American Society of Civil Engineers Geo-Institute
GeoCongress 2008
9-12 March 2008
New Orleans, Louisiana, U.S.A.

Using EPS-Block Geofoam for Levee Rehabilitation and Construction

John S. Horvath[1], Ph.D., P.E., M.ASCE

[1]Professor, Manhattan College, Civil and Environmental Engineering Department, Bronx, NY 10471, U.S.A.; john.horvath@manhattan.edu

ABSTRACT: *Block-molded expanded polystyrene (EPS-block)* is the material of choice worldwide for most of the functional applications of the *cellular-geosynthetic* product family called *geofoam*. In particular, the use of EPS-block for the very common geofoam functional application of *lightweight-fill* is now considered a generic, commodity design alternative in routine geotechnical engineering practice. Despite the relatively widespread use of EPS-block geofoam for certain lightweight-fill applications such as road embankments, there are many other applications that have received relatively little attention and use to date in practice. One such underutilized lightweight-fill application that has significant potential worldwide is for levees. There are technical and economic benefits for both new and existing levees. The primary benefits derive from the fact that EPS-block geofoam has a density approximately 1% that of soil so can have a significant impact on both reducing stress-dependent settlements and improving stability, issues that are often critically important for levees. This paper outlines the technical bases for using EPS-block geofoam for levees as well as describes case histories where this concept has been used in practice.

INTRODUCTION

EPS-block geofoam is now widely accepted and increasingly used throughout the world as the geofoam material of choice because of its inherent material properties, multifunctional capabilities, and lower cost relative to other geofoam materials (Horvath 1995). In particular, applications utilizing its lightweight-fill geosynthetic function under both gravity and seismic loads is now considered a generic, commodity design alternative in routine geotechnical engineering practice. However, the vast majority of projects where the lightweight-fill function of EPS-block geofoam has been utilized to date have involved transportation earthworks and earth-retaining structures for roads and railways. Thus there are other potential applications still to be identified, researched, and developed to their full potential. One of the more intriguing of these is the use of EPS-block geofoam with water-resources structures in general and levees in particular.

OVERVIEW

This paper focuses on the use of EPS-block geofoam for its lightweight-fill functional application with levees. The presentation and discussion of this subject is divided into three sections. The first addresses the technical issues associated with this particular application. Sufficient information is presented for an experienced geotechnical engineer to be guided as how to logically analyze and design a levee incorporating EPS-block geofoam within the levee cross-section. The second section describes some case histories where this geotechnology has actually been used in practice. While the number of known case histories is relatively small available information indicates that they have been successful which should lend confidence to pursue this geotechnology further in the future. The third and final section makes some suggestions for both refining this geotechnology in future applications as well as possible areas of novel technological development to make this geotechnology more attractive economically.

TECHNICAL ISSUES

Application Concept

The primary benefits of the geosynthetic function of lightweight-fill derive from the fact that EPS-block geofoam has a density approximately 1% that of soil yet if properly designed and specified can have surprising load-carrying capacity (e.g. spread footings for buildings and even road bridges have been founded directly on EPS blocks). Because both the vertical stresses that act on a subgrade beneath a levee under gravity loading as well as the additional inertia forces that develop within a levee under seismic loading are linearly proportional to material density, there are obvious benefits to using EPS-block geofoam as a lightweight-fill material for levees under a wide range of loading conditions and geotechnical behavior modes. These include both initial (undrained) and primary-consolidation settlements as well as bearing capacity and slope stability, all of which are often critically important issues for levees by virtue of the soft-ground conditions on which many levees are constructed.

With this basic understanding of how EPS-block geofoam can be used conceptually to enhance the performance of levees, Figure 1 illustrates the generic execution of this concept. A core portion of a levee that would otherwise consist of soil is constructed (if new) or reconstructed (if existing) to include an assemblage of EPS blocks. Research and experience indicates that if proper design and construction protocols are

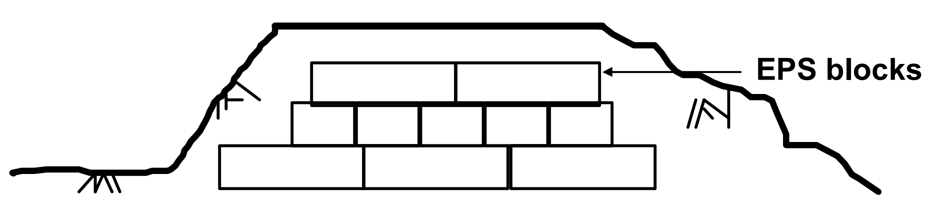

FIG.1. Generic example of levee incorporating EPS-block geofoam.

followed this assemblage of individual blocks will perform as a homogeneous, isotropic mass, even under dynamic loading such as seismic shaking.

Note that the volume of EPS to be used as a relative proportion of the cross-sectional volume-per-unit-length of the levee is not fixed but is a project-specific design variable. The cross-sectional geometry of the assemblage of EPS blocks is not fixed either although a stair-stepped geometry as shown in Figure 1 is generally considered desirable when practicable so that differential settlements of the levee in a plane transverse to its longitudinal axis (i.e. in the same plane depicted in this figure) do not occur abruptly between the portions of the levee without and with the EPS-block geofoam and cause cracking within the levee soils.

Analysis and Design Methodology

The use of EPS-block geofoam for levees as illustrated in Figure 1 is actually a relatively generic lightweight-fill application where load bearing in vertical compression on the EPS blocks is the primary behavioral mode to consider for both analysis of existing fills and design of new ones. Thus the decades of extensive worldwide experience with analyzing and designing lightweight fills for roads using EPS-block geofoam is directly applicable to the levee application.

The current state of practice for analyzing and designing lightweight fills for roads that incorporate EPS-block geofoam in their subgrade is stiffness- and displacement-based as opposed to the strength-based approach used in the early years (1970s-1980s) of this geotechnology (Stark et al. 2004a, ASTM 2005). The reasons for this evolution of analysis and design methodologies are discussed in detail in Horvath (1995) with a concise summary in Horvath (1999).

This stiffness-and-displacement-based methodology has as its technical basis the fact that in uniaxial compression block-molded EPS has nominally linear-elastic behavior up to what is called the *elastic-limit stress*. This is assumed to be the uniaxial compressive stress corresponding to 1% compressive strain as measured in the standard rapid loading tests normally specified by the reference standards cited in current standards developed for EPS-block geofoam (Stark et al. 2004b, ASTM 2004). The elastic-limit stress also turns out to be a convenient threshold for defining the stress level beyond which long-term compressive creep strains are likely to be significant. Thus the elastic-limit stress can be used to define a limiting stress for both linear-elastic behavior under transient loads and acceptable long-term creep magnitudes under permanent loads. Note that the slope of the stress-strain curve between 0% and 1% compressive strain has historically been defined as the *initial tangent Young's modulus* although based on currently available knowledge it is perhaps more accurately defined as the *initial secant Young's modulus*.

As noted above, a levee incorporating EPS-block geofoam can be modeled reasonably as a road embankment. A key design variable for such earthworks is the vertical distance between the pavement surface and top of the EPS blocks. For roads, this is based on the need to have a pavement system within this depth as well as to place the EPS deep enough so that reasonable vertical-normal-stress attenuation of live loads from vehicles occurs. Prevention of differential icing is also a consideration in climates where freezing or near-freezing temperatures can occur. Experience indicates that the vertical distance between the pavement surface and the top of the EPS blocks is typically of the order of 1 metre (3 ft).

Note, however, that this rule-of-thumb is not applicable for levees. Not only are pavement, vehicle, and differential-icing considerations typically not relevant but far more important is the fact that buoyant uplift of the assemblage of EPS blocks is typically the critical design consideration for levee applications. Because of its closed-cell structure and extremely low density, EPS floats readily and permanently in water. Therefore, the uplift water pressure that might act at the base of the assemblage of EPS blocks during the design life of the levee must be estimated and a sufficient downward stress provided on the top of the assemblage of EPS blocks to counteract this. Historically this has been done by placing sufficient soil on top of the assemblage of EPS blocks so that the vertical overburden stress from the soil counteracts the expected uplift water pressure. In round numbers this is typically a one-to-two ratio, i.e. 1 metre of soil counteracts 2 metres of head at the base of the assemblage of EPS blocks. Note that side friction along the sides of the assemblage of EPS blocks is typically neglected in this simplistic analytical model although it certainly is present and could be included a more-refined analysis.

As an alternative to resisting uplift water pressures by dead-weight alone, there have been proposals, at least in concept, to use some type of vertically-oriented tiedown system using ground anchors as the primary component to restrain the assemblage of EPS blocks against uplift. These tiedown elements, which would terminate at their top within a reinforced-portland-cement-concrete slab cast over the top of the assemblage of EPS blocks, are typically proposed to be installed in what is referred to as the *passive* mode which means they would be left unstressed after installation. While such a tie-down system appears effective from a simplistic equilibrium-of-forces perspective the issue of displacements needs to be considered carefully. This is because typical passively-installed bar-type tiedown elements require significant displacement at the top of the element to mobilize the design force, typically of the order of tens of millimetres (one inch or more). Such displacements of the anchorage system might prove detrimental to the long-term stability of the assemblage of EPS blocks in particular and levee in general. In addition, there is the likelihood that during times of no uplift water pressures that these anchorage elements would actually act as de facto minipiles in compression due to inevitable secondary (creep) settlements of the levee. Such undesirable-but-unavoidable compression loading could structurally compromise the anchorage elements (due to buckling) and/or overlying slab (due to punching-shear failure of the anchor heads through the slab).

The final major design detail to note is the need for mechanical connectors between the EPS blocks. Although the friction angle between the molded surfaces of EPS blocks is relatively high (of the order of 30º), research and experience have clearly indicated the need to provide supplemental shear resistance between horizontal block surfaces, at least when seismic or other dynamic loads are expected. Given the potential for uplift water pressures that could tend to cause distortion between the assemblage of EPS blocks, it would seem advisable to use mechanical connectors with levees even if seismic or other dynamic loading is not a design consideration unless and until future research indicates that such connectors are unnecessary.

Material Requirements

The mechanical (stress-strain-time-temperature) properties of block-molded EPS are discussed in detail in Horvath (1995) with an updated summary in Stark et al. (2004a). The most relevant mechanical characteristic of block-molded EPS is that it can be molded within a range of densities/unit weights (roughly 12 to 40 kg/m^3 (0.75 to 2.5 lb/ft^3) on a routine basis although both lower and higher values have been obtained in practice). If all aspects of the molding process are equal except for density, research indicates that there is a proportional relationship (which may or may not be linear based on the particular database used) between EPS density and the key stiffness parameters of elastic-limit stress and initial Young's modulus (Horvath 1995, Stark et al. 2004a).

That having been said, experience indicates that it is very important to emphasize that density/unit weight alone should never be used as the sole criterion for assessing these critical stiffness parameters for block-molded EPS, whether for design or manufacturing quality control and assurance purposes. The reason is that it is possible for block-molded EPS of a given density to have a range in stiffness properties depending on numerous variations that can occur during the actual molding process. Therefore design using EPS-block geofoam should always be done by first analytically determining the minimum elastic-limit stress and initial Young's modulus that is required to satisfy the anticipated compressive stresses on the EPS blocks. Then a project-specific, performance-based specification should be developed using appropriate standards as a guideline. At the present time there are two standards that have been promoted for use in U.S. practice although they could be used worldwide. One was developed specifically for use with roads where load demands, especially under seismic loading, are relatively severe (Stark et al. 2004b). The other is simply a slightly-modified version of the long-used standard for non-load-bearing thermal insulation used in buildings (ASTM 2004). Either standard is likely to be satisfactory for the relatively modest load demands of most levee applications. The important thing is that both standards have material requirements that include required minimums for the stiffness parameters and not just material density. It cannot be emphasized too strongly that material density alone is not sufficient as a material-design parameter any more than soil density alone defines the strength and stiffness of soil.

CASE HISTORIES

River Torne - United Kingdom

The first known use of EPS-block geofoam as lightweight fill incorporated within a levee was in the U.K. to raise an existing levee along the River Torne in Humberside. This work is believed to have been executed circa 1995 on behalf of the National Rivers Authority (now part of the Environment Agency) as it was reported in a trade publication in early 1996 (*Ground Engineering* 1996) and then discussed in greater detail by Sanders (1996). This project involved a 100-metre (330-foot) long section of an existing levee where EPS-block geofoam was used in an attempt to break the never-ending cycle of levee settlement on soft ground that is caused by using soil to restore a levee to its design grade to compensate for settlement. The levee in question had apparently settled as much as 800 millimetres (32 inches) in the approximately five years prior to its rebuilding using EPS-block geofoam. The design cross-section used was very similar to that shown conceptually in Figure 1. Other design details employed were:

- placing a geotextile on the existing soil subgrade exposed after excavating into the core of the existing levee,
- encapsulating the assemblage of EPS blocks on all four sides with a geomembrane, and
- installing a drain pipe that led from within the assemblage of EPS blocks to an external drainage ditch on the landside of the levee.

The design logic for use of the planar geosynthetics (geotextile and geomembrane) and drainage system were not discussed in Sanders (1996).

No further published information is known about this project and its performance to date. However personal communication in January 2000 with the EPS molder (manufacturer) that supplied this project indicated it was apparently sufficiently successful that one or more additional levee projects had been executed in the U.K. by that date. However no details were available about these follow-on projects nor has additional information concerning possible subsequent projects since 2000 been found.

Roaring River Slough - Solano County - State of California, U.S.A.

Subsequent to the initial public reporting in 1996 of the first River Torne project there was an effort made to educate design professionals and owning agencies worldwide about the potential use of EPS-block geofoam with levees. What is believed to have been the first project in the U.S.A. to embrace this geotechnology was the reconstruction and raising of a levee located along the Roaring River Slough in the Suisun Marsh in Solano County, California. This work was performed circa 1999 under the auspices of the State of California Department of Water Resources. The construction plans and under-construction photos for this project suggest that the design concept used for the first River Torne project was used for guidance to a significant extent, including the use of both geotextile underlayment and geomembrane encapsulation of the assemblage of EPS blocks. However the use of the drainage system from within the EPS blocks to the landside of the levee was apparently not replicated on the Roaring River Slough project.

Figure 2 shows the Roaring River Slough project under construction. Figure 2a shows EPS blocks temporarily stockpiled on site and being placed using a backhoe. It appears that a backhoe was the primary, if not exclusive, piece of mechanical equipment used for most if not all of the work including not only moving soil and EPS blocks but placing the rolled planar geosynthetics as well.

(a) **(b)**

FIG. 2. Roaring River Slough project under construction.

This photo does highlight a very significant benefit and superiority of EPS-block geofoam as a lightweight-fill material and that is its extraordinary ease of handling in very remote and difficult-to-access project sites. Although apparently not utilized on this project would be the ability to bring the EPS blocks to levee project sites via barge if necessary or desired. Figure 2b shows the geomembrane being installed over a section of the levee where the EPS blocks have already been placed. Although this project is known to have been completed successfully no further information is available concerning the performance of this project or any other similar projects performed in the U.S.A. to date.

SUGGESTIONS FOR IMPROVEMENTS

Although the basic geotechnology of using EPS-block geofoam as lightweight fill in various types of earthworks is reasonably well known and mature, there are various specific applications that are more or less developed than others in terms of specific design details, documented case-history performance, education of design professionals and owners, and other considerations that are necessary to advance a technology to meet its full potential. At this point in time, this is certainly true with regard to using EPS-block geofoam as a lightweight-fill material for use with levees. Despite at least a decade of such use there is relatively little documented information about projects that have been executed and how they have performed. It is hoped that this will change in the future with greater acquisition and sharing of knowledge.

Coincident with this it is hoped that design professionals will carefully reconsider design details used with such earthworks rather than simply replicate what has been used before. Specifically, the use of planar geotextiles (geotextiles and geomembranes) to underlay and encapsulate the assemblage of EPS blocks should be critically evaluated. Such details are not used with EPS-block geofoam fills in general so there should be well-defined reasons for using them with the levee application. Use of planar geosynthetics obviously adds cost, not only for materials but also for placement in what can be a very remote working environment. This is exemplified in Figure 2(b) where the need to transport and handle planar geosynthetics was not a trivial aspect of the construction. In summary, there should be a rational, zero-based assessment of all design details associated with using EPS-block geofoam for levees in order to develop a cost-effective yet technically-adequate design. The need for an overall efficient design detail is particularly important for levees given the enormous potential for applying this geotechnology.

SUGGESTIONS FOR FUTURE DEVELOPMENTS

Consistent with the suggestion to focus on developing efficient, cost-effective designs there should be research into developing cost-effective block-molded EPS to be used with levee applications. EPS cost-per-unit-volume is a significant design consideration and more than one-half the cost of EPS is due to raw-material cost which is highly dependent on the always-volatile price of petroleum (crude oil). One intriguing aspect of using EPS-block geofoam for levees is that although it is a load-bearing application the compressive stresses are likely to be less than those typically encountered in more-severe earthwork applications such as road embankments. Consequently it might be possible to develop an EPS block specifically for levee applications that contains a significant relative quantity of 'regrind' which is the EPS-industry term for in-plant recycled material such as production scrap. Use of regrind reduces raw material costs when making EPS. However it also produces material that has a reduced stiffness and elastic-limit stress. Nevertheless because the material-stiffness requirements for many levee applications are likely to be modest it may be possible to develop a formulation for EPS blocks incorporating regrind that meets the technical requirements but is very cost effective. Such an EPS block would also be attractive as a 'green' product that makes productive use of waste material (regrind).

REFERENCES

ASTM (2004). "Standard specification for rigid cellular polystyrene geofoam." *Standard D6817-04*, ASTM Intl.

ASTM (2005). "Standard guide for use of expanded polystyrene (EPS) geofoam in geotechnical projects." *Standard D7180-05*, ASTM Intl.

Ground Engineering (1996). "NRA banks on lightweight fill." Jan.-Feb.: 12.

Horvath, J. S. (1995). *Geofoam geosynthetic*. Horvath Engineering, P.C., Scarsdale, NY, U.S.A., 229 p.

Horvath, J. S. (1999). Discussion of "Status of ASCE standard on design and construction of frost protected shallow foundations" by L. S. Danyluk and J. H. Crandell. *J. of Geotechnical and Geoenvironmental Engrg.*, 125 (2): 166-167.

Sanders, R. L. (1996). "United Kingdom design and construction experience with EPS." *Proc. Intl. Sym. on EPS Construction Method (EPS Tokyo '96)*, Tokyo, Japan: 236-246.

Stark, T. D., Arellano, D., Horvath, J. S. and Leshchinsky, D. (2004a). "Geofoam applications in the design and construction of highway embankments." *NCHRP Web Document 65*, Transportation Research Board.

Stark, T. D., Arellano, D., Horvath, J. S. and Leshchinsky, D. (2004b). "Guideline and recommended standard for geofoam applications in highway embankments." *NCHRP Report 529*, Transportation Research Board.