Use of EPS Geofoam in Seismic and Slope Applications
AEG, Salt Lake City, Utah, May 9th, 2013

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Topics

- Introduction to EPS
- Protection of Buried Pipelines from Permanent Ground Displacement
- Static and Seismic Earth Pressures Against Buried Structures and Facilities
- Slope and Embankment Applications
Expanded Polystyrene (EPS) Geofoam Applications & Technical Data

The EPS Industry Alliance
1298 Cronson Boulevard
Suite 201
Crofton, MD 21114
800.607.3772
info@epscentral.org
www.epsmolders.org
General Applications

2.1 Road construction over poor soils
2.2 Road widening
2.3 Bridge abutment
2.4 Bridge underfill
2.5 Culverts, pipelines & buried structures
2.6 Compensating foundation
2.7 Rail embankment
2.8 Landscaping & vegetative green roofs
2.9 Retaining and buried wall backfill
2.10 Slope stabilization
2.11 Stadium & theater seating
2.12 Levees
2.13 Airport runway/taxiway
2.14 Foundations for lightweight structures
## ASTM D6817 Physical Property Requirements of EPS Geofoam

<table>
<thead>
<tr>
<th>Property</th>
<th>EPS12</th>
<th>EPS15</th>
<th>EPS19</th>
<th>EPS22</th>
<th>EPS29</th>
<th>EPS39</th>
<th>EPS46</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, min., kg/m³(lb/ft³)</td>
<td>11.2 (0.70)</td>
<td>14.4 (0.90)</td>
<td>18.4 (1.15)</td>
<td>21.6 (1.35)</td>
<td>28.8 (1.80)</td>
<td>38.4 (2.40)</td>
<td>45.7 (2.85)</td>
</tr>
<tr>
<td>Compressive Resistance, min., kPa (psi) at 1 %</td>
<td>15 (2.2)</td>
<td>25 (3.6)</td>
<td>40 (5.8)</td>
<td>50 (7.3)</td>
<td>75 (10.9)</td>
<td>103 (15.0)</td>
<td>128 (18.6)</td>
</tr>
<tr>
<td>Compressive Resistance, min., kPa (psi) at 5 %</td>
<td>35 (5.1)</td>
<td>55 (8.0)</td>
<td>90 (13.1)</td>
<td>115 (16.7)</td>
<td>170 (24.7)</td>
<td>241 (35.0)</td>
<td>300 (43.5)</td>
</tr>
<tr>
<td>Compressive Resistance, min., kPa (psi) at 10 %</td>
<td>40 (5.8)</td>
<td>70 (10.2)</td>
<td>110 (16.0)</td>
<td>135 (19.6)</td>
<td>200 (29.0)</td>
<td>276 (40.0)</td>
<td>345 (50.0)</td>
</tr>
<tr>
<td>Flexural Strength, min., kPa (psi)</td>
<td>69 (10.0)</td>
<td>172 (25.0)</td>
<td>207 (30.0)</td>
<td>240 (35.0)</td>
<td>345 (50.0)</td>
<td>414 (60.0)</td>
<td>517 (75.0)</td>
</tr>
<tr>
<td>Oxygen index, min., volume %</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
</tr>
</tbody>
</table>
Geofoam Advantages

- **Light weight material**
  - Reduces static and seismic loads to walls, buried structures
  - Improves slope stability (static & dynamic)
  - Reduces consolidation settlement on soft ground

- **Controlled Compression (Compression Inclusion)**
  - Can undergo elastic and plastic deformation but maintains general shape
  - Reduces load to buried structures by compression and mobilization of surround soil strength
Beginnings of Geofoam

Figure 3. Excavation of the first EPS embankment at Flom bridge (EPS and polyurethane as protective layer).

Flom Bridge – 1972 - Norway
LESSONS LEARNED

At the time of the first project we were particularly concerned about the following
- the constant vibrations of the traffic which possibly could cause horizontal
  movements of the fill structure
- leakage of petrol following a tanker accident which could cause the embankment to
dissolve

In order to safeguard the repeated vibrations, the first EPS embankment was meant to be built up
with a small slope towards the centre of the road. The contractor eventually ignored this, and such
precautions were later never prescribed.

In order to protect against petrol leakage, the embankment was protected with a 10 cm polyurethane
cover. Very soon it also became apparent that the risk for an overturning tanker on an EPS
embankment was extremely low, and that the use of a concrete slab was a more practical way of
combining the required protection of the underlying EPS blocks with the need for pavement strength
and binding together the EPS structure.
Typical Roadway Construction

Details of Geofoam Construction at Bridge Abutments
Geofoam Embankments

Freestanding Embankment

Sloped Embankment

UTA – Light Rail – Salt Lake City, Utah
Topics

- Introduction to EPS
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Sources of Permanent Ground Deformation

- Tectonic Faulting
- Subsidence and Settlement
- Landsliding and Other Types of Mass Movement
- Liquefaction and Lateral Spread
- Karst
- Collapsible Soils
- Expansive Soils
Fault-Induced Pipeline Rupture
Pipelines (Protection for Normal and Reverse Faults)

Shallow Burial – Normal Faulting
Pipelines (Protection for Strike Slip Faults)

Alaskan Pipeline – Strike Slip Fault
Wasatch Fault at Little Cottonwood Canyon
Pipelines (Light-weight Cover Over Normal Faults)

Profile (Longitudinal) View

Bending Moments in Pipe from 2 m offset
Pipelines (Light-weight Cover Over Normal Faults)

Displacement Vectors During Failure

Lightweight-Cover System
(X-sectional View)

Video
Vertical Uplift Tests
Force-Displacement Curves from Uplift Tests

Vertical Displacement (m) vs. Uplift Force (kN)

- Geofoam Section
- Soil Section
Pipelines (Light-weight Cover Over Faults)

Questar Gas Line
3500 South Street
Salt Lake City, Ut
Horizontal Offset from Permanent Ground Displacement
Horizontal Offset from Permanent Ground Displacement
Horizontal Offset from Permanent Ground Displacement

![Graph showing force vs. displacement for different tests.](image)
Horizontal Offset from Permanent Ground Displacement
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Reduction of Settlement around Buried Structures

Federal Courthouse

IHC Hospital – Murray, Ut

Casino/Hotel – Reidoso, NM
Earth Pressure Theory - Active Case

\[ (1 \pm k_v)qB \]

\[ k_h qB \]

Tension cracks

\[ (1 \pm k_v)W \]

\[ k_h W \]

\[ \theta \]

\[ \phi \]

\[ P_{ae} \]

\[ H \]

\[ z_c \]

\[ A_1 \]

\[ A_2 \]

\[ A_3 \]

\[ A_3' \]

\[ A_1' \]

\[ B \]

\[ C \]

\[ C_w \]

\[ T \]

\[ N \]

\[ F \]

\[ \alpha \]
Reduction of Seismic Earth Pressure (Hazarika, 2002)

Buried Structures and Walls (Compressible Inclusion)

Fig. 1. Use of geofoam as compressible buffer

[Graph showing normalized wall height vs. lateral seismic stress (kPa), with curves for sandy backfill and hybrid system.]
Reduction of Peak Seismic Thrust

EPS panel spacing, \( d \) (m) vs. Isolation efficiency (%)
Reduction of Peak Seismic Thrust

Diagram showing the elevation (m) and horizontal distance (m) with labeled sections EPS Buffer 1, EPS Buffer 2, Rigid wall face, and Soil.
Reduction of Peak Seismic Thrust

![Graph showing isolation efficiency vs. EPS thickness for single and double EPS buffer systems.](image)

**Fig. 8.** Seismic isolation efficiency in relation to the total EPS thickness for single rectangular and double EPS buffer systems.
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Seismic Stability Considerations

• Primary Modes of Potential Failure
  • Global Stability of slope/embankment with strong motion
  • Sliding (Basal, Interlayer and Cap)
  • Rocking and Sway (Internal yielding and damage to corners)
  • Overturning (for slender aspect ratios)
  • Bearing Capacity?
Conceptual Reconstruction of Failed Slope with EPS

Step 1 - Soil nailing and shotcreting of existing slope and create bench for geotextile placement.

pre-existing slope

soil nails

shotcrete facing with weep drains

bench
Step 2 - Rebuild slope and roadway with geofoam 2/4 and tiebacks.

- barrier
- rebuilt roadway
- drainage ditch
- concrete lined
- light gage cable
- tiebacks placed in geofoam at each level.
- steepened back slope (slope > 1V:1.5H)
- bedding sand (level)
- level bench

reinforced shotcrete facing

cables anchored at face of plates or ribs
Slope Remediation and Roadway Widening – 2nd Mesa Arizona
Slope Remediation and Roadway Widening – 2nd Mesa Arizona

Figure provided by AZTEC Engineering Inc.
Soil Nail Stabilization of Slope

Step 1 - Soil nailing and shotcrete of existing slope and create bench for geotextile placement.

pre-existing slope

soil nails

shotcrete facing with weep drains

bench
Placement of EPS

Step 2 - Rebuild slope and roadway with geosynthetic clay liners and tiebacks.

- Rebuilt roadway
- Barrier

Concrete lined drainage ditch

Light gage cable ties placed in geosynthetics at each level.

Steepened back slope (slope > 1V:1.5H)

Geosynthetic clay liner (GCL)

Level bench

Remediated sheet pile facing

Cables anchored at toe w/ plates or ties
Construction of Load Distribution Slab
Finished Roadway
Global Stability Failure (Philippines)
Global Stability Failure
Final Slope Configuration
Seismic Evaluation of Free-Standing Embankments

Freestanding Embankment

UTA – Light Rail – Salt Lake City, Utah
Sliding Evaluations

**FLAC (Version 5.00)**

**LEGEND**

30-Mar-08 18:20
step 17000
-3.333E+00 < x < 6.333E+00
-2.383E+01 < y < 4.283E+01

Density
- 1.800E+01
- 1.845E+03
- 2.305E+03

Net Applied Forces
- max vector = 2.041E+05

Dynamic Apply Conditions
- O = Both DOFs Quelled
- * = Free Field Boundary

Grid plot

Interface id#s

Steven Bertlott
University of Utah

(8 m high x 20 m wide)

**T_o = 0.5 s**

Combined cap

Interfaces

Free-field (infinite) boundary

Quiet boundary (non-reflective) base
Horizontal Acceleration Response Spectra

Response Spectra (5% Damping)

<table>
<thead>
<tr>
<th>Motion</th>
<th>Earthquake</th>
<th>M</th>
<th>R (km)</th>
<th>Component</th>
<th>PGA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1989 Loma Prieta, CA</td>
<td>6.9</td>
<td>8.6</td>
<td>Capitola 000</td>
<td>0.52</td>
</tr>
<tr>
<td>2</td>
<td>1989 Loma Prieta, CA</td>
<td>6.9</td>
<td>8.6</td>
<td>Capitola 090</td>
<td>0.44</td>
</tr>
<tr>
<td>3</td>
<td>1999 Duzce, Turkey</td>
<td>7.1</td>
<td>8.2</td>
<td>Duzce 180</td>
<td>0.35</td>
</tr>
<tr>
<td>4</td>
<td>1999 Duzce, Turkey</td>
<td>7.1</td>
<td>8.2</td>
<td>Duzce 270</td>
<td>0.54</td>
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<tr>
<td>5</td>
<td>1992 Cape Mendocino, CA</td>
<td>7.1</td>
<td>9.5</td>
<td>Petrolia 000</td>
<td>0.59</td>
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<tr>
<td>6</td>
<td>1992 Cape Mendocino, CA</td>
<td>7.1</td>
<td>9.5</td>
<td>Petrolia 090</td>
<td>0.66</td>
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<tr>
<td>7</td>
<td>1994 Northridge, CA</td>
<td>6.7</td>
<td>6.2</td>
<td>Sylmar 052</td>
<td>0.61</td>
</tr>
<tr>
<td>8</td>
<td>1994 Northridge, CA</td>
<td>6.7</td>
<td>6.2</td>
<td>Sylmar 142</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Graph showing spectral acceleration (g) vs. period (sec) for different motions.
Vertical Acceleration Response Spectra

Response Spectra (5% Damping)

- Spectral Acceleration (g)
- Period (sec)

Legend:
- ▲ Motion 4
- ■ Motion 1
- ▼ Motion 2
- ● Motion 3
# Elastic Properties for Sliding Evaluations

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Layer No.</th>
<th>( \rho ) (kg/m(^3))(^4)</th>
<th>( E ) (MPa)(^5)</th>
<th>( \nu )(^6)</th>
<th>( K ) (MPa)(^7)</th>
<th>( G ) (MPa)(^8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation Soil</td>
<td>1-10</td>
<td>1840</td>
<td>174</td>
<td>0.4</td>
<td>290.0</td>
<td>62.1</td>
</tr>
<tr>
<td>Geofoam</td>
<td>11-18</td>
<td>18</td>
<td>10</td>
<td>0.103</td>
<td>4.2</td>
<td>4.5</td>
</tr>
<tr>
<td>UTBC(^1)</td>
<td>19</td>
<td>2241</td>
<td>570</td>
<td>0.35</td>
<td>633</td>
<td>211</td>
</tr>
<tr>
<td>LDS(^2) &amp; PCCP(^3)</td>
<td>19</td>
<td>2401</td>
<td>30000</td>
<td>0.18</td>
<td>15625</td>
<td>12712</td>
</tr>
</tbody>
</table>

\(^1\) Untreated base course, \(^2\) Load distribution slab, \(^3\) Portland concrete cement pavement, \(^4\) Mass density, \(^5\) Initial Young’s modulus, \(^6\) Poisson’s ratio, \(^7\) Bulk modulus, \(^8\) Shear modulus
## Interface Properties for Sliding Evaluations

<table>
<thead>
<tr>
<th>Contact Surface</th>
<th>Interface number (bottom to top)</th>
<th>Normal and Shear Stiffness (k_n = k_s) (MPa)</th>
<th>Friction angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geofoam-soil</td>
<td>1</td>
<td>102</td>
<td>31(^1)</td>
</tr>
<tr>
<td>Geofoam-Geofoam</td>
<td>2-8</td>
<td>102</td>
<td>38</td>
</tr>
<tr>
<td>Geofoam-Lump Mass</td>
<td>9</td>
<td>102</td>
<td>38(^2)</td>
</tr>
</tbody>
</table>

\(^1\) A glued interface was used for interface 1 in FLAC because the geofoam is abutted against the panel wall footing and cannot slide. \(^2\) Neglects any tensile or shear bonding that may develop between the top of geofoam and base of the load distribution slab.
Displacement Vectors from FLAC

Video
Relative and Total Sliding Displacement

LEGEND

31-Mar-08 10:36
step 289234
Dynamic Time 2.00000E+01

HISTORY PLOT
Y-axis:
160 rel1 (FISH)
170 rel2 (FISH)
180 rel3 (FISH)
190 rel4 (FISH)
200 rel5 (FISH)
210 rel6 (FISH)
220 rel7 (FISH)
230 rel8 (FISH)
240 reltotal (FISH)

X-axis:
1 Dynamic time

Total rel. displacement
Rel. disp. layers 1 and 2
Rel. disp. layers 2 and 3
Rel. disp. layers 3 and 4

Displacement (m)

Time (s)
<table>
<thead>
<tr>
<th>Case</th>
<th>Horizontal Motion</th>
<th>Vertical Motion</th>
<th>Displacement (m)</th>
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</thead>
<tbody>
<tr>
<td>1a</td>
<td>1</td>
<td>Not applied</td>
<td>0.06</td>
</tr>
<tr>
<td>1b</td>
<td>1</td>
<td>1</td>
<td>0.06</td>
</tr>
<tr>
<td>2a</td>
<td>2</td>
<td>Not applied</td>
<td>0.05</td>
</tr>
<tr>
<td>2b</td>
<td>2</td>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>3a</td>
<td>3</td>
<td>Not applied</td>
<td>0.06</td>
</tr>
<tr>
<td>3b</td>
<td>3</td>
<td>2</td>
<td>0.06</td>
</tr>
<tr>
<td>4a</td>
<td>4</td>
<td>Not applied</td>
<td>1.3</td>
</tr>
<tr>
<td>4b</td>
<td>4</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>5a</td>
<td>5</td>
<td>Not applied</td>
<td>0.005</td>
</tr>
<tr>
<td>5b</td>
<td>5</td>
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<td>0.01</td>
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<td>6</td>
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<td>3</td>
<td>0.06</td>
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<tr>
<td>7a</td>
<td>7</td>
<td>Not applied</td>
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<td>7b</td>
<td>7</td>
<td>4</td>
<td>0.6</td>
</tr>
<tr>
<td>8a</td>
<td>8</td>
<td>Not applied</td>
<td>0.6</td>
</tr>
<tr>
<td>8b</td>
<td>8</td>
<td>4</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Shear Keys to Prevent Sliding
Light weight EPS cover systems can be effective in preventing rupture of steel-pipelines undergoing vertical offset from permanent ground displacement.

Preliminary modeling results suggest that static and seismic earth pressures can be reduced significantly using EPS placed against buried structures.

Because of its light-weight nature, EPS geofoam offers significant benefits in slope reconstruction.

Large, free-standing EPS embankments are generally stable for earthquakes, but overall stability can be improved by including shear keys, adhesives or other mechanical or structure countermeasures.
Questions?