6/m^3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total =</strong></td>
<td><strong>$100,000</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>

Total cost is for 10 m length of embankment.
I-15 Embankment Construction
1-stage MSE wall with lime cement columns
Lime Cement Stabilized Soil

Lime Cement Column Rig

Auger / Mixer for Lime and Cement

125 kg/m$^3$ 15% lime 85% cement

$M = 30$ Mpa (design); $Su$ 300 to 400 kPa
Lime Cement Column Installation Pattern
1-Stage MSE Wall Construction

1-stage MSE placed over columns

Finished MSE wall
1-Stage MSE Wall with Lime Cement Stabilized Soil Cost and Schedule Comparison

<table>
<thead>
<tr>
<th>Geotechnology</th>
<th>Various Construction Activities (With Typical Unit Cost)</th>
<th>Associated Costs (Year 2000)</th>
<th>Time (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime Cement Columns</td>
<td>Existing Embankment Removal ($6/m³)</td>
<td>$9,500</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Lime Cement Column Installation (0.8 m column - $17.5/m, 0.6 m column - $16/m)</td>
<td>$97,000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>One-Stage MSE Wall/Embankment Construction ($200/m² wall face)</td>
<td>$43,500</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1-stage Embankment Construction, Surcharging, Settlement, and Removal (Placement - $9/m³, Removal $6/m³)</td>
<td>$10,000</td>
<td>8.75</td>
</tr>
<tr>
<td></td>
<td>Total =</td>
<td>$160,000</td>
<td>12</td>
</tr>
</tbody>
</table>

Total cost is for 10 m length of embankment
I-15 Reconstruction
Geofoam Embankment
### I-15 Reconstruction Geofoam Properties

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>ASTM Test Procedure</th>
<th>Type VIII Accepted Value</th>
<th>Type II Accepted Value</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>D1622</td>
<td>18 kg/m³</td>
<td>22 kg/m³</td>
<td>± 10 %</td>
</tr>
<tr>
<td>Compressive Resistance</td>
<td>D1621</td>
<td>90 kN/m²</td>
<td>104 kN/m²</td>
<td>minimum @ yield or 10 percent axial deformation</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>C203</td>
<td>208 kN/m²</td>
<td>276 kN/m²</td>
<td>Minimum</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>C272</td>
<td>3</td>
<td>3</td>
<td>&lt; % by volume</td>
</tr>
</tbody>
</table>

Table 2. Properties of Type VIII Geofoam Specified for the Reconstruction I-15 Project.

* I-15 used 1.25 pcf density exclusively (i.e., type VIII geofoam)
Geofoam (I-80 State Street to 200 West St.)
Geofoam Embankment Construction

Base Sand

Footing for Panel Wall and Block Placement
Geofoam Embankment Construction

Geofoam cut and placed around piling at bridge abutment

Nearly Completed Geofoam Embankment with Vertical Face

Transition Zone with MSE Wall
Geofoam Embankment Construction

Reinforced Concrete
Load Distribution Slab

Completed Load Distribution Slab
Geofoam Embankment with Tilt-up Panel Wall
Cost and Schedule Comparison

<table>
<thead>
<tr>
<th>Geofoam</th>
<th></th>
<th>0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Embankment Removal ($6/m^3)</td>
<td>$1,500</td>
<td></td>
</tr>
<tr>
<td>Bedding Sand ($7/ton, with 1 crew 1 week)</td>
<td>$5,500</td>
<td></td>
</tr>
<tr>
<td>Geofoam Embankment ($45/m^3)</td>
<td>$65,000</td>
<td>2</td>
</tr>
<tr>
<td>Tilt-up Panel Wall ($200/m^2 wall face)</td>
<td>$20,000</td>
<td>0.75</td>
</tr>
<tr>
<td>Load Distribution Slab ($60/m^2 surface area)</td>
<td>$23,000</td>
<td>0.5</td>
</tr>
<tr>
<td>Embankment Above Geofoam ($9/m^3)</td>
<td>$5,000</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Total =</strong></td>
<td><strong>$120,000</strong></td>
<td><strong>4</strong></td>
</tr>
</tbody>
</table>

Total cost is for 10 m length of embankment
Final Cost and Schedule Comparison

Cost represents total construction costs for each system for a 10-m long reach of interstate. Construction time is typical for embankments built on the I-15 Reconstruction Project.
Performance Monitoring
Objectives of Geofoam Arrays

• Measure Creep Settlement of Geofoam Mass (10 yr.)
• Measure the Pressure Distribution within Geofoam
• Measure Differential Settlement in Transition Zones
• Measure Lateral Earth Pressure at Abutments
• Monitor for Differential Icing at Geofoam / Embankment Transition Zones
• Model Stress / Strain Behavior
Typical Geofoam Array

ROW OF SURVEY POINTS AT FACE OF WALL
25 MM - PVC STAND PIPE
ROW OF SURVEY POINTS ALONG INSIDE EDGE OF MOMENT SLAB
ROW OF SURVEY POINTS ALONG OUTSIDE EDGE OF EMERGENCY LANE

CONCRETE PAVEMENT
ROAD BASE
LOAD DISTRIBUTION SLAB

LEVEL 7.5
LEVEL 6
LEVEL 4
LEVEL 2
LEVEL 0

SQUARE PLATE WITH MAGNET RING
GEOFOAM BLOCKS
GRANULAR BACKFILL

VIBRATING WIRE TOTAL PRESSURE CELL
BEDDING SAND

6.5 TO 7.3 m
HEIGHT VARIES

6.5 TO 7.3 m
HEIGHT VARIES

LEVEL 4
LEVEL 2
LEVEL 0

LEVEL 4
LEVEL 2
LEVEL 0

2.5 m
3300 South Geofoam Array Installation

Magnet Extensometer and Pressure Cell Installation

Hotwire Cut for Pressure Cell

Pressure Cell Cast in Bridge Abutment

Pressure Cell in Base Sand
3300 South Array Settlement Data

Settlement (mm)

Approx. 1% Construction Strain
3300 South Geofoam Array
Damage to Connections During Construction
Loading

Damaged Connection

- Approximately 1% loading strain can be expected.
- Strain due to seating of untrimmed block and elastic compression.
- Damaged connection was later repaired by dowels.
- Rigid connect should be avoided.
Settlement at Toe of Wall

Graph showing settlement over time with various stages including Geofoam Embankment Placement, Pavement Placement, Toe Berm Placement, and Post-Construction.
Geofoam Transition Zones
Post-Construction Settlement

Transition slope
3.5 H : 1 V

Transition zone

Baseline survey completed on 11/10/99.
Settlement Monitoring 100 South Street

1% construction strain projected 0.5 % additional 50 yrs.
Pressure Cell Measurements in Geofoam

Pressure Versus Time
3300 South Street Geofoam Array

Pressure (kPa) vs. Date

- Sta. 25+315, Level 0
- Sta. 25+347, Level 0
- Sta. 25+315, Level 6
- Sta. 25+347, Level 5
- Sta. 25+315, Level 9
- Sta. 25+347, Level 8
Geofoam Performance Summary

1. Geofoam fills are performing as expected

2. Approximately 1 percent vertical strain occurred during construction.
   a. Strain due to seating and compression of geofoam.
   b. This strain can damage rigid connections.

3. Approximately 0.3 percent creep strain (15 mm) has occurred in the geofoam for an 8-year post construction period. This is acceptable and within the expected performance.

4. The vertical stress distribution that develops in a geofoam wedge fill is complex, but generally diminishes with depth.

5. Pressure cell measurements suggest that approximately 45 kPa of vertical stress has developed in the center of the geofoam mass. This is approximately 50 percent of the compressive strength of the geofoam.
Settlement Comparison
I-15 Geotechnologies

- 900 W. St. Embankment
- 400 S. St. Embankment
- 2400 S. St. Embankment
- 200 S. St. MSE Wall w/ PV Drains
- LCC 13.5 m Within
- LCC Wall Face
- 3300 S. St. Geofoam Fill w/ Toe Berm
- 3300 S. St. Geofoam Fill w/out Toe Berm

Settlement (mm)

Elapsed Time (days) from Beginning of Fill Placement
Settlement Conclusions
I-15 Geotechnologies

• Geofoam has met the 75 mm (3 inch) in 10-yr settlement goal in all cases.

• LCC Treated soil has met the 75 mm in 10-yr settlement goal.

• 2-Stage MSE Walls have not met the 75 mm in 10-yr settlement goal for the MSE wall and embankments monitored. The expected range of settlement for these system is 100 (4 in) to 150 mm (6 in) for a 10-year post construction period.
Principal Investigators

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