I-15 Reconstruction Project: Innovative Foundation and Embankment Construction

Steven F. Bartlett, Ph.D., P.E.
Assistant Professor
University of Utah
I-15 Reconstruction – Project Extents

Beg. Project 10600 S.

End Project 600 N.
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)
  - Kiewit, Granite, Washington Construction
- 4 Year Construction Duration (1997 - 2001)
- 144 Bridges/Overpass Structures
- 160 Retaining Walls (mostly MSE Walls)
- Approximate $6 M Research Program (4 years)
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
Selected Topics

PV Drains

Surcharing

Geotextile Reinforced Slopes
Selected Topics (cont.)

2-Stage MSE Walls

Geofoam – Light Weight Fill

Lime Cement Columns
# Quantity and Cost Summary

<table>
<thead>
<tr>
<th>Embankment or Treatment Type</th>
<th>Approximate Quantity</th>
<th>Average In Place Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthen Embankment</td>
<td>5,000,000 m³</td>
<td>$9 / m³</td>
</tr>
<tr>
<td>Pre-fabricated Vertical Drains</td>
<td>7,400,000 m</td>
<td>$1.50 / m (without pre-drilling)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$3.00 / m (with pre-drilling)</td>
</tr>
<tr>
<td>High Strength Geotextile</td>
<td>670,000 m²</td>
<td>$12 / m²</td>
</tr>
<tr>
<td>Geofoam Embankment (Type VIII)</td>
<td>107,000 m³</td>
<td>$60 / m³ (without wall)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$70 / m³ (with wall)</td>
</tr>
<tr>
<td>Surcharge Fill Removal</td>
<td>500,000 m³</td>
<td>$6 / m³</td>
</tr>
<tr>
<td>Slag Light Weight Aggregate</td>
<td>141,000 m³</td>
<td>$18 / m³</td>
</tr>
<tr>
<td>Scoria Light Weight Aggregate</td>
<td>50,000 m³</td>
<td>$31 m³</td>
</tr>
<tr>
<td>Lime Cement Column Treatment</td>
<td>68,000 m</td>
<td>$16 / m (0.6 m diameter)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$18 / m (0.8 m diameter)</td>
</tr>
<tr>
<td>Mechanically Stabilized Earth (MSE) Walls</td>
<td>160 walls</td>
<td>$200 / m² face of wall (one-stage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$300 / m² face of wall (two-stage)</td>
</tr>
</tbody>
</table>

Table 1. Foundation treatments and embankment used on the I-15 Reconstruction Project with approximate quantities and unit costs (adapted from Saye et al., 2001).
Settlement of Soft Clays in Salt Lake Valley

Approximate 2 years of primary settlement
Consolidation Properties

Preconsolidation Stress (kPa) vs. Depth (m)

Compression Ratio vs. Depth (m)

In situ Vertical Effective Stress

Depth (m)
Typical I-15 Embankment Construction

- Temporary Wire Wall
- Surcharge
- Geotextile
- New embankment
- Existing embankment
- Alluvium
- Prefabricated Vertical Drains
- Lake Bonneville Silts and Clays
- Pleistocene Sands and Gravels
Prefabricated Vertical Drains

PV Drain Spacing 1.5 to 2.5 m triangular spacing

Placement of anchor bar

PV drain pushed into ground

Installed drain
PVD Installation Issues

1. Consolidation times need to be reduced to 3 to 6 months to accommodate schedule.

2. Large, atypical mandrels and anchor plates may cause excessive disturbance and reduce time rate of consolidation.

3. PV drains spaced too closely together may cause disturbance and reduce time rate of consolidation.

4. PV drain contractor may not be able to push drains through existing embankment.

Mandrel used on the I-15 Project
Rate of Consolidation Vs. Drain Spacing

\[ \frac{c_{ve}}{L_a c_v} \text{ Based on I-15 Disturbance} \]
\[ \text{Lab } c_v = 0.081 \text{ m}^2/\text{day} \]

- \( \Delta \) Calculated Behavior with Disturbance Effects
- \( \Theta \) 'Undisturbed' Behavior: \( c_v(\theta) = 0.036 \text{ m}^2/\text{day} \)

- \( t_{95} \) (days)
- Triangular Drain Spacing (m)
Pre-drilling of PV Drains Required through Existing Embankment

Cost:

$1.50/m (without predrilling)

$3.00/m (with predrilling)

Approximate 3 drill rigs req’d for one PV drain rig
PV Drain Summary

1. PVDs reduced settlement to 3 to 6 months and were the key component to I-15 success.

2. PVDs performed as expected.

3. Size and geometry of installation mandrel and anchor plate should be controlled by specification.

4. PVDs should not be spaced closer than 1.5 m triangular spacing for Lake Bonneville Deposits.

5. Predrilling was required for installation through large (8 m high) preexisting embankments.
Surcharging to Reduce Settlement

5 million cubic meters of embankment placed on project

Model for Secondary Consolidation

Rate of Secondary Settlement w/ Surcharge
Rate of Secondary Settlement w/o Surcharge

3 inches in 10 years

Log Time (years)
Surcharging to Reduce Settlement

Amount of Surcharge

\[ \frac{C_{\alpha}}{C_{\alpha, \text{N.C.}}} = 1.847 \cdot 1.083 \log(\text{AAOS} \%, \text{R}^2 = 0.823, \text{SD} = 0.119) \]
Surcharging Summary

1. Design goal was to reduce secondary settlement to 3 inches or less in 10 years.

2. Post construction monitoring has shown that surcharging has been successful in achieving this goal.

3. Surcharges of 30 to 40 percent of the final embankment height were used.

4. Large surcharged fills introduced stability concerns in some locations.

5. Surcharge were to remain in place until 98 percent EOP consolidation was reached.
Geotextile Installation in Reinforced Slopes

Geotextile placement on sloped, pre-existing embankment

Geotextile lapped into MSE wall
Stability Criteria for Reinforced Slopes

<table>
<thead>
<tr>
<th>Stability Parameter</th>
<th>Threshold Level 1</th>
<th>Threshold Level 2</th>
<th>Threshold Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Displacement Rate (mm/day)</td>
<td>3.8 - 7.6</td>
<td>7.6 - 25.0</td>
<td>&gt; 25.0</td>
</tr>
<tr>
<td>Displacement Ratio (DR)</td>
<td>0.2 - 0.3</td>
<td>0.3 – 0.4</td>
<td>&gt; 0.4</td>
</tr>
<tr>
<td>Piezometric Head Increase</td>
<td>--------</td>
<td>&gt; 200% of Load due to Fill Placement</td>
<td>same as threshold 2</td>
</tr>
<tr>
<td>Response Action</td>
<td>• Notify Field Construction Manager of threshold 1 • Increase Monitoring Frequency</td>
<td>• Stop Fill Placement • Prepare Specific Action Plan • Implement Plan if Conditions Worsen</td>
<td>• Buttress Slope and Remove Fill • Notify Senior Project Management • Notify UDOT</td>
</tr>
</tbody>
</table>
Stability Criteria - Displacement Ratio

DR = horz. Displacement / vert. settlement

Horz. displacement from Vertical inclinometers

Vert. Settlement from Settlement plates
Stability Summary

1. Large embankments with surcharge introduced foundation stability issues at many bridge crossings.

2. No embankment failures occurred on the project.

3. High strength geotextile (max. 3 layers) was used to achieve global stability with a FS of 1.3.

4. Staged construction was used in many locales to reduce geotextile requirements.

5. Vertical inclinometers and settlement plates were used to monitor stability.

6. Stability criteria based on the displacement ratio (DR) proved to be the most useful means of monitoring embankment stability.
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
MSE Wall Settlement and Deformation Issues

Settlement Impacts to Adjacent Structures

Deformation of Welded Wire Face at Toe of Wall
3500 South MSE Wall Array

Instrumented Reinforcing Elements

Survey Points

Embankment Fill

Reference Bench Mark

Magnet-Reed Extensometer

Horizontal Inclinometers

Vertical Inclinometers
Objectives of MSE Wall Arrays

1. Monitor Stress and Strains within Wall and Foundation

2. Determine Settlement Distribution Away from Wall

3. Monitor Transitions Zones

4. Deformation Modeling

UTAH STATE AGGIES
Strain Gauges on Welded-Wire Reinforcing

Horizontal reinforcing (bar mat) with strain gages.

Strain gage wiring at face of MSE wall
3500 South MSE Wall Array

Inclinometer and Sondex Locations

Reading of Sondex Extensometer
3500 S. MSE Wall Deformations

a) Undeformed Wall

\[ \Delta \theta = 0.2 \text{ degrees} \]

\[ \Delta V = 20 \text{ inches} \]

b) Exaggerated Deformed Wall

\[ \Delta H = 3.5 \text{ inches} \]
MSE Wall Summary

1. Large primary consolidation settlement req’d use of two stage MSE wall with flexible wire face.

2. Flexible faces can deform during construction and post-construction.

3. Increasing the horizontal reinforcement in the bottom half of the wall can reduce the deformation, but not completely eliminate it (horizontal buldge reduce by a factor of 2.)

4. Material type, compaction and construction procedures can also help in reducing face deformation.

5. Specifications should be written to control allowable face deformation.

6. Zone of settlement influence is 1.5 times wall height.
Geofoam Embankment For Settlement Reduction

Geofoam Embankment from State St. to 200 W. Along Interstate I-80, Salt Lake City, Utah
Geofoam Placement Areas

100,000 cubic meters of Geofoam
Geofoam Cross Section (Typical)

- 35 cm Concrete Pavement
- 15 cm Reinforced Concrete Load Distribution Slab
- 60 cm Base Material
- Sloped Embankment (1.5 H to 1 V max.)
- Bedding Sand (20 cm min.)
- Geofoam Block
- Wall Footing
- Tilt-up Concrete Fascia Panel Wall
## 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 Embankment

Construction of Geofoam Embankment and Footing for Tilt-up Panel Wall

Leveling Course of Sand for Geofoam Embankment
Geofoam Embankment

Geofoam cut and placed around piling at bridge abutment

Nearly Completed Geofoam Embankment with Vertical Face

Transition Zone with MSE Wall
Load Distribution Slab Atop Geofoam

Reinforced Concrete Load Distribution Slab atop Geofoam

Completed Load Distribution Slab
Geofoam (Finished Cross Section)
Geofoam for Rapid Construction
Comparison of Construction Times

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Geofoam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Construction</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Settlement</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Finish Work</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>
Geofoam wall system (total cost) is about $\frac{3}{4}$ times more expensive than conventional 2-Stage MSE wall with PV drains.
3300 South 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 LAN**
- **CONCRETE PAVEMENT**
- **ROAD BASE**
- **LOAD DISTRIBUTION SLAB**
- **SQUARE PLATE WITH MAGNET RING**
- **GEOFOAM BLOCKS**
- **GRANULAR BACKFILL**
- **VIBRATING WIRE TOTAL PRESSURE CELL**
- **BEDDING SAND**

**Levels:**
- **LEVEL 0**
- **LEVEL 2**
- **LEVEL 4**
- **LEVEL 6**

**Height:**
- **6.5 TO 7.3 m**
- **HEIGHT VARIES**

**Dimensions:**
- **2.5 m**
- **6.5 TO 7.3 m**
Objectives of Geofoam Arrays

• Measure Creep Settlement of Geofoam Mass (10 yr.)
• Measure the Pressure Distribution within Mass
• 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
3300 South Geofoam Array Installation

Magnet Extensometer and Pressure Cell Installation

Pressure Cell Cast in Bridge Abutment

Pressure Cell in Base Sand

First Method of Placing Pressure Cell
Improved Method of Placing Pressure Cell

Hot Wire Cut

Pressure Cell Placed in Cut
3300 South Magnet Extensometer Data

Date

Settlement (mm)

Construction Completed (7/28/99)

1% Construction Strain

- Level 0
- Level 2
- Level 4
- Level 6
- Level 8
- Level 9
- Load Distribution Slab placed
- Load Distribution Slab Curb placed
- Granular Borrow
- Grass-Covered Base
100 South Magnet Extensometer Data Post-Construction Settlement

Figure 37 – Projected settlement trend for I-15 geofoam at 100 South.

1% construction strain

2% total in 50 yrs.
3300 South Geofoam Array
Damage to Connections During Construction Loading

- 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 connection should be avoided.
Geofoam Transition Zones
Post-Construction Settlement

Transition slope
3.5 H : 1 V

Baseline survey completed on 11/10/99.
Geofoam Pressure Cell Measurements

Pressure Versus Time
3300 South Street Geofoam Array

Date

0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0
Pressure (kPa)

1/20/99 3/21/99 5/20/99 7/19/99 9/17/99 11/16/99 1/15/00 3/15/00 5/14/00 7/13/00 9/11/00 11/10/00 1/9/01 3/10/01 5/9/01 7/8/01 9/6/01 11/5/01

Sta. 25+315, Level 0
Sta. 25+347, Level 0
Sta. 25+315, Level 6
Sta. 25+315, Level 9
Sta. 25+347, Level 5
Sta. 25+347, Level 8

Sta. 25+347, Level 8
Sta. 25+347, Level 5
Sta. 25+315, Level 9
Sta. 25+315, Level 6
Sta. 25+347, Level 0
Sta. 25+315, Level 0

LEVEL 0
LEVEL 2
LEVEL 4
LEVEL 6
Geofoam Conclusions

1. Geofoam fills are performing as expected with no major issues.
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 0.2 percent creep strain (15 mm) has occurred in a 2-year post construction period.
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.
6. Creep strain will be relatively small for dead loads that are less than 50 percent of the compressive strength.

7. Creep strain in a 10 year post-construction period is expected to be 0.25 to 0.3 percent (18 to 21 mm).

8. Transition zones with the MSE wall need to be designed carefully to minimize differential settlement in the transition zone.
Lime Cement Column Rig

Auger / Mixer for Lime and Cement

Lime Cement Stabilized Soil

125 kg/m³ 15% lime 85% cement

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

1-stage MSE placed over columns

Finished MSE wall
Lime Cement Column Array
Objectives of Lime Cement Column Array

1. Determine the Primary Consolidation
2. Measure the Primary Settlement in the Treated Area and at adjacent structure
3. Measure the Secondary Settlement over 10 yr. Period
4. Determine the Modulus of Treated Area versus Untreated Ground
5. Measure the Shear Strength of the Treated Ground
6. Model the Construction and Long-Term Deformation Behavior
Pressure and Settlement Cells at Lime Cement Column Array

Pressure and Settlement Cells Atop Column
Horizontal Inclinometers
Borehole Magnetic Extensometer
Fill Height vs. Load on Lime Cement Columns

Stress ratio = 10:1
Inclinometer Measurements at LCC Array

Wall face
Ground Settlements at LCC Array

(July 98 to November 01)
Magnetic Extensometer Measurement

23 cm of settlement at magnet extensometer location w/ 12 cm of settlement below column installation depth
Horizontal Displacements from Vertical Inclinometer

Max. = 4 cm
LCC Construction Performance

1. Primary Consolidation Settlement was reduced from about 1.0m to 0.2 m at LCC array.

2. Construction Settlement of about 18 cm occurred at MSE wall face.

3. Construction Settlement of about 3 to 4 cm occurred at nearby bldg.

4. Lateral Displacement of about 4 cm occurred at wall face.

5. Column is carrying about 10 times the stress as the adjacent untreated ground.

6. Installation rates and cost became an issue with Wasatch Constructors and this technology was only used at one location.
## Long-Term Array Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-80 @ 300 W.</td>
<td>MSE Wall on Lime Cement Columns</td>
</tr>
<tr>
<td>I-15 @ 3300 S.</td>
<td>Geofoam Wall (Creep &amp; Load)</td>
</tr>
<tr>
<td>I-15 @ 3500 S.</td>
<td>MSE Wall (Deformation &amp; Settlement)</td>
</tr>
<tr>
<td>I-15 @ 200 S.</td>
<td>MSE Wall (Settlement)</td>
</tr>
<tr>
<td>I-15 @ S. Univ.</td>
<td>Embankment (Settlement)</td>
</tr>
<tr>
<td>I-80 @ W. Temple</td>
<td>MSE Wall (Lt. Weight Backfill)</td>
</tr>
<tr>
<td>I-15 @ 800 S.</td>
<td>Geofoam (Lateral Earth Pressure)</td>
</tr>
<tr>
<td>I-15 @ 100 S.</td>
<td>Geofoam (Differential Icing)</td>
</tr>
<tr>
<td>I-15 @ 2100 S.</td>
<td>Embankment (Settlement)</td>
</tr>
<tr>
<td>I-15 @ 400 S.</td>
<td>Embankment (Settlement)</td>
</tr>
</tbody>
</table>
Questions

UTAH STATE AGGIES

UTAH UTES

Bartlett@civil.utah.edu

SYRACUSE ORANGEMEN