Long-Term Settlement Performance Monitoring, I-15 Reconstruction Project, Salt Lake City, UT

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Roadway Widening (I-15 Project)

Salt Lake City, Utah, USA
2002 Host of Winter Olympics
I-15 Reconstruction - Quick Facts

• Single Largest Design-Build Highway Contract in U.S.
  • Kiewit (Prime Contractor)
  • Woodward Clyde Consultants (Geotechnical Consultant)
• 17 Miles of Urban Interstate
• Widen from 6 lanes to 10 lanes
• $1.5 Billion U.S. – Largest Design-Build Contract at that time
• 4 Year duration (1997 - 2001) before 2002 Winter Olympics
• 144 Bridges/Overpass Structures
• 160 Retaining Walls (mostly MSE Walls)
• 100,000 m3 of EPS Geofoam (World’s Largest Geofoam Project)
• Approximate $6 M Research Program (4 years)
Project Requirements

1. Widen interstate from 6 lanes to 10 lanes
2. Complete project in 4 years (prior to 2002 Olympics)
3. Maintain at least 2 lanes of traffic each way during entire project
4. Minimize amount of property that needs to be purchased (i.e., stay with current right-of-way)
5. Minimize construction settlement impacts to adjacent structures and utilities
6. Reduce post-construction settlement to 75 mm in 10 years
7. Complete project within budget ($1.5 B)
Interstate System in Salt Lake Valley
Soft Sediments in Salt Lake Valley

Cone Penetrometer (CPT) Profile in Salt Lake Valley

- Upper Bonneville Clay
- Lower Bonneville Clay
- Interbeds

Soft Lake Bed deposits
Settlement During Construction in 1960s

- Primary Consolidation Settlement: 4.5 ft
- Time (days): 1965-1969
- Fill Height (ft): 37 ft
- Final Fill Height: 27 ft
Consequences of Settlement Conventional Embankment

Settlement of Approach Area
Typical I-15 Embankment Construction

- Temporary Wire Wall
- 2-Stage MSE Wall
- Prefabricated Vertical Drains
- Surcharge
- Geotextile
- New embankment
- Existing embankment
- Alluvium
- 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
Pre-drilling of PV Drains Required through Existing Embankment

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

1. PVDs reduced primary consolidation settlement to 3 to 6 months and were a key component to I-15 success and on-time completion of project.

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 of PVD's through large (8 m high) preexisting embankments.
Geotextile Installation in Reinforced Slopes

Geotextile placement on sloped, pre-existing embankment

Geotextile installed on 3H:1V slope

Geotextile lapped into MSE wall
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
Surcharging to Reduce Settlement

5 million cubic meters of embankment placed on project

Model for Secondary Consolidation

- Beginning of Primary Settlement
- End of Primary Settlement
- Remove Surcharge
- Rate of Secondary Settlement w/ Surcharge
- Rate of Secondary Settlement w/o Surcharge
- 3 inches in 10 years
- Log Time (years)

Intermediate 13

UDOT

Utah Department of Transportation
<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>
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Typical MSE Wall Instrumentation

Settlement Impacts to Adjacent Structures
Figure 4-5. Proximity of residential structure adjacent to the 200 South MSE wall.
200 South Street MSE Wall Instrumentation

Figure 4-6. Instrumentation layout at the 200 South MSE wall.
200 South Street MSE Wall Instrumentation

Figure 4-7. Construction and post construction settlement profile for the 200 South MSE wall site.
200 South Street MSE Wall Instrumentation

Figure 4-8. Rate of post-construction foundation creep for 200 South Street MSE wall.
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 bulge 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 define allowable face deformation and it should be measured and controlled.

6. Zone of significant settlement influence is extends a distance of about 1.5 times wall height as measured from the face of the all.
900 West Embankment

Figure 2-2. Central Salt Lake City Instrumentation Arrays.
Post-Construction (Secondary) Consolidation Settlement at Other Embankment Arrays

Figure 4-20. Rate of post-construction foundation creep for Large Earthen Embankment Sites.
Sloped Earthen Embankment Settlement Performance Summary

1. Surcharges of 30 to 40 percent of the final embankment height were used in the downtown area of the project.

2. Large surcharged fills introduced slope stability concerns in some locations, but no failures occurred on the project.

3. Surcharges were to remain in place until 98 percent EOP consolidation was reached.

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

5. Post construction monitoring has shown that surcharging has been generally successful in achieving this goal, except at 900 W and 400 South embankment. However, the 900 W embankment was not surcharged and has undergone 6.5 inches of secondary settlement in 10 years.
Lime Cement Treatment Area (2400 S. 300 W.)
Lime Cement Stabilized Soil

Lime Cement Column Rig

Auger / Mixer for Lime and Cement

125 kg/m³  15% lime  85% cement

M = 30 Mpa (design); Su 300 to 400 kPa
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. Measure the Shear Strength of the Treated Ground
5. Model the Construction and Long-Term Deformation Behavior
Pressure and Settlement Cells at Lime Cement Column Array

Pressure and Settlement Cells Atop Column
Borehole Magnetic Extensometer
23 cm of settlement at magnet extensometer location w/ 12 cm of settlement below column installation depth
Horizontal Inclinometers
Horizontal Inclinometer Measurements at LCC Array

Wall face
Ground Settlements at LCC Array
(August 99 to June 2010)

Figure 4-3. Construction and post construction settlement profile for the lime cement column area.
Post-Construction Ground Settlements at LCC Array
(August 99 to June 2010)

Figure 4-4. Rate of post-construction foundation creep for lime cement columns.
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 south wall of nearby bldg.
4. Secondary consolidation settlement of 6.2 cm (2.5 inches) has occurred at the wall face in 11 years.
5. Lateral Displacement of about 4 cm occurred at wall face.
6. Column is carrying about 10 times the stress as the adjacent untreated ground.
Geofoam Embankment from State St. to 200 W. Along Interstate I-80, Salt Lake City, Utah
Geofoam Embankment Construction

Nearly Completed Geofoam Embankment with Vertical Face

Geofoam cut and placed around piling at bridge abutment

Transition Zone with MSE Wall
Load Distribution Slab Atop Geofoam

Reinforced Concrete Load Distribution Slab atop Geofoam

Completed Load Distribution Slab
Typical Geofoam Monitoring 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
- SQUARE PLATE WITH MAGNET RING
- GEOFOAM BLOCKS
- GRANULAR BACKFILL
- VIBRATING WIRE TOTAL PRESSURE CELL
- BEDDING SAND
- LEVEL 0
- LEVEL 2
- LEVEL 4
- LEVEL 6
- 6.5 TO 7.3 m
- HEIGHT VARIES
- 2.5 m

SYRACUSE ORANGEMEN
3300 South Geofoam Array Installation

Magnet Extensometer and Pressure Cell Installation

Pressure Cell in Base Sand

Pressure Cell Cast in Bridge Abutment

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

Hot Wire Cut

Pressure Cell Placed in Cut
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
100 South Magnet Extensometer Data
Post-Construction Settlement

Figure 4-9. Compressive strain for magnet extensometers within the geofoam embankment at 100 South.
3300 South Array (VW Pressure Cells)
Geofoam Transition Zones Post-Construction Settlement

Transition slope
3.5 H : 1 V

Transition zone

Baseline survey completed on 11/10/99.
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 0.3 to 0.4 percent creep strain has occurred in a 10-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 30 kPa of vertical stress has developed in the center of the geofoam mass. This is slightly below the allowable dead load for the embankment.
Comparison of Overall Settlement Performance of Arrays
Questions

http://www.civil.utah.edu/~bartlett/GeoOmaha/

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