
Discussion of “Numerical Modeling of Geofam Embankments” by M. P. Newman, S. F. Bartlett, and E. C. Lawton

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Introduction

Expanded polystyrene (EPS) is a polymeric (plastic) material that was discovered/invented in then-West Germany circa 1950. In its generic block-molded product form, it has been used in geotechnical applications as a lightweight fill material for road construction since at least circa 1970 (Horvath 1995). Despite the fact that EPS used in this way is a relatively mature geotechnology, the number of instrumented case histories that have been documented in the literature is relatively few. Therefore, the authors' paper is a welcome contribution to the literature. However, the discussor believes there are a number of items in the paper that require critical comment and, in some cases, correction.

Terminology

One of the unfortunately enduring misconceptions that is perpetuated in this paper is that the terms “EPS” and “geofam” are synonymous. That is simply incorrect. In reality, the term geofam has a surprisingly complex history that continues to the present.

Presently available information indicates that the earliest known use of the term geofam was during the 1980s, when it was a registered trademark in the United States for a proprietary EPS product in commercial production. The discussor first became aware of this in 1997. Subsequent investigation by the discussor indicated that this product apparently had relatively limited geographic distribution and production life, reportedly only in Alaska for construction related to the Trans-Alaska Pipeline System. Legal trademark registration “geofam” for this product ended in 1988 [U.S. Patent and Trademark Office (USPTO) 2010].

Because the term geofam had received such limited geographic and temporal dissemination, it was largely unknown, and it was independently redefined by the discussor and reportedly others more or less contemporaneously in the early 1990s. At the time of its rediscovery, the term was intentionally broadened in its definition and used as a generic term applied to a newly defined family of geosynthetic materials and derivative products (Horvath 1995). Thus, as currently defined, geofam materials can be polymeric, vitreous, or cementitious in composition, but they always have the common element of a structure consisting of numerous closed, small, gas-filled cells. Therefore, it is clear that the usage of the term geofam for almost 20 years now and continuing in the present is in a broad, generic context similar to other geosynthetic product categories such as geomembrane and geotextile. As with other types of geosynthetics, when dealing with geofam, the composition of a specific material or product must be clearly defined. Therefore, the correct term for block-molded EPS as a geofam

material is “EPS-block geofam.” Using the “block” identifier is neither trivial nor redundant because EPS can also be manufactured in a shape-molded form (e.g., the ubiquitous white foam beverage cup). EPS-shape geofam products exist and can have geosynthetically relevant properties that are different from EPS-block geofam products because of complex stress anisotropies introduced during the shape-molding process. Therefore, defining an EPS-geofam product as being block- or shape-molded is an important detail.

In recent years, this terminology issue has become unexpectedly clouded because the term “geofam” has once again been filed as a registered trademark in the United States for a resinous-grout product that is completely unrelated to the broad, generic definition in widespread use since the early 1990s (USPTO 2010). How this recent legal development will impact on the use of the term geofam in a broad geosynthetics context remains to be seen.

A final comment regarding terminology is that EPS should not be referred to as being “extruded,” as was done in the original article. There is another type of polystyrene-based foam called “extruded polystyrene” (XPS) that is manufactured in a process that is altogether different from EPS and produces a material with a closed-cell structure and mechanical (stress, strain, time, and temperature) properties that are entirely different from EPS. XPS has been and is also used as a geofam material, although on a much more limited basis compared to EPS for technical and economic reasons.

Manufacturing Quality of Block-Molded EPS

The authors imply that there were several issues related to the manufactured quality of EPS blocks encountered on the I-15 project that were standard or typical for geofam applications. The discussor disagrees strongly with these implications, which can be highly misleading to potential users of EPS-block geofam.

To begin with, EPS blocks that have a noticeable postmolding curvature along their longitudinal axis, called “banana blocks” in the trade for obvious reasons, are indicative of either poor mold performance or poor molding practice (Horvath 2009). This and similar block deformities, such as sunken faces, are simply not an inherent, unavoidable result of the postmolding cooling of EPS blocks once they are released from the mold, but rather clear indications of poor manufacturing quality for any number of reasons.

Furthermore, that banana blocks were allowed on the I-15 project because they conformed to the project specification should not be taken as an indication that such blocks would always be allowed in geofam applications. Their use on the I-15 project was simply an artifact of the specification developed for that project that was unique to that project. During the past decade, guideline standards for developing project-specific specifications for EPS-block geofam for road applications in the United States have been developed, and these standards would simply not allow such malformed blocks to be used (Stark et al. 2004a, b; Arellano et al. 2009). To date, these standards have been used to craft EPS-block geofam specifications for a number of major projects involving interstate highways, such as I-90/I-93 in Boston (the “Boston Big Dig”) and the Woodrow Wilson Bridge carrying I-95 over the Potomac River in the District of Columbia and the states of Maryland and Virginia. These projects and other, smaller projects have clearly demonstrated that it is possible to routinely supply

EPS blocks in large quantities and in a variety of material densities with acceptable geometric tolerances free of gross curvature.

This issue of geometric distortion of EPS blocks used for geofoam applications is not trivial, as clearly evidenced by the information provided in this paper. To begin with, having to independently (good quality-assurance practice would dictate that one would not want to rely solely on contractor judgment for this) check each block for its direction of curvature and place each block preferentially with its concave ‘bad side’ facing downward is collectively time consuming when a very large number of blocks are to be placed. More importantly, it is clear from both the measured and calculated results presented by the authors (the system stiffnesses portrayed in Fig. 5 show this most clearly) that the overall “slop” in the assemblage of EPS blocks caused by using distorted blocks routinely and consistently on this project was the cause of a significant proportion of the overall vertical compression of the fill. In the discussor’s opinion, this contribution to compression is largely avoidable if more stringent, yet routinely achievable, material specifications are used that would preclude the use of malformed EPS blocks. When such specifications are used, an EPS-block molder (manufacturer) has a choice to either adopt better molding practices in the first place so as not to generate blocks with postmolding distortion or trim distorted blocks before they leave the plant.

Engineering Properties of Block-Molded EPS

Using block-molded EPS as a lightweight fill material is classified as a “small-strain” geofoam application in which design is governed by displacements and the serviceability limit state. Specifically, compressive strains within an assemblage of EPS blocks under service loads must be kept within a stringent limit, typically taken to be 1%, to prevent excessive long-term compression of the EPS because of both nonrecoverable (plastic) and creep strains (Horvath 1995; Stark et al. 2004a, b).

A key material property when designing for small-strain EPS-block geofoam applications is the secant (formerly referred to as tangent) Young’s modulus within the nominally linear-elastic initial portion of the unconfined axial compressive stress versus axial strain loading of EPS. The authors refer to correlation of this modulus with the molded density of the EPS. Such modulus-density correlations always need to be viewed with care because they are affected by numerous EPS manufacturing and testing protocol variables (Horvath 1995, 2009). In particular, the small-strain modulus of EPS can be significantly affected by the presence of recycled EPS scrap (referred to as “regrind” or “grind” in the trade) in the mixture of particles used to mold an EPS block. This regrind issue is noted because the EPS-block geofoam specification used for the I-15 project is known to have included specific language concerning the use of regrind. Again, as noted previously, the specification used on this project should not be taken as necessarily representative of one used universally or even widely on other projects in the United States that use EPS-block geofoam as a lightweight fill material in road construction. The reference standard mentioned previously (Stark et al. 2004a, b; Arellano et al. 2009) contains no such explicit mention of regrind.

Design Details

The authors imply that a “load distribution slab” (LDS) is a mandatory feature of any fill employing EPS blocks beneath a road to prevent overstressing of the underlying EPS blocks. This should have been stated more clearly as reflecting their professional

design opinion as opposed to incontrovertible fact that is accepted universally, which it is not.

The need for an LDS in this application is highly controversial and even contentious. This is rooted in incomplete knowledge of both how an LDS came to be used in this application and subsequent research that involved pavement sections both without and with an LDS. This discussion is not the proper forum to discuss this issue in detail. However, there are certain relevant facts that should be noted:

- Despite the use of LDSs in practice for almost 40 years, there is still no clear understanding of exactly how they behave, i.e., is it simply load reduction simply because of the thickness of the slab (as is generally assumed in routine practice) or does slab flexure play a role in the process?
- There are several national standards for EPS-block geofoam as lightweight fill for roads employed by European countries that do not mandate the use of an LDS, and this position has been adopted in several research studies conducted in the United States (Horvath 1995; Stark et al. 2004a, b; Arellano et al. 2009).
- The absence of an LDS in and of itself does not explain the cause of observed failures of roads constructed on EPS-block geofoam fills, nor does the presence of an LDS guarantee that failure will not occur. Experience to date is that failures are generally the result of overstressing the EPS beyond its small-strain elastic limit stress and that such overstressing can occur even when an LDS is used (Horvath 1999, 2004, 2010a).

As a final comment on the LDS issue, it is worth noting that the density of EPS used on the I-15 project was unusually low (18 kg/m^3) for EPS blocks used beneath any type of road. In fact, the discussor is not aware of any other project, certainly one built to interstate standards, that used material with such a low density. As noted in Horvath (1995), the de facto minimum EPS density for road applications worldwide has historically been taken to be 20 kg/m^3 , even when an LDS is used, based on decades of experience in several countries, such as Norway and Japan, that pioneered the routine use of EPS-block geofoam as a lightweight fill material going back to circa 1970. In addition, in areas where seismicity must be considered (and the I-15 project area discussed by the authors certainly fits into this category) experience has been that stand-alone embankments incorporating EPS-block geofoam into their cross section are typically susceptible to a behavioral mode called “seismic rocking” that causes stress concentrations in portions of the EPS blocks because of the Mc/I effect (Riad and Horvath 2004; Riad 2005). The behavioral phenomenon of seismic rocking was first identified in full-scale shake table tests conducted in Japan and can cause crushing of EPS unless material of sufficient small-strain stiffness is used. Even in areas with modest seismic potential compared to Salt Lake City, such as Boston, experience has shown that EPS almost twice the density of that used on the I-15 project is required to prevent overstressing of the EPS due to seismic rocking (Riad and Horvath 2004; Riad 2005).

Measured and Calculated Results

It is the discussor’s opinion that the stress measurements obtained by using the total pressure cells are highly questionable as to their accuracy despite the various explanations given by the authors to explain the various unusual behaviors, such as negative and cyclic stresses, depicted collectively in Figs. 4, 7, 9, and 11. The use of total pressure cells in geotechnical applications has long been controversial and questionable because of the general issue of stiffness

compliance between the cell and its surrounding materials and the concomitant result of either overregistration or underregistration (Dunncliff 1988). Given the relatively low stiffness of block-molded EPS with a density of 18 kg/m^3 compared to normal earth materials, the performance of the cells reported in this paper is particularly questionable. The cyclic behavior shown in Fig. 4 is particularly hard to accept as being correct for the reason given by the authors, i.e., thermal expansion and contraction of the EPS blocks. EPS is an extremely efficient thermal insulator, and historically this has been its primary use in a wide variety of applications, including insulated pavements and railways, at least a decade before its use as a lightweight fill material (Horvath 1995). When used to prevent seasonal freezing of pavement subgrades and railway track systems, only relatively thin (of the order of 50–100 mm) panels of EPS are required even in the most severe climates with seasonal ground freezing. Therefore, in the absence of any two-dimensional thermal analyses of the I-15 project fills presented by the authors to prove to the contrary, it is difficult to envisage significant seasonal thermal changes penetrating into the EPS mass far enough to cause the stress variations shown throughout the EPS mass. Thus, it seems more likely that the causes of the observed seasonal-cyclic fluctuations had other causes, perhaps in the fluid used to fill the cells. The discussor has had experience with deaired ethylene glycol-water mixtures as a fluid for pressure sensors many years ago and found the mixture to be quite unstable thermally so that it produced erratic and unreliable results in the sensors.

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Queries

1. Would it be helpful to spell out Mc/I?
2. Is the “Manufacturing quality issues” article accepted now?
3. The volume, issue, and pages of the “Emerging trends” article have been inserted - please confirm.
4. The Horvath 2010b reference is not cited in the text. OK to remove?