Expanded PolyStyrene (EPS) Blocks: Innovative Solutions in the Construction of EPS Structures

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What is EPS?

- EPS is short for Expanded PolyStyrene
- A generic commodity material used in commercial and engineering applications
- In load bearing applications, EPS is referred to as Geofoam or EPS Geofoam
What is EPS?

- Polymeric solid spherical beads with diameters \( \approx 0.2 \) to 3.0 mm

- Beads are pre-expanded \( \approx 50 \) times in volume under controlled steam and high temperature into cellular spheres known as "pre-puff"

- EPS block is formed by further expansion and fusion of the "pre-puff" under controlled high temperature and steam inside steel molds providing final shape of a block
EPS Molded Blocks
Applications in Massachusetts

- Central Artery / Tunnel (CA/T) Project - Approx. 42,000 CY – In Service
- Whittier Bridge / I-95 Improvement Project - Approx. 20,000 CY – Under Construction
Whittier Bridge Background

- EPS pursued as a side fill application to mitigate global stability and settlements of an underlying soft clay layer.
Whittier Bridge Background

- EPS blocks effectively placed against side slope
- An MSE wall alternative design requires straps extending to 70% of height and SOE to construct the straps
CA/T Background

• EPS Embankments were pursued on CA/T Project as a cost and schedule initiative at the suggestion of the Federal Highway Administration (FHWA)
• 12 candidate structures evaluated on I-90/ I-93 South Bay Interchange for redesign as EPS fills
• 8 EPS structures replacing transition bridges of the original design concept
ORIGINAL DESIGN CONCEPTS

1. Precast Concrete Bridge

2. Elevated Slab-On-Piles

3. Fill over Slab-On-Piles
South Bay Interchange – During Construction
Why EPS?

- Unit weight 1.0 – 2.0 pcf (≈ 1±2% soil self weight)
- Very low density of EPS significantly reduces dead loads i.e. high % of total loads
- Total load reduction ⇔ major cost savings for structures founded on weak soil subgrades
- Offers additional cost and schedule advantages as it eliminates the need for deep foundations, soil pre-loading, and removal of poor soils
Additional Advantages

1. Self-stable structurally, does not require lateral supports
2. No lateral pressure on adjacent structures ($\nu \approx 0.1$)
3. Construction does not require specialty labor or machinery
4. Blocks assembled under all weather conditions
5. Not susceptible to freeze-thaw cycles
6. Outstanding insulation properties
7. No water absorption inside expanded "closed" cells
8. Water absorption is reversible between fused cells
9. Inert, non-toxic, and environmentally safe
10. Extremely durable in the ground with indefinite service life
COST

• EPS is a derivative of oil affected by World Prices
• Unit cost of EPS block material in place varies by region and volume
• 2014 unit cost for EPS100 installed in NE ranges from $100 / cu. yd → $120 / cu. yd
• EPS wins over alternative lightweight fill materials when **ALL** factors and benefits are considered and **NOT ONLY** on a cost / volume basis
Limitations & Design Solutions

**LIMITATIONS**

1. Susceptible to Buoyancy
2. May dissolve in Diesel fuels

**SOLUTIONS**

1. Secondary lightweight fill material used to offset buoyancy forces
2. A) Roadway System with adequate protection for the blocks to contain possible fuel spills
   B) Adequate drainage
EPS Structure - Typical Cross-Section
TYPICAL GEOMETRY

- All ramps with vertical sides
- Overall height $H$ varies $\approx 6 \rightarrow 27$ ft. above existing grade
- Width $W$ mostly constant $\approx 27$ ft. on average
- Majority of ramps are slender with many segments of $H/W$ ratio $\leq 1$
- Widest ramp is shallow $\approx 55$ ft. wide
- One curved ramp with small $R \approx 310$ ft.
- Some ramps with profile grade of up to $\pm 7\%$
CA/T - EPS HIGHLIGHTS

1. Project Design Criteria and Seismic Behavior
2. Project Specification
3. Side Covering System
4. Special EPS Applications & Curved Construction
Project Design Criteria and Seismic Behavior
PROJECT DESIGN CRITERIA

Marked first time implementation of AASHTO Standard Specification for Highway Bridges (16th Edition) into EPS design, including:

1. Dead and live loads
2. Wind and seismic loads
3. AASHTO Group load combinations with applicable increases in allowable stresses
4. Factors of Safety against sliding and overturning for external stability analysis
DESIGN PHILOSOPHY

• Design based on Service Loads and Allowable Stress Design (ASD)
• Net stress increase on existing subgrade is not allowed
• Design considers buoyancy effects
System Elasticity is represented by the combined flexural and shear stiffness of the relatively “massless” EPS blocks.
TRADITIONAL SEISMIC BEHAVIOR

1. Rigid body sliding
   (in longitudinal direction)
TRADITIONAL SEISMIC BEHAVIOR

2. Flexible horizontal sway
   (in transverse direction)
NEWLY RECOGNIZED SEISMIC BEHAVIOR

3. Seismic Rocking

\[ \frac{P}{A} \pm \frac{Mc}{I} = \text{Subgrade} \]
SEISMIC ROCKING EFFECTS

Regions of **SIGNIFICANTLY HIGH** normal stresses (Mc/I) due to seismic rocking

Regions of **HIGH** normal stresses (Mc/I) due to seismic rocking
SEISMIC ROCKING IMPACTS

- Controlled the design of most CA/T - EPS structures given their H/W ratio
- Confirmed by a coincidental review of shake table tests results conducted in Japan on slender EPS embankments with (H/W ≈ 0.66, 1.28, 1.70)
- EPS blocks removed at the conclusion of the tests showed evidence of crushing in the same areas where the highest seismic stresses were computed analytically in the design
EPS Blocks with high normal stresses (P/A) due to gravity loading
COMBINED EFFECTS

- EPS 100 (2.0 pcf density) used throughout all EPS structures and ramps on CA/T Project
Project Specification
SPEC HIGHLIGHTS

- MQC Submittal reviews
- MQA, block verification, testing and acceptance
- **Material properties**
- Development and approval of Shop Drawings
- Product delivery, storage and handling
- CQC, construction tolerances, block placement
- Site preparation, block disposal
Key to EPS Success?

1. Properly molded block
MATERIAL PROPERTIES

- A new EPS material designation "EPSxx" was introduced
- "xx" represents elastic limit in (kPa)
- Elastic limit ($\sigma_e$) is a **KEY** design parameter
  $\sigma_e = \text{allowable compressive stress}$ corresponding to 1% strain
- "xx" x 100 gives Elastic Modulus of EPS, allowing calculation of material strains
# AASHTO Material Properties

<table>
<thead>
<tr>
<th>AASHTO Material Designation</th>
<th>Minimum Allowable Dry Unit Weight of entire EPS block (Lbs/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPS40</td>
<td>1.00</td>
</tr>
<tr>
<td>EPS50</td>
<td>1.25</td>
</tr>
<tr>
<td>EPS70</td>
<td>1.50</td>
</tr>
<tr>
<td>EPS100</td>
<td>2.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AASHTO Material Designation</th>
<th>Dry Density (Lbs/ft³)</th>
<th>Compressive Strength (Psi)</th>
<th>Flexural Strength (Psi)</th>
<th>Elastic Limit Stress (Psi)</th>
<th>Initial Tangent Young’s Modulus (Psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPS40</td>
<td>0.90</td>
<td>10</td>
<td>25</td>
<td>5.8</td>
<td>580</td>
</tr>
<tr>
<td>EPS50</td>
<td>1.15</td>
<td>13</td>
<td>30</td>
<td>7.2</td>
<td>725</td>
</tr>
<tr>
<td>EPS70</td>
<td>1.35</td>
<td>15</td>
<td>40</td>
<td>10.2</td>
<td>1015</td>
</tr>
<tr>
<td>EPS100</td>
<td>1.80</td>
<td>25</td>
<td>50</td>
<td>14.5</td>
<td>1450</td>
</tr>
</tbody>
</table>
COMPRESSIVE STRENGTH TESTING

EPS100 SAMPLE BR 188

ELASTIC MODULUS
2x2 in. TEST SAMPLE BR 188 A

\[ y = 17.844x - 1.5317 \]

\[ R^2 = 0.9973 \]
Sampling locations A1, B1 and C1 are at or near the top or bottom (contact) surface of the block.
Sampling locations A2, B2, B3, C2 and C3 are at or near the center (or mid-height) of the block.

L = Length of block; W = Width of Block; H = Height of block
Sampling locations A1, B1 and C1 are at or near the top or bottom (contact) surface of the block. Sampling locations A2, B2, B3, C2 and C3 are at or near the center (or mid-height) of the block.

L = Length of block; W = Width of Block; H = Height of block

**EPS SAMPLING**

1. Prior to cutting the test specimen, EPS molder shall provide the total dry weight of the block as a whole, the corresponding unit weight in pcf and overall dimensions of the block.

2. Each test specimen shall be cut by a hot wire apparatus, shall have orthogonal sides and perfectly planar faces.

3. The following number of EPS test specimen with the corresponding shown sizes shall be provided by the EPS Molder:

<table>
<thead>
<tr>
<th>SPECIMEN SIZE</th>
<th>NUMBER OF TEST SPECIMENS AT EACH LOCATION</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Location</td>
<td>A1</td>
</tr>
<tr>
<td>1&quot;x 4&quot;x 12&quot;</td>
<td>4&quot;x 4&quot;x 8&quot;</td>
<td>2</td>
</tr>
<tr>
<td>2&quot;x 2&quot;x 2&quot;</td>
<td>4&quot;x 4&quot;x 4&quot;</td>
<td>2</td>
</tr>
<tr>
<td>12&quot;x 12&quot;x 12&quot;</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

4. Test specimen shall be marked A1, A2, B1, B2, etc., together with a block identification if more than one EPS block is being used.

5. EPS Molder shall include in their letter to the CA/T Project the following information:
   1) Bead size as well as identity and name of bead supplier
   2) Type of raw material used i.e. whether modified or flame retardant material
   3) Pentane content i.e. normal or low volatile material
   4) Whether block was trimmed after molding prior to measuring the dimensions requested in item (1) above.
   5) Certification that no regrind is used and that the blocks used for the test specimens are in conformance with CA/T Specification 909.101 for Block-molded Expanded Polystyrene.
1. For each test specimen size at each individual location, ONE specimen shall be tested by CA/T-TSD Materials Lab and ONE specimen tested by an independent third party lab.

2. The following are the locations designated for each test:
   C1 & C2 used for compression strength, elastic limit and tangent modulus.
   C3 for flexural strength test.
   B1 & B2 for unit weight (density test).
   A1 & A2 for compression strength, elastic limit and tangent modulus.
   B3 would be available for additional compression strength testing if additional testing is required.

<table>
<thead>
<tr>
<th>SAMPLE LOCATION</th>
<th>TESTING RESULTS</th>
<th>A1</th>
<th>A2</th>
<th>C1</th>
<th>C2</th>
<th>B3</th>
<th>AVG.</th>
<th>Specs.</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength (*)</td>
<td>25 psi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic Tangent Modulus</td>
<td>1450 psi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic Limit</td>
<td>14.5 psi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) = Per ASTM C-165 at 10% strain rate

<table>
<thead>
<tr>
<th>SAMPLE LOCATION</th>
<th>TESTING RESULTS</th>
<th>B1</th>
<th>B2</th>
<th>AVG.</th>
<th>Specs.</th>
<th>Pass / Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight per ASTM C-303</td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
<td>1.8 pcf</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAMPLE LOCATION</th>
<th>TESTING RESULTS</th>
<th>C3</th>
<th>AVG.</th>
<th>Specs.</th>
<th>Pass / Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Strength per ASTM C-203</td>
<td>-</td>
<td></td>
<td>N/A</td>
<td>50 psi</td>
<td></td>
</tr>
</tbody>
</table>
Side Covering
Side Covering Facts

- Not required to support EPS structurally
- Primary function is long-term protection of blocks
- Provides an architectural finish to the exterior exposed surfaces i.e. aesthetic function
- Proper selection of a side cover may result-in significant cost and schedule savings
**Exterior Insulation and Finish System (EIFS)**

**EPS SUBSTRATE** [EPS 100]

**EPS BOARD BASE** (EPS 40)
(1 pcf density, 2 3/4 in. thick)

**POYMERIC ADHESIVE** mixed with **PORTLAND CEMENT**

**BASECOAT**

**4.5 oz. FIBERGLASS STANDARD IMPACT REINFORCING MESH**

**REINFORCED FINISH COAT**

**20 oz. FIBERGLASS HIGH IMPACT REINFORCING MESH**
fully embedded within the **BASE COAT**

Decorative, Protective & Textured **ELASTOMERIC FINISH COAT & SEALER**
Typical Cross-Section
EIFS Side Covering
EIFS

- EIFS achieved uniformity in appearance with other precast concrete curtain walls of adjacent CA/T transition structures
- Final product weights approx. 1.5 psf
- EIFS material properties compatible with EPS substrate
- CA/T – EPS/EIFS application believed to be the first on a transportation structure worldwide
EIFS – Typical Elevation
EIFS – Typical Details at Termination Points
Finished EIFS – CA/T - Ramp X
Finished EIFS – CA/T - Ramp X
Finished EIFS – CA/T - Ramp X
Finished EIFS – Ramp KK
EIIFS / EPS Fire Performance

- No available ASTM Standards addressing Fire Performance of EIFS installed on EPS blocks
- Full Scale Fire Tests were necessary to assess Fire Performance of the system
EIFS / EPS Fire Testing

• 2 - EPS/EIFS wall mock-up assemblies were constructed for full scale fire tests at Omega Point Lab in San Antonio, TX
• Mock-ups used same materials and details in conformance with approved Submittals
• 2 Full Scale Fire Tests conducted: a pallet fire and 100 gallon diesel pool fire,
• Test duration on each wall was 30 minutes
EIFS Fire Test Conclusions

- EIFS provided significant protection for EPS
- Size of both fires manageable at 30 minutes
- Structural damage to EPS substrate was limited
- No adverse effects on structural safety or integrity of EPS blocks assembly
- EPS / EIFS assembly **satisfied** 30 minutes fire resistance requirement established by Boston Fire Dept. (BFD)
Special EPS Applications & Curved Construction
Key to EPS Success?

1. Properly molded block
2. Properly Constructed blocks
Temporary / Permanent Ramp KK
Temporary / Permanent Ramp KK
Steel Connector Plates
Permanent Ramp KK – Leveling Bedding Layer
Permanent Ramp KK – First Layer Blocks Assembly
Permanent Ramp KK - Blocks Assembled East Side
Temporary Ramp KK - Early Blocks Placed
Temp Ramp KK - Advancing Block Placement
Temporary / Permanent Ramp KK – In Service
Temporary Ramp KK Demo
Temporary Ramp KK Demo Complete
Curved Ramp F under Construction
Curved Ramp F under Construction
Project Credits

Owner:

Massachusetts Turnpike Authority (MTA) - CA/T Project

Management Consultant:

Joint Venture Bechtel / Parsons Brinckerhoff (B/PB)

EPS Consultant:

Dr. John S. Horvath, P.E.

EIFS Fire Consultant:

Koffel Associates, Inc.

Section Design Consultant:

Joint Venture Berger / Lochner / Stone & Webster

Contractor:

Modern Continental Construction, Inc.
Acknowledgment

- CA/T - EPS Embankments are the outcome of extensive joint effort between B/PB and MTA
- The EPS redesign initiative resulted in several innovations establishing new National Design and Construction Standards for EPS applications on transportation structures
- The guidance and strong support of the FHWA Office of Infrastructure to pursue and advance EPS technology was instrumental to its success on the CA/T Project
Thank you
Questions ?