

WHITE PAPER

ABSTRACT

Many issues – including weather, aging roadways and bridges, population growth, highway congestion, erratic energy markets and accompanying volatile gas prices, demographic shifts, material placement issues, and a growing, global sustainability ethic – influence the development, expansion, and restoration of structures and infrastructures. These influences often result in construction in tight placement conditions, cold weather environments, or over marginal soils incapable, without site amendments or technology interventions, of supporting required loads.

This white paper assesses alternative methods available for light-weight fill and geotechnical insulation applications and promotes cellular concrete as a sustainable, cost-effective solution for simplifying construction in tight placement applications and on marginal lands.

People who can benefit from reading this white paper include project owners and developers and their architectural, geotechnical, and structural engineering teams; governmental officials, regulators, and permit-granting agency staff; pavement contractors and other construction professionals; students and educators; media professionals; development assessment committee members; and members of other organizations or the general public interested in structure and infrastructure project development and restoration.

Included in this educational white paper is information on light-weight aggregate fills, rigid cellular polystyrene geofoam fills (including molded expanded polystyrene blocks and extruded polystyrene boards), and cellular concrete fills (including cellular lightweight concrete fills, lightweight structural concrete fills, and pervious cellular lightweight concrete fills). An appendix to the white paper compares material characteristics of lightweight aggregate, expanded polystyrene geofoam, extruded polystyrene geofoam, cellular lightweight concrete, and pervious cellular lightweight concrete fills.

Simplifying Construction on Marginal Lands



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KEYWORDS

Aggregate gradation; air and noise pollution; ballasting; Brownfield redevelopment; bulkheads; carbon dioxide emissions; carbon footprint; Cellular Concrete Solutions; cement grout; cement slurry; ceramic matrix; clay; compacted lifts; cold-weather placement provisions; compressive resistance at one percent (1%) strain; concrete form-work; engineered foam liquid concentrates; EPS; EPS geofoam block; expanded clay; expanded shale; expanded slate; extended mastics; extruded polystyrene; fire hazards; first-flush; flame retardant; geofoam; Geofoam Research Center; geomembranes; geotechnical thermal insulation applications; geo-textile cover; green building accreditation; ground water; heat of hydration; hot-wire tool; hydrochlorofluorocarbon blowing agent (HCFC); hydro-fluorocarbon blowing agent (HFC); infill development; in-line mixing; internal friction angle; LEED points; lightweight aggregate fill; marginal land; Mearl Geofoam Pervious™; moderate-strength, cellular lightweight concrete fill; molded expanded polystyrene; Most Innovative Product, 2008 World of Concrete; normal-weight-fill materials; out-gassing; pentane; pervious cellular lightweight concrete (PCLWC); petroleum hydrocarbons; plate compactors; plain concrete slab; plasticizer; polyethylene film; polystyrene beads; polystyrene resin granules; polyvinyl chloride (PVC); preformed foam; pre-installation meeting; pre-loading; recycled content; quality assurance programs; regrind; reinforced concrete slab; rigid cellular polystyrene (RCPS); shale; slate; smart foam liquid concentrates; snowmelt wet periods; stable air bubbles (cells); staged construction; static rollers; stormwater events; surcharging; sustainability; traffic congestion; ultra-light-weight fill; ultra-violet (UV) degradation; underground piping; virgin geofoam feedstock; XPS; and XPS geofoam board.

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TABLE OF CONTENTS

Simplifying Construction on Marginal Lands

INTRODUCTION	4
LIGHTWEIGHT AGGREGATE FILL	4
LWA CONSIDERATIONS AND LIMITATIONS	5
RIGID CELLULAR POLYSTYRENE GEOFOAM FILLS	6
GEOFOAM CONSIDERATIONS AND LIMITATIONS	7
CELLULAR LIGHTWEIGHT CONCRETE FILLS	11
CLWC/PCLWC CONSIDERATIONS AND LIMITATIONS	13
MATERIAL SYNERGIES PROVIDE ADDITIONAL TOOLS FOR “CONSRUCTION OVER MARGINAL LANDS” TOOLKITS	16
CONCLUSION	16
AUTHOR’S NOTE	17
NEXT STEPS	18
RESOURCE SECTION	19
ABOUT CELLULAR CONCRETE SOLUTIONS	20
APPENDIX A - MATERIAL CHARACTERISTIC COMPARISONS	21

Simplifying Construction on Marginal Lands

INTRODUCTION

In 2009, the Wisconsin Department of Transportation began an eight-year program of modernization and reconstruction of the Interstate 94 North-South Freeway Corridor, a 35-mile transportation artery running from the Illinois state line to the Mitchell Interchange in Milwaukee County. The project includes reconstructing the roadway from the ground up, constructing an additional lane in each direction (for a total of eight lanes), moving all exit ramps to the right side of the freeway, interchange and on-and-off-ramp improvements, and safety upgrades for frontage roads.

Like many other transportation arteries around the world, the 40-year-old North-South Freeway Corridor was in critical need of reconstructing. The freeway's deterioration endangered public safety and, as a key southern gateway to the state, threatened the smooth flow of traffic and commerce throughout Wisconsin. Traffic studies indicated widening the freeway to eight lanes was necessary to safely and efficiently accommodate anticipated future increases in traffic congestion.

Accommodating vehicle traffic increases – in Wisconsin and globally – frequently involves realignment of existing roadways and/or roadway embankment widening. These actions often create geotechnical challenges, the result of necessary construction over soft or loose native soils incapable of supporting required loads. Infill development and Brownfield redevelopment can create similar geotechnical challenges, requiring site improvements or technology interventions to accommodate construction over marginal lands.

Construction in cold climates can present many engineering challenges, including insulation and bearing support for pavements and slabs, frost-protection for shallow foundations, shallow utility insulation and support, and foundation construction on permafrost.

These and other engineering challenges encountered when undertaking construction on marginal lands can be successfully navigated through the use of lightweight fill technology solutions, including lightweight aggregate fills and cellular material fills – molded expanded polystyrene (EPS), extruded polystyrene (XPS), or lightweight cellular concrete.

LIGHTWEIGHT AGGREGATE FILL

Lightweight aggregate (LWA) fills supply weight-critical solutions to many geotechnical challenges on marginal lands, providing needed load reduction from vertical and lateral earth pressure applied by the fill material and reducing over-turning forces compared to normal-weight-fill materials.

Made by expanding select minerals – most often clay, shale, or slate – in a rotary kiln at high temperatures, LWA fills are produced as closely controlled, low-density, engineered gradings (particle size distribution) that are structurally strong, stable, durable, permeable, chemically-inert, and

insulating. The mineral expansion produces a cellular structure of largely non-connecting, spherical pores (bubbles), surrounded by a ceramic matrix, and creates low-density fill materials ranging from around 45 pounds per cubic foot to 65 pounds per cubic foot. Coupled with a high internal friction angle, LWA fills can reduce vertical and lateral forces on marginal land projects by as much one-half compared to normal-weight-backfill materials.

LWA Considerations and Limitations –

When job site density parameters allow, LWA fills help convert marginal native soils into functional land. The properties of LWA vary, depending on aggregate sources and grading. Custom aggregate gradations can require ordering and material processing lead time.

A pre-installation meeting involving project specifiers and construction managers, the LWA manufacturer, and the LWA fill installer is often held to verify project requirements, substrate conditions, product specifications, delivery and storage logistics, safety and quality assurance program provisions, installation instructions, and the manufacturer's warranty requirements. LWA is installed like normal-weight-aggregate fills, with the same equipment used in typical normal-weight-aggregate fill applications (loaders, static rollers, plate compactors). A durable, permeable material, the use of LWA fills in geotechnical applications can minimize/eliminate the need for extensive (and often expensive) drainage systems. In addition, the thermal insulating properties of LWA can provide protection from freezing in underground piping and other thermally-sensitive applications.

Project engineers must use caution in the use of LWA to ensure underlying soils are stable enough to carry the in-place density of the lightweight material, or the LWA fill can settle into the subsoil. On some projects, site conditions can require pre-loading, surcharging, or staged construction for settlement mitigation, extending project schedules. To minimize settlement, LWA is placed in uniform, compacted lifts (typical lift thicknesses range from 6-inches to 12-inches, depending on project requirements), with each lift achieving 85% compaction. Precautions are necessary when working adjacent to LWA fill to ensure the material does not become over-compacted, as compaction affects the in-place density and drainage characteristics of the material. Construction equipment, other than for placement and compaction, should not be operated on exposed LWA fill.

Because of its porosity, LWA fill can absorb a significant portion of the "first flush" of stormwater events and snowmelt-runoff wet periods. The low density of LWA fill allows more material to be delivered per truckload, compared to normal-density-fill materials, reducing the number of truckloads required to deliver the same volume of product, and resulting in lower delivery costs, less fuel consumption, reduced project air and noise pollution, and less traffic congestion. But, depending on how far the project is from a LWA manufacturing plant and/or distribution center, these benefits may be offset by the cost, fuel consumption, air and noise pollution, and traffic congestions involved in acquisition of raw materials, LWA

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manufacturing, grading, storage, and distribution, and final delivery of the LWA fill to the project site.

Developed in the early years of the 20th Century, LWA fills can provide reliable, economical geotechnical solutions, and simplify construction on marginal lands, when job site density parameters allow. LWA fill can also be used in geotechnical thermal insulation and lightweight structural fill applications, though placement and compaction can be difficult in cold-weather conditions or closed quarters like swimming pool structural fill applications.

RIGID CELLULAR POLYSTYRENE MEARL GEOFOAM FILLS

When underlying site soils are not stable enough to carry the in-place density of a LWA fill, weight-critical solutions to geotechnical challenges on marginal lands incorporate other cellular material technologies – either rigid cellular polystyrene (RCPS) fills or cellular lightweight concrete fills. RCPS solutions include molded expanded polystyrene (EPS) and extruded polystyrene (XPS) and are reviewed in this section of this white paper.

Cellular lightweight concrete solutions are reviewed in later sections of this white paper.

RCPS fills are closed-cell, polystyrene foam materials used in geotechnical applications, and, since 1992, are known generically as geof foam (lower-case “g”). The rigid, low-density, polystyrene foam fills are produced at block molding or board manufacturing plants in one of two ways:

- By a three-stage, molded-bead method producing expanded polystyrene (EPS). EPS geof foam begins as polystyrene beads, which contain a pre-foaming, hydrocarbon blowing agent, most often, pentane. In the pre-expansion phase, the blowing agent, upon contact with steam, boils, creating a cellular structure, and the polystyrene beads expand by as much as 50 times their original volume. In the stabilization phase, the expanded beads go through a maturing period, which lasts until the expanded beads reach equilibrium in temperature and pressure. In the final, molding phase, the mature beads are placed within a block mold and reheated with steam, further expanding the beads until the mold cavity is filled completely and the beads are fused together. The molding phase produces large “boards” or blocks of EPS, ranging in thickness from 0.375- to 36-inches, in width from 12- to 48-inches, in length from 48- to 192-inches, and in density from 0.70 to 2.4 pounds per cubic foot.
- By a continuous extrusion process producing extruded polystyrene (XPS). XPS geof foam begins as solid polystyrene resin granules. The granules are fed into an extruder and melted, forming a viscous fluid, and useful additives are added and mixed. A fluorocarbon-gas blowing agent – most often hydrochlorofluorocarbon (HCFC)

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or hydrofluorocarbon (HFC) – is injected to expand the mixture. Under carefully monitored heat and pressure conditions, the expanded, foamable mixture is pushed through a die, forming the extruded material to the desired shape. The rigid foam is then trimmed to the final product dimensions, called “boards,” and ranging in thickness from 0.4- to 4-inches, in width from 16- to 48-inches, in length from 48- to 108-inches, and in density from 1.2 to 3.0 pounds per cubic foot.

Block or board geofoam density is controlled during the manufacturing process. These geofoams are used as lightweight or ultra-lightweight-fill soil substitutes and in geotechnical insulation applications. XPS geofoam is typically used in geotechnical insulation applications due to its superior ability to withstand freeze-thaw cycles and its high, long-term insulating power, which is not compromised by typical in-place moisture exposure. Though XPS geofoam also works well as a lightweight-fill soil substitute, project economics favor the use of EPS geofoam blocks for geotechnical lightweight fill applications.

The use of geofoams as lightweight fill began in several countries, including the U.S., in the 1960s. Their cellular structure is strong enough to support most types of loads associated with geotechnical applications, and with densities as low as one percent (1%) to two percent (2%) of normal-weight fill materials, geofoams significantly reduce stresses on the underlying subgrades of marginal lands.

Typical geofoam lightweight fill construction begins with placement of a geo-textile cover and installation of a compacted, free-draining, coarse, angular or sub-angular fill material to form a level, working base and provide uniform support for the geofoam blocks. On some projects, a layer of sawdust or woodchips is installed to serve as the working base.

The geofoam is placed manually in the site excavation as replacement fill or installed in successive layers to construct an embankment, often based on shop drawings demonstrating how to install the individual blocks. In handling and fabrication, care is exercised to minimize damage to the blocks or boards. EPS block and XPS board can be supplied in pre-cut dimensions for immediate use or cut at the job site with a saw or hot-wire tool. Layered block or board layout and placement is staggered to interlock, similar to laying up a brick wall.

A 4-inch to 6-inch thick plain or reinforced concrete slab is often formed and placed on the top geofoam surface as a protective cover, and, in embankment situations, to provide for load distribution. In some situations, adequate soil cover can provide the necessary protection required for fortification and reduced stress intensities at the geofoam surface.

Mearl Geofoam Considerations and Limitations –

For high-volume projects, lead time is often necessary for manufacturers

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to produce the required geofoam quantity for the job. Some specifications give a minimum aging time – from as little as three days to as much as two weeks – for EPS geofoam blocks, to allow for some out-gassing of residual blowing agent. Some projects need multiple manufacturers to meet the required volume. Because there is direct relationship between the molding equipment used and other manufacturing variables, including recycled content and additives (flame retardant, insect protection, etc.), geotechnical engineers for large-volume projects will often apply conservative design-density parameters to account for differences between products supplied by multiple sources. Compressive resistance at one percent (1%) strain is often the overriding design consideration when using materials supplied by multiple sources.

Lightweight and ultra-lightweight geofoam fill applications often require shop drawings demonstrating the location and placement sequence for installing the individual blocks. In these instances, each block must be labeled in correspondence to the shop drawings and shipped and stockpiled in shop drawing placement sequence.

Though job site placement of geofoam blocks or boards is quick and efficient for experienced installers, project mobilization can be time consuming. A pre-installation meeting involving project specifiers and construction managers, the geofoam manufacturer, and the geofoam installer is often held to verify project requirements, substrate conditions, product specifications, delivery and storage logistics, safety and quality assurance program provisions, installation instructions, and the manufacturer's warranty requirements. Because geofoam is manufactured off-site, it must be inventoried and stored at the plant, loaded onto one or more tractor-trailer vehicles, and transported to the job site. For some projects, geofoam is installed on delivery without requiring on-site inventory, stockpiling, storage, or protection measures. On other projects, trucking and job site logistics require the geofoam to be unloaded, re-inventoried, and stockpiled at one or more designated, protected, job site storage areas, incurring additional labor, material, and equipment (crane and/or telehandler) costs.

As noted above, caution must be taken during storing, loading, transporting, unloading stockpiling, handling and job site fabrication to minimize damage to geofoam blocks or boards. Block or board geofoam punctures easily, and direct application of concentrated loads – during storage, stockpiling, and job site fabrication – should be avoided. If moisture enters the in-place application through a puncture, specified strength and density of the geofoam fill can become compromised.

Block or board geofoam dissolves when it comes in contact with gasoline, highly solvent extended mastics, coal tar pitch, or other organic fluids. The concrete slab installed over the geofoam to facilitate load transfer also serves to provide protection from chemical attack for the in-place geofoam. Sometimes, geomembranes are incorporated in lightweight fill project

EPS and XPS geofoams work best when used to reduce naturally occurring forces like gravity and earthquakes rather than to strengthen or stiffen a structure or infrastructure to resist these forces.

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designs to provide additional protection for the geofoam from petroleum hydrocarbons. But note: Experience in roofing applications suggests geofoam should not be placed in direct contact with polyvinyl chloride (PVC) geomembranes, as the plasticizer in the PVC can migrate over time into the geofoam, causing the foam to soften and the PVC to become brittle. Research is required to ensure compatibility between geofoams and geomembranes.

Though geofoams are produced with flame-retardant additives, the combustible nature of geofoam blocks or boards requires attention to fire hazard mitigation during storage, stockpiling, and installation. Block or board geofoam should never be exposed to flames or other ignition sources, including cigarettes or welding sparks. The product's combustible nature raises concerns when geofoam is used in fill applications in areas where wildfire activity is prevalent. Sometimes, sand firewalls are constructed in on-site storage areas or between clusters of in-place geofoam.

Block or board geofoam is susceptible to ultra-violet (UV) degradation, resulting in dusting, discoloration, and slight embrittlement of the material surface. Studies suggest material property changes related to geofoam UV degradation are largely superficial. But most geofoam manufacturers recommend when geofoam is stored outdoors prior to installation, the material should be protected from sunlight with opaque polyethylene film, tarps, or similar materials.

As a lightweight material, geofoam must be ballasted to prevent displacement by wind or high water conditions, both during storage and in all phases of placement. Over time, geofoam will absorb moisture, with XPS geofoam tending to absorb less moisture than EPS geofoam. This moisture absorption can result in thermal property degradation of the in-place geofoam. R-Value losses from moisture absorption can range from 33 percent to 44 percent (33% - 44%) for EPS geofoam and 10 percent to 22 percent (10% - 22%) for XPS geofoam, leading to an in-field preference for the use of XPS geofoam in most geotechnical insulation applications.

Should changes be required at the job site to accommodate unanticipated site conditions requiring modifications in material density or multiple fill thicknesses, or to deal with quality assurance concerns, geofoam installation job flow can be impacted, increasing costs and lengthening the project construction schedule.

For cold regions where differential icing can occur, best management practices for embankment pavement design provide for an adequate thickness – 20- to 32-inches – of a well-graded subbase material containing a high degree of fines to retain moisture, to be placed over the protective concrete slab covering the geofoam.

Use of regrind (shredded, recycled EPS foam scrap) in EPS geofoam production varies, manufacturer to manufacturer, raising concerns about

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the in-place performance of the physical properties of delivered geofoam materials from multiple manufacturing sources. Some studies, including a research report by C.L. Bartholomew for Widener University in 1992, show the physical property values of EPS geofoam block containing regrind are generally lower than for virgin geofoam block. Bartholomew suggested the lower block physical properties would still be acceptable for most geotechnical applications. Other studies show regrind can alter bead fusion to a less-packed bonding state, resulting in lower block compressive strength and modulus and higher moisture absorption. Studies initiated at the Geofoam Research Center at Syracuse University suggest when the percentage of regrind is limited to five percent (5%) or less for EPS geofoam block production, the resulting final product will exhibit predictable engineering properties similar to virgin geofoam.

Some industry resources reference the use of regrind of ten percent (10%) or greater in EPS geofoam production. But – perhaps to protect proprietary production processes and intellectual property rights – these resources provide limited information on the physical properties and in-place performance of these non-virgin geofoam blocks.

Off the record, some EPS industry insiders speak of competitors introducing as much as 40 percent to 65 percent (40% - 65%) regrind content in their block manufacturing processes. Independent verification of these allegations is beyond the scope of this white paper, and online research did not substantiate the assertions or reveal what results the claimed higher percentages of regrind content have on the physical properties of the material as used in geotechnical applications.

On its web site, GeoTech Systems Corporation, makers of TerraLite EPS geofoam, has published a document titled *Universal Specification for Geofoam Fills*. Under the “Material” section of this specification, GeoTech Systems Corporation recommends “Geofoam shall be fabricated using virgin feedstock manufactured into blocks having no more than fifteen percent (15%) regrind content” and infers (but does not specifically indicate) TerraLite EPS geofoam containing 15% regrind content conforms to the physical properties published in the table of Physical Properties of TerraLite EPS Geofoam included in its *Universal Specification*.

Visit <http://geosyscorp.com/noframes/documents/geospec.htm> to review the specification.

EPS and XPS geofoams work best when used to reduce naturally occurring forces like gravity and earthquakes rather than to strengthen or stiffen a structure or infrastructure to resist these forces. When construction is required over marginal soils incapable – without geotechnical engineering interventions – of supporting required loads, or in cold weather environments requiring geotechnical insulation applications, geofoam lightweight fills and geofoam insulation applications provide effective solutions for geotechnical challenges. Associations advancing the interests

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of EPS and XPS geofoam manufacturers also tout the use of geofoam in lightweight structural fill applications, though installation can be difficult in closed quarters like swimming pool structural fill applications.

In ultra-lightweight fill situations, geofoam may be the only solution for construction on marginal lands.

CELLULAR LIGHTWEIGHT CONCRETE FILLS

As stated above, when underlying site soils are not stable enough to carry the in-place density of a LWA fill, weight-critical solutions to geotechnical challenges on marginal lands incorporate other cellular material technologies – either rigid cellular polystyrene fills or cellular lightweight concrete (CLWC) fills. When used in geotechnical fill applications, CLWC falls under the broad definition of geofoam (little “g”) – the generic family name for any manufactured material created by an internal expansion process resulting in a material with a texture of numerous, closed-cell foam geotechnical material or product – and shares useful material properties with its EPS and XPS geofoam “cousins,” most notably, low-density and thermal insulation.

First used in Europe in the 1920s, CLWC fills provide engineered, lightweight geotechnical solutions, and simplify construction on marginal lands, except in ultra-lightweight fill applications. Because of the outstanding flow characteristics of the material in its plastic state, its self-leveling and self-compacting properties, and the ability to precisely control in-place material strength and density, CLWC is an ideal solution for most moderate-strength, lightweight structural fill challenges, including difficult placement applications like swimming pool structural fill.

Traditional CLWC fills are engineered, closed-cell, low-density, concrete fills with special properties germane to solving a sweeping assortment of geotechnical challenges. Manufactured at the job site by the substitution of a uniform cellular structure of air voids (bubbles) for some or all of the aggregate particles found in traditional concretes (air voids of up to 80 percent of total volume are common), typical cast-in-place CLWC fills are monolithic fill applications with precisely-controlled densities ranging from 20 to 65 pounds per cubic foot.

For geotechnical fill applications, CLWC fills are manufactured on site by blending preformed foam into a cement slurry or grout. The preformed foam is produced at the job site by blending an engineered foam liquid concentrate with water and compressed air in predetermined proportions in a foam generation unit. The blended liquid expands in volume, creating preformed foam with a density range of about 2.0 to 3.5 pounds per cubic foot.

The chemical composition of the engineered foam liquid concentrates produces stable air cells, which remain unbroken during production (blending, mixing, pumping) and placing of the material and until the CLWC fill hardens.

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The preformed foam is blended into the cement slurry or grout in one of two ways. For the first way, a trailer-mounted CLWC batch plant is used to produce and place the material. The job site batch plant requires trucking for the delivery only of the batch plant and cement, eliminating the need for a haul-truck staging area as required in LWA fill applications. For the second way, slurry or grout – batched at the local ready-mix plant and transported to the job site – is discharged by transit mixer to the hopper of a job site concrete pump. Engineered foam liquid concentrate is preformed as described above and injected and mixed into the delivered slurry or grout in the pump line, not the transit mixers. Known as “in-line mixing,” this method expands the volume of the delivered slurry or grout about 3.8 times (one seven-cubic yard slurry or grout load producing 27 cubic yards of CLWC), eliminating approximately a quarter of the number of haul trucks – and corresponding delivery costs, fuel consumption, carbon dioxide emissions, noise pollution, and traffic congestion – needed to provide a LWA fill solution.

The ability to precisely control material density and strength, and the self-leveling and self-compacting characteristics of the cast-in-place material, make CLWC fills excellent solutions for geotechnical challenges on marginal lands. Engineered CLWC fills maintain their shape following placement, do not require pre-loading for project-area settlement mitigation, will not liquefy during seismic events, and provide a 2-to-1 point-load-distribution edge or greater, compared with competing geotechnical fill materials.

When free-draining, lightweight material solutions are required, recent innovations in foam liquid concentrate technology now enable the production of pervious cellular lightweight concretes (PCLWC), permeable, open-cell, lightweight concrete engineered to meet project-specific density, strength, and drainage characteristics.

In instances where projects are sited on marginal lands with areas of soft or loose soils incapable of supporting typical aggregate loads, the use of PCLWC technology permits designers and geotechnical engineers to control both site bearing capacity and drainage characteristics. A key benefit of PCLWC is its ability to minimize/eliminate the time and cost involved in design, manufacturing, and installation of extensive (and often expensive) drainage systems.

Other PCLWC benefits include:

- High bearing capacity – PCLWC is stronger than soils, EPS and XPS geofoms, or compacted LWA fills, providing strength and stability without disturbing/redirecting natural water flow.
- Low density – PCLWC provides load reduction without sacrificing strength and stability, ideal for reducing vertical loads over weak soils.

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- Environmental soundness – PCLWC reduces project carbon dioxide emissions (versus compacted lightweight aggregate fill or rigid cellular polystyrene lightweight foam fills alternatives) and provides enhanced filtering capability, which keeps site ground water cleaner.

PCLWC weighs considerably less than compacted lightweight aggregate fill, is self-leveling and self-compacting, and can be pumped into hard-to-access areas. In many applications, the in-place costs of PCLWC solutions are less expensive than compacted lightweight aggregate fill or rigid cellular polystyrene lightweight foam fills alternatives.

Cellular concrete fills are typically purchased from and produced and placed by geotechnical contractors with expertise and experience in cellular concrete insulating and geotechnical applications. CLWC and PCLWC are cast-in-place materials most typically installed by pumping the self-compacting material in thick, two- to four-foot lifts, depending on bubble size. Installation rates of more than 100 yards per hour are common and the materials have been successfully pumped over 500 ft. vertically, and 5,000 ft. horizontally without breakdown or segregation problems. Cast-in-place installation methods differ for various types of cellular concrete applications, with some applications requiring the on-site fabrication and installation of bulkheads to contain the fluid, self-leveling material. Cellular concrete fills are covered by other material and are not surface-finished.

CLWC/PCLWC Fill Considerations and Limitations –

CLWC and PCLWC fills provide value-engineered solutions when LWA material solutions are too heavy, site access is limited, or project schedules must be contracted. Though lead time is rarely necessary for contractors to produce cellular concrete, spot cement shortages like those experienced periodically in the U.S. from 2003 to 2005 can require active coordination between contractors and cement suppliers to ensure cement availability at the job site. Since 2004, cement producers – globally, and in the U.S. – have embraced aggressive production-expansion strategies, and the cement industry should be well positioned to meet general economic growth demands as world economies slowly improve.

Mobilization for job site production and placement of CLWC or PCLWC fills is equipment, labor, and time efficient, requiring minimal trucking, no storage, stockpiling, or protection measures, and no traffic schedule. This efficiency is possible when experienced cellular concrete contractors manage the lightweight fill project – using engineered foam liquid concentrates and foam generation units made specifically for job site cellular concrete production – and work with project engineers through quality assurance programs (QAPs) to ensure the wet density of the material produced at the job site meets project specifications. Pre-installation meetings, similar to those used for EPS geofoam lightweight and ultra-lightweight fill projects are often held for CLWC or PCLWC fill applications, but include less participants – since material manufacturing and installation are performed by the same company – and a simplified agenda – since

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the cast-in-place, monolithic CLWC or PCLWC fill does not require shop drawings demonstrating the location and placement sequence for installing individual geofoam blocks, and placement instructions, delivery logistics, and storage issues are less complex for CLWC or PCLWC fill applications.

The precise density control achieved with job-site-produced cellular concrete accommodates multiple density requirements easily, without the need to segregate material in several storage locations based on material density. Project job flow is little impacted, should changes be needed to accommodate unanticipated site conditions requiring modification in material density or volume.

For cold regions where differential icing can occur, best management practices for embankment pavement design over marginal lands provide for an adequate thickness – 20- to 32-inches – of a well-graded subbase material containing a high degree of fines to retain moisture, to be placed over the CLWC or PCLWC fill. The many useful material properties inherent in cellular concretes allow CLWC fills to play multi-faceted roles in many thermal insulation applications, often providing, in addition to insulating value, load reduction, padding, corrosion reduction, high load capacity, and rigid-support. Cellular concrete is a more durable insulating material, compared to EPS and XPS geofoam materials, especially in manufacturing and resource sector construction applications where there is substantial potential for exposure to chemicals and fire hazards. Cold weather placement of cellular concrete is aided by the insulating nature of the material and the significant amount of heat generated within the material during cement hydration. Cellular concrete has one-fifth the density of ordinary concrete; the temperature rise within cellular concrete from cement hydration is five times faster than ordinary concrete. Cold weather placement provisions for CLWC fills often require only placing insulating tarps over the material.

Like EPS and XPS geofoams, the low densities of some CLWC and PCLWC fills can result in uplift forces due to buoyancy, and design and installation measures must be taken to ensure against uplift during in-place service.

Unlike EPS and XPS geofoams, CLWC and PCLWC fills do not need to be ballasted during construction and are not susceptible to puncture, moisture absorption, ultra-violet (UV) degradation, chemical attack, or combustion.

CLWC and PCLWC fills can help achieve sustainable building solutions in many areas, including:

- Disaster (fire) resistance
- Durability
- Indoor air quality – The absence of VOC emissions from cellular concrete support indoor air quality in frost protected shallow foundation, and foundation on permafrost structure, applications.

Mobilization for job site production and placement of CLWC or PCLWC fills is equipment, labor, and time efficient, requiring minimal trucking, no storage, stockpiling, or protection measures, and no traffic schedule.

- Locally produced – The raw materials used to make the cement slurry or grout for cellular concrete production are abundant in most areas of the world and are usually obtained or extracted from sources within 300 miles of the project. Cellular lightweight concrete fills are produced on-site. Local production reduces shipping distances for fill materials, minimizing fuel requirements for transportation and handling, and associated noise, energy, and carbon dioxide emissions. On-site production of cellular concrete in geotechnical applications reduces a project's carbon footprint significantly. Projects with volumes exceeding 10,000 cubic yards of geotechnical fill use an on-site batch plant that produces and pumps cementitious slurry, with trucking needed only for the delivery of cement. Such was the case in Queens, NY, during construction of Citi Field, the home of the New York Mets. More than 17,000 cubic yards of pervious cellular lightweight concrete were batched on-site, eliminating the need for a fill-truck staging area outside the stadium and removing more than 1,000 trucks from the Van Wyck Expressway, Grand Central Parkway, and other borough streets. For projects with volumes of 10,000 cubic yards or less, cellular concrete production also happens on site, by treating slurry or grout manufactured at a local ready-mix plant and delivered and discharged by transit mixer to the hopper of a job site concrete pump. Preformed foam is injected into the delivered mix in the pump hose — not the transit mixer. This in-line method expands the volume of the delivered mix about 3.8 times (i.e., one seven cubic-yard slurry load produces 27 cubic yards of cellular concrete), eliminating up to 55% of the trucks (and the accompanying road traffic congestion) that would have been required if a granular fill option would be used.
- Minimal site disruption – When used as pavement underlayment, pervious cellular lightweight concrete can reduce the amount of excavation required by as much as 50%, minimizing site disruption, saving time and money, and reducing the project's carbon footprint.
- Recyclable – Cellular concrete is inert and can be safely removed and reused. One green use of recycled cellular concrete is as aggregate in vegetated roof construction.
- Recycled content – Cellular concrete can incorporate ground granulated blast-furnace slag or fly ash in the slurry or grout mix design without adversely affecting cellular concrete performance. The use of these post-industrial by-products eliminates the need to landfill the materials and reduces the need for virgin materials in cellular concrete production – and the environmental impacts from the extraction and processing of these virgin materials.
- Stormwater runoff detention management – a link to additional information is included in the Resource Section of this white paper.

On-site production of cellular concrete for geotechnical applications reduces a project's carbon footprint significantly.

- Thermal performance (see above).

The physical properties of CLWC fills are closely related to the type, quantity, and quality of the foam liquid concentrate used; the constitution and proper proportioning and production of preformed foam and other mix ingredients; and the execution of proper batching, mixing, blending, and cast-in-place installation protocols.

Mearl Geofoam 60 Pervious™ (upper-case “G”) is an engineered, smart foam liquid concentrate developed by Cellular Concrete Solutions, which enables the production of PCLWC. The patent-applied-for product was introduced and named the Most Innovative Product – Concrete Making Materials Category – at the 2008 World of Concrete (WOC), the only product in 2008, out of 144 entries, to win both the attendees’ choice and WOC-assembled panel of industry experts’ choice Most Innovative Product awards. Geofoam (upper-case “G”) has been used as a trade word since the mid 1980s to describe Cellular Concrete Solutions’ (and its forerunner company, Mearl Corporation’s) foam liquid concentrates for geotechnical applications.

MATERIAL SYNERGIES PROVIDE ADDITIONAL TOOLS FOR “CONSTRUCTION OVER MARGINAL LANDS” TOOLKITS

For ease of comparison, this white paper portrays lightweight aggregate fills, EPS and XPS geofoam fills, and cellular lightweight concrete fills (impermeable and permeable) as separate, competing technologies for enabling construction over marginal lands. While this too typically occurs in the real world, there can be project advantages, as Dr. Horvath suggests, to combining the technologies in complementary ways at the job site.

For example, using LWA fill as the free-draining material fill used to form a level, working base and uniform support for geofoam block fill in ultra-light fill applications (replacing the coarse, angular or sub-angular fill material typically specified) would reduce the in-place density of the typically specified free-draining base material by as much as fifty percent (50%). Using PCLWC fill as the permeable material fill used to form the level, working base and uniform support for geofoam block fill in ultra-light fill applications would reduce the in-place density of the typically specified free-draining base material by as much as seventy-five percent (75%).

CONCLUSIONS

Many issues influence the development, expansion, and restoration of structures and infrastructures, resulting often in construction in tight placement conditions, cold weather environments, or over marginal soils incapable, without site amendments or technology interventions, of supporting required loads.

When job site density parameters permit its use, LWA fill technology can provide reliable, economical geotechnical solutions, and simplify construction on marginal lands. LWA fill can also be used in geotechnical

Smart Foam Liquid Concentrates:

1. Are designed specifically for cellular concrete production.
2. Are designed to create their unique physical properties only when mixed with cementitious materials and a chemical reaction occurs.

thermal insulation and lightweight structural fill applications, though placement and compaction can be challenging in cold-weather conditions or closed quarters like swimming pool structural fill.

EPS geofoam lightweight fills and XPS geofoam insulation applications provide effective solutions for many geotechnical challenges. In ultra-lightweight fill situations, geofoam lightweight fills may be the only solution for construction on marginal lands.

Cellular concretes – CLWC and PCLWC – supply engineered, low-density fill solutions germane to solving a sweeping assortment of geotechnical, thermal insulation, and structural fill challenges. Because they are manufactured on site, are cast-in-place in thick lifts with minimal labor and no vibration or tamping, and reach virtually 100% compaction within a few hours of placement, cellular concretes simplify the construction process on marginal lands, and often provide significant productivity, environmental, and economic gains over LWA fill technology and EPS and XPS geofoam design, mobilization, and installation methods. Cellular concretes:

- Balance effectively load reduction and strength requirements
- Provide consistent, predictable performance
- Supply insulating, energy absorption, and fire-resistance properties
- Increase project quality and productivity
- Improve job site safety
- Support sustainable/green building objectives
- Can contribute to LEED points and Green Building accreditation.

When a lightweight, cost-effective fill material is required for thermal insulation, structural support, or to enable construction on marginal lands, CLWC and PCLWC fill solutions often simplify design, mobilization, and constructability issues, providing the best alternatives for project success.

See Appendix A on pages 21-23 for charts comparing material characteristics of the lightweight fill materials described in this white paper.

AUTHOR'S NOTE

Our nephew Jeffrey, a grade-school student blessed with energy, patience, imagination, curiosity, and scientific career ambitions (at least for now), visited during the creation of this white paper and transformed our kitchen into a laboratory to demonstrate the lightweight fill technologies described above.

He used three of our Rubbermaid TakeAlongs Small Deep Squares™ food

Cellular concretes help simplify the construction process on marginal lands, providing productivity, environmental, and economic gains over LWA fill technology and EPS and XPS geofoam design, mobilization, and installation methods.

storage containers to represent areas of loose job site native soils, incapable of supporting required loads without site improvements. He used peppercorns and our pepper grinder to “manufacture” and “process” a custom-graded LWA fill. He used EPS packing materials from my new iMac™ computer, a hacksaw, and his math skills to “manufacture” EPS geofoam block, scaled to represent “48-inch widths” when placed in two layers inside one of the containers. He used Bisquick Shake and Pour™ pancake batter to “batch” CLWC. He worked out the math and used a serving spoon and salad fork to place and compact the peppercorn-based LWA fill – in scaled, “9-inch lifts” – completely filling one of the containers. He manually placed the packing-material-based EPS geofoam blocks to completely fill the second container, being careful to orient the second block layer at 90° to the first layer and using duplex-head nails to bound the two layers together. He “cast-in-place” the Bisquick-based CLWC, completely filling the third container, in two, scaled, 48-inch lifts.

Which lightweight fill “kitchen” technology did Jeffrey think best simplified construction on his “marginal lands?”

Which geotechnical lightweight fill technology do you think best simplifies construction on marginal land?

NEXT STEPS

(1) Learn more about cellular lightweight concrete fills or request help for a specific project by contacting Rich Palladino, President of Cellular Concrete Solutions: 888.235.5015 | rpalladino@cellular-concrete.com

(2) Share the information included in this white paper with others within your sphere of influence.

APPENDIX A - LIGHTWEIGHT FILL MATERIAL CHARACTERISTICS

Appendix A begins on page 21.

Cellular concretes simplify construction on marginal lands because they are manufactured on site, are cast-in-place in thick lifts with minimal labor and no vibration or tamping, and reach virtually 100% compaction within a few hours of placement.

RESOURCE SECTION

Book –

Chapter 47: “Fouad H. Fouad on Cellular Concrete” in Significance of Tests and Properties of Concrete and Concrete-making Materials, by Joseph F. Lamond, and J. H. Pielert; edition: 5, published by ASTM International, in 2006; ISBN 0803133677, 9780803133679; pp 561 to 569 of 664 pages.

Online –

Visit www.cellular-concrete.com Be sure to check out the “Links”, “Support”, and “White Paper” sections and sign up for the free, quarterly eNewsletter, *Smart Foam Liquid Concentrate Solutions for Construction, Mining, and Manufacturing Applications*.

White Paper Links:

White Paper 1 –

What is Cellular Concrete ... and If It is So Great, Why Doesn't Everyone Use It?

White Paper 2 –

Improving Stormwater Runoff Management

White Paper 3 –

Revolutionizing Mine Tailings Disposal and Backfill

Associations –

Expanded Shale, Clay & Slate Institute (ESCSI) –

ESCSI is the international trade association for manufacturers of rotary kiln-produced expanded shale, expanded clay, and expanded slate lightweight aggregate. Visit www.escsi.org

The EPS Molders Association –

The EPS Molders Association is dedicated to the advancement and growth of innovative building technologies using expanded polystyrene. Visit www.epsmolders.org

The Extruded Polystyrene Foam Association (XPSA) –

XPSA is a trade association representing manufacturers of Extruded Polystyrene Foam (XPS) insulation products and the industry's raw material suppliers. Visit www.xpsa.com

ABOUT CELLULAR CONCRETE SOLUTIONS

Cellular Concrete Solutions engineers integrated, smart foam liquid concentrate solutions for construction, mining, and manufacturing applications, applying research, innovation, and technical expertise and support to help specifiers, contractors, mining professionals, and manufacturers expand markets, improve quality and job site safety, and reduce project and environmental costs.

The innovative Cellular Concrete Solutions product line includes protein, synthetic, and protein/synthetic blend liquid foam concentrate formulations for use in insulated concrete roof deck and floor construction, low slump and lightweight concrete applications, and mining and geotechnical applications, including pervious cellular lightweight concretes.

The engineered foams are designed to release their unique physical properties only when mixed with the cementitious materials and a chemical reaction occurs. Construction professionals find Cellular Concrete Solutions' smart foam liquid concentrates to be the most stable preformed products in the cellular concrete industry, durable cell structures not affected by long pump runs, extended mixing, or most fly ashes or ground granulated blast-furnace slags.

Smart foam liquid concentrate products include:

Geotechnical Solutions

- Mearl Geofoam Non Pervious™
- Mearl Geofoam 40 Non Pervious™
- Mearl Geofoam Pervious™

Roof Deck and Floor Solutions

- Mearlcrete 40™

Precast Solutions

- Mearlcell 3532-40™

Ready-Mix Solutions

- Cellflow™

Material Transport

- Mearl Transport™

Cellular Concrete Solutions also sells foam generation systems designed specifically for producing consistent foam for cellular concrete production, including jobsite-tough tank generators, tankless auto generators, and portable, lab-foam generators for producing accurate results in the laboratory.

More information about smart foam liquid concentrates and Cellular Concrete Solutions is available online at www.cellular-concrete.com



Sharing our research, innovation, and technical expertise and support to help you expand markets, improve quality and job site safety, and reduce project and environmental costs.

Appendix A: LIGHTWEIGHT FILL MATERIAL CHARACTERISTICS COMPARISONS

<u>Material Characteristics</u>	<u>*LWA Fill</u>	<u>*EPS geofoam Fill</u>	<u>*XPS geofoam Fill</u>	<u>*CLWC Fill</u>	<u>*PCLWC Fill</u>
Requires manufacturing lead time	sometimes	sometimes	sometimes	seldom	seldom
Manufactured off site	yes	yes	yes	no	no
Manufactured on site	no	no	no	yes	yes
Requires delivery of raw materials for job site production	no	no	no	yes	yes
Requires delivery of manufactured material to job site	yes	yes	yes	no	no
Requires job site stockpiling, storage, and/or protection measures for delivered material	sometimes	often	often	no	no
Requires plant quality assurance Program (QAP)	yes	yes	yes	yes	yes
Requires job site QAP	yes	yes	yes	yes	yes
Requires job site inventory control, when multiple densities are required	yes	yes	yes	no	no
Predictable engineering performance	yes	yes	yes	yes	yes
Free-draining/permeable	yes	no	no	no	yes
Insulating	yes	yes	yes	yes	yes
Combustible	no	yes	yes	no	no
Self-leveling	no	no	no	yes	yes
Self-compacting	no	no	no	yes	yes
Abrasion Resistant	yes	no	no	yes	yes
Subject to buoyancy uplift forces	sometimes	sometimes	sometimes	sometimes	sometimes

* Key:

LWA Fill = Lightweight Aggregate fill; EPS Geofoam Fill = Molded Expanded Polystyrene Geofoam Fill; XPS Geofoam Fill = Extruded Polystyrene Geofoam Fill;

CLWC Fill = Cellular Lightweight Concrete Fill; PCLWC Fill = Pervious Cellular Lightweight Fill

<u>Material Characteristics</u>	<u>LWA Fill</u>	<u>EPS geofoam Fill</u>	<u>XPS geofoam Fill</u>	<u>CLWC Fill</u>	<u>PCLWC Fill</u>
Subject to Water Absorption	yes	yes	yes	no	no
Subject to chemical attack (organic fluids or their vapors)	no	yes	yes	no	no
Subject to ultra violet (UV) degradation	no	yes	yes	no	no
Subject to insect infestation	no	sometimes	sometimes	no	no
Puncture/deformation resistant during handling, stockpiling, and/or installation	yes	no	no	yes	yes
In-place durability (when assembled/placed correctly)	yes	yes	yes	yes	yes
Inert	yes	yes	yes	yes	yes
Cold-weather construction possible	yes	yes	yes	yes	yes
Various types available to meet project density and strength requirements	yes	yes	yes	yes	yes
Typical material density range	45 lb/ft ³ - 65 lb/ft ³	0.7 lb/ft ³ – 2.4 lb/ft ³	1.0 lb/ft ³ – 3.0 lb/ft ³	20 lb/ft ³ - 65 lb/ft ³	20 lb/ft ³ - 65 lb/ft ³
Typical in-place bulk density range	45 lb/ft ³ - 65 lb/ft ³	0.7 lb/ft ³ – 2.4 lb/ft ³ plus compacted leveling course, and protective concrete slab or cover material	1.0 lb/ft ³ – 3.0 lb/ft ³ plus compacted leveling course, and protective concrete slab or cover material	20 lb/ft ³ - 65 lb/ft ³	20 lb/ft ³ - 65 lb/ft ³
Used in ultra-lightweight fill applications	no	yes	sometimes	no	no
Used in thermal insulation applications	yes	sometimes	yes	yes	yes
Used in lightweight, moderate strength, structural fill applications	yes	sometimes	sometimes	yes	sometimes
Requires placement in uniform, thin, compacted lifts	yes	no	no	no	no
Requires compaction testing	yes	no	no	no	no
Requires shop drawings for on-site fabrication and/or assembly	no	recommended	recommended	no	no

<u>Material Characteristics</u>	<u>LWA Fill</u>	<u>EPS geof foam Fill</u>	<u>XPS geof foam Fill</u>	<u>CLWC Fill</u>	<u>PCLWC Fill</u>
Requires job site forming and/or bulkhead fabrication and setting	no	sometimes	sometimes	sometimes	sometimes
Requires cast-in-place installation in thick, self-leveling and self-compacting lifts (often 48-inches thick)	no	no	no	yes	yes
Requires ballasting in job site storage and placement phases	no	yes	yes	no	no
Requires spike grids or adhesives to bound multiple material layers together (minimizing block slippage)	no	yes	yes	no	no
Requires preloading, surcharging, or staged construction	sometimes	no	no	no	no
Best management practices required in areas subject to differential icing	sometimes	yes	yes	yes	yes
Requires pre-installation meeting recommended	recommended	recommended	recommended	recommended	
Uses HFCs or HFCs in the manufacturing process	no	no	often	no	no
Can require a curing period for off-gassing of blowing agent	no	yes	yes	no	no
Supports sustainable development	yes	yes	yes	yes	yes
Can contribute to LEED points and Green Building accreditation	yes	yes	yes	yes	yes
Can be combined with other lightweight fill in complementary ways at the job site	yes	yes	yes	yes	yes
Enables construction on marginal land	yes	yes	yes	yes	yes