American Society of Civil Engineers Geo-Institute
Geo-Trans 2004
July 27-31, 2004
Los Angeles, California, U.S.A.

CELLULAR GEOSYNTHETICS IN TRANSPORTATION APPLICATIONS

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ABSTRACT: *Cellular geosynthetics* is the generic term for geosynthetic materials and products with either a closed- or open-cell texture. This includes the product categories of *geofoams* and *geocombs* that are the focus of this paper. Cellular geosynthetics have begun to have a noticeable impact in engineered construction, especially transportation applications. This is because they offer a wide range of geosynthetic functions that, with few exceptions, are unavailable from traditional planar geosynthetics such as geogrids, geomembranes and geotextiles. This paper summarizes the geofoam and geocomb materials and products that are available currently, and highlights their functions and typical applications on transportation-related projects with an emphasis on new trends and developments.

INTRODUCTION

Materials with a cellular structure, whether natural or manufactured, are noteworthy for a variety of reasons. They are extraordinarily efficient in that they use relatively small proportions of solid material per unit volume of the overall material. Cellular materials with a solid fraction that is only 2% of the total volume (a porosity of 98% in geotechnical terms) are manufactured routinely. What is noteworthy is that the solid fraction is arranged in such a way that the overall material usually has remarkable stiffness and strength despite its very low density. In addition, the significant void space in cellular materials can sometimes be used productively to store fluids as well as other, softer solids.

SCOPE AND ORGANIZATION OF PAPER

Cellular geosynthetics is a broad topic so there must be a focus to limit this paper to the available space. To begin with, this paper is confined to manufactured materials,

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of which there are currently three categories: *geocells*, *geocombs* and *geofoams*. Only the latter two are discussed here.

The use of geofoams and geocombs in geotechnical engineering practice increased dramatically worldwide during the 1990s. As a result, engineers are now at least somewhat familiar with the more-common geofoam materials such as expanded polystyrene (EPS) and foamed portland-cement concrete (FPCC), and their now-routine use as lightweight fill. However, geofoams and geocombs offer many more geosynthetic functions and potential applications than as lightweight fill for roads. After a brief review of available materials and products and an update on current activities related to their use as lightweight fills, this paper focuses on the broader functions and transportation-related applications. Those seeking more detail than can be presented in this paper will find a detailed treatment of geofoams in Horvath (1995), with summaries in PIARC (1997) and Horvath (1999). The bibliography in Horvath (2001) is useful as a starting point for more-advanced study and research, and is also a reference source for topics not explicitly cited in this paper.

GEOFOAMS

Definition

Although most geotechnical engineers have heard the term geofoam, misconceptions about its definition continue. Since the early 1990s, geofoam has been the generic term for any synthetic geomaterial created in an expansion process using a gas (*blowing agent*) and resulting in a texture of numerous closed cells. Therefore geofoam is not just one material or product. It is actually a very diverse family of many different kinds of materials and products.

Materials

Several proven geofoam materials exist. There are additional materials that have been tried over the years but were found to be technically unacceptable. The latter are not listed here but are discussed for their historical interest in Horvath (1995).

Geofoam materials can be divided into three major categories:

- polymeric (plastic),
- cementitious (typically using portland cement) and
- cellular glass.

The polymeric category is further subdivided depending on the polymer chemistry and specific manufacturing process used:

- rigid cellular polystyrene (RCPS), which can be either expanded polystyrene (EPS) or extruded polystyrene (XPS);
- polyethylene (PE);
- polyethylene-polystyrene (PE-PS) blend; and
- polyurethane (PUR).

Despite the relatively large number and variety of geofoam materials, as a result of more than 40 years of in-ground experience EPS has emerged worldwide as the material of choice in most applications.

Products

Geofoams that can only be manufactured in a factory (which includes the dominant EPS) are typically molded or cut into the final block or panel shape required for the particular application. However, field cutting of a block or panel to accommodate a particular construction situation can easily be done using a variety of tools. Geofoams such as PUR or FPCC that are foamed in place simply fill the shape of the volume that is to be filled.

Functions and Applications

Lightweight Fill

Although not the oldest geofoam functional application, lightweight fill using blocks of EPS is perhaps the most intuitive. It is by far the most widely known and commonly used. Because the use of EPS geofoam for lightweight fills is a fairly mature technology going back to at least 1972, current research and development efforts are concentrated on improving technical understanding and ease of use as well as finding new and innovative applications. Significant recent or current activities of interest in the U.S.A. include:

- inclusion of EPS geofoam as a viable ground-improvement technology in various educational efforts of the Federal Highway Administration (FHwA) and National Highway Institute since the late 1990s (USDOT 2004a; USDOT 2004b);
- development and publication of the first comprehensive standards specifically for using EPS geofoam for roads (Stark et al. 2002). The draft version of these standards was used as the basis for design of numerous innovative fills on the Boston 'Big Dig' (Riad et al. 2003b; Horvath 2003; Riad et al. 2004);
- recent recognition by the FHwA of the benefit of *accelerated construction* and the specific mention of EPS geofoam in that context (USDOT 2002; Riad et al. 2003a);
- broader applications beyond the well-known and widely used road, airfield and railway earthworks that include:
  - supporting shallow foundations for relatively lightly loaded buildings and small bridges directly on the EPS blocks,
  - backfills and fills behind earth retaining structures to drastically reduce both gravity and seismic loads acting on the structures;
- development of 'anti-buoyancy' shape-molded EPS blocks (Figure 1); and
- development of an improved design for inter-block mechanical connectors as there is increasing evidence that the traditional barbed-plate design leaves a lot to be desired under the repetitive, multi-directional shaking typical of earthquakes.

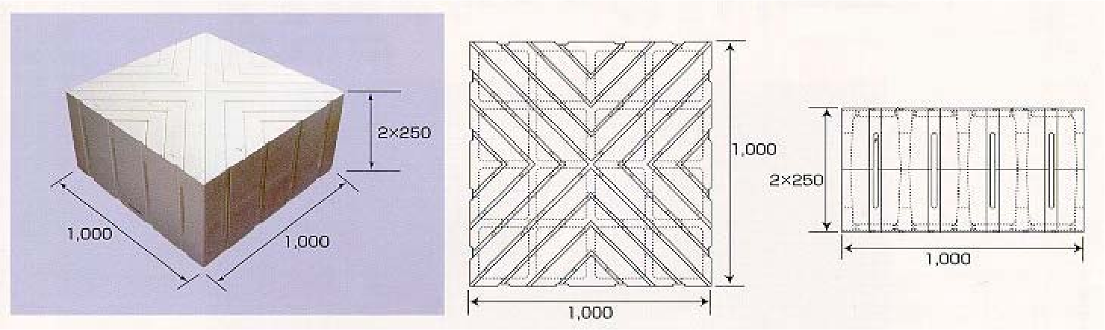

FIG. 1. EPS-Geofoam 'Anti-Buoyancy' Blocks Developed in Japan (all dimensions in millimetres)

Thermal Insulation

This is the first known geofoam functional application, dating back at least to the early 1960s, and one developed initially with transportation applications in mind. A wide variety of polymeric materials as well as cellular glass have been used successfully as thermal insulation although EPS and XPS now predominate. However, despite almost four decades of proven, successful use thermal insulation of pavements and railways can be classified as an underutilized geofoam function in many countries, including the U.S.A. This is all the more surprising given the fact that the use of plastic foams as thermal insulation in transportation applications was actively researched and patented in the U.S.A. in the 1960s.

Current activities related to this function are largely confined to either rediscovering applications or playing catch-up with usage in other areas, notably northern Europe. Some of the more-interesting transportation-related applications are:

- above the roof slab of shallow buried structures such as cut-and-cover tunnels and parking garages to limit seasonal thermal changes and concomitant thermal expansion and contraction of the roof which can cause structural problems;
- with shallow foundations to allow shallower embedment (referred to in the literature as the *frost-protected shallow foundation* concept);
- beneath pavements and railway track to prevent or at least limit subgrade freezing and concomitant frost heave (and the problems that eventual thawing creates such as potholes);
- behind earth-retaining structures, including soil-nailed walls, to prevent freezing of the drainage systems and/or retained soil;
- above liquid-bearing utility lines to allow shallower embedment while preventing freezing of the contents (referred to in the literature as *frost shielding*);
- beneath the inverts of open culverts to prevent *frost jacking*; and
- beneath the lining of mined tunnels to prevent freezing of their ground-water drainage systems.

Note that some of these applications are appropriate to all climates. Thus thermal insulation using geofoams is not just a 'cold-climate' geotechnology as many believe.

Drainage (Fluid Transmission)

This is a geofoam function that has been relatively little used to date although it was identified at least as far back as the 1970s. The primary reason for its modest use is that if drainage is all that is desired in a given application then there are other geosynthetics such as sheet-drains and geonets that can provide this at a lower cost compared to a geofoam-based product.

However, geofoam drainage products (only plastic foams have proven to be useful in this functional application) have a distinct advantage over these other types of geosynthetic drainage products in that they can be multifunctional depending on the specific material and product used. This multifunctionality has, in general, not been fully appreciated and utilized to date. Thus if designers made use of the fact that a geofoam drainage product can simultaneously provide other geosynthetic functions such as thermal insulation and compressible inclusion (defined subsequently) then the use of geofoam-based drainage products could increase significantly. On transportation-related projects such multifunctional applications would be particularly useful with virtually every type of earth-retaining structure.

Noise and Vibration Damping

The vibrations considered here are limited to small-amplitude motions associated with motor vehicles and trains which typically cause serviceability problems (usually human perception and complaints). Seismic vibrations fall under the lightweight fill or compressible inclusion functional categories depending on the particular application.

This is another little-researched and little-used geofoam function that dates back at least to the 1980s. It is certainly a niche application which accounts for some of its modest use. Another reason is that there is no simple, universal analytical approach that can be used. Rather, each application needs to be evaluated on a case-specific basis which can be analytically demanding. Nevertheless, polymeric geofoams have proven to be useful in applications such as attenuating ground-borne vibrations from motor vehicles and trains, and noise from trains.

Compressible Inclusion

This is one of the newer geofoam functions (since circa 1980s) but has the potential to be the most widely used of all because of the number of potential applications, especially those involving earth-retaining structures where there is a real potential to revolutionize construction. Thus the potential impact on transportation is significant (Horvath 2004a).

There was a fair amount of analytical research into compressible-inclusion applications that occurred during the 1980s and 1990s that continues to this day. During the same time frame there was also considerable research and development into cost-effective materials and products based on EPS and *resilient (elasticized)* EPS to act as the compressible inclusion. An introduction to the subject of compressible inclusions can be found in Horvath (1998a) with a more-detailed treatment of the analytical aspects in Horvath (1998b) and Horvath (2000).

The potential applications for geofoam compressible inclusions include:

- allowing shear-strength mobilization of soil adjacent to rigid and/or non-yielding earth-retaining structures to reduce lateral earth pressures acting on these structures. This includes the *Reduced Earth Pressure (REP)* concept that reduces pressures to approximately the active state and the *Zero Earth Pressure (ZEP)* concept in which geosynthetic tensile reinforcement acts synergistically with the compressible inclusion to reduce lateral earth pressures to close to zero;
- accommodating the volume change of soil or rock that may be inherently expansive or subject to freezing, e.g. adjacent to an earth-retaining structure. The extensive occurrence of expansive (swelling) soils worldwide makes this also a potentially very useful application; and
- accommodating structure movement such as that which occurs with integral-abutment bridges (Horvath 2000; Horvath 2004b). An example of a recent project application is shown in Figure 2.

FIG. 2. Geofoam Geocomposite Used as a Compressible Inclusion on a Bridge Project in the Commonwealth of Virginia, U.S.A.

Structural/Miscellaneous

This final category is the one most recently identified and is an eclectic collection of applications, mostly using various types of polymeric foams and all of them with potentially significant transportation-related applications:

- insulated wall forms for cast-in-place (CIP) portland-cement concrete (PCC) construction;
- lightweight facing panels for mechanically stabilized earth walls (MSEW);
- void formers for CIP PCC construction;
- crash barriers for motor vehicles and aircraft;
- impact cushioning for rock sheds in mountainous regions; and
- void filling and foundation remediation using foam grouts.

Note that in many of these applications other geofoam functions could be utilized if desired. For example, wall forms could be designed to act as a drainage layer and compressible inclusion in addition to providing post-construction thermal insulation.

GEOCOMBS

Definition

A geocomb is an open-cell polymeric material with a honeycomb-like cross-section that is created in an extrusion process performed in a fixed plant. A geocomb is essentially a bundle of open-end tubes (Figure 3). Each tube is of the order of 25 mm (1 in) across and the material is approximately 96% voids overall (a porosity of 96%).

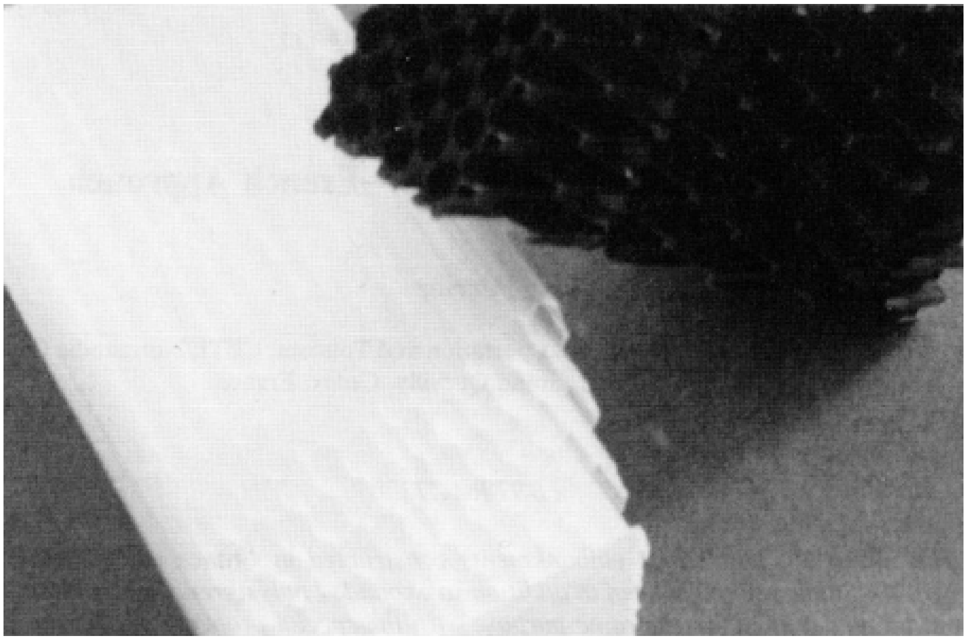

FIG. 3. Sections of Geocomb Blocks Illustrating Open-Cell Structure

Geocombs are one of the newer geosynthetic product families to be identified. Although the materials currently referred to as geocombs (the term was coined only in 1999) have been used in France and its territorial affiliates since the 1980s, they have become more widely known only in the last few years. They are still not readily available outside of France although this appears to be changing.

Materials

Two different polymers are known to have been used for geocombs to date: a translucent polypropylene (PP) that appears white in photographs and black polyvinylchloride (PVC). The PP product line appears to be predominant in terms of past and current use.

Products

The extruded honeycomb material is typically factory cut into panel- or block-shaped pieces that are the basic final product. The blocks have dimensions that are close to those of EPS geofoam as used for lightweight-fill applications (approximately 600 x 1200 x 4800 mm (2 x 4 x 8 ft)). In many cases, the geocomb product has a non-woven geotextile that is factory bonded to one or both open ends of the tubes to prevent solid particles from entering them once the blocks are in place. The panels or blocks are placed with the tubes oriented vertically as the overall product is significantly stiffer when loaded in a direction parallel to the tube axes as opposed to perpendicular to them.

Functions and Applications

Lightweight Fill

This appears to be the predominant geocomb functional usage to date and the one most widely documented in the literature (PIARC 1997; Perrier 1997). Geocomb blocks are broadly comparable to EPS-geofoam blocks in terms of load-carrying capability when used as lightweight fill for roads (Figure 4). Although geocomb costs more than EPS geofoam per unit volume and has an overall density approximately twice that of EPS, geocombs have the distinct advantage of having virtually no buoyancy upon submergence as their open-cell structure allows water to fill the void spaces. This can be a crucial advantage that makes geocomb the lightweight-fill material of choice in applications where permanent or potential submergence is an important design consideration.

Drainage (Fluid Storage and Transmission)

A geosynthetic function that appears to be of growing interest is to make use of the significant open-cell structure and porosity of geocombs in applications where fluid handling, primarily of water, is the primary function. Not only do geocombs readily transmit water but they can also be used to store water for some indefinite period of time. The primary application for this appears to be on transportation-related projects where temporary storage followed by subterranean disposition of storm-water runoff is a benefit. For example, what amounts to a subterranean reservoir with a very efficient 96% voids per unit volume can be constructed without limit beneath parking lots and similar paved areas.

FIG. 4. Geocomb Blocks Used as Lightweight Fill on a Bridge Project in France

REFERENCES

Horvath, J. S. (1995). *Geofoam geosynthetic*, Horvath Engr., P.C., Scarsdale, NY.

Horvath, J. S. (1998a). "The compressible inclusion function of EPS geofoam: an overview of concepts, applications, and products." *Res. Rpt. No. CE/GE-98-1*, Manhattan Coll., Sch. of Engr., Civil Engr. Dept., Bronx, NY.

Horvath, J. S. (1998b). "The compressible-inclusion function of EPS geofoam: analysis and design methodologies." *Res. Rpt. No. CE/GE-98-2*, Manhattan Coll., Sch. of Engr., Civil Engr Dept., Bronx, NY.

Horvath, J. S. (1999). "Geofoam and geocomb: lessons from the second millennium A.D. as insight for the future." *Res. Rpt. No. CE/GE-99-2*, Manhattan Coll., Sch. of Engr., Civil Engr. Dept., Bronx, NY.

Horvath, J. S. (2000). "Integral-abutment bridges: problems and innovative solutions using EPS geofoam and other geosynthetics." *Res. Rpt. No. CE/GE-00-2*, Manhattan Coll., Sch. of Engr., Civil Engr. Dept., Bronx, NY.

Horvath, J. S. (2001). "Geomaterials research project - geofoam and geocomb geosynthetics: a bibliography through the second millennium A.D." *Res. Rpt. No. CGT-2001-1*, Manhattan Coll., Sch. of Engr., Ctr. for Geotechnology, Bronx, NY.

Horvath, J. S. (2003). "Innovative aspects of the use of expanded polystyrene (EPS) on Boston's 'Big Dig'." *Res. Rpt. No. CGT-2003-1*, Manhattan Coll., Sch. of Engr., Ctr. for Geotechnology, Bronx, NY.

Horvath, J. S. (2004a). "Controlled yielding using geofoam compressible inclusions: new frontier in earth retaining structures." *Proc. Geo-Trans 2004*, ASCE.

Horvath, J. S. (2004b). "Integral-abutment bridges: a complex soil-structure interaction challenge." *Proc. Geo-Trans 2004*, ASCE.

Perrier, H. (1997). "Ultra light cellular structure - French approach", *Geotextiles and Geomembranes*, Elsevier Sci. Ltd., London, U.K., 15 (1-3), 59-76.

PIARC Tech. Comm. C12 on Earthworks, Drainage, Subgrade. (1997). "Matériaux legers our remblai/lightweight filling materials." *Document No. 12.02.B*, PIARC - World Road Association, France.

Riad, H., Ricci, A., Osborn, P. and Horvath, J. S. (2003a). "Expanded polystyrene (EPS) geofoam for road embankments and other lightweight fills in urban environments." *Proc. Soil and Rock America 2003*, Cambridge, MA.

Riad, H., Ricci, A., Osborn, P., Wood, D. C. and Horvath, J. S. (2003b). "Innovative aspects of the use of expanded polystyrene (EPS) on Boston's 'Big Dig'." preprint paper No. 03-2823, Trans. Res. Bd. 82nd Ann. Mtg., Washington, DC.

Riad, H. L., Ricci, A. L., Osborn, P. W., D'Angelo, D. A. and Horvath, J. S. (2004). "Design of lightweight fills for road embankments on Boston's Central Artery/Tunnel project." *Proc. Fifth Intl. Conf. on Case Hist. in Geotech. Engr.*, New York, NY.

Stark, T. D., Arellano, D., Horvath, J. S. and Leshchinsky, D. (2002). *Guidelines for geofoam applications in embankment projects*, Final (Phase II) Rpt. - Natl. Coop. Hwy. Res. Prog. Proj. No. 24-11.

U.S. Dept. of Trans., Fed. Hwy. Admin., Bridge Technology (2002). <www.fhwa.dot.gov/bridge/bescan.htm> (4 April 2004).

U.S. Dept. of Trans., Fed. Hwy. Admin., Bridge Technology (2004a). <www.fhwa.dot.gov/bridge/geotra.htm#nhi_13234> (4 April 2004).

U.S. Dept. of Trans., Fed. Hwy. Admin., Bridge Technology (2004b). <www.fhwa.dot.gov/bridge/eps.htm> (4 April 2004).