Manhattan College

Center for Geotechnology

Geomaterials Research Project
-
Cellular Geosynthetics 2001: Geofoam Lightweight Fills and Beyond

Research Report No. CGT-2001-5

by

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November 2001

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<www.engineering.manhattan.edu/civil/CGT/T2rpts.html>.

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The Manhattan College School of Engineering *Center for Geotechnology* and Its Mission

The **Manhattan College School of Engineering** ***Center for Geotechnology*** **(CGT)** is a unique organization that strives to be more than the typical academic research center or institute. It was founded in 2001 at the personal initiative of Prof. John S. Horvath, Ph.D., P.E. of the Civil Engineering Department who serves as its first Director. The CGT is the result of Prof. Horvath's evolutionary realization after almost 30 years of geotechnical engineering practice that the explosive growth in geotechnical and geoenvironmental engineering technology has made it difficult for the engineering practitioner to keep abreast of new technical developments. The traditional academic approach of simply publishing research results in narrowly disseminated technical reports and papers (a philosophy of "if you print it, they will learn") has proven to be an increasingly ineffective way of reaching practitioners and moving the state of art to the state of practice. There is an ever-growing gulf between these two states of knowledge in geotechnical engineering. The critical need for a total rethinking of how life-long continuing education is achieved not only for engineering practitioners but academicians themselves is evidenced by the appearance of "teach-the-teacher" training courses in drilled shaft foundations and geosynthetics beginning in the late 1980s. If even academicians cannot keep up with new developments by reading journal papers and conference proceedings, how can practitioners be expected to? The stagnation of geotechnology also affects current engineering students and perpetuates the cycle. The desirability of involving the practitioner in the process of formulating research programs so that they may have a more direct and immediate benefit to practice is also something that is now recognized more and more.

The CGT seeks to address the current need for effective, meaningful continuing education by recognizing that the cycle of growth for any technology has three interdependent components, what can be called the "trilogy of technology". Like a three-legged stool, each of these components must be of equal length and strength if a given technology is to succeed. Thus the CGT has adopted a holistic strategy of supporting geotechnology growth by recognizing the need to concurrently address:

- Technology advancement through research and development that involves not only the engineering practitioner but also other end users of geotechnology such as construction contractors and material manufacturers to the greatest extent practicable.

- Technology transfer (T^2) through education of engineers, contractors and manufacturers in a multi-faceted, proactive way.

- Technology documentation through standards development so that all end users (practitioners, contractors and manufacturers) of a given technology work to a common set of guidelines.

This trilogy-of-technology growth cycle is the cornerstone of all activities of the CGT. It is important to note that the interaction of these three components, which is embodied in the CGT logo of three interconnected arrows shown on the cover of this report, is never completed but assumes a constant cycle that leads to continuous growth of a technology.

The CGT receives no direct financial support on a regular basis from Manhattan College. Thus the success and growth of the CGT is totally a function of outside funding from individuals and organizations whose philanthropic philosophies are consistent with the stated goal of the CGT to treat technology growth in a more holistic fashion than is typically done in academia and considers the entire process from research to standards with end-user input at all stages. In addition, as part of its mission to promote technology transfer through education to the greatest extent practicable the CGT is willing to partner with industry and other academic institutions not only in research but also technology transfer and standards activities on any topic relevant to geotechnical or geoenvironmental engineering. The new Manhattan College School of Engineering William J. Scala Academy Room, which is located on the main floor of the Leo Engineering Building and available for CGT activities, offers modern facilities for hosting technology transfer activities. One benefit of Manhattan College's location on the northern edge of New York City adjacent to both Interstate I-87 and mass transit is that it is quite accessible (including free off-street parking adjacent to Leo Engineering Building) from both within and outside the City. When appropriate, the CGT will bring its technology transfer activities off campus to meet the needs of a particular activity.

Regardless of financial support, the ultimate success and growth of the CGT will depend on its being responsive to the needs of the engineering practitioner. Towards this end, the CGT welcomes input from practitioners on an ongoing, continual basis. Suggestions for future research and technology transfer activities based on perceived needs in practice are always welcome. There is no topic that is too modest or simple for consideration. In fact, much of the research conducted by Prof. Horvath since he came to Manhattan College in 1987 has been based on ideas, large and small, that he developed as a result of his years in engineering practice.

Additional information about the CGT as well as access to published documents and other resources can be found on the Internet at <www.engineering.manhattan.edu/civil/CGT.html>.

Preface

This report contains the text of a lecture given by me during Autumn 2001 to officially launch the Manhattan College Center for Geotechnology (CGT). This lecture was first given to a dinner meeting of the Geotechnical Group of the Boston Society of Civil Engineers Section of the American Society of Civil Engineers (BSCES/ASCE) on 24 October 2001 in Boston, Massachusetts. This lecture was next given at Manhattan College on the evening of 14 November 2001 to an open audience as a special event to mark the establishment of the CGT. The content of this lecture, a state-of-knowledge overview of cellular geosynthetics, dealt with a subject that has occupied most of my research time since I came to Manhattan College in late 1987. As such, I thought it was a fitting topic to launch the CGT.

It was not possible to reproduce in this report the numerous presentation images ("slides") that were an integral part of this lecture. However, many of these images can be found on the first product offering in the CGT's Technology Transfer Through Distance Learning Program. It is a CD-based primer on cellular geosynthetics that features a digital lecture plus accompanying printed notes as well as a copy of my scholarly monograph "*Geofoam Geosynthetic*" and is suitable for individual or group use. Information on obtaining a copy of this educational product can be found on the CGT's website at:

<www.engineering.manhattan.edu/civil/CGT/T2dl.html>.

Those whose intellectual curiosity may be whetted by this report and who would like to learn more about designing with cellular geosynthetics are encouraged to attend my two-day workshop "Designing with Cellular Geosynthetics (Geofoams and Geocombs)" which will be given for the first time in the New York Metropolitan area on 10-11 January 2002 at Manhattan College. This workshop contains information sufficient to allow a civil engineer to begin to design with cellular geosynthetics with confidence. Information about this workshop as well as comments by past attendees (I have been giving this workshop nationwide since January 1999) can be found on the CGT website at:

<www.engineering.manhattan.edu/civil/CGT/T2edu.html>.

In closing, the establishment of the Center for Geotechnology marks a professional-development highpoint for me in my 15th year as a member of the Manhattan College faculty. I thank all those who have contributed directly and indirectly to the development of the CGT and look forward to its growth in the years to come. I am particularly grateful to the former Interim Dean of Engineering, Dr. Helen C. Hollein, P.E., and the current Dean of Engineering, Dr. Richard H. Heist, for their time and deep personal interest during the past two years that helped me formulate and crystallize the concept of the CGT.

I also thank the BSCES/ASCE for the invitation to lecture in October 2001. This was a highpoint of my almost 30-year career as a civil/geotechnical engineer. Their predecessor organization, the Boston Society of Civil Engineers (BSCE), is believed to have been the first civil engineering professional society in the U.S.A., predating the formation of the American Society of Civil Engineers by a few years. The greater Boston area was the center of modern geotechnical engineering development in the U.S.A. during the 1920s and 1930s. Numerous legendary names in geotechnical engineering from Terzaghi to the Casagrande brothers on down have spoken before the BSCE. Boston remains geotechnically vibrant to this day, with innumerable geotechnical innovations used on the ongoing Central Artery ("Big Dig") Project that began in the 1980s. I am also privileged to have been involved in this project in a small way

as a consultant for subgrade modeling of cut-and-cover tunnel base slabs as well as the use of EPS-block geofoam as lightweight fill.

Finally, I also acknowledge all those from around the world who have been part of the great sharing of knowledge relative to geofoams and geocombs that has allowed these fascinating materials to become a larger and ever-growing part of geotechnical engineering practice.

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INTRODUCTION

Materials with a cellular structure, whether created naturally or manufactured, are arguably the most efficient and fascinating in nature for several reasons:

- They use relatively small proportions of solid material per unit volume of the overall material. Materials with a solid fraction that is only 1% of the total volume (a porosity of 99% in geotechnical terms) are manufactured routinely. However, the solid fraction of these materials is arranged in such a way that the overall material usually has remarkable stiffness and strength despite its low density.

- The significant void space in cellular materials can, in some cases, be used productively to store fluids (gas and/or liquid) as well as other, softer solids.

Cellular materials are the very embodiment of the philosophy of Richard Buckminster "Bucky" Fuller to make less do more. However, despite their inherent efficiencies and versatility cellular materials have not been exploited to date in geotechnical engineering applications anywhere near the extent possible. This is changing rapidly and is the subject for this evening's lecture.

SCOPE AND ORGANIZATION OF LECTURE

Cellular geomaterials are a surprisingly broad topic so there must be a focus to limit this lecture to the available time. To begin with, this lecture is confined to manufactured cellular geomaterials which are now recognized as geosynthetics. There are currently three types or families of cellular geosynthetics: *geocells*, *geocombs* and *geofoams*. Only the latter two are discussed here. Although geocells have a cellular structure once they are installed at a project site, they are useful only when the cells are completely filled with another material, typically soil or portland-cement concrete (PCC). On the other hand, geofoams and geocombs are stand-alone materials.

The use of geofoams and geocombs in geotechnical engineering practice increased dramatically worldwide during the 1990s and this continues into the 21st Century. As a result, most engineers are now at least somewhat familiar with the more-common geofoam materials and their applications such as expanded polystyrene (EPS) and foamed PCC used as lightweight fills for road construction[a]. However, geofoams and geocombs offer many more geosynthetic functions and potential geotechnical applications than this. After a brief review of available geofoam and geocomb materials, and an update on current activities related to their popular use as lightweight fills, this lecture will focus on the broader functions and applications of these fascinating geosynthetic materials.

Before beginning the main part of this lecture, it is of interest to note that geofoams and, more recently, geocombs have been actively researched at Manhattan College by the author since 1988. This work is still ongoing and is now being conducted under the auspices of the new Manhattan College *Center for Geotechnology* (CGT) under the CGT's Geomaterials Research Project. Information about the CGT and how to access its extensive technology transfer (T^2) information, much of it on geofoams, that has been posted on the World Wide Web can be found at the front of this report. Information about specific current and upcoming CGT activities related to cellular geosynthetics can be found in the Preface of this report.

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[a] Those seeking an introduction to geofoams will find a detailed treatment in Horvath (1995), with summaries in *Matériaux* (1997), Elias et al. (1998), Horvath (1999) as well on the Internet at:

<www.engineering.manhattan.edu/civil/CGT/T2olrcellprim.html>.

GEOFOAMS

Definition

Although by now most geotechnical engineers in the U.S.A. have heard the term "geofoam", misconceptions about its definition continue to proliferate. Simply stated, a geofoam is any synthetic material, used in a geotechnical application, created in an expansion process that results in a material with a texture of numerous closed cells. The expansion process requires a gas that is referred to generically as the *blowing agent*. Knowing which specific blowing agent (they vary) is used to make a particular geofoam material is important for environmental, health and safety reasons. Geofoam manufacturing may be done in a fixed plant or in-situ. Note that the key concept here is that geofoam is not just one material or product as some claim. It is actually a surprisingly diverse family of many different kinds of materials and products.

Materials

A wide variety of proven geofoam materials exist. There are even more materials that have been tried over the years in geotechnical applications but were found to be technically unacceptable. The latter are not discussed in this lecture.

Geofoam materials can be divided into several 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:

- expanded polystyrene (EPS),
- extruded polystyrene (XPS),
- polyethylene (PE),
- polyethylene-polystyrene (PE-PS) blends and
- polyurethane (PUR).

Note that "styrofoam" does not appear anywhere in the above list. Contrary to what most people in the U.S.A. think, this is not the generic term for plastic foam. Rather, it is the registered trademark of a specific brand of a particular type of plastic foam (XPS). There is a very simple rule of thumb to follow: only plastic foam that is colored blue is *Styrofoam*®. This point is emphasized here as correct terminology is important in order to avoid misunderstandings during design and problems and claims during construction.

Despite the relatively large number and variety of geofoam materials, EPS has emerged worldwide as the material of choice in most applications for several reasons:

- it is the most versatile and the only one that can provide each of the geosynthetic functions discussed subsequently;

- with few exceptions, it can meet the technical needs of most geofoam applications; and

- it is generally the most cost effective.

Situations where geofoam materials other than EPS are used are noted in the discussions that follow.

Something to note in the myriad applications of cellular geosynthetics is that they are used with other geosynthetics, typically traditional "planar" products such as geotextiles, in almost all applications. In some cases these other geosynthetics are factory bonded to the geofoam or geocomb to create geocomposites. In other cases the other geosynthetics are used synergistically with the geofoam or geocomb to produce a technical outcome that neither product could achieve on its own. Thus a design assessment of cellular geosynthetics should always look at the larger picture and consider how geosynthetics in general can be used to create a cost-effective design alternative.

Products

Geofoams that can only be manufactured in a factory are typically molded or cut into the final desired shape required for the particular application. However, field cutting of a product to accommodate a particular construction situation can easily be done using a variety of tools. Geofoams that are foamed in place simply fill the shape of the volume that is to be filled.

Functions and Applications

Lightweight Fill

Although it is not the oldest geofoam application, lightweight fills are by far the most widely known and commonly used, including here in Boston on the Big Dig where both foamed PCC as well as block-molded EPS have been and are being used.

Because the use of geofoams for lightweight fills represents a fairly mature technology going back at least 30 years (even if some engineers are only just learning about it), current R&D efforts are concentrated on refining and improving technical understanding and ease of use as well as finding new and innovative applications. These efforts are focused on EPS-block geofoam as it is globally the geofoam material of choice in most lightweight fill applications. Significant recent or current R&D activities of interest include:

- development and publication of the first true geofoam-application-specific design, material, product and construction standards in the U.S.A. for block-molded EPS. These were developed from scratch (not a simple "makeover" of an existing standard) in American Association of State Highway and Transportation Officials (AASHTO) format for use with road construction although they are sufficiently general so as to be useful for a much broader range of lightweight fill applications. A draft interim version of these standards was published in April 2000 (Horvath et al. (2000), with an abstract posted on the Manhattan College Center for Geotechnology website) and a final interim version should be published in 2002. This is work is being done by a multi-institutional research team managed out of the University of Illinois at Urbana-Champaign. Funding is being provided by the National Cooperative Highway Research Program (NCHRP) under Project 24-11 and is administered by the Transportation Research Board (TRB).

- preparation of charts and other design aids to simplify design for road embankments on soft soils. This work is also being performed as part of NCHRP Project 24-11;

- broader applications beyond 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, and
    - water resources structures such as flood levees;

- development of "anti-buoyancy" shape-molded EPS blocks, one of several innovative *EPS-shape geofoam* products that were developed around the world in the 1990s; 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.

Thermal Insulation

This is the first known geofoam functional application, dating back at least to the early 1960s. A wide variety of polymeric materials as well as cellular glass have been used successfully as thermal insulation although EPS and XPS predominate. However, despite almost four decades of proven, successful use thermal insulation 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 geotechnical applications was actively researched and patented in the U.S.A. in the 1960s. Therefore, 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 applications (and certainly of great interest to a Northeastern U.S. audience) are:

- below-ground portions of buildings in all climates (for life-cycle energy savings),

- below-ground portions of refrigerated buildings and tanks in all climates (for life-cycle energy savings and to prevent subgrade freezing),

- landfill liners in all climates (to protect the integrity of clay liners),

- shallow buried structures such as cut-and-cover tunnels and parking garages in all climates (to limit seasonal thermal changes and concomitant thermal expansion and contraction of the structure roof which can result structural problems),

- pavements and railway track in cold climates (to prevent or at least limit subgrade freezing and concomitant frost heave),

- liquid-bearing utility lines in cold climates (to allow shallower embedment),

- shallow foundations in cold climates (to allow shallower embedment),

- earth retaining structures in cold climates (to prevent freezing of the drainage systems and/or retained soil).

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 drains: 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, compressible inclusion, noise and vibration damping, and structural then the use of geofoam-based drainage products could increase significantly.

Some typical applications where a geofoam-based drainage geocomposite can be cost effective include:

- groundwater drainage around:
  - building basements and
  - earth retaining structures; and

- collection and drainage of ground-borne gases such as radon and methane around building basements.

Noise and Vibration Damping

It is important to note that the vibrations considered here are limited to the relatively small-amplitude types 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 -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 worldwide because of the sheer number of potential applications. However, most compressible-inclusion applications require a surprisingly small amount of geofoam product which is why the geofoam industry has done relatively little to date to promote this function. Another reason for the relatively slow growth of compressible-inclusion usage worldwide is that this functional application is not simply an intuitive variation of something geotechnical engineers have done for decades (as lightweight fills are for example). The use of compressible inclusions represents and requires a whole new way of thinking when it comes to earth retaining structures.

There was a fair amount of analytical research into compressible inclusion applications that occurred during the 1990s and 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 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, 2000).

The potential applications for geofoam compressible inclusions include:

- allowing shear-strength mobilization of soil adjacent to rigid, non-yielding (non-displacing) earth retaining structures to reduce lateral earth pressures acting on these structures. This includes the Reduced Earth Pressure (REP) Wall concept that reduces pressures to approximately the active state and the Zero Earth Pressure (ZEP) Wall 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. This can be either adjacent to an earth retaining structure or below a structural slab;

- accommodating structure movement such as that which occurs with integral-abutment bridges; and

- reducing ground settlements adjacent to earth retaining structures when used synergistically with geosynthetic tensile reinforcement (ZEP-Wall concept).

Structural/Miscellaneous

This final functional category is the one most recently identified circa the 1990s and is an eclectic collection of applications, mostly using various types of polymeric foams:

- as wall forms for cast-in-place (CIP) PCC construction. Note that these forms are designed to be left in place to provide post-construction thermal insulation for the structure;

- facing panels for mechanically stabilized earth (MSE) walls;

- 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 material with a honeycomb-like cross-section (hence the name) that is created in an extrusion process performed in a fixed plant. A geocomb is essentially a bundle of open-end tubes.

Geocombs are one of the newer if not the newest 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 (where they are called *structures alveolaires ultra légères* (SAUL) or *ultra light cellular structures* (ULCS) in English), they have become more widely known only in the last few years. They are still not readily available outside of France although this is changing.

Materials

Two different polymers are known to have been used for geocombs to date:

- a translucent polypropylene (PP) and
- black polyvinylchloride (PVC).

The PP product line appears to be predominant in terms of past and current use. In each case the tubes are of the order of 1 inch (25 millimetres) across and the material is approximately 96% voids overall (a porosity of 96%). This compares to EPS-block geofoam which is about 98% voids overall (porosity of 98%).

Products

The extruded honeycomb 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 blocks as used for geofoam lightweight-fill applications (approximately 2 x 4 x 8 feet (600 x 1200 x 4800 mm)). 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 filling them.

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. This is but one of significant differences from block-molded EPS which is inherently isotropic in all its mechanical (stress-strain-time) and thermal properties.

Functions and Applications

Lightweight Fill

This appears to be the predominant geocomb functional usage to date and the one most widely documented (*Matériaux* 1997, Perrier 1997). Although geocomb blocks cost more than and have an overall density approximately twice that of EPS-block geofoam, geocombs have the distinct advantage of having virtually no buoyancy upon submergence as their open-cell structure allows water to fill the void space. Experience to date indicates that this can be a crucial advantage that makes a geocomb block the lightweight fill material of choice in applications where permanent or potential submergence is an important design consideration. Experience to date suggests that geocomb blocks are broadly comparable to EPS-block geofoam in terms of load-carrying capability when used as lightweight fill for roads.

Drainage (Fluid Storage and Transmission)

A geosynthetic function that appears to be of growing interest is to make use of the significant void volume and open-cell structure 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 in site-development work where temporary storage followed by subterranean disposition of storm-water runoff is a benefit. 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.

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