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GEOFOAM DESIGN AND CONSTRUCTION GUIDELINES

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

APRIL 2014
1.0 INTRODUCTION

This document presents guidelines for the use of geofoam on Department roadway and structure projects. Geofoam is an extremely lightweight material that can be used to construct embankments and backfill behind structures. This document includes a discussion of the typical properties of geofoam, applications where geofoam may be beneficial, variables that affect the cost of using EPS geofoam, and geofoam design and construction requirements and considerations. Appendix A of this document includes a profile and section view of a geofoam embankment as well as details for use on Department projects, and Appendix B includes a sample calculation for determining the compressive resistance requirements of the geofoam for the anticipated loading.

1.1 Definition of Geofoam

Geofoam is a generic term used to describe any foam material that is used for a geotechnical application. Geofoam is an extremely lightweight, manufactured material produced by an expansion process that yields numerous closed, gas filled cells. A “blowing agent gas”, which is typically something other than air, fills the cells during the manufacturing process. Air eventually displaces the blowing agent gas after the geofoam is manufactured. Most geofoam materials are polymeric (i.e., plastic), and the most commonly used polymer to make geofoam is polystyrene.

1.2 Overview of Geofoam Manufacturing Process

There are currently two methods used to manufacture polystyrene foam, and they are the molding method and the extrusion method.

- The molding method is a two-step process where in the first step tiny polystyrene beads are expanded to make “pre-puff”, and in the second step the pre-puff is fused together in a molding process. This material is typically referred to as expanded polystyrene (EPS), it is white, and the individual beads can generally be seen.
- The extrusion method is a single, continuous process that produces expanded polystyrene foam referred to as extruded polystyrene (XPS). XPS foam is typically colored (i.e., blue, pink, etc.) during the manufacturing process for proprietary purposes only.

Note that the term “styrofoam” is commonly and erroneously used as a generic term, when in actuality this term is a registered trademark for a specific brand of XPS foam. Consequently, the term styrofoam should not be used when referring to EPS or XPS foam in general terms.

Polystyrene foam is manufactured in a variety of shapes and sizes depending upon the method and equipment used by individual manufacturers. EPS foam is usually molded in “block” form, and a typical block can measure 2 feet high by 4 feet wide by 16 feet long. The molded blocks are then cut in the factory to the size required for the specific application. XPS foam is typically extruded in “sheets” no thicker than 4 inches. Since the block form of foam is more convenient for large volume applications compared to thin sheets, EPS foam is almost
exclusively used on roadway and structure projects. The remainder of this document will concentrate on EPS geofoam.

1.3 Expanded Polystyrene (EPS) Geofoam Properties

The physical properties of EPS geofoam are varied and controlled during the manufacturing process, and these properties are specified in ASTM D6817, “Standard Specification for Rigid Cellular Polystyrene Geofoam”. Seven types or designations of EPS geofoam are listed in D6817, including: EPS12, EPS15, EPS19, EPS22, EPS29, EPS39 and EPS46. Note that the EPS number designation corresponds to the required density of the geofoam in kilograms per cubic meter ($\text{kg/m}^3$). For example, the minimum required density of EPS22 is 21.6 kg/m$^3$.

<table>
<thead>
<tr>
<th>Physical Property Requirements of EPS Geofoam$^{(1)}$ (Reference: ASTM D6817, TABLE 1)</th>
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<tbody>
<tr>
<td><strong>Property</strong></td>
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<tr>
<td>Density (pcf)</td>
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<td>Compressive Resistance at 1% Deformation (psi)</td>
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<td>Compressive Resistance at 5% Deformation (psi)</td>
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<tr>
<td>Oxygen Index (Vol. %)</td>
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<td>Water Absorption (Vol. %, max)</td>
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$^{(1)}$ All values minimum unless indicated otherwise.

The two properties of geofoam that are of particular interest for geotechnical applications and that are listed in D6817 are the minimum density and the minimum compressive resistance. Based on the requirements of D6817 for the seven EPS geofoam types, the minimum density varies from 0.7 to 2.85 pounds per cubic foot (pcf), and the minimum compressive resistance varies from 2.2 to 18.6 pounds per square inch (psi), as measured at 1% strain/deformation. Due to the very small variation in density between the seven different types of EPS geofoam, and since this variation will generally be negligible with respect to geotechnical and structural analyses, the compressive resistance will typically control the selection of the geofoam designation required for the specific project application. As discussed in Section 2.0 of this document, geofoam types EPS22 and EPS39 will be most commonly used on Department projects. Note that the Department’s Geofoam Lightweight Fill Specification refers to EPS22 as Type 1 geofoam and EPS39 as Type 2 geofoam.
Note that only geofoam products included in Bulletin 15 can be used unless project specific approval is obtained to use another manufacturer or EPS designation.

1.4 Typical Uses of EPS Geofoam

EPS geofoam used on roadway and structure projects typically weighs less than 2 lbs/ft$^3$. In comparison to other materials, EPS geofoam weighs approximately:

- 1% to 2% of the weight of typical earth materials (i.e., soil and rock)
- 3% of the weight of typical lightweight aggregates
- less than 10% of foamed/cellular concrete.

1.4.1 Settlement Control

Since EPS geofoam is extremely lightweight, it is typically used for settlement control. When the magnitude and/or time rate of settlement estimated from the load of traditional embankment material is not tolerable, measures must be taken to reduce settlement and/or decrease the time needed for settlement to occur. These measures often include one or more of the following:

- wick/prefabricated vertical drains or sand columns
- preload or surcharge embankment
- ground improvement – deep dynamic compaction (DDC), stone/aggregate columns, jet grouting, etc.

In lieu of these measures, EPS geofoam can be used as the fill material to construct embankments to significantly reduce, or completely eliminate, settlement.

Long-term (i.e., secondary consolidation) settlement of organic soils cannot be mitigated using conventional measures typically used for primary consolidation (i.e., wick drains, preload embankment, DDC, etc.). Therefore, the extremely light weight of EPS geofoam can be particularly useful to eliminate or significantly reduce secondary consolidation settlement when such settlement is anticipated and the expected magnitude over the life of the facility will potentially pose a problem.

Similarly, EPS geofoam may be useful in minimizing or eliminating differential settlement. For instance, if an embankment or structure is proposed to be widened, and settlement from traditional fill materials are estimated to create differential settlement that is not tolerable, or settlement that may be detrimental to existing pavement or structures, the use of EPS geofoam may be a viable option. Additionally, where intolerable settlement of an approach embankment to a bridge that is founded on a “rigid”, deep foundation is anticipated, the use of EPS geofoam may be beneficial to eliminate or reduce the settlement to a tolerable amount.

Embankments constructed over existing utilities, archeological areas or other sensitive features could also be constructed with EPS geofoam to reduce the load and corresponding settlement, and minimize the impact of embankment construction. If used over utilities, it would be important that the EPS geofoam system (including membrane barriers) be replaced as per
original design should any work be conducted on utilities that requires removal of the geofoam system.

1.4.2 Slope Stability

EPS geofoam can also be considered for fill material where global slope stability is a concern, either for new embankment construction or for remediation of a slope failure/landslide. The EPS geofoam blocks are extremely light weight and add insignificant loads, and therefore are advantageous when constructing embankments on unstable/low shear strength material. Replacing existing soil/rock embankment material with EPS geofoam (i.e., load reduction) may be sufficient to remediate an active landslide when used to reduce the driving force along the failure plane.

1.4.3 Structure Backfill

Under certain conditions EPS geofoam is advantageous for backfilling behind structures. The light weight of the EPS geofoam applies insignificant vertical load to structure foundations. Additionally, due to the light weight of the geofoam and since geofoam blocks are inherently stable when stacked vertically, virtually no lateral load is applied to bridge abutments and retaining walls from EPS geofoam when used as backfill. In such situations, either the EPS geofoam must extend beyond the limits of the active earth pressure wedge, or lateral loads from fill placed behind the EPS geofoam must be accounted for in the design. Geofoam can be used for structure backfill on new structures or where the height of an existing structure must be increased but the existing foundation cannot support the load from traditional structure backfill material.

1.5 Economic Analyses of EPS Geofoam

Although EPS geofoam has some unique and beneficial qualities that other materials do not have, in most cases there will be other more economical options, other than geofoam, that will accommodate project needs. For example, in lieu of using EPS geofoam to limit settlement lightweight foamed concrete may be a viable option, or a surcharge embankment, with or without wick drains and a quarantine period may be an option. Alternatively, a ground improvement or modification technique may be used to either increase the strength of the foundation soil or transfer loads to a deeper, more competent stratum. As in any design situation, where multiple feasible options exist to address the site conditions and project needs, an economic analysis should be performed and considered to help select the most viable alternative.

Similar to other construction materials and alternatives, there are multiple factors that must be considered when estimating the cost of EPS geofoam for use on a roadway or structure project. Below are some, but not necessarily all, of the factors that must be taken into account when considering the cost of EPS geofoam for a specific project. Cost data that was gathered at the time this document was prepared is presented later in this section. The cost data presented herein is for information purposes only, and should not be used for estimating the cost of EPS geofoam for a specific project unless the information is verified. When preparing a cost estimate for a
specific project, manufacturers and suppliers of EPS geofoam should be contacted to obtain current price information, and bid tabulations from recent projects that included EPS geofoam can also be considered.

1.5.1 EPS Geofoam Cost Versus Density

The cost of EPS geofoam is directly related to the density of the geofoam. The density of the geofoam is controlled by the amount of polystyrene used, and the higher the geofoam density the more polystyrene is needed. Therefore, the material cost of the EPS geofoam increases as the density increases. Below are costs for various types of EPS geofoam that were obtained from a manufacturer in early 2014:

\[
\begin{align*}
\text{EPS19} &= $60/cy \\
\text{EPS22} &= $70/cy \\
\text{EPS29} &= $90/cy \\
\text{EPS39} &= $125/cy
\end{align*}
\]

These prices assume a quantity of at least 10,000 cubic yards will be used, include an approximately $3.50/cy transportation cost for shipping within 200 miles of the factory, but do not include the cost of placing the material. Due to the considerable cost difference between the various geofoam densities it is important to determine the appropriate density for the intended application.

1.5.2 EPS Geofoam Cost Versus Crude Oil Price

As previously indicated the most commonly used polymer to make EPS geofoam is polystyrene. Polystyrene consists of long chains of the styrene monomer or molecule, and the raw materials used to make styrene are obtained from crude oil. Consequently, the cost of the raw materials (i.e., styrene) used to make EPS geofoam will vary with the cost of crude oil. Information obtained from an EPS manufacturer’s website in early 2013 indicated the following relationship between the price of a barrel (BBL) of crude oil and the price of various types of EPS geofoam. These prices do not include freight/transportation cost.

\[
\begin{align*}
\text{EPS15} &= $40.50 \quad $140/BBL \quad $50.50 \\
\text{EPS22} &= $52.00 \quad $73.00 \\
\text{EPS29} &= $63.00 \quad $90.00
\end{align*}
\]

Note that in early 2013, the price of crude oil was approximately $100/BBL.

As previously discussed the density of the EPS geofoam is dependent upon the amount of raw materials (i.e., styrene) that are used, which is why as is observed above, the price of EPS geofoam disproportionally increases with higher geofoam density as crude oil price rises. As the price of crude oil fluctuates, it is likely that the price of EPS geofoam will fluctuate as well. This price relationship can be significant depending upon the volatility of crude oil prices, and can be problematic since a cost estimate completed for a project during design, may not reflect market
prices by the time a project is bid. A significant change in the price of crude oil would most likely change the cost of the EPS geofoam, which could make it more or less economically viable than originally believed. Additional discussion on this topic is provided in the NCHRP Project No. 24-11(02) Final Report.

1.5.3 Transportation Cost

The cost of transporting the EPS geofoam from the manufacturer to the project site must be considered. Similar to any material, the longer the distance of the haul the more expensive the material will be to use. As discussed above, one estimate from a manufacturer indicated transportation cost at approximately $3.50 per cubic yard for a project site located within 200 miles of the manufacturing facility. Based on other available shipping cost information, this price is probably more reasonable for a shorter hauling distance of approximately 100 miles to the site. Since the geofoam is extremely lightweight, shipping constraints are based on volume and not weight. Typically approximately 125 cubic yards of material can be transported in a single load.

1.5.4 Placement Cost

When estimating the cost of EPS geofoam, placement of the blocks must be accounted for in addition to material and transportation costs. Information included in the NCHRP Web Document 65 indicates placement cost can vary from $10 to $25 per cubic yard. These costs were from projects constructed more than a decade ago (i.e., pre-2003); therefore, more up to date costs should be obtained when estimating EPS geofoam costs for a specific project. Placement cost will depend on numerous variables, including total volume of material placed, experience of contractor, complexity of the geometry and amount of specialty fabrication/cutting required.

1.5.5 Hydrocarbon Resistant Geomembrane Cost

EPS geofoam is not resistant to petroleum products, including gasoline and diesel fuel, as well as other solvents. This is discussed in more detail in Section 2.0 of this document. Consequently, when EPS geofoam is used on Department projects, a hydrocarbon resistant geomembrane must be used to encapsulate the geofoam (refer to Appendix A). The geomembrane must be accounted for in the cost estimate. Hydrocarbon resistant geomembranes are more costly to manufacture than conventional geomembranes used for water containment and municipal landfills. Available data at the time this document was prepared indicates that the material cost alone can be approximately $10 per square yard. Therefore, the cost of the hydrocarbon resistant geomembrane will be a significant part of the overall EPS geofoam system. Some situations may require the use of a concrete distribution slab constructed on top of the geofoam. If a concrete slab is required by design, its cost must also be accounted for in the EPS geofoam system.

1.5.6 Miscellaneous Costs

Other miscellaneous costs that must be considered when estimating the cost of EPS geofoam for use as lightweight fill include: bedding material, mechanical connectors, insecticide and any
non-standard, project specific requirements. Although these costs are typically minimal compared to cost factors discussed above, they should none the less be included in a cost analysis or estimate.

1.6 References

There were numerous references consulted to prepare this document, and many of them provide a more detailed discussion on topics presented herein. It is recommended that these and other references be consulted when considering the use of EPS geofoam on a project. Some EPS geofoam references are listed below:


2.0 DESIGN REQUIREMENTS AND CONSIDERATIONS

Geotechnical analyses are required to design EPS geofoam embankments. At a minimum settlement and global slope stability analyses must be performed. In some cases, additional analyses including bearing resistance, sliding and seismic stability must be performed. These analyses are discussed below along with other design requirements and considerations for the use of EPS geofoam on Department projects. Additional details and discussion concerning analyses associated with EPS geofoam embankments can be found in the NCHRP Web Document 65.

2.1 Settlement Analyses

In most cases EPS geofoam will be used, at least in part, to eliminate or reduce the estimated settlement from embankment construction to a tolerable level. Settlement analyses must be performed to not only justify the need for the use of EPS geofoam in place of more standard and economical fill materials (i.e., embankment material or structure backfill), but to also determine the required limits of the EPS geofoam within the embankment cross-section. Immediate, consolidation, and secondary consolidation settlement must be considered.
Once it is determined that EPS geofoam is needed and is a viable alternative, the settlement analysis will indicate one of several scenarios with respect to placement limits. These may include constructing the entire fill section using EPS geofoam (with exception of required embankment cover), constructing a limited zone of the fill using EPS geofoam (this could include specific vertical limits of the fill or a specific horizontal area where load reduction is required), or some combination of the two.

Since EPS geofoam is of substantially higher cost than standard embankment and structural fill materials, it may be very important to limit the amount of EPS geofoam in the embankment cross-section. Where settlement analyses indicate it is acceptable and when practical, construct the lower portion of the embankment cross-section with standard materials, and place EPS geofoam above the embankment/structure backfill material to complete construction of the embankment. Conversely, settlement analyses may indicate that the load from the embankment cover material and pavement section above the EPS geofoam embankment results in unacceptable settlement. In these cases it may be necessary to remove in-situ material below the proposed embankment and replace it with EPS geofoam in order to balance the load from the cover material and pavement section. Since EPS geofoam has a density much less than that of water it is important that the local groundwater elevation be identified, so as to avoid problems with buoyancy.

2.2 Global Slope Stability Analyses

EPS geofoam is often used to address settlement concerns; therefore, the in-situ soil that the geofoam is placed on is often soft, saturated and low strength. It is important that global slope stability be considered when designing an EPS geofoam embankment. Global slope stability analyses should be performed similar to analyses performed for conventional embankments constructed with earth materials. Since the in-situ foundation material will often be saturated, cohesive soil, both undrained and drained shear strength parameters must be used in the analyses.

Similar to the settlement analyses, slope stability analyses should be performed to not only verify the stability of the proposed embankment configuration, but to also optimize the amount of EPS geofoam used (because of its high cost relative to conventional embankment materials). In many cases settlement will control the amount of geofoam needed in the embankment cross-section, and the slope stability analyses are performed to verify stability of the proposed embankment cross-section. However, when settlement does not control, and when practical and economical, use the slope stability analyses to help determine the most appropriate embankment configuration and placement location of the EPS geofoam.

The difficulty in performing the global slope stability analyses is how to most accurately model the shear strength of the EPS geofoam embankment. NCHRP Web Document 65 and Project No. 24-11(02) Final Report presents several methods to model the EPS geofoam embankment. However, each method has shortcomings, and there is currently no widely recommended or accepted method. Based on review of these methods and independent analyses, the methods discussed below must be used to analyze slope stability of geofoam embankments for Department projects.
1. The foundation material supporting the EPS geofoam must be analyzed by modeling the geofoam, cover materials, pavement section, traffic surcharge and any other loads as a uniform surcharge load applied at the base of the geofoam fill. This method eliminates the need to assign shear strength parameters to the EPS geofoam. For a typical embankment cross-section with side slopes (refer to Appendix A), the surcharge load will vary along the base of the geofoam due to variation in cover thickness materials, extent of pavement section, traffic surcharge and other possible loads. Load distribution through the geofoam should not be used when calculating the surcharge load to be applied at the base of the geofoam.

As an example, assume a 20-foot-high geofoam embankment is proposed. The embankment has 2H:1V side slopes, and a minimum of 4 feet of embankment cover (measured perpendicular to slope face) will be placed on the side slopes. Three feet of cover will also be placed over the geofoam beneath the pavement section, and a 2-foot-thick pavement section is anticipated. The surcharge loads applied at the base of the geofoam fill for the slope stability analysis would consist of an approximately 600 psf uniform surcharge beneath the side slopes of the embankment, and an approximately 1,000 psf uniform surcharge beneath the roadway/pavement portion of the embankment. The 600 psf surcharge accounts for approximately 5 feet of embankment cover material (measured vertically over side slopes) and the negligible weight from the geofoam. The 1,000 psf surcharge accounts for 3 feet of embankment cover, 2-feet-thick pavement section, traffic surcharge load of 360 psf and negligible weight from the geofoam.

2. In addition to analyzing the geofoam foundation material as discussed above, the internal stability of the geofoam embankment and compound failures extending through the geofoam embankment and into the foundation material must be considered. These failure modes must be analyzed by modeling the EPS geofoam with a shear strength value consisting of a combination of friction and cohesion to simulate failure both along joints between blocks and through individual blocks. NCHRP Web Document 65 suggests using a shear strength consisting of 25% of the cohesion of a geofoam block, and 75% of the interface friction angle between geofoam blocks. The geofoam block cohesion is assumed to equal half of the compressive resistance at 1% strain, and a block interface friction angle of 30 degrees is commonly used. Therefore, for Type 1 geofoam (i.e., EPS22), the shear strength used in the slope stability analysis to model the geofoam would consist of cohesion equal to 0.9 psi (i.e., 25% of 3.65 psi) and an internal friction angle equal to 22.5 degrees (i.e., 75% of 30 degrees).

Note that if seismic slope stability analyses are required, Method 1 discussed above cannot be used because in a pseudo-static analysis the seismic force must be applied at the center of gravity of the sliding mass.
2.3 EPS Geofoam Compressive Resistance

Since all EPS geofoam is extremely lightweight, the compressive resistance of the EPS geofoam, and not the density, will likely be the property that controls the geofoam type required for a specific project and application. In order to estimate the required compressive resistance of the EPS geofoam, the vertical load(s) proposed to be placed on it must be estimated. These vertical loads typically fall into two areas (however other load conditions that may occur must be considered). The first are service loads comprised of (but not necessarily limited to) dead loads from embankment cover, pavement and traffic live loads. The second are construction live loads from construction equipment used during placement and compaction of cover materials and pavement. Some combination of construction loads with already placed cover materials may also control. Note that construction live loads will typically control, but all combinations must be considered to determine the critical loading condition.

ASTM D6817 includes physical property requirements for seven types of EPS geofoam, and these are also shown in Section 1.3 above. Compressive resistance requirements for EPS geofoam are reported at strains of 1%, 5% and 10%. As indicated in ASTM D7180, the compressive resistance at 1% strain should be used to select the appropriate EPS geofoam type for the anticipated long-term loads. The compressive resistance at 1% strain, which is also referred to as the elastic limit stress, provides acceptable short-term deflections and limits long-term creep deformation. The compressive resistance at 5% or more strain is into the plastic behavior region of the EPS geofoam where long-term creep deformation can be a problem.

Detailed discussions on the procedure for estimating vertical load applied to the EPS geofoam from dead and live load is included in NCHRP Web Document 65 and Project 24-11(02) Final Report. However, these NCHRP reports only address the service condition; they do not discuss loading conditions during construction. Both service and construction loading conditions are discussed below.

2.3.1 Live Load

The most severe live load applied to roadways is typically wheel loads from large trucks, and these loads can result in pressures of over 100 psi at the point of load application. These pressures are well above the compressive resistance of EPS geofoam, and therefore is the reason large trucks and other equipment are not permitted directly on the surface of EPS geofoam. Wheel loads do, however, dissipate quickly with depth due to load distribution, which is commonly assumed to occur at a ratio of 1H:2V or flatter, depending upon the material the load is distributed through (i.e, soil, aggregate, concrete, etc.). Consider a dual tire with a contact area of 100 square inches at the surface (i.e., point of application), and a pressure distribution of 1H:2V with depth, which is commonly used for soil/embankment. The distributed contact area at a depth of 6 inches is nearly 3 times the contact area at the surface, and the distributed contact area at a depth of 18 inches is over 8 times the contact area at the surface. The load distribution with depth quickly reduces the pressure from wheel loads. For instance, with 4 feet of cover material placed on top of EPS geofoam, the pressure from wheel loads is typically less than approximately 4 psi.
2.3.2 Dead Load

Dead load applied to EPS geofoam embankments is typically from the cover materials and pavement section that is placed on top of the geofoam. Unlike wheel loads, these dead loads are not distributed with depth due to the large area of the applied load. Considering that the typical unit weight of soil embankment and pavement ranges from approximately 120 to 140 pcf, each foot of these materials placed on top of EPS geofoam results in approximately 1.0 psi pressure to the geofoam. Because of this, only the minimum necessary cover materials and pavement should be placed on top of EPS geofoam and, the geofoam should always be placed in the upper portion of the embankment above the traditional earth embankment materials in order to limit the dead load placed on the EPS geofoam.

2.3.3 Sample Calculations

Sample calculations were prepared and are included in Appendix B. The calculations were done for conditions that are representative of a typical EPS geofoam embankment designed and constructed in accordance with the Department’s Geofoam Lightweight Fill Specification and this Use Guideline. Construction loads/conditions and final loads/conditions were considered. These calculations represent specific project conditions and assumptions. Calculations must be performed and submitted that represent specific project conditions and needs if they differ from those presented in Appendix B. A discussion of the sample calculations is provided below.

2.3.3.1 Construction Condition - Case 1:

As previously stated due to the relatively low compressive resistance of EPS geofoam, construction equipment is not permitted directly on the surface. Therefore, the load from construction equipment at the surface of the geofoam was estimated after placement and compaction of one lift (i.e., 6 inches) of capping material over top of the EPS geofoam. The load from a triaxle truck was used in the calculation since these trucks are typically used to haul embankment material and are likely to be the most economical method of hauling material. Case 1 construction condition estimates the pressure on the surface of the EPS geofoam, and a summary of the calculation is presented below.

Assumptions:
- 21,400 lbs. axle load per Trucker’s Handbook, Publication 194, October 2010
- Axle has two sets of dual tires with load of 10,700 lbs per dual set of tires
- Assume dual tire contact area of 20 inches by 5 inches, which corresponds to approximately 105 psi tire pressure
- Tire load distributed at 1H:2V through 6 inches of capping material on top of EPS geofoam
- No load factor applied since this is short term loading condition

Results for pressure on surface of EPS geofoam:
- Pressure from live load = 37.4 psi
- Pressure from dead load = 0.5 psi (from 6 inches of capping material)
- Total pressure = 38 psi
Conclusions:

- Total calculated pressure of 38 psi exceeds the compressive resistance of EPS22 at both 1% and 5% deformations (i.e., 7.3 and 16.7 psi, respectively, see Section 1.3); therefore, geofoam with a higher compressive resistance is needed at the top of the geofoam block fill.
- Total calculated pressure of 38 psi exceeds the compressive resistance of EPS39 at 1% deformation (i.e., 10.9 psi), and slightly exceeds the compressive resistance of EPS39 at 5% deformation (i.e., 35 psi).
- Since construction loads are short-term, it is acceptable to exceed compressive resistance of EPS at 1% deformation, but short-term loads should not exceed compressive resistance of EPS at 5% deformation.
- It is believed that the calculation was performed very conservatively, and since the calculated pressure of 38 psi is nearly equal to the 5% deformation strength, EPS39 or stronger is acceptable to use on the surface of the EPS geofoam block fill.

2.3.3.2 Construction Condition - Case 2

Case 2 construction condition is the same as Case 1 except the pressure was estimated 1 foot below the surface of the EPS geofoam. Additionally, the assumption was made that the tire load distributed through the EPS geofoam on a 1H:2V per NCHRP Web Document 65. A summary of this calculation is presented below.

Results for pressure 1 foot below the surface of the EPS geofoam:
- Pressure from live load = 12.2 psi
- Pressure from dead load = 0.5 psi
- Total pressure = 13 psi.

Conclusions:

- Total calculated pressure of 13 psi exceeds the compressive resistance of EPS22 at 1% deformation (i.e., 7.3 psi), but not the compressive resistance of 5% deformation (16.7 psi).
- Since construction loads are short-term, it is acceptable to exceed compressive resistance of EPS at 1% deformation, but short-term loads should not exceed compressive resistance of EPS at 5% deformation.
- EPS22 is acceptable at a depth of 1 foot below the top of the geofoam fill (i.e., below 1-foot-thick layer of EPS39) based on the assumed/modeled construction loads.

2.3.3.3 Final Condition

Calculations were performed to estimate the pressure on the surface of the EPS geofoam (i.e., top of EPS39) and 1 foot below the surface of the EPS geofoam (i.e., top of EPS22) at the end of construction once the cover material, including pavement section, are in place and traffic is on the roadway. Calculations were performed for both 4 feet and 6 feet of cover over the EPS
geofoam. This cover thickness includes the pavement section, embankment and capping material. A summary of these calculation are presented below.

Assumptions:
- Use same axle/dual tire load used in Construction Condition – Case 1 and 2.
- Increase live load by 20% for 4 feet of cover and 10% for 6 feet of cover (i.e., dynamic load allowance factor (IM)) per DM-4, 2012, Section 3.6.2.2.
- Use unit weight of 135 pcf for cover material, which is relatively high to account for future addition of wearing surface.

Results with 4 feet of cover:
- Pressure from live load = 3.6 psi/2.5 psi (surface/1 ft below surface)
- Pressure from dead load = 3.8 psi (surface and 1 ft below surface)
- Total factored pressure = 7.4 psi/6.3 psi (surface/1 ft below surface)

Results with 6 feet of cover:
- Pressure from live load = 1.7 psi/1.3 psi (surface/1 ft below surface)
- Pressure from dead load = 5.6 psi (surface and 1 ft below surface)
- Total factored pressure = 7.3 psi/6.9 psi (surface/1 ft below surface)

Conclusions:
- The estimated pressures at the surface of the geofoam fill (i.e., top of EPS39) of 7.4 and 7.3 psi are well below the compressive resistance of EPS39 at 1% deformation; therefore, EPS39 is capable of resisting the long-term loads/conditions modeled in the calculations.
- The estimated pressures 1 foot below the surface of the geofoam fill (i.e., top of EPS22) of 6.3 and 6.9 psi are below the compressive resistance of EPS22 at 1% deformation; therefore, EPS22 is capable of resisting the long-term loads/conditions modeled in the calculations.
- More than 6 feet of cover, including pavement section, embankment and capping material, will overstress the EPS22 geofoam.

2.3.4 Selection of EPS Geofoam Type Based on Calculation Results

Project specific versions of the calculations discussed above must be used to select the EPS geofoam type. As previously discussed, the long-term pressure on the EPS geofoam cannot exceed the compressive resistance of the geofoam at 1% strain. The calculation performed for the Final Condition indicates that the maximum estimated long-term pressure on the surface of the EPS geofoam is approximately 7 psi based on the assumed thickness of cover material and pavement section. Based on ASTM D6817, EPS22 geofoam has a compressive resistance of 7.3 psi at 1% strain, and is therefore adequate for this final loading condition. However, the calculations also indicate maximum short-term pressures of 38 psi on the surface of the geofoam, and 13 psi 1 foot below the surface during construction. The compressive resistance of EPS22 geofoam is 16.7 psi at 5% strain, which is considerably less than the estimated construction pressure of 38 psi. Therefore, in order to maintain short-term pressures below the compressive resistance at 5% strain, EPS39 geofoam, which has a compressive resistance of 35 psi at 5%
strain, must be used at the surface. Note that the calculations performed are believed to be conservative, and therefore it is acceptable that the calculated short-term pressure slightly exceeds the 5% compressive resistance. Since the estimated pressure of 13 psi 1 foot below the surface is less than the compressive resistance of EPS22 geofoam at 5% strain, EPS22 geofoam is acceptable below the 1 foot layer of EPS39 geofoam.

Based on these calculations the Department’s Geofoam Lightweight Fill Specification requires that a 1 foot thick layer of EPS39 geofoam be used at the surface of the geofoam block fill, and EPS22 geofoam be used for the remainder of the geofoam embankment. Note that EPS39 is not needed to cap the side slopes of the EPS22 geofoam fill since triaxle trucks will not have adequate space to operate in this area. If specific project loads/pressures warrant the need to use other EPS geofoam types, calculations must be prepared to justify the types that are recommended. For example, the calculation discussed above was based on between 4 feet to 6 feet of cover material. If more cover material is used EPS22 geofoam will most likely not have sufficient compressive resistance and will not be able to be used. Also note that the standard specification will need to be modified to correspond with the geofoam type recommendations from the calculations that differ from standard requirements.

It is worthwhile restating that the compressive resistance of EPS geofoam increases as the density increases, and the cost of the EPS geofoam increases as the density increases. This cost increase is typically significant. Therefore, from an economics point of view, it is important to specify an EPS geofoam type that has adequate compressive resistance, but not an overly conservative (i.e., high) compressive resistance. Simply put, optimize the design to strike the proper balance between strength requirements and cost. This may include the use of a load distribution enhancement such as geocell if the cost analysis justifies this type of treatment. However, minimum fill cover must still be maintained for thermal design considerations and needs.

2.4 Other External Stability Analyses

In addition to external stability analyses for settlement and slope stability, the NCHRP documents discuss external stability for bearing, sliding, overturning and uplift resistance, and seismic stability. It is anticipated that these external stability issues will not typically control the design of EPS geofoam embankments on Department projects; however, all external stability modes must be considered during design, providing calculations as necessary to verify the controlling design mode.

It is anticipated that bearing will not control if the use of geofoam is for settlement mitigation. If there is fill behind the geofoam blocks, say for example where blocks are part of a sidehill fill or part of a retaining structure, sliding and possibly overturning must be checked. If a high water table exists or the application is in a tidal region (i.e., fluctuating ground water table) then uplift may need to be addressed.

2.4.1 Bearing Resistance
The bearing resistance of embankment foundations is typically independently addressed by the settlement and global slope stability analyses for most situations. For example, if settlement calculations indicate excessive foundation settlement is anticipated, it is likely that an analysis would indicate that the foundation material has insufficient bearing resistance to support the proposed embankment/structure. Similarly, if the global (i.e., deep seated) slope stability safety factor of an embankment is less than required, it is also likely that an analysis would indicate that the foundation material has insufficient bearing resistance. The bearing capacity/resistance analysis method presented in the NCHRP documents is the same basic concept as the bearing resistance for spread footings on soil that is presented in DM-4, and this general approach should be used if a bearing resistance analysis is necessary (especially where treatment for settlement involves soft foundation materials).

2.4.2 Sliding and Overturning Resistance

NCHRP also discusses analyses to ensure that the EPS geofoam embankment has sufficient sliding and overturning resistance from unbalanced water pressure, wind and lateral earth pressure.

As discussed later, geofoam used on Department projects should generally not be placed below groundwater or the anticipated high water elevation (i.e., 500 year storm); consequently, unbalanced hydrostatic pressure should rarely occur. If unbalanced hydrostatic pressure develops it will likely be in applications when geofoam is used behind a retaining wall or abutment, and not for a typical embankment section. Therefore, similar to any retaining wall analysis, unbalanced hydrostatic pressure must be accounted for during design.

NCHRP indicates sliding or overturning of EPS geofoam embankments from wind pressure is very unlikely. The weight and shear strength of cover materials make such a failure mechanism difficult. Therefore, at this time failure modes resulting from wind loads do not have to be considered unless the embankment will be exposed to hurricane force winds, or there are other significant factors of concern. Note that this is relative to final design conditions, not construction conditions. It is the contractor’s responsibility to temporarily secure EPS geofoam blocks during construction to prevent dislodging from wind or other forces. Wind loads during construction do not have to be considered as part of the design, however, contractor responsibility for wind loads, and necessary securing of geofoam blocks, must be clearly indicated in the construction provisions.

Lateral earth pressure from soil or aggregate backfill placed behind EPS geofoam must also be considered during design. For example, if EPS geofoam is used to backfill behind an abutment or retaining wall and embankment material (Pub 408, Section 206) is used to construct the remainder of the embankment cross-section, lateral earth pressure from the embankment material may be applied to the geofoam which in turn will transfer the lateral load to the wall or abutment. As indicated by NCHRP lateral earth pressure should be conservatively assumed to be transmitted without dissipation through the geofoam to the back of the abutment/wall. In order to avoid developing lateral earth pressure, the embankment material behind the EPS geofoam must be placed at a slope that is independently stable, such as 2H:1V (i.e., sufficiently beyond the active earth pressure wedge such that no lateral loads can be transferred to the wall).
Mechanical connectors, typically small steel plates with barbs, are available and sometimes used to improve the sliding resistance between EPS geofoam blocks, particularly from seismic loading. Based on current available information, the actual effectiveness of these mechanical connectors is questionable, and therefore, generally should not be required on Department projects. They may however be used by the contractor, at their discretion, to facilitate placement of the blocks and help prevent movement during construction. There is no known negative effect of using mechanical connectors, but they likely will increase the cost of the EPS geofoam embankment. Metal stamped mechanical connectors may not be considered in the design for stability of geofoam applications. If some type of mechanical fastening is required for final design conditions, or to facilitate use of geofoam due to loads from construction sequencing, these must be specifically designed, and their adequacy demonstrated for the specific situation and application. An alternative to mechanical connectors is the use of shear keys. As indicated in NCHRP Project No. 24-11(02) Final Report, these shear keys consist of half-height blocks of EPS geofoam that are periodically placed to interrupt the horizontal joints that are typical in most geofoam embankments.

2.4.3 Hydrostatic Uplift Resistance

EPS geofoam is susceptible to uplift when submerged in water because of its extremely low weight/density. Geofoam used on Department projects should generally not be placed below the groundwater level, or below the anticipated high water level if placed in the vicinity of a stream, river, etc. However, if it is necessary to place any part of the geofoam embankment below water, an analysis must be performed to ensure that sufficient cover material is placed over the EPS geofoam embankment to prevent uplift. Anchorage of the blocks may also be necessary to facilitate construction. Traffic loads and any other temporary or short-term loads should not be included when calculating the uplift resisting force. Use a minimum safety factor of 1.2 if the hydrostatic uplift force is a short-term condition; a safety factor of 1.5 is required if the uplift force is a long-term condition, such as when any part of the EPS geofoam is submerged beneath the static/long-term groundwater level or on cyclical basis in tidal areas, or similar regularly fluctuating groundwater level.

2.4.4 Seismic Stability

Seismic stability analyses should also be considered when using EPS geofoam as an embankment material. In general follow the same basic Department seismic slope stability procedures to analyze EPS geofoam embankments that are used to analyze conventional embankment/backfill materials. The NCHRP reports also provide guidance on performing these analyses. Seismic global slope stability should be considered for EPS geofoam embankments with both sloping and vertical (i.e., wall) sides. When EPS geofoam is used as a retaining wall backfill, seismic overturning and internal stability should also be considered. Based on information presented in NCHRP, and since the peak horizontal ground acceleration in most of parts of Pennsylvania are low, seismic conditions will not likely control the design of the EPS geofoam embankments.
2.5 Cover Requirements

EPS geofoam must be covered with a minimum of 4 feet of cover material, which includes 6 inches of capping material, soil embankment material, and the pavement section (refer to Appendix A). However, in order to not overstress the EPS22 geofoam, the maximum combined thickness of the cover material (i.e., capping material, soil embankment material and pavement section) that is placed over the EPS geofoam should not exceed six feet. If it is not possible to reduce the total, maximum, combined thickness to 6 feet, then EPS geofoam with a compressive resistance higher than the compressive resistance of EPS22 must be used. Costs for the denser geofoam should be considered and balanced against needs of thicker cover materials, and/or design of surcharge loads to limit resulting pressures on geofoam.

The cover material is needed because EPS geofoam acts as an insulator by preventing heat from the ground to reach the pavement section. Premature freezing of the roadway surface can occur if an inadequate thickness of cover material is used between the EPS geofoam and pavement section. Additionally, the cover material distributes wheel loads applied to the pavement which reduces the stress on the EPS geofoam. Four feet of embankment cover is also needed over the EPS geofoam on embankment side slopes and over areas that pavement will not be constructed (refer to Appendix A).

2.6 Buoyancy Considerations

EPS geofoam will float due to its very low density. The density is so low that a 4-feet-thick block of EPS22 geofoam will only penetrate approximately 1 inch below the surface of water, while the remaining approximately 47 inches will stay above the surface of the water. Consequently, when geofoam is used on Department projects, the bottom of the geofoam should be placed above the static groundwater level and above the anticipated high water level (i.e., 500 year storm elevation) if used in the vicinity of a stream, river, etc. EPS geofoam may only be placed below groundwater or the anticipated high water level after carefully considering all other options and determining that submerging the EPS geofoam is the best alternative.

If any part of the EPS geofoam embankment may become submerged during the life of the embankment, buoyancy calculations must be performed. These calculations must consider final, temporary (e.g., high water level during flood event) and short-term (e.g., during construction) conditions, and both normal and high water levels must be used in the analyses. Soil cover must be used to overcome buoyancy forces for final and temporary conditions; anchoring is not permitted to resist final and temporary buoyancy forces. Anchoring is permitted to resist buoyancy forces that develop during short-term conditions. If analysis indicates tie down anchors or other mechanical means are necessary to prevent uplift, then the use of EPS geofoam should be reconsidered due to the additional cost and effectiveness of these mechanical means. Use tie downs or other mechanical means only after discussion with and approval from the DGE.

2.7 Hydrocarbon Resistant Geomembrane

Since EPS geofoam is petroleum based material, it will degrade when in contact with many petroleum products, organic solvents and some vegetable based oils, including the vapors from
these products. Liquids and their vapors that will degrade EPS geofoam include but are not limited to gasoline, diesel, kerosene, mineral spirits, acetone and benzene. Therefore, during design of an EPS geofoam embankment, the design must accommodate the potential of a spill of these types of products on the roadway, and the consequences of damage to the EPS geofoam. A hydrocarbon resistant geomembrane must be used to protect the EPS geofoam from spills of these harmful liquids on the roadway. While the cost of a geomembrane protection envelope is not insignificant, the cost of repair and service interruption as the result of spill, are much greater.

As indicated in the Department Geofoam Lightweight Fill Specification, the hydrocarbon resistant geomembrane must be listed in Bulletin 15 and manufactured from a tri-polymer consisting of polyvinyl chloride, ethylene interpolymer alloy and polyurethane, or a comparable polymer combination. When a geomembrane is used, it will typically encapsulate the entire EPS geofoam mass in order to protect the geofoam from damage from both liquids and vapors (refer to Appendix A). An alternate system, such as a geomembrane over just the top surface of the geofoam can be considered. However, the alternate system must provide the level of protection similar to the protection provided by complete encapsulation, and must accommodate the collection and handling of any liquids and vapors. This may include the need for special drainage, venting or other methods of control and/or protection. Details will have to be developed to seal around any drainage pipes, inlet boxes or other control devices and/or obstructions. As vapors from spills can be just as damaging as direct liquid contact, full encapsulation with a hydrocarbon resistant membrane is the preferred method of protection.

The NCHRP publications discuss the possibly of using a lightly reinforced, 4-inch thick concrete slab to protect the EPS geofoam from spills of harmful liquids. Inevitable cracking of the concrete slab makes a geomembrane a much more effective option to protect the EPS geofoam from spills of damaging solvents. Additionally, a geomembrane provides the ability for total encapsulation, which the concrete slab cannot. Therefore, on Department projects, the use of a concrete slab to protect the EPS geofoam from harmful spills should not be used. However, a concrete slab can be used if needed for other design purposes, such as to help distribute wheel loads.

2.8 Layout, Transitioning and Side Slopes

During design the geotechnical engineer is responsible for determining the limits of the EPS geofoam within proposed embankments based on the results of the external stability analyses (i.e., settlement, global slope stability, etc.). The geotechnical designer must coordinate with roadway/structure engineer(s) to show these limits on the contract drawings (i.e., plans, cross-sections, details, etc.). The geotechnical designer should not specifically detail the size and orientation of each block. Block size can vary between manufacturers, and the Department’s Geofoam Lightweight Fill Specification indicates minimum block size and required block placement orientation. Furthermore, the specification requires the contractor to submit a shop drawing prior to placing blocks that shows the location and orientation of each block. Numerous requirements in the specification must be met with respect to orientation of blocks and location of joints between blocks. Only the limits and width, height and slope requirements should be indicated for the geofoam block fill, but not individual block size or orientation.
Due to the dissimilar properties of EPS geofoam and typical embankment materials, and to avoid differential settlement, abrupt changes between these materials should be avoided. In the longitudinal direction of the roadway, gradually transition from embankment to EPS geofoam. The NCHRP report indicates that the transition between the EPS geofoam and embankment should be designed so that differential settlement does not exceed 1:200 (vertical to horizontal). In the transverse direction, particularly when used behind retaining walls, it is recommended to use EPS geofoam beneath the entire paved roadway width to avoid a crack in the pavement from differential settlement between EPS geofoam and embankment material. If not used full width, then gradual tapering must be required. All transitions must be carefully designed to prevent abrupt changes in base stiffness and load response.

When using EPS geofoam to construct typical “trapezoidal” shaped embankments, design the side slopes of the embankments no steeper than 2H:1V. The embankment cover material will not typically have adequate strength to provide sufficient veneer stability for slopes steeper than 2H:1V. Uniformly step the EPS geofoam on the side slopes, similar to typical soil benching details, to help improve stability of the cover material. Do not trim the EPS geofoam blocks to match/parallel the final slope of the embankment. If embankment slopes steeper than 2H:1V are proposed, special details must be developed and analyses must be provided to verify that the embankment cover on the side slopes will be stable. EPS geofoam can be designed with a vertical face and be internally stable, but structural support/facing is required. If it is known that native materials are inadequate for a 2H:1V slope, then design accordingly by either flattening the slopes or providing treatment measures and details.

2.9 Drainage Pipes, Utilities and other Typical Roadway Features

Roadway embankments typically contain drainage pipes and inlet boxes, and often also have underground utilities, utility poles, light poles, signs, guide rail posts and other appurtenances. These can be incorporated into an EPS geofoam embankment, but careful consideration should be given during design. When possible, locate these appurtenances outside the limits of the EPS geofoam or in the embankment cover material above the EPS geofoam. Drainage pipes, utilities and other features can be located within the EPS geofoam, however, this will require special fabrication of blocks at the factory or field cutting to fit blocks around obstructions, which can be costly. Additionally, geomembrane protection for the EPS geofoam is more difficult and costly to install around obstructions. A concrete slab may be required to support light poles, signs and other heavier features, but any load from this slab must be accounted for when calculating the pressure on the EPS geofoam.

3.0 CONSTRUCTION REQUIREMENTS AND CONSIDERATIONS

Construction requirements for the use of EPS geofoam to construct roadway embankments are provided in the Pub. 408, Section 2XX Geofoam Lightweight Fill Specification. This section of Publication 293 provides background information for some of these requirements. These requirements must be accounted for during design of EPS geofoam embankments. A typical profile view, section and details are provided in Appendix A.
3.1 Material Requirements

EPS geofoam used on Department projects must be supplied by a manufacturer that is listed in Bulletin 15, and must meet the requirements of ASTM D6817 and Table A as indicated in the Pub. 408, Section 2XX Geofoam Lightweight Fill Specification. As previously discussed, calculations indicate that geofoam types EPS22 and EPS39 will be required for most Department projects. EPS22 will typically be used to construct the majority of the geofoam embankment with the exception of the top 1 foot where EPS39 geofoam must be used. Other EPS types (i.e., densities) can be used if necessary and justified, and if calculations demonstrate its adequacy. If other EPS types are necessary, a job specific specification must be developed most likely consisting of revisions to Section 2XX Geofoam Lightweight Fill. Additional material requirements are discussed below.

3.1.1 Dimensions, Squareness, and Planarity

Table A of the Department specification requires blocks to have minimum dimensions of 4 feet wide by 8 feet long. The EPS22 blocks must be at least 2 feet high, and the EPS39 blocks used at the top of the EPS geofoam fill must be at least 1 foot high. EPS geofoam blocks are manufactured in a variety of sizes, but these minimum required dimensions are commonly used for roadway projects, and most manufacturers are capable of supplying blocks with these dimensions. The minimum dimensions are specified to help limit the number of joints and meet joint spacing/location requirements, which are intended to help construct an internally stable embankment. Blocks with dimensions smaller than these can be supplied where necessary for project specific fill geometry (i.e., such as to complete a row or layer of blocks or for block placement around obstructions).

EPS geofoam blocks must be manufactured with perpendicular and planar faces, except as needed for project specific fill geometries. The corner or edge of all adjacent faces must be perpendicular within the tolerance indicated by the specification. Perpendicular faces are required so adjacent blocks fit tightly with no or little open space between blocks. The faces of the blocks must also be planar (i.e., flat and not warped) within the tolerance indicated by the specification. This is required so loads are uniformly distributed to the entire block face/surface and not to just high spots on the block. This is also required so adjacent blocks fit tightly with no or little open space between blocks. Flat top surfaces also prevent ponding water from precipitation that may occur during placement of the blocks.

3.1.2 Regrind

EPS geofoam blocks must be manufactured with virgin polystyrene and not regrind material (i.e., recycled geofoam). It is currently unclear what the effects of the use of regrind are on the properties of EPS geofoam blocks, or what percent regrind is appropriate to use. Should adequate, reliable information become available concerning the impact of regrind on the performance of EPS geofoam blocks, the use of regrind in the manufacture of EPS geofoam for Department projects will be re-evaluated.
3.1.3 Flammability

EPS geofoam blocks must be manufactured with a flame retardant to meet the flammability requirements (i.e., minimum oxygen limit) indicated in Table A of the specification. Flame retardant is used specifically to prevent fires during construction because once the EPS geofoam is covered with embankment the potential for ignition of the geofoam is very low. While the use of flame retardant does increase the cost of manufactured geofoam blocks, it is worthwhile insurance relative to the cost associated with a fire in a geofoam fill. Note that the flame retardant prevents the EPS geofoam from burning but it does not prevent it from melting. Additionally, the flame retardant does not prevent fires from outgassing. Outgassing is discussed later in this chapter in Section 3.2, Seasoning.

3.1.4 Insecticide

An insecticide must also be included in the geofoam blocks to prevent attack from termites and other insects. No documented cases of damage from insect attack on EPS geofoam fills was found, but insect attack on geofoam used in the building construction industry is known. Insecticide is commonly used and is not expected to significantly increase the cost of manufacturing the EPS geofoam blocks. Note that if the EPS geofoam mass is fully encapsulated with a geomembrane, insecticide is not needed since the geomembrane would provide an effective barrier from insect attack.

3.2 Seasoning

As discussed earlier in Section 1.1 a gas, called a blowing agent, is used to manufacture EPS geofoam. A variety of gases can be used, including pentane and butane. Immediately after the geofoam is manufactured (i.e., released from the mold), the blowing agent begins to “escape” from the blocks. This process is called outgassing, and seasoning is the term used to describe the period of time required for the majority of the blowing agent to escape the EPS geofoam. If EPS geofoam blocks are placed in a large, tightly placed mass, such as a roadway embankment, before the blocks are seasoned, the gas can become trapped in the joints between blocks and ignite, melting and damaging the geofoam.

The seasoning time required for EPS geofoam is not definitive. A period of 72 hours is typically recommended, and is the minimum seasoning period required by the Department specification. The seasoning time is dependent upon several factors, including air temperature and air circulation. EPS geofoam blocks season faster at higher temperatures. The Department specification requires a minimum temperature of 68 degrees Fahrenheit in the seasoning room/facility. Additionally, the blocks must have adequate space between all faces of the block to allow the gas to escape, the room must have adequate ventilation to promote circulation of air around each block, and the seasoning room must protect the blocks from moisture and ultraviolet (UV) radiation.
3.3 Delivery and Storage on Site

EPS geofoam blocks are typically delivered to the site in a box trailer or on a flatbed trailer. Blocks must be protected from damage during delivery and offloading at the project site. Each block delivered to the project site must be labeled. The label must include:

- the manufacturer’s name
- ASTM EPS designation per Table A
- date the block was molded
- the weight (in pounds) and density (in pounds per cubic foot) of each block as measured after the minimum required seasoning period

The manufacturer’s name is required because on some projects, particularly large ones, more than one manufacturer may be used by the contractor to supply EPS blocks. The EPS designation is required because typically two types of EPS geofoam will be used on a project. The date is required for quality control tracking purposes, and the weight and density are required so that blocks can periodically be weighed at the project site for QA/QC purposes. It is the contractor’s responsibility to provide a scale for the Engineer’s use at the project site that is appropriate for weighing EPS geofoam blocks.

If geofoam blocks are not immediately placed to construct the proposed geofoam embankment when delivered to a project, they can be temporarily stored on site. The designated storage area must be secure and located away from any heat source or construction activity that produces heat, flame, sparks, etc. Personal tobacco smoking is not permitted in the storage area. Even though the blocks contain a fire retardant, adequate measures must be in place to protect the blocks from flames and heat. EPS geofoam blocks must also be protected from contact with and exposure to vapors from organic solvents, including but not limited to acetone, benzene and mineral spirits, and petroleum based solvents, including but not limited to gasoline, kerosene and diesel fuel.

The blocks must be stored off of the ground, and no part of the block can be stored in standing water. The blocks must be protected from discoloration and dusting caused by excess exposure to sunlight, but a cover cannot be used directly over the blocks, because a cover may trap heat and cause excessive temperatures that could damage the blocks. Equipment and vehicles cannot traverse the blocks, and foot traffic must also be kept to a minimum. If blocks are exposed to wind, it is the contractor’s responsibility to secure the blocks with sandbags or other similar “soft” weights that do not damage the blocks.

3.4 Contractor Submittal

As discussed in Section 2.0 of this chapter, during design the engineer/designer must indicate the limits of the EPS geofoam block, but not the actual layout of individual blocks. It is the contractor’s responsibility to prepare a submittal that details individual block placement that follows the requirements of Department specifications. Some of these requirements are discussed below:
1. Unless specifically indicated otherwise on the contract drawings, Type 1 geofoam blocks (EPS22) will be used for the main body of the fill, and a minimum thickness of 12 inches of Type 2 geofoam blocks (EPS39) will be placed on top of the Type 1 geofoam blocks. Type 2 geofoam blocks are not required to be used on side slopes of the block fill.

2. Use the maximum amount of full size blocks that the placement geometry allows. Additionally, the blocks must be placed with their minimum dimension (i.e., thickness) oriented vertically because this orientation will produce the most internally stable geofoam embankments. Only in cases where a limited number of blocks are necessary to achieve geometric requirements should blocks be oriented other than with the minimum dimension vertical.

3. A minimum of two layers of blocks must be used at all locations unless specifically indicated otherwise on the contract drawings. This can consist of one layer of Type 1 geofoam capped with a layer of Type 2 geofoam, or two layers of Type 1 geofoam on side slopes or under other unpaved areas. The use of only one block beneath roadways has shown signs of sliding instability and premature pavement distress. This instability was most likely where minimal cover was placed over the EPS geofoam. Due to the “thicker” cover requirements in the Department specification, sliding instability most likely will not be a problem even if one layer of blocks is used. Regardless however, to adhere to best practices, a single layer of blocks should be avoided where possible.

4. The plane on which a given layer of blocks is placed must be parallel to the longitudinal axis/profile of the roadway alignment (refer to Appendix A). Essentially, the subgrade surface on which the first layer of blocks is placed must be parallel to the longitudinal profile of the roadway. This is required to avoid or reduce the need to trim EPS blocks at or near the top of the block fill to meet required tolerances. Excessive trimming of blocks will not only be time consuming and costly, but will most likely result in an overall lower quality top of block surface.

5. The longitudinal axes of the uppermost layer of blocks must be perpendicular to the longitudinal axis of the road alignment. It has been found that the blocks and pavement section perform better when the top layer of blocks are oriented in this direction.

6. Within a given layer of blocks, the longitudinal axes of all blocks must be parallel to each other, and vertical joints between adjacent longitudinal rows of blocks must be offset a minimum of 2 feet. Additionally, the longitudinal axes of blocks for layers above and/or below a given layer must be perpendicular to the longitudinal axes of blocks within that given layer. These requirements for longitudinal axis orientation and joint location are to prevent continuous joints and provide an interlocking system of blocks that is internally stable.
7. The blocks must be covered with a 6-inch compacted layer of capping material to protect the geotextile and geomembrane from damage. The total thickness of cover over top of the block fill, which includes capping material, embankment material, and pavement section, must be a minimum of 4 feet but not exceed 6 feet.

3.5 Damage

Care must be taken during loading, shipping, unloading, temporary storage and placement of EPS geofoam to avoid damaging the blocks. While some minor damage to the blocks may occur during normal handling procedures, excessive damage will reduce the bearing area of the blocks, which results in higher stresses on the blocks. These higher stresses may exceed the design stress of the EPS geofoam and cause unacceptable deformation. Excessive damage also may prevent the blocks from fitting tightly, which could reduce the internal stability of the EPS geofoam embankment. Excessive or unacceptable damage requires the block to be replaced at the contractor’s expense, but “undamaged” portions of these blocks can be used on the project where partial blocks are needed.

Damage includes but is not limited to dents, gouges, divots and missing corners/pieces. The Department specification defines unacceptable damage as any of the following:

1. Volumetric damage of more than 0.5% of the volume of the single block. The minimum EPS22 block size required by the specification has a total volume of 64 cubic feet; therefore, the sum of the volumetric damage to a single block cannot exceed 3.2 cubic feet for this size block.

2. Surface damage of more than 5% of the load bearing area of the single block. Using the dimensions of the minimum required block size, the load bearing area is typically 32 square feet. Therefore, no more than 1.6 square feet of damage to this load bearing surface is acceptable.

3. In addition to Item 2 above, surface damage of more than 5% of the total block surface area is unacceptable. This includes all surfaces of the block, not just load bearing surfaces.

4. Continuous damage of more than 20% of the length of any side of a single block is also unacceptable.

Damaged areas on horizontal bearing surfaces that are acceptable per the above criteria shall be filled with dry, fine sand meeting the requirements of the Department specification. Do not fill open vertical surfaces with sand.

3.6 Cutting

EPS geofoam blocks will need to be cut in order meet project specific fill geometries and to fit around obstructions. These “specialty” blocks can either be fabricated in the factory or on the project, the latter being more typical. Typically these blocks are not molded to the required
size/shape but instead they are cut from full size blocks. Numerous tools have been used to cut blocks, including a hot wire, chain saws, hand saws and other mechanical cutting and shearing devices. For Department projects, EPS geofoam blocks may only be cut in the factory or field with a hot wire.

This hot wire is made of nickel chromium (NiCr) that is connected to an electricity source. When electricity passes through the wire, it gets hot and cuts (i.e., melts) the EPS geofoam. The hot wire method of cutting allows for accurate and clean/smooth cut block faces. Chain and hand saws and other cutting methods usually do not yield cut faces as clean/smooth as the hot wire and are therefore not permitted for use on Department projects.

Geofoam blocks that are cut must be to the maximum dimensions possible, cutting full length and width (where practical), and to the necessary thickness, maintaining a smooth and level surface. Field and factory cuts must be smooth and flat on all surfaces, unless curved surfaces are needed to fit tightly. Blocks must be cut to within 0.5 inch of the required or specified dimensions.

3.7 Subgrade Preparation

One of the most important steps of successfully constructing an EPS geofoam embankment is preparation of the subgrade. In general the subgrade must be prepared in accordance with Section 206.3(a). It must be relatively smooth and free of any localized hard spots or protrusions that could damage the geomembrane or geofoam blocks, and it must be free of standing water. As previously discussed, the subgrade must be prepared smooth and parallel with the longitudinal profile grade of the roadway so that the horizontal surfaces of the blocks are parallel with the longitudinal profile grade (refer to Appendix A). The subgrade should be level in a direction transverse to the roadway. Any cross slope for the final roadway must be developed in the cover materials above the geofoam blocks.

Once the subgrade is prepared, a 6-inch loose leveling/bedding course is placed. The bedding material can consist of AASHTO No. 10 Coarse Aggregate, Type A Cement Concrete Sand, or Type C Mortar Sand. The loose leveling course permits fine grading for the first layer of blocks, and allows the blocks to be “seated”. It is critical that the first layer of blocks be stable and level so that it is easier to maintain alignment and tolerances of remaining layers of block. Once the leveling course is prepared, geotextile and the hydrocarbon resistant geomembrane are placed. Placement of these is discussed in further detail below in Section 3.8, Placement.

3.8 Placement

The EPS geofoam blocks should be placed in accordance with the approved placement plan prepared by the contractor, and as directed in the field by the Representative. The main body of the fill will typically consist of Type 1 geofoam (i.e., EPS22) unless otherwise required by design. These blocks will extend from the bottom of the geofoam fill to approximately 1 foot below the top surface of the geofoam fill. The last/top 12 inches (minimum) of the geofoam block fill will consist of a cap block which will be addressed later in this section. Where
possible, the factory skin (i.e., molded, uncut surface) of the blocks should be placed as the outer layer to help minimize the amount of water absorbed by the blocks.

Blocks must be placed by hand. Wheeled, tracked or other equipment is not permitted to be operated directly on the surface of geofoam blocks as this may result in overstressing the blocks and cause damage. Equipment, such as conveyors, lifts and cranes may be used to transport or lift blocks, as long as its use does not involve traversing the blocks with the equipment or results in damage to the geofoam blocks. Use only full-size blocks (i.e., blocks of minimum dimensions indicated in Table A of the specification) except where partial or cut blocks are needed to meet project specific fill requirements. If geofoam blocks are warped/crowned but within the acceptable tolerance indicated by the specification, place these blocks with the crown upward to prevent the ponding of water.

Assure full contact between blocks so that stresses are carried by the full block bearing surface and not concentrated on portions of the block. Do not leave standing water, accumulated snow or ice, or debris of any kind on previously placed EPS blocks prior to placement of subsequent blocks. De-icing salts, such as sodium chloride or other products, can damage/degrade EPS geofoam and are not permitted to be used.

Since geofoam blocks are extremely lightweight, they can be displaced by wind. During placement of geofoam blocks, temporarily secure them with sandbags or other similar “soft” weights that do not dent or otherwise damage blocks until the soil cover is placed. Mechanical connectors (i.e., barbed, metal plates) may be used to help prevent the movement of blocks from wind, however, the effectiveness of the connectors will be dependent upon the severity of wind conditions. The contractor may elect to use mechanical connectors to help secure the geofoam blocks, but they should not be required by the designer unless specifically needed for stability of the final embankment condition or if necessary to address some other temporary or long-term need. If used, the cost of mechanical connectors must be incidental to the geofoam blocks.

The upper 12 inches (minimum) of the geofoam fill beneath the roadway, shoulders and median will typically consist of a cap block of Type 2 geofoam (i.e., EPS39). The denser and stronger EPS 39 geofoam is required to address anticipated construction loads as previously discussed in Section 2.0 of this chapter. EPS39 geofoam is not needed on the side slopes of the embankment since construction loads are not expected to be as high. The top layer of blocks should be placed in the same manner as the lower layers of block.

The top surface of the geofoam fill must be constructed relatively smooth so that the hydrocarbon resistant geomembrane has an even bearing surface to prevent stress concentrations and possible damage. The Department specification requires the top surface of the blocks to be constructed to within a tolerance of ±1/2 inch over a 10 foot interval of the design longitudinal profile of the blocks and design transverse slope of the blocks. Additionally, the finished surface of the blocks beneath pavement sections must be constructed to within ±0.1 foot of the top of block design grade, and the finished surface of the blocks on side slopes must be constructed to within ±0.2 foot of the top of block design grade. Any adjustments for grade can be made by trimming either Type 1 or Type 2 geofoam blocks, but the Type 2 geofoam blocks must have a minimum thickness of 12 inches.
3.9 Hydrocarbon Resistant Geomembrane

As previously discussed unless an adequate alternate method of protection can be provided, the EPS geofoam fill must be completely encapsulated in a hydrocarbon resistant geomembrane (refer to Appendix A). The geomembrane must be one continuous layer connected by field welding the seams with a hot wedge welder. Hot air or solvents cannot be used because they are more likely to damage the geofoam compared to using a hot wedge welder. Particular care must be taken when placing the geomembrane on the stepped side slopes of the geofoam. The membrane must be sufficiently loose so embankment placement and compaction does not stretch or otherwise damage the geomembrane. A Class 4, Type A geotextile must be wrapped around the outside of the entire geomembrane to aid in protection from damage. Any portions of the geomembrane that are damaged during construction must be repaired by welding on geomembrane patches according to the Department specification.

3.10 Capping and Embankment Material

Once the blocks, geomembrane and geotextile are placed, they must be covered with a 6-inch minimum compacted lift of capping material. The capping material must be relatively fine material to minimize the risk of damaging the geomembrane during placement and compaction of the material. The capping material can consist of either:

- Material meeting the requirements of Section 206.2(a)1.a, Soil, except 100% of the material must pass the ¾ inch sieve.
- AASHTO No. 10 Coarse Aggregate, Type A Cement Concrete Sand or Type C Mortar Sand. Note that these are the bedding materials used for the leveling course discussed in Section 3.7, Subgrade Preparation.

The capping material must be placed on top of the geotextile, including on the horizontal surfaces of the side slopes, prior to placement of embankment material. The capping material must be placed within 2 weeks after placement of the geotextile to help prevent degradation of the geotextile. The capping material should be placed and compacted in accordance with Section 206.3, except the following provisions are required to help prevent damage to the geofoam blocks and geomembrane:

1. Heavy equipment cannot be operated directly on top of the blocks. Pneumatic tired equipment must be used to spread the capping material, but sharp, sudden turns are not permitted. Tracked equipment cannot be used to spread the capping material.
2. Capping material must never be end dumped just off the blocks.
3. Capping material must be bladed to an 8-inch thick loose lift across the blocks with pneumatic tired equipment.
4. Capping material cannot be end dumped directly on the blocks and cannot be stockpiled on the block fill.
5. Capping material must be compacted using a smooth drum in static (non-vibratory) mode.
6. A single triaxle truck load of capping material can be end dumped onto previously placed and compacted capping material. The dumped material must be spread as soon as practically possible.

Once the capping material is placed and compacted, embankment material meeting the requirements of Section 206.2(a)1.a, Soil, can be placed to finished grade. The soil should be placed and compacted in general accordance with Sec 206.3. Once the 6-inch compacted layer of capping material is in place, conventional earth hauling equipment (i.e., triaxial trucks or smaller) may drive over the embankment, and tracked equipment may be used to spread the embankment material. However, similar to capping material, embankment material cannot be stockpiled or end-dumped into piles on the geofoam fill at any time because this could overstress or damage the EPS geofoam. A single triaxle load of embankment can be end-dumped on previously placed and compacted capping and embankment material, but it must be spread as quickly as practically possible.

On the side slopes of the geofoam fill, place and compact soil cover starting at the bottom of the slope in such a manner as to prevent damage to the geofoam, geomembrane and geotextile. As previously discussed, capping material must be placed over the horizontal surfaces of the side slopes prior to placement of embankment material. Embankment material is permitted to be placed directly against the vertical surfaces on the side slopes.
Appendix A

Geofoam Embankment Details, Profile and Section Views
TYPICAL GEOFOAM LONGITUDINAL
PROFILE VIEW
NOT TO SCALE

ROADWAY LONGITUDINAL
PROFILE GRADE

PAVEMENT SECTION

4' MIN.
6' MAX.

GEOFOAM BLOCK (TYP.)

6" BEDDING MATERIAL

2' MIN. JOINT OFFSET

TYPICAL GEOFOAM EMBANKMENT SECTION
NOT TO SCALE

NOTE:
GEOMEMBRANE/GEOTEXTILE
NOT SHOWN. SEE DETAIL.
Appendix B

Calculations for Determination of Required EPS Geofoam Compressive Resistance and Density
1) INTRODUCTION
This appendix presents calculations for determination of required EPS geofoam compressive resistance and density. The objective is to determine the required compressive resistance of geofoam blocks to support both Construction Loads/Conditions and Final Loads/Conditions.

2) CONSTRUCTION LOADS/CONDITIONS
a) Assumptions:
i) Triaxle trucks will be used to deliver embankment to be placed over geofoam blocks.
ii) Triaxle trucks will be loaded to maximum permitted weight per “Trucker Handbook” (PennDOT Publication 194, Oct. 2010).
   Per page 23:
   (1) Maximum weight per inch of tire is 800 lbs on any one wheel.
   (2) Steering axle weight cannot exceed 20,000 lbs.
   (3) Axles spaced less than 6 feet apart have maximum weight limit of 18,000 lbs.
   (4) Three and four axle trucks are permitted to have up to 21,400 lbs on each tandem axel.

Based on above: Use maximum permitted axle load \( (L_{\text{max}}) = 21,400 \) lbs.

\[ \text{Note: Since construction loading is temporary/short-term, do not apply load factor for impact/dynamic loading.} \]

iii) For wheel/tire contact area, use similar approach to “Concrete Pipe Handbook,” American Concrete Pipe Association, 1981.
   (1) Typical tire width for triaxle is 9 inches. For dual tires assume 20 inch width.
   (2) Typical tire pressure is 80 to 100 psi.

\[ \text{Note: Based on discussions with some quarry owners, triaxle tire pressures typically run between 100 and 110 psi. Thus, to be conservative use a tire pressure \( (P_t) \) of 105 psi.} \]

Therefore, maximum permitted axle load of 21,400 lbs, the load on a dual set of tires is:
\[
\frac{L_{\text{max}}}{\text{No. sets of dual tires}} = \frac{21,400 \text{ lbs}}{2 \text{ sets of dual tires}} = \frac{10,700 \text{ lbs}}{\text{set of dual tires}}
\]

b) Determine dual tire contact area \( (A_t) \):
\[
A_t = \frac{L_{\text{max}}/\text{set of dual tires}}{P_t} = \frac{10,700 \text{ lbs}}{105} = 102 \text{ in}^2
\]

c) As previously indicated, assume a single tire width of 9 inches and a dual tire width \( (W) \) of 20 inches (refer to Figure B-1). Therefore, tire contact length is:
\[
L = \frac{A_t}{W} = \frac{102 \text{ in}^2}{20 \text{ in}} = 5 \text{ in}
\]
d) Estimate Pressure on Top Layer of Geofoam from Dual Tires of Triaxle Dump Truck:

i) Triaxle dump trucks and other “heavy” equipment cannot operate directly on top of the geofoam because the pressure would exceed the compressive resistance of the geofoam, resulting in damage to the EPS blocks.

ii) In accordance with the specification, one layer of capping material must be placed (by blading material) and compacted to 6 inches prior to operating triaxle trucks and other “heavy” equipment on the geofoam embankment (refer to Figure B-2).

iii) Distribute the wheel load through the 6 inches of compacted capping material \( (D_c) \) to estimate pressure on top of geofoam block. Based on various references, pressure is mostly distributed through capping material somewhere between a 1H:2V or 1H:1V. Use 1H:2V pressure distribution as a conservative approach (refer to Figure B-3).
iv) Determine the loaded area ($A$) at top of geofoam blocks (i.e., bottom of 6 inches of capping material):

$$A = (L)(W) = 11 \text{ in} \times 26 \text{ in} = 286 \text{ in}^2$$

v) Determine the equivalent uniform pressure ($P$) at top of geofoam blocks:

$$P = \left(\text{Distributed Pressure from Tires}\right) + \left(\text{Pressure from 6 inches Capping}\right)$$

$$P = \frac{L_{\text{max}}}{A} + (D_c)(\gamma) = \frac{10,700 \text{ lbs}}{286 \text{ in}^2} + \frac{(0.5 \text{ ft})(130 \text{ lb/ft}^3)}{144 \text{ psi}} = 37.9 \text{ psi} \sim 38 \text{ psi}$$

Note: This is believed to be conservatively high, due to the steep 1V:2H slope assumed in the calculations for transfer of tire pressure through the capping material resulting in low distribution of the loads.

<table>
<thead>
<tr>
<th>Table B-1 – Geofoam Type and Properties</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
<td>EPS22</td>
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<td>EPS22</td>
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<td>EPS29</td>
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<tr>
<td>EPS29</td>
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<tr>
<td>EPS39</td>
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<tr>
<td>EPS39</td>
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</tbody>
</table>

vi) Conclusion: The pressure from long-term (i.e., Final Conditions) loads on the geofoam must not exceed the EPS geofoam compressive resistance at 1% deformation. However, pressure from short-term (i.e., Construction Conditions) loads on the EPS geofoam can exceed the compressive resistance at 1% deformation, but should not exceed the compressive resistance at 5% deformation. EPS39 geofoam should perform satisfactorily under construction loads due to the conservative nature of the calculations (refer to Table B-1).

⇒ EPS39, 5% Compressive Strength = 35.0 psi \sim 38 psi \quad \therefore \quad OK

e) Determine the required thickness of the first layer of EPS39 geofoam blocks beneath the capping material for distributing stress to underlying EPS22 geofoam:

i) Assume 1 foot thick layer of EPS39 geofoam (refer to Figure B-4).

![Figure B-4 – Typical Geofoam Embankment with 1 foot EPS39 Geofoam](image)
ii) Per NCHRP Web Report 65, page 6-45, vertical stress distribution through EPS geofoam can be approximated by assuming a 1H:2V distribution.

iii) As done in previous calculation, assume 1H:2V pressure distribution through capping material (refer to Figure B-5).

iv) From page 3 of calculation, assume dual tire contact area of 20” x 5”.

v) Determine the loaded area (A) at top of EPS22 geofoam blocks (refer to Figure B-5).

\[
A = (L)(W) = 23 \text{ in} \times 38 \text{ in} = 874 \text{ in}^2
\]

![Figure B-5 – Pressure Distribution Dimensions of EPS39 Geofoam and Capping](image)

Note: The 18 inches includes the 1 foot thick layer of EPS39 Geofoam with a 6 inch layer of compacted capping material.

f) Determine the equivalent uniform pressure (P) at top of EPS22 geofoam blocks:

\[
P = \frac{L_{\text{max}}}{A} + (D_c)(y) = \frac{10,700 \text{ lbs}}{874 \text{ in}^2} + \frac{(0.5 \text{ ft})(130 \text{ lb/ft}^3)}{144 \text{ psf/psi}} = 12.7 \text{ psi} \sim 13 \text{ psi}
\]

Conclusion: The estimated pressure of 13 psi is below the compressive resistance of EPS22 geofoam at 5% deformation (i.e., 16.7 psi). Therefore, 1 foot of EPS39 geofoam is sufficient at the surface of the geofoam block fill, and EPS22 geofoam is acceptable to use below the EPS39 geofoam.

⇒ **EPS22, 5% Compressive Strength = 13.0 psi < 16.7 psi ∴ OK**

g) Proceed to check stresses for final loading conditions.

3) **FINAL LOADS/CONDITIONS** (refer to Figure B-6)

a) Assumptions:

i) Geofoam will be covered with a minimum of 4 feet, but not exceeding 5 feet of material. “Material” includes:
   - (1) Capping material
   - (2) Embankment material
   - (3) Pavement section

ii) Use dual wheel load that was used in Construction Loads/Conditions calculations.

\[
L_{\text{max}} = 10,700 \text{ lbs/set of dual tires} \quad \text{(Unless noted otherwise)}
\]
b) Calculate load factor (IM) per DM-4, 2012, Section 3.6.2.2.

\[
IM = 40(1 - 0.125D_E) \geq 0\% , \text{where}
\]

\[
IM = \text{Dynamic Load Allowance} \\
D_E = \text{Minimum Depth of Cover}
\]

For \( D_E = 4 \text{ ft} \) (i.e., min. required per Geofoam Spec)

\[
IM = 40\left(1 - 0.125(4 \text{ ft})\right) = 20\% \geq 0\% \therefore \text{OK}
\]

c) Determine total load (\( L'_{\text{max}} \)) when applying load factor (IM) to wheel load.

\[
L'_{\text{max}} = (1.20) \left(10,700 \text{ lbs/ set of dual tires} \right) = 12,840 \text{ lbs/ set of dual tires}
\]

d) Estimate Pressure at top of EPS39 Geofoam:

i) Assume a 1H:2V distribution through pavement section and embankment. Distributed area (A) at top of EPS39 geofoam is:

\[
A_1 = L + 2 \left(\frac{D_{\text{min}}}{2}\right) = 5 \text{ in} + 2 \left(\frac{48 \text{ in}}{2}\right) = 53 \text{ in}
\]

\[
A_2 = W + 2 \left(\frac{D_{\text{min}}}{2}\right) = 20 \text{ in} + 2 \left(\frac{48 \text{ in}}{2}\right) = 68 \text{ in}
\]

\[
A = (A_1)(A_2) = 53 \text{ in} \times 68 \text{ in} = 3,604 \text{ in}^2
\]

ii) Estimate pressure (P) at top of EPS39 geofoam using factored dual axle load and pressure from pavement section, embankment, and capping material. Assume 135 pcf to account for future wearing surface overlay.

\[
P = \frac{L'_{\text{max}}}{A} + (D_E)(y) = \frac{12,840 \text{ lbs/ set of dual tires}}{3,604 \text{ in}^2} + \frac{(4 \text{ ft})(135 \text{ lb/ft}^3)}{144 \text{ psi}} = 7.4 \text{ psi}
\]

\[\Rightarrow \text{EPS39, 1\% Compressive Strength} = 7.4 \text{ psi} < 15.0 \text{ psi} \therefore \text{OK}\]
e) Estimate pressure (P) at 1 foot below top of EPS39 geofoam (i.e., at top of EPS22 geofoam). Assume dead load is relatively unchanged from 1 foot of EPS39 geofoam. Add additional pressure distribution to account for 1 foot of EPS39 geofoam.

\[ P = \frac{L_{\text{max}}'}{244} + (D_{E})(y) = \frac{12,840 \text{ lbs/set of dual tires}}{5,200 \text{ in}^2} + 3.8 \text{ psi} = 6.3 \text{ psi} \]

⇒ **EPS22, 1% Compressive Strength = 6.3 psi < 7.3 psi :: OK**

f) Check pressures:

i) At top of EPS39 geofoam for 6 Feet of cover (pavement section, embankment & capping material):

(1) For IM = 1.10, \( L'_{\text{max}} = 11,770 \text{ lbs/set of dual tires} \)

(2) For 6 feet, \( A_t = 7,084 \text{ in}^2 \)

\[ P = \frac{L_{\text{max}}'}{A_t} + (D_{E})(y) = \frac{11,770 \text{ lbs/set of dual tires}}{7,084 \text{ in}^2} + \left( \frac{6 \text{ ft}(135 \text{ lb/ft}^3)}{144 \text{ psi/psi}} \right) = 7.3 \text{ psi} \]

⇒ **EPS39, 1% Compressive Strength = 7.3 psi < 15.0 psi :: OK**

ii) For 1 foot below top of EPS39 geofoam (i.e., at top of EPS22 geofoam). Assume dead load is relatively unchanged from 1 foot of EPS39 geofoam. Add additional pressure distribution to account for 1 foot of EPS39 geofoam. Using the same factored load above:

\[ P = \frac{L_{\text{max}}'}{(92 \text{ in} + 12 \text{ in})(77 \text{ in} + 12 \text{ in})} + (D_{E})(y) = \frac{11,770 \text{ lbs/set of dual tires}}{9,256 \text{ in}^2} + 5.6 \text{ psi} = 6.9 \text{ psi} \]

⇒ **EPS22, 1% Compressive Strength = 6.9 psi < 7.3 psi :: OK**

g) Conclusions: Estimated pressures for the final loading condition were calculated for cover (i.e., pavement section, embankment and capping material) thickness varying from 4 feet to 6 feet. Based on the calculations, the pressures at the top of the geofoam block fill (i.e., EPS39 geofoam) and 1 foot below the top (i.e., EPS22 geofoam) are below the 1% compressive resistance of the geofoam.