Design of Geofoam Embankment for the I-15 Reconstruction

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I-15 Reconstruction - Quick Facts

- Single Largest Highway Contract in U.S.
- 17 Miles of Urban Interstate
- $1.5 Billion Design-Build
- 4 Year Construction Duration (Summer 2001)
- 144 Bridges/Overpass Structures
- 160 Retaining Walls (mostly MSE Walls)
- 3.8 Million m$^3$ of Embankment Fill
- 100,000 m$^3$ Geofoam Embankment
Primary Uses of Geofoam on the I-15 Project

- Reduce Settlement to Protect Buried Utilities
- Improve Slope Stability of Embankments
- Rapid Construction in Time Critical Areas
Settlement Reduction (continued)
Subsurface Profile in Salt Lake Valley

CPT Tip Resistance, kPa

Depth (m)

Alluvium
Bonneville Clay
Pleistocene Alluvium
Cutler Clay

Soft Clay (10-m thick)
Settlement Reduction (continued)

Settlement on I-15, Salt Lake City (1964 - 1968)

- Primary Settlement: 1.4 m Settlement
- 2.5 year duration

[Graph showing settlement over time with specific values and timelines marked]
Settlement Reduction (continued)
Buried Utilities

- NEW FILL
- Buried Pipeline
- Ruptured Pipeline

[Diagram showing the burial of pipelines with new fill and the location of a ruptured pipeline.]
Settlement Reduction (continued)
Buried Utilities along Roadway

Geofoam Embankment from State St. to 200 W. Along Interstate I-80, Salt Lake City, Utah
Improve Slope Stability (continued)

Diagram of Potential Instability at Bridges

- Bridge Deck
- Failure surface
- Soft Clay
- Cracks
Improve Slope Stability

Details of Geofoam Construction at Bridge Abutments
Rapid Construction

(Typical Embankment Construction for I-15)

Geotechnical Wick Drains

1/2 SLOPE WIDTH MINIMUM

NEW EMBANKMENT

1.5

1.5

1

NEW EMBANKMENT SHOULDER

SURCHARGE

EXISTING EMBANKMENT

GEOTEXTILE

WICK DRAINS

LTDOT GOING THE EXTRA MILE
Rapid Construction

(Typical Embankment Construction for I-15)

- Wick Drain Installation (4 weeks)
- Grading and Geotextile (4 weeks)
- Wall Construction + Settlement Time (6 weeks + 24 weeks)
- Concrete Panel Placement (2 weeks)
Rapid Construction
(Typical Geofoam Construction for I-15)

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

- Tilt-up Concrete
- Fascia
- Panel Wall
- Wall Footing
Rapid Construction

(Typical Geofoam Construction for I-15)

Grade Preparation (1 week)

Block Placement (3 weeks)

Load Distribution Slab Construction (2 weeks)

Panel Wall Construction (1 Week)
Rapid Construction

(Comparison of Construction Time)

<table>
<thead>
<tr>
<th>Construction Stage</th>
<th>Conventional (Weeks)</th>
<th>Geofoam (Weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Construction</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Settlement</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Finish Work</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>50</td>
</tr>
</tbody>
</table>
Design Considerations

- Material Type
- Dimensions
- Density
- Compressive Strength
- Allowable Load & Creep
- Interface Friction
- Stability of Internal Slope
- Bedding Material & Compaction
- Concentrated Loads

- Moisture Absorption
- Buoyancy
- Thermal Resistance
- Differential Icing
- Chemical Attack
- Flammability
- Insect Infestation
- Ultra Violet Degradation
- Durability
Design Considerations (Material Type)

- Expanded Polystrene (EPS)*
  - virgin feedstock
  - maximum of 5 percent regrind content

* Extruded Polystrene (XPS) is also available, but was not used on the I-15 project
Design Considerations (EPS Block Dimensions)

Dimension tolerance 0.5 percent

- If tolerance is met, no trimming is necessary
- If tolerance is not met, shop trimming is necessary
## Design Considerations (EPS Density)

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Test C 578</th>
<th>Type XI</th>
<th>Type I</th>
<th>Type VIII*</th>
<th>Type II</th>
<th>Type IX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Density (kg/m³)</td>
<td>C303 / D 1622</td>
<td>12</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>Minimum Density (kg/m³)</td>
<td>C303 / D 1622</td>
<td>11</td>
<td>15</td>
<td>18</td>
<td>22</td>
<td>29</td>
</tr>
</tbody>
</table>

* Type VIII was used for I-15 Reconstruction
## Design Considerations
(EPS Minimum Compressive Strength)

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<th>Property</th>
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<th>Type II</th>
<th>Type IX</th>
</tr>
</thead>
<tbody>
<tr>
<td>kPa (10% Strain)</td>
<td>C 165 / D 1621</td>
<td>35</td>
<td>69</td>
<td><strong>90</strong></td>
<td>104</td>
<td>173</td>
</tr>
</tbody>
</table>

* Type VIII was used for I-15 Reconstruction
Strain Rate for Testing = 5 mm / minute
Design Considerations
(EPS Minimum Compressive Strength Versus Density)

(Source: Bartlett et al. 2000)

\[ \sigma_d = 7.3 \times D - 47 \text{ where } D = \text{Density in kPa.} \]
**Design Considerations (Allowable Stress and Creep)**

* Allowable Stress Must Maintained Below 1% Axial Strain to Minimize Long-Term Creep

\[ \sigma_d = \text{stress at 5\% strain} \]

\[ 0.4 \sigma_d \]

**Simplified Formula:**

Allowable Stress = 0.4 \( \sigma_d \)

Allowable Stress = 0.4 \times 120 = 48 \text{ kPa}

Source: Negussey (1997)
Design Considerations
(Allowable Stress and Creep)

**Allowable Stress**

\[(\text{Dead Load} + \text{Live Load}) \leq 0.4 \sigma_d\]

**Dead Load** = Weight of Load Distribution Slab + Weight of Base Material + Weight of Pavement.

**Dead Load** = 30 % of \(\sigma_d\) = 0.3 \(\sigma_d\)

**Live Load** = Traffic Loads

**Live Load** = 10 % of \(\sigma_d\) = 0.1 \(\sigma_d\)
Design Considerations
(Creep Data from Norway)

Measured Data
(3.5 years)

Theoretical Model

Fig. 7 Deformation / creep in the test fill

(Source: Aaboe, 2000)
Design Considerations
(Creep Data from Norway)

Theoretical Model

(Source: Aaboe, 2000)
Design Considerations (Interface Friction)

- Interface Friction Need for Design Against Sliding

\[ \tau = \sigma_n \tan \phi \]

- \( \tau \) = sliding shear resistance
- \( \sigma_n \) = normal stress
- \( \tan \phi = 0.6 \) (Design Value)
- \( \phi = 31 \) degrees (Design Value)
Design Considerations
(Interface Friction)

Figure 8. Interface Friction Between EPS Geofoam and Sand

Design Value = 31 deg.

Source: Negussey (1997)
Design Considerations
(Stability of Internally Sloped Embankments)

Maximum Back Slope = 1.5 H to 1.0 Vertical for Embankment to Guarantee Internal Slope Stability

(Do Not Allow Transfer of Horizontal Force)
Design Considerations
(Stability of Internally Sloped Cuts and Hillsides)

- Reinforced Slope
- Soil Nails, Soil Anchors, or Other Reinforcement
- Cut Slope or Landslide
Design Considerations (Bedding Material and Compaction)

Bedding Sand Function

- free draining sand or fine gravel
- provides leveling course
- provides drainage

Bedding Sand (20 cm min.)
Design Considerations
(Bedding Material and Compaction)

Gradation Specification for Bedding Sand

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>50mm</th>
<th>13mm</th>
<th>6mm</th>
<th>2mm</th>
<th>0.425mm</th>
<th>0.075 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Passing</td>
<td>95 - 100</td>
<td>65-100</td>
<td>50-100</td>
<td>40-70</td>
<td>10-40</td>
<td>0-5</td>
</tr>
</tbody>
</table>

(Percent Passing)

* Materials with more than 20 percent of the samples containing between 5 and 7 percent minus 0.075 mm material shall not be accepted for use.
Design Considerations
(Bedding Material and Compaction)

Grade Preparation and Leveling

(*Maximum lift thickness = 20 cm)
Design Considerations (Concentrated Loads)

- Uncovered geofoam damages easily from tire loads
- Do not use heavy equipment atop geofoam until the load distribution slab is placed
- Use light-weight construction equipment
- Protect with plywood sheeting
Design Considerations
(Moisture Absorption - Above High Groundwater Elevation)

(Source: Aaboe, 2000)
Design Considerations
(Moisture Absorption - Below Groundwater)

(Source: Aaboe, 2000)
Design Considerations
(Moisture Absorption - Design Values)

- Installation of EPS **above** high groundwater
  - Design Moisture Content = 1 percent by volume

- Installation of EPS that is **periodically submerged**
  - Design Moisture Content = 5 percent by volume

- Installation of EPS **below** groundwater
  - Design Moisture Content = 10 percent by volume
Design Considerations (Buoyancy)

100-year design flood event

\[ F_{\text{resisting}} = 1.3 \times F_{\text{uplift}} \]
Design Considerations (Thermal Resistance)

- R-value = heat flow through a unit width of material.
- R-value for geofoam is about 4 (18 kg/m³ density).
- R-value for soil and concrete is less than 1.

(Negussey, 1997)
Design Considerations
(Differential Icing - Cold Regions only)

No Icing

Pavement

Soil

Icing

EPS

Good Heat Transfer

Poor Heat Transfer

Base material has heat capacity and prevents pavement from icing as rapidly.

Proper Design to Prevent Icing
Design Considerations (Chemical Attack)

- Solvents that Dissolve Geofoam
  - Gasoline
  - Diesel
  - Other Petroleum Based Fuels
  - Organic Fluids

- Protection Against Accidental Spills
  - Concrete Load Distribution Slab
  - Geomembrane
  - Fascia Panel Wall with Coping
Design Considerations
(Chemical Attack - Protective Barriers)

- Concrete Pavement (35 cm)
- Load Distribution Slab (15 cm - Reinforced)
- Geomembrane Petroleum Resistant (3 component) for exposed side slope only
- Tilt-up Panel Wall
Design Considerations
(Chemical Attack - Protective Barriers)

- Tripolymer Geomembrane
  - Polyvinyl Chloride
  - Ethylene Interpolymer Alloy
  - Polyurethane

- 9 mm thickness minimum (total)
Design Considerations (Flammability)

- Geofoam is Combustible and Must Be Protect Against Open Flame or Heat
- Material Specification should include:

  “Flame Retardant Additive and a UL Certification of Classification as to External Fire Exposure and Surface Burning Characteristics.”
Design Considerations (Insect Infestation)

- Chemical (Borate) can be added to stop termite or insect infestation.
Prolonged Exposure ( > 90 days) to sunlight can lead to discoloration of geofoam and decrease in the internal angle of friction on the surface of the geofoam.
Design Considerations (UV Degradation)

• Geofoam should not be left uncovered more than 90 days.

• UV exposure times greater than 90 days require “power-washing” to remove degraded geofoam surface where the load distribution slab is placed.

• Side surface where tilt-up panel wall is placed does not require power-washing.
Design Considerations (Durability Data from Norway)

Note: No loss of compressive strength with time is evident (Source: Aaboe, 2000).
(Questions ???)