TRB Webinar: Guidelines for Geofoam Applications in Slope Stability Projects

David Arellano, University of Memphis
Steven Bartlett, University of Utah
Ben Arndt, Yeh & Associates, Inc.
Moderated by: Mohammed Mulla, North Carolina DOT

July 27, 2017
Webinar Outline

• Overview of problem statement and background on use of geofoam
• Engineering properties of block-molded expanded polystyrene for slope stabilization
• Design methodology overview
• Construction practices & cost considerations
• Update on previous standard for slope stability applications
• Question and answer session
Overview of problem statement & background on use of geofoam

David Arellano, University of Memphis
Slope stabilization

US 160
Durango, CO. Photos: Sutmoller
Slope stabilization
Overview of EPS Block Placement Configuration

Completed Road
### Geofoam Types (ASTM D 6817)

#### ASTM D6817 Physical Property Requirements of EPS Geofoam

<table>
<thead>
<tr>
<th>Type</th>
<th>EPS12</th>
<th>EPS15</th>
<th>EPS19</th>
<th>EPS22</th>
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<th>EPS46</th>
</tr>
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<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 10 %&lt;sup&gt;A&lt;/sup&gt;</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>
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<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>
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Problem Statement

- New roadway alignments and/or widening of existing roadway embankments will be required to solve the current and future highway capacity problem.
- Roadway construction often exacerbates the landslide problem in hilly areas by alternating the landscape, slopes, and drainages and by changing and channeling runoff (Spiker and Gori, 2003).
- Geofoam provides an alternative slope stabilization and repair technique that is based on reducing the driving forces.
Previous NCHRP Results: NCHRP 24-11
Guidelines for Geofoam Applications in Slope Stability Projects

PRELIMINARY DRAFT FINAL REPORT

Prepared for
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Transportation Research Board
of
The National Academies

This report, not released for publication, is furnished only for review by members or participants in the work of CRP. This report is to be regarded as a privileged document; dissemination of the information included herein must be approved by CRP.

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Newark, Delaware

January 7, 2011

NCHRP 24-11(02)

a) Slope-sided fill.

b) Vertical-sided fill (Geofoam wall).
Research Objective

• To develop a comprehensive document that provides both state-of-the-art knowledge and state-of-practice design guidance to those who have primary involvement with roadway embankment projects with design guidance for use of EPS-block geofoam in slope stability applications.
Primary Research Products 24-11(02)

- Relevant Engineering Properties
- Economic Data
- Design Guideline
- Detailed Numerical Example
- Material & Construction Standard
Engineering properties of block-molded expanded polystyrene for slope stabilization

Steve Bartlett, University of Utah
Key Properties

• Density
  • Indicator of quality, strength and compressive resistance of EPS
  • Required for vertical stress and buoyancy calculations

• Compressive Resistance (Elastic Young’s Modulus)
  • 1 % axial strain values used to determine allowable loads
  • Dead loads and live loads limited to prevent excessive long-term creep

• Interface Friction
  • Geofoam to Geofoam
  • Geofoam to Backfill (sand)

• Shear Strength (Seismic Design Only)
  • Shear strength of shear keys (if used)
Design properties - ASTM D6817

<table>
<thead>
<tr>
<th>Physical Properties of Foam-Control EPS Geofoam¹,²</th>
</tr>
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<tbody>
<tr>
<td>TYPE - ASTM D6817</td>
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<td>Density, min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 lb/ft³ (kg/m³)</td>
<td>0.70</td>
<td>0.90</td>
<td>1.15</td>
<td>1.35</td>
<td>1.80</td>
<td>2.40</td>
<td>2.85</td>
</tr>
<tr>
<td>1 psi (kPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive resistance @ 1% deformation, min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 psi (kPa)</td>
<td>2.2</td>
<td>3.8</td>
<td>5.8</td>
<td>7.3</td>
<td>10.0</td>
<td>15.0</td>
<td>18.8</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 psi (kPa)</td>
<td>220</td>
<td>360</td>
<td>580</td>
<td>730</td>
<td>1090</td>
<td>1500</td>
<td>1860</td>
</tr>
<tr>
<td>Flexural Strength min.</td>
<td>10.0</td>
<td>25.0</td>
<td>30.0</td>
<td>35.0</td>
<td>50.0</td>
<td>80.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Water Absorption by total immersion, max., volume %</td>
<td>4.0</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
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<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Buoyancy Force</td>
<td>1 lb/ft³ (kg/m³)</td>
<td>61.7</td>
<td>61.5</td>
<td>61.3</td>
<td>61.1</td>
<td>60.6</td>
<td>60.0</td>
</tr>
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This standard is commonly used to specify the minimum required values for construction.
Density

EPS block density is controlled by the amount of styrene beads used to make the block. More beads produce higher density.

raw styrene beads  steam expanded (1st steam heating)

block molding (2nd steam heating)  block placement
Density

\[ \sigma_d = 7.3 \times D - 47 \text{ where } D = \text{Density} \]

Design Compressive Strength Versus Density
Density and Buoyancy

F_{resisting}

F_{uplift}

Surface water

Ground water

Drainage Sand
Compressive Resistance

2-in cube samples usually tested for QC
Compressive Resistance

Normalized Vertical Stress

Vertical Strain (%)

Design Value

EPS19-4
Compressive Resistance and Creep

![Graph showing vertical strain vs. time](image)

- **EPS 25**
- **Time, t (min)**
- **Vertical strain, \( \varepsilon_v \) (%)**
- \( C_{ae} \)
- "one log cycle"
Compressive Resistance and Creep

![Graph showing compressive strain over time](image)

- South Extensometer
- North Extensometer

End of Construction, 10 Years, 50 Years

Elapsed Time (days) from Completion of Geofoam Placement

Construction Strain Limit

50 Year Strain Limit
• Interface Friction Need for Design Against Sliding

\[ \tau = \sigma_n \tan \phi \]
\[ \tau = \text{sliding shear resistance} \]
\[ \sigma_n = \text{normal stress} \]
\[ \tan \phi = 0.6 \ (\text{Design Value}) \]
\[ \phi = 31 \text{ degrees (Design Value)} \]
Interface Friction

![Graph showing friction coefficient vs. normal stress for Foam-Foam and Sand-Foam interfaces. The design value is indicated at 0.6.]
Shear Strength (Seismic Design)
Figure 2.10. Shear stress vs. displacement of EPS specimens under 15 kPa normal stress at different loading rates.
Design methodology overview

David Arellano, University of Memphis
Major Components of an EPS-Block Geofoam Slope System

- Fill Mass (EPS blocks and soil cover, if any)
- Existing Slope Material (Foundation Material)
- Existing Slope Material (Upper Slope)
- Pavement System

• Failure Modes
  • External instability
  • Internal instability
  • Pavement system failure
External Instability
Static and Seismic Slope Stability
(Existing Soil Slope Material Only)
Static and Seismic Slope Stability
(Both Fill Mass and Existing Soil Slope Material)
External Seismic Stability Failure: Horizontal Sliding of the Entire Embankment & Overturning of an Entire Vertical Embankment about the Toe of the Embankment
Bearing Capacity Failure & Settlement
External Stability Summary of Failure Mechanisms

• Static slope stability
• Settlement
• Bearing capacity
• Seismic
  • seismic slope instability
  • seismic-induced settlement
  • seismic bearing capacity failure
  • seismic sliding
  • seismic overturning

•
Internal Instability
Internal Seismic Stability Failure
Horizontal Sliding
1. Selection of EPS type directly below the pavement system
   • Traffic and gravity stresses on top of the geofoam.
2. Selection of EPS type at various depths within the EPS block fill mass.
   • Traffic and gravity load stresses at various depths within the geofoam.
## EPS Geofoam Types (ASTM D 6817)

### ASTM D6817 Physical Property Requirements of EPS Geofoam

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<td>Compressive Resistance, min., kPa [psi]</td>
<td>35 (5.1)</td>
<td>55 (8.0)</td>
<td>90 (13.1)</td>
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<td>300 (43.5)</td>
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<td>Compressive Resistance, min., kPa [psi]</td>
<td>40 (5.8)</td>
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<td>24.0</td>
<td>24.0</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Estimated Largest Preliminary Stress (kPa)</th>
<th>Preliminary EPS Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>96</td>
<td>$EPS39$</td>
</tr>
<tr>
<td>0.75</td>
<td>58</td>
<td>$EPS29$</td>
</tr>
<tr>
<td>1.0</td>
<td>38</td>
<td>$EPS19$</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>$EPS19$</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>$EPS19$</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>$EPS19$</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>$EPS19$</td>
</tr>
</tbody>
</table>
Load Distribution Slab
External Stability Summary of Failure Mechanisms

• Horizontal Sliding
• Load Bearing Failure
Pavement System Failure
Pavement Design

Pavement crack
Overview of EPS Block Placement Configuration

Completed Road
Overall Design Procedure

1. Background investigation including stability analysis of existing slope
2. Select a preliminary type of EPS and assume a preliminary pavement system design (if necessary)
3. Optimize volume & location of EPS fill or assume a preliminary fill mass arrangement
4. Modify optimized EPS fill as needed for constructability
5. Does slope include roadway at head of slide? (See Figure 13 (b))
   - Yes, proceed to Step 4
   - No, skip to Step 10
6. Does required pavement system result in a change in overburden stress compared to the preliminary pavement system design developed in Step 2?
   - Yes
     - Return to Step 5
   - No
7. Static slope stability (external) acceptable?
   - Yes
     - Does slope include roadway at head of slide? (See Figure 13 (b))
       - Yes, proceed to Step 4
       - No, skip to Step 10
     - Settlement (external) acceptable?
       - Yes
         - Bearing capacity (external) acceptable?
           - Yes
             - Bearing capacity (internal) acceptable?
               - Yes
                 - Design Details
               - No
                 - Return to Step 3
           - No
             - Return to Step 3
         - No
           - Settlement (internal) acceptable?
             - Yes
               - Bearing capacity (external) acceptable?
                 - Yes
                   - Bearing capacity (internal) acceptable?
                     - Yes
                       - Design Details
                     - No
                       - Return to Step 3
                 - No
                   - Return to Step 3
             - No
               - Return to Step 3
           - No
             - Return to Step 3
         - No
           - Return to Step 3
   - No
     - Return to Step 3
8. Seismic stability (internal) acceptable?
9. Does slope include roadway at head of slide? (See Figure 13 (b))
   - Yes, proceed to Step 4
   - No, skip to Step 10
10. Seismic stability and overturning (external) acceptable?
11. Seismic stability (external) acceptable?
12. Bearing capacity (external) acceptable?
13. Bearing capacity (internal) acceptable?
14. Will inter-block connectors meet Step 7 requirements?
15. Return to Step 2 and use EPS blocks with higher elastic limit stress
16. Settlement (external) acceptable?
17. Settlement (internal) acceptable?
1. Background investigation including evaluation of existing stability of slope

2. Select a preliminary type of EPS and assume a preliminary pavement system design (if necessary)

3. Optimize volume & location of EPS fill or assume a preliminary fill mass arrangement.
Optimization Procedure

• The optimal location of the EPS mass within the overall slope cross-section is not intuitively obvious.
  • Obtain results of preliminary slope stability analysis.
  • Copy or input stability analysis results into spreadsheet.
  • Set up optimization equations in spreadsheet.
  • Use Solver Add-In to perform optimization.
Optimization Procedure

Stability analysis results from optimization procedure

Stability analysis results of modified layout
4.
Modify optimized EPS fill as needed for constructability

5.
Static slope stability (external) acceptable?

Yes

Optimize volume & location of EPS fill based on required seismic stability. Modify optimized fill as needed for constructability. Recheck static slope stability.

No

6.
Seismic stability and overturning (external) acceptable?

Yes

No
4 Modify optimized EPS fill as needed for constructability

No

Will the use of inter-block connectors meet Step 6 requirements?
-If Yes, Proceed to next step
-If No, Proceed to Step 4

No

7 Seismic stability (internal) acceptable?

No

Yes

Proceed with next step
Increasing Block Resistance

Figure 3.6. Geofoam shear key illustration (Insulfoam).
Does required pavement system result in a change in overburden stress compared to the preliminary pavement system design developed in Step 2?

- If yes, proceed to Step 8
- If no, skip to Step 10

Return to Step 5 (Static slope stability)
10 Load bearing (internal) acceptable?

Yes

OR

Return to Step 8 and modify pavement system

No

Return to Step 2 and use EPS blocks with higher elastic limit stress
11 Settlement (external) acceptable?

Yes

12 Bearing capacity (external) acceptable?

Yes

13 Design Details

No

Return to Step 3

No

Return to Step 3
Overall Design Procedure

1. Background investigation including stability analysis of existing slope

2. Select a preliminary type of EPS and assume a preliminary pavement system design (Preliminary)

3. Optimize volume & location of EPS fill or assume a preliminary fill mass arrangement

4. Static slope stability (external) acceptable?

5. Seismic stability and overturning (external) acceptable?

6. Seismic stability (internal) acceptable?

7. Does required pavement system result in a change in overburden stress compared to the preliminary pavement system design developed in Step 2?

8. DOES slope include roadway at head of slide? (See Figure 13 (b))
   - If yes, proceed to Step 8
   - If no, skip to Step 11

9. Pavement system design

10. Settlement (external) acceptable?

11. Bearing capacity (external) acceptable?

12. Does inter-block connectors meet Step 7 requirements?

13. Design Details

Modifications:
- Modify optimized EPS fill as needed for constructability
- Modify optimized EPS fill to meet Step 8 requirements
- Modify optimized EPS fill to meet Step 3 requirements
- Recheck static slope stability.
- Return to Step 2 and use EPS blocks with higher elastic limit stress
Additional Design Considerations
Overview of EPS Block Placement Configuration
Long-Term Durability

• 1972 Norway Flom Bridge
• First major lightweight fill project.
• Over 40 years of extensive worldwide use.

Aaboe & Frydenlund (2011)
Design Considerations: Ultraviolet Radiation

Photo: Sutmoller
Design Considerations: Flammability

- Two known fires worldwide – both in Norway
- Geofoam can be manufactured with flame retardant additives.
- Storage and handling of geofoam blocks should be done with attention to fire safety.

Frydenlund and Aabøe (1996)
Design Considerations: Liquid Petroleum Hydrocarbons

Photos: Sutmoller
Groundwater Control During Construction

• “Site flooding as a result of a heavy rain that caused previously placed blocks to float and move out of position was the underlying cause in all cases.”

(Horvath 2010)
Key Assumptions of Design Procedure

• Based on a self-stable adjacent upper slope to prevent earth pressures on the EPS fill mass that can result in horizontal sliding between blocks.

• Based on the installation of a permanent drainage system.
Overview of Slope Excavation

Water at Bottom of Cut
Placement of Subsurface Drainage

Subsurface Drainage System & Drainage Channel

Drainage Channel Diverts Water Away From Slope
Construction practices & cost considerations

Ben Arndt, Yeh & Associates, Inc.
Using Geofoam for Embankment Failures
Using Geofoam for Embankment Failures
Existing Roadway with low strength embankments.
Roadway Widening Project

Slope Factor Safety < 0.99
Creates an unstable roadway template

Slope Factor Safety < 0.99
Mitigating the failure
Mitigating the failure?

Slope Factor Safety $> 1.30$
Mitigating the failure?

- Centerline
- Overburden Clay
- Concrete Cap
- EPS
- Previous Failure Surface
- Underdrain System (Benched on slope)
- Claystone
- Daylight Drainage

Slope Factor Safety
> 1.30
Depth of Bedrock
FOS = 1.38
Depth of Bedrock
FOS = 1.23
Case Histories Examples Corridors Yeh and Associates, Inc. have designed Geofoam Applications:

- US 50 – Montrose, CO
- US 160 – Durango, CO
- SH 13 – Rifle, CO
- US 26/89 – Jackson, WY
Site Conditions Colorado

- Sandstones and shales of the Mesaverde Group and Mancos Shale
- Highway embankments and fills exhibit low shear-strength properties when wetted and are prone to landslides and embankment failures.
- Overall the subject sites consisted of approximately 15 to 25 feet of low to medium plasticity clays underlain by weathered to unweathered shale/claystone bedrock.
Colorado US 50

Roadway Pavement Distress
MSE Walls Not Effective
Colorado US 50

1:1 Backslope or Flatter
Colorado US 50

Well Aligned Block Interlock System
Colorado US 50

Damaged Blocks to Outside
Colorado US 50

Cut with Hot Wire (No Chainsaws)
Project
• $3.9 Million Overall Project - 3 sites
• $56/CY Geofoam Placement (26,000 CY)
• 2 Season Construction
Colorado SH 13

Pavement Distress!
June 2010

WYOMING Highway 26/89

Pavement Distress!
Record Snow Winter
2011 to 2012
Project
• $2.2 Million Overall Project
• $90/CY Geofoam Placement (2,500 CY)
• 3 Month Construction
Geofoam Lightweight Fill

Reoccurring Construction Issues:

1. Handling of blocks to avoid damage
2. Layout
3. Acceptable gaps between blocks (1/4 inch - 1 inch)?
4. Accommodating short term settlement prior to paving.
Update on previous standard for slope stability applications

David Arellano, University of Memphis
Availability of Standards

• ASTM Standards
  • D6817 StandardSpecification for Rigid Cellular Polystyrene Geofoam
  • D7180 StandardGuide for Use of Expanded Polystyrene (EPS) Geofoam in Geotechnical Projects
  • D7557 StandardPractice for Sampling of Expanded Polystyrene Geofoam Specimens

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<tr>
<td>Compressive Resistance, min., kPa (psi) at 5 %</td>
<td>35 (5.1)</td>
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<td>90 (13.1)</td>
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<td>Compressive Resistance, min., kPa (psi) at 10 % A</td>
<td>40 (5.8)</td>
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<td>414 (60.0)</td>
<td>517 (75.0)</td>
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</tr>
</tbody>
</table>
Proven Technology

• Has been used in roads since 1972.
  • Proven durability
• Proven technology in various transportation applications.
• Design guidelines are available.
• Construction quality control and assurance standards available.
• FHWA designated priority, market-ready technology.
  • FHWA Resource Center serves as a resource for State DOTs.
  • GeoTechTools: Web-based geotechnical solutions for soil improvement, rapid embankment construction, and stabilization of the pavement platform.
Technology Information

Lightweight Fill

A lower unit weight of fill is used for roadway embankment construction and for other applications in combination with other technologies to reduce the magnitude of applied load and seismic horizontal forces so that the total embankment settlement can be reduced and stability can be increased. Advantages include accelerated construction, reduced structural requirements for resisting lateral loads, reduced settlement and stability problems, and suitability for wide variety of projects. This technique is applicable to embankments on soft soils and embankment widening.

Lightweight fill technology refers to six different categories of lightweight fill materials:

- Aggregate (includes pumice, scoria, Expanded Shale, Clay & Slate (ESCS), and slag)
- Cellular concrete (something referred to as foamed concrete)
- Fly ash
- Geofoam
- Shredded tire (sometimes referred to as Tire Derived Aggregate (TDA))
- Wood fiber
Download multiple documents

Check the individual boxes beside documents or use the "Check All" button to select the documents for download. After checking the desired documents, select the "Download Zip File" button at left to download your documents.

SHRP 2 ratings for Lightweight Fill

<table>
<thead>
<tr>
<th>Degree of Technology Establishment</th>
<th>Potential Contribution to SHRP 2 Renewal Objectives</th>
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<tr>
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<td>Rapid Renewal of Transp. Facilities</td>
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</table>

(Rating Scale: 1 = not established or low applicability, 5 = well established or high applicability)

See the SHRP 2 R02 Technology Ratings Summary for a legend and description of rating development.
Summary of Applications

- Road construction over poor soils
- Road widening
- Bridge abutment
- Bridge under fill
- Culverts, pipelines & buried structures
- Rail embankment
- Slope stabilization
- Airport taxiway
- Retaining and buried wall backfill
- Compensating foundations

- Landscaping & vegetative green roofs
- Stadium & theater seating
- Levees
- Foundations for lightweight structures
- Noise and vibration damping
- Compressible application
- Seismic application
- Permafrost embankments
- Rock fall/impact protection
Question & answer session