Selected Engineering Properties and Applications of EPS Geofoam

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Abstract

Expanded polystyrene (EPS) geofoam is a lightweight material that has been used in engineering applications since at least the 1950s. Its density is about a hundredth of that of soil. It has good thermal insulation properties with stiffness and compression strength comparable to medium clay. It is utilized in reducing settlement below embankments, sound and vibration damping, reducing lateral pressure on sub-structures, reducing stresses on rigid buried conduits and related applications.

This study is an overview on EPS geofoam. EPS manufacturing processes are described followed by a review of engineering properties found in previous research work done so far. Standards and design manuals applicable to EPS are presented. Selected EPS geofoam-engineering applications are discussed with examples.

1. Introduction

Expanded Polystyrene, EPS, geofoam is a super-lightweight, closed cell, rigid, plastic foam. Its unit weight puts it in a separate category compared to other types of engineering lightweight materials as shown in table 2-1. In 1950, expanded polystyrene was invented (BASF, 1997). Geofoam has now been successfully utilized in a number of countries all over the world. Some of these countries are Norway, The Netherlands, the United States, Japan, Germany and Malaysia.

In Norway the first road insulation project with EPS geofoam was performed in 1965 (Aabee, 2000) and the first road embankment project utilizing EPS geofoam was completed in 1972 (Frydenlund, 1991) when the National Road 159 Flom Bridges project involved replacing one meter of ordinary fill material with blocks of EPS in embankments adjoining a bridge founded on piles to firm ground. The embankments were resting on a 3m thick layer of peat above 10m of soft, sensitive clay. Before using EPS geofoam, settlement rates were of the order of 20-30 cm annually and accelerating due to frequent adjustments of the road level. Settlement was successfully halted after using EPS geofoam. In the Netherlands the first EPS geofoam projects start early seventies (van Dorp, 1996)

Table 2-1 Types of Lightweight Materials (after Miki, H., 1996)

Lightweight Material	Unit Volume Weight (tf/m^3)*	Description
EPS Blocks	0.01 ~ 0.03	Ultra lightweight, expandable synthetic resins
Expanded Beads Mixed Lightweight Soil	0.7 approx. or more	Variable density; similar compaction and deformation characteristics to soil; can use excess construction soil
Air Foamed Mortar and Air Foamed Lightweight Stabilized Soil	0.5 approx. or more	Density adjustable; flow able; self-hardening; and can use excess construction soil
Coal Ash, Granulated Slag, etc.	1.0 ~ 1.5 approx.	Granular material; self hardening
Volcanic Ash Soil	1.2 ~ 1.5	Natural material

Hollow Structures	1.0 approx.	Corrugated pipes, box culverts, etc.
Wood Chips	0.7~ 1.0	Usually to be used below ground water level; anti leaching measures needed
Shells	1.1 approx.	Sized 12 to 76 mm; interlocking effects
Tire Chips	0.7~ 0.9	Usually used above ground water level; cover soil layer at least 0.9m is required

* 1tf ≈10000 N

Even though EPS geofoam was used in the United States much earlier than in most countries, subsequent progress was slow. Recently, EPS geofoam is used in a growing trend in a number of applications in the States. The largest volume of EPS geofoam in one project is about 100,000 cubic meters in Salt Lake City in the reconstruction of interstate I-15.

The first EPS geofoam application in Japan was an embankment fill in 1985 (Miki, H., 1996) where 470 cubic meters were utilized in the project. EPS geofoam fill as high as 15m was constructed (Yamanaka, et al., 1996)

In Germany, although EPS was used for the first time in the 1960s as frost protection layers in pavement, it was first used in highway construction in March of 1995 (Hillmann, 1996) where EPS was utilized to minimize the differential settlement of a bridge approach. EPS geofoam as a lightweight fill material was first introduced in 1992 in Malaysia (Mohamad, 1996).

EPS geofoam structures performed well under static loading as will be seen in the example applications in this chapter. Experience in Japan with EPS geofoam showed that EPS geofoam structures also performed well under seismic loading. During the years of 1993 to 1995 strong earthquakes occurred in various parts in Japan. Hotta, et al., (1996) reported 5 earthquakes of magnitude range 6.6 to 8.1. Al-though some damage occurred to EPS sites, Hotta et al., considered that EPS embankments are highly stable during earthquakes

This chapter presents a background about this lightweight material. First the chemical composition is described together with the manufacturing process of the raw material and the final product, the geofoam blocks. The main manufacturing steps that control the characteristic of the final product are highlighted.

Selected properties of EPS geofoam are presented with a literature survey about the implication of these properties. Density, compression behavior, interface friction, time-dependent behavior, tension behavior and other engineering properties are presented. Previous laboratory work that is of importance to engineering applications is shown. Important design and construction concerns are identified.

Standards that control the material testing or the design in a number of countries is shown. Finally, examples of the various engineering applications are shown with related details for some of them.

2. EPS Geofoam Manufacturing

Expandable polystyrene is the raw material or resin used for the molding of expanded polystyrene, EPS, geofoam. Expandable polystyrene is a plastic/polymeric material with a chemical composition of C8H8 (Ravve, 2000). Polymers are long chain molecules in which one to three basic units, monomers, are repeatedly linked over and over in a process called polymerization.

Polymerization of styrene monomer used to be followed by impregnation of the polymerized polystyrene beads with a blowing agent. Today almost all process carries out polymerization and impregnation in a one step process as shown in figure 2-1. The reaction occurs in a single reactor designed to control the temperature and pressure of the reaction. Styrene monomer and water is charged to the reaction kettle equipped with an agitator. Various chemicals are added to affect suspension of the monomer in water and to control the polymerized bead growth, molecular weight and other parameters necessary to produce the desired product. In the second phase of the process, the blowing agent is added under pressure and impregnates the soft polystyrene beads. The total batch cycle takes a little less than ten hours. When completed the entire batch is dumped to de-water the system. The beads are then dried. The beads are screened to obtain different bead sizes. They will be in different grades each has its own specification and use. Some are good for leak resistant containers (Huntsman, 1999d), some are for impact absorption packaging applications (Hunts-man, 2000), some are for general block and shape molding operations (Huntsman, 1999b), etc. They are packaged and transferred to the geofoam block manufacturer.

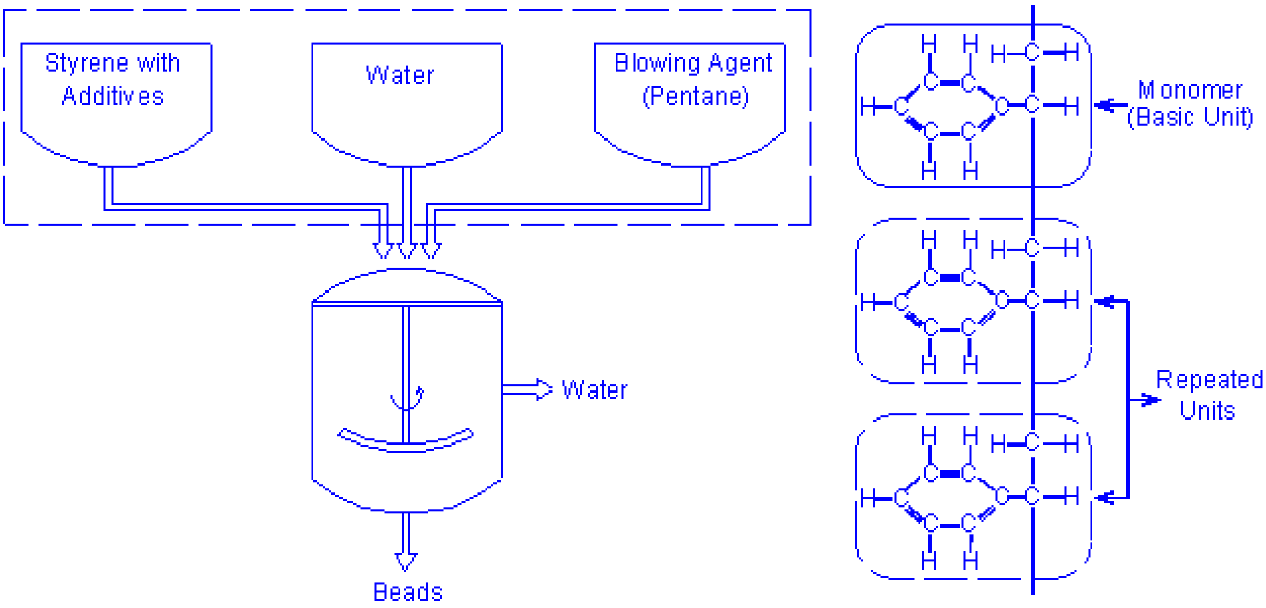

Figure 2-1 Expandable Polystyrene Beads Manufacturing Process

Figure 2-2 shows the process of manufacturing geofoam from the expandable polystyrene beads. Five stages can be seen in the figure. First the beads are fed to a vertical tank containing an agitator and a controlled steam input. The final material density is determined at this stage. Density adjustment is carried out by controlling the length of the time the beads remain in the expander and/or the pressure in the ex-pander. Second, the expanded beads, called prepuffs, are stored in the open air for few hours as a drying stage. Third, the prepuffs are stored in large silos until transferred for the following step. During storage they are allowed to reach an ambient temperature. This process takes as long as three days or as short as few hours. This process is called the stabilization process, as condensation of the blowing agent and the surrounding water vapor occurs. The prepuffs then are poured in a mold of various sizes, depending on the manufacturer. A 0.6m X 1.2m X 2.4m is a common mold size. Steam is injected from the walls of the mould through longitudinal tiny slots where fusion takes place. Approximately 5% of recycled expanded polystyrene (re-grind) is shredded and mixed with the prepuffs. Additional expansion and fusion takes place. The molded block is then pushed out where it is ultimately taken to a storage place to dry.

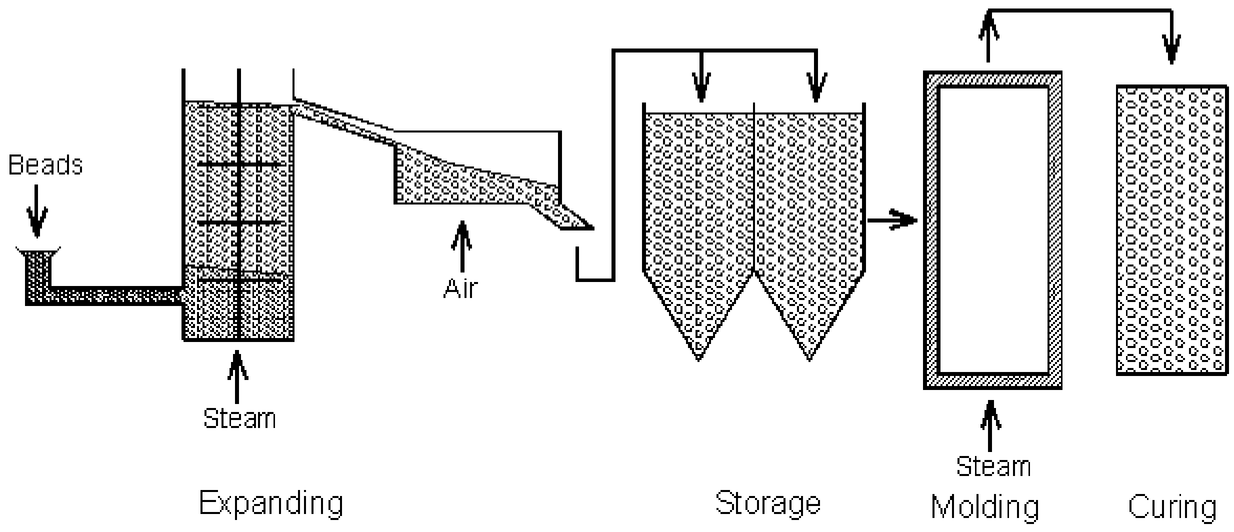

Figure 2-2 EPS Geofoam Manufacturing Process

The basic EPS product is white, although it can be colored otherwise. About 140 geofoam manufacturer plants are distributed throughout the United States (Negussey, 1998). Material prices vary depending on the type and density of geofoam, as well as on the job, size and location.

3. Material Properties

EPS geofoam is a lightweight material with a good insulation and energy abs-sorption characteristics. On the other hand, its strength and stiffness are comparable to some types of soils.

3.1 Density

EPS geofoam density can be considered the main index in most of its proper-ties. Compression strength, shear strength, tension strength, flexural strength, stiff-ness, creep behavior and other mechanical properties depend on the density. The cost of manufacturing an EPS geofoam block is considered linearly proportional to its density. Non-mechanical properties like insulation coefficients are also density de-pendent.

EPS densities for practical civil applications range between 11 and 30 kg/m3. For other applications like insulation higher densities are more efficient (van Dorp, 1988). With its lightweight property, geofoam blocks can be easily handled after manufacturing, during curing, transportation or placement in the field. Two workers can handle a 0.6m X 1.2m X 2.4 m half size block of an average weight of 35 kg for 20 kg/m3 density EPS geofoam.

In the United States, manufacturers and designers working with EPS geofoam are familiar with density classification used by thermal insulation standards, C 578-95. Table 2-2 shows 5 EPS types, which are categorized by ASTM C 578-95. Tables 2-3 and 2-4 show EPS densities used in two other countries.

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3.2 Compression

3.2.1 Compressive Strength and Stress Strain Curve

Figure 2-3 shows the uniaxial compression stress strain curve of EPS geofoam for two different densities. The two densities shown are considered the extreme values for most engineering applications done so far. Specimens are 0.05m cubes tested at a displacement rate of 0.005m/min. From the figure the stress strain curve can be simply divided into two main straight lines connected with a curved portion. The slope of the straight-line portions increase with density. The stress at any strain level increases also with the density. The bead size has no important effect on the compressibility of cut specimens (BASF Corp., 1968)

Table 2-2 ASTM C 578-95 EPS Densities

Type	XI	I	VIII	II	IX
Density (kg/m^3)	12	15	18	22	29

Table 2-3 EPS Types in Japan (after Miki, G., 1996)

Type	D-12	D-16	D-20	D-25	D-30
Density (kg/m^3)	12	16	20	25	30

Table 2-4 EPS Types in United Kingdom (after Sanders, 1996)

Type	Standard Duty (SD)	Heavy Duty (HD)	Extra Heavy Duty (EHD)	Ultra Heavy Duty (UHD)
Density (kg/m^3)	12	16	20	25

There is no defined shear rupture for EPS geofoam under compression. As will be shown later in chapter six, more than 70 % strains are reached without any break point and the tests were stopped because the maximum travel of the machine head was reached. The 1%, the 5%, and the 10% strains are common reference strain level, at which the stress is considered as the strength of the material. Tables 2-5, show the compressive strength of EPS geofoam as given by ASTM C578-95.

EPS geofoam under confining compression Sun (1997) reported that with in-crease in confining stress the strength and initial tangent modulus decrease. Sun concluded these results based on axial deviator stress strain curves, which are important for submerged EPS geofoam.

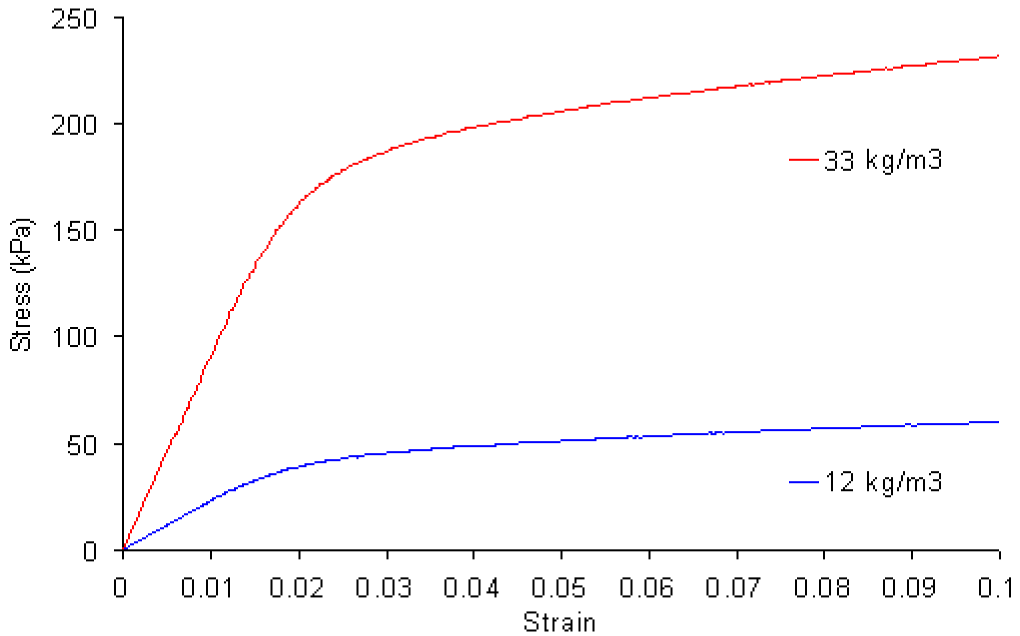

Figure 2-3 EPS Uniaxial Compression Stress Strain Curves (after Negussey and Elragi, 2000b)

Table 2-5 EPS Types in United Kingdom (after Sanders, 1996)

Density (kg/m^3)	12	15	18	22	29
Compressive Strength at 10% Strain (kPa)	35	69	90	104	173

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3.2.2 Initial Elastic Modulus

The stress strain curve of EPS geofoam has an initial linear portion. The value of the slope of this initial portion is defined as the initial tangent modulus. Also it is known as Young's Modulus as well as the modulus of elasticity. EPS geofoam initial modulus is a function of the density as shown from figure 2-4. For EPS geofoam, as shown from the same figure, there is no agreement from the researchers on a constant value for each density. For a 20kg/m3 density the initial modulus ranges between 5Mpa and 7.75Mpa, which means a 55% difference. The relation is linear for some researchers (Horvath, 1995b and Miki, H., 1996) while it's nonlinear for others (Duskov, 1997 and Eriksson and Trank, 1991). The researchers used specimens with vary dimensions.

Duskov, (1990) reported that the back calculated moduli of elasticity of EPS geofoam were found to be between 13 MPa and 34 MPa under pulse force. These values were observed to be much higher than the value of the modulus of elasticity (5MPa) obtained under the semi static loading. Duskov (1997) after testing 20kg/m3 EPS geofoam, reported that low temperatures, water absorption level, and exposure to freeze-thaw cycles, separately or combined, seem to have no negative influence on the mechanical behavior of the EPS geofoam that he had tested. Elragi et al. (2000) showed the effect of sample size on the initial Modulus. For larger specimens, the initial modulus is higher.

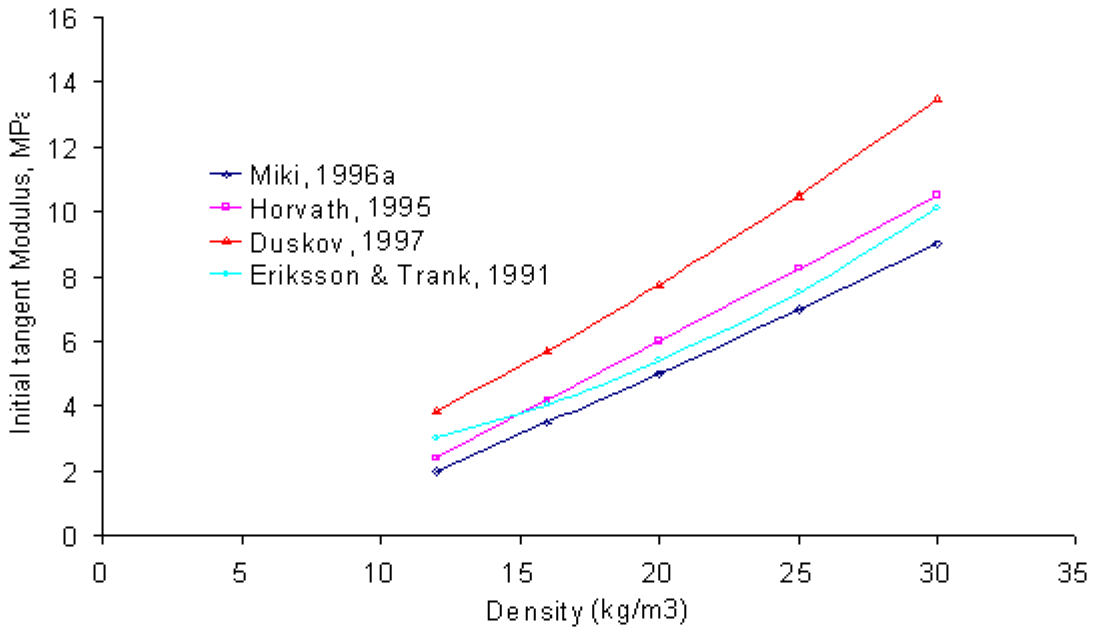

Figure 2-4 Initial Tangent Modulus for EPS geofoam

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3.2.3 Poisson's Ratio

Poisson's ratio is an index of the lateral pressure of EPS geofoam on adjacent structural elements, in contact, for a certain applied vertical load on the EPS geofoam mass. Value range between 0.05 and 0.5 are found in the literature for EPS geofoam as shown in table 2-6. These values range from material like water (Poisson's ratio equals to 0.5) to rigid materials like concrete (Poisson's Ratio equals to 0.15) Chapter three presents a solution to this discrepancy.

Table 2-6 EPS Types in United Kingdom (after Sanders, 1996)

Reference	Yamanaka, et al. (1991)	Negussey and Sun (1996)	GeoTech (1999a)	Duskov et al. (1998)	Ooe, et al. (1996)	Sanders (1996)	Momoi and Kokusyo (1996)
Poisson's Ratio	.075	.09 and 0.33	0.05	0.1	0.08	.05 up to 0.2	0.5

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3.2.4 Loading Rate Effect

The compression behavior of EPS geofoam is strain rate dependent (Negussey, 1997). Higher strain rates result in higher initial modulus and higher com-press ion strength. A more extensive work is shown in chapter three.

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3.2.5 Cyclic Loading

EPS geofoam may experience cyclic loading in a number of situations. This can include traffic loading and dynamic loading. The majority of laboratory testing and field observations suggest that the cyclic load behavior of block molded EPS geo-foam is linear elastic provided that the strains are no greater than approximately 1%. For three loading cycle tests, the initial tangent modulus in the second and third cycles is much less than those for the first cycle, when the three cycles are loaded to 10% strain (Eriksson and Trank, 1991). Flaate (1987) reported that cyclic load tests show that EPS geofoam will stand up to an unlimited number of load cycles provided the repetitive loads are kept below 80% of the compressive strength. More cyclic loading testing results are shown in chapter three.

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3.3 Tension

Tensile strength of EPS material can be an indication of the quality of fusion of the prepuffs and any recycled EPS geofoam used in the process (Horvath, 1995b). From figure 2-5 it can be seen that the tension strength increases with the density.

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3.4 Flexural

Flexural strength tests are widely used as a quality control test in EPS geo-foam manufacturing plants. The maximum stress is calculated assuming the material is linear elastic up to failure. Although this is not an accurate assumption, the calculated values are widely used in quality control. The material fails in tension as a crack on the tension side appears at the moment of failure.

The flexural strength increases with density of the material as shown in table 2-7. From table 2-7 and figure 2-5 it can be seen that the values of the flexural strength are almost the same as the tension strength since the mode of failure is tension in the outer points

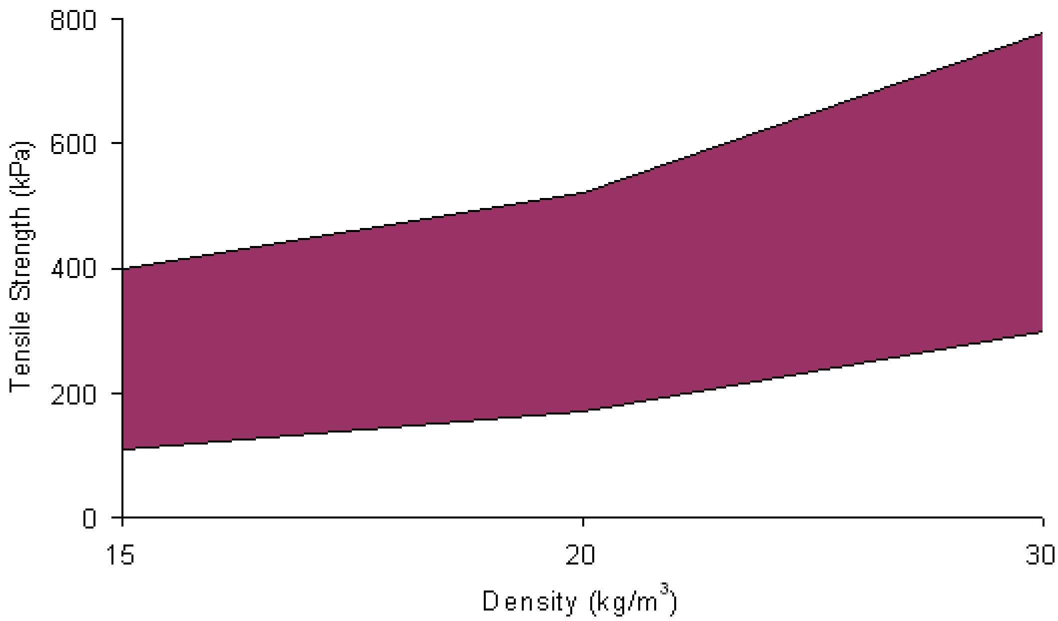

Figure 2-5 EPS Geofoam Tensile Strength (after BASF, Corp., 1997)

Table 2-7 ASTM C 578-95 EPS Flexural Strength

Density (kg/m^3)	12	15	18	22	29
Minimum Flexural Strength (kPa)	70	173	208	276	345

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3.5 Creep

EPS geofoam is susceptible to time dependent creep deformation when a constant stress level is applied. A number of parameters affect the creep behavior of EPS geofoam, among which is the density. Creep deformations decrease with density in-crease (Sun, 1997).

Figure 2-6 represents the results of three 0.05m cube specimens each are subjected to an unconfined axial stress for a period of over 500 days. The stresses are 30%, 50% and 70% of the strength of the material. The three specimens are of type VIII and minimum density of 18kg/m3. It can be seen from the figure that the creep behavior is stress level dependent. For the lower stresses, very little creep deformation occurred after 500 days.

Both full scale and laboratory creep tests have been performed (Aab?e, 2000) A test was done with 2m height of geofoam loaded to 52.5% of its compressive strength. Results observed in a three year period show continuous deformation with time. The strain after the three years was about 1% and slightly increasing with time. The full-scale test was for an EPS bridge abutment. Stresses in the geofoam abutment ranged between 25 and 60% of EPS strength at 5% strain.

Observed deformation after 10 years in operation shows negligible creep. The effect of specimen size on the creep behavior and further creep results and observations are shown in chapters three and five.

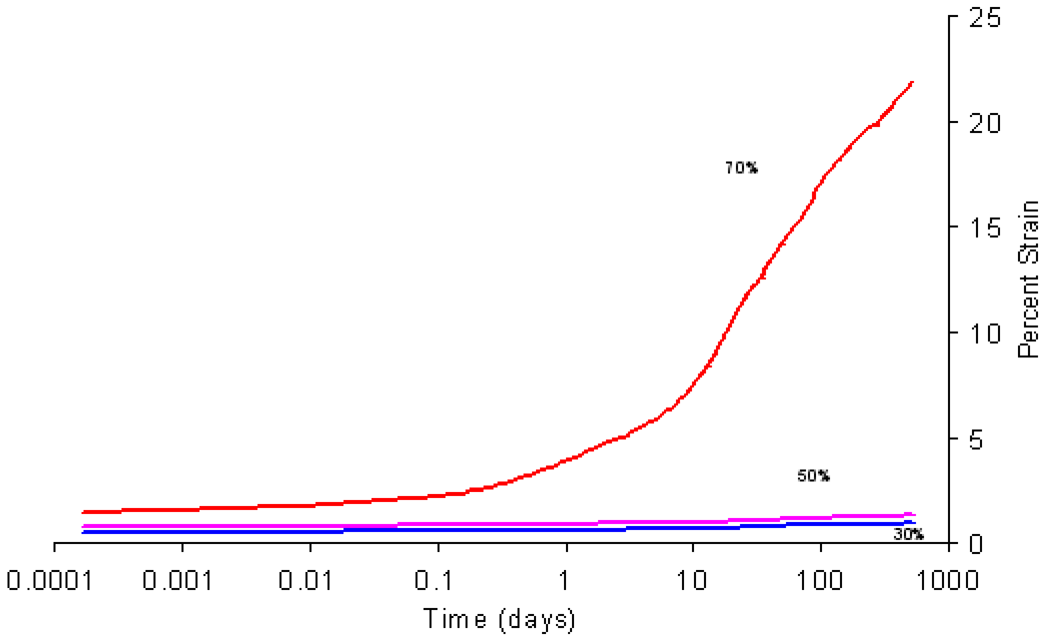

Figure 2-6 EPS Creep Behavior for Different Stress Levels (after Sheeley, 2000)

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3.6 Interface Friction

Sheeley (2000) did a comprehensive study of geofoam interface shear behavior for small and large samples. Normal stresses in the range of practical interest were used and different interfaces were investigated. Geofoam to geofoam interface shearing developed peak and residual strengths are shown in figure 2-7. The effect of density on interface strength of geofoam was negligible. There was difference between wet and dry interface strengths in the range of normal stresses used in practice and for short-term exposure to water. A strong adhesive bond developed between geofoam and cast in place concrete interfaces and both peak and residual interface strengths were high. The interface strength between geofoam and geomembrane surfaces was low. Substitution of a concrete load distribution slab with a geomembrane may therefore result in a much weaker interface. Values of both peak and residual friction factor are shown in table 2-8. Although values of 0.65 were reported for EPS geofoam to EPS geofoam interface, 0.5 can be considered a conservative coefficient of friction as Nomaguchi (1996) obtained from both static and dynamic tests.

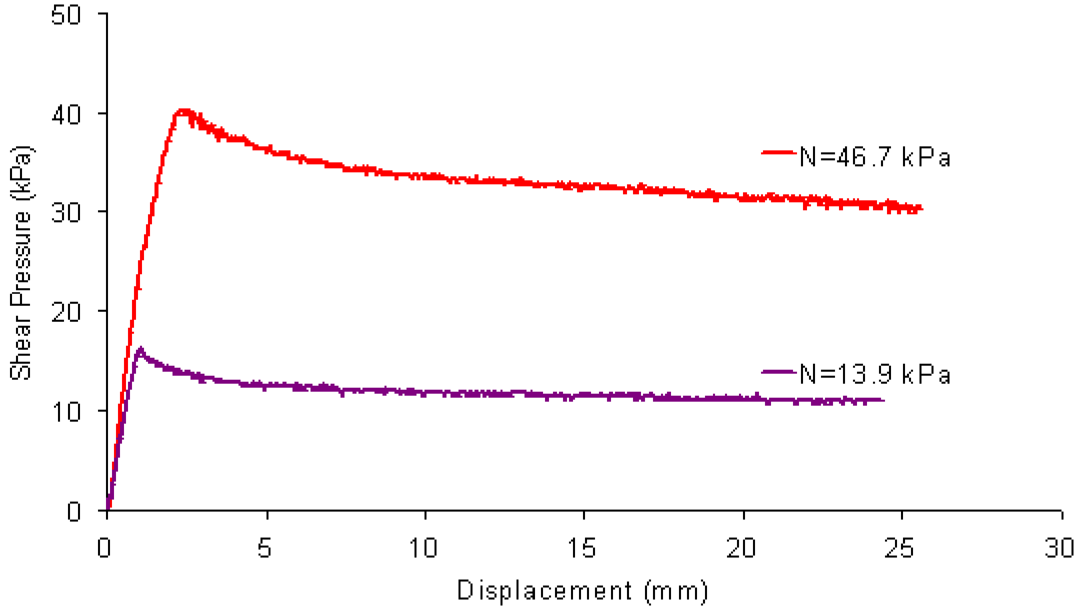

Figure 2-7 EPS Interface Friction (after Sheeley, 2000)

In practice, metal binder plates are sometimes used to attach foam layers to each other. Sheeley and Negussey (2000) reported that binder plates did not provide increased shear resistance in one directional loading and had reduced resistance in reverse loading and reloading.

Kurose and Tanaka (1996) have proposed a new technique in which H and C shaped EPS blocks could be successfully used in embankment construction. The main idea is to have interlocked EPS blocks to act as one unit.

Table 2-8 EPS Geofoam Interface Friction Factors (after Sheeley and Negussey, 2000)

Interface	Peak Factor	Residual Factor
Foam-Foam, 20kg/m^3(dry)	0.85	0.70
Foam-Foam, 20kg/m^3(wet)	0.80	0.65
Foam-Foam, 30kg/m^3(dry)	0.85	0.65
Foam-Foam, 30kg/m^3(wet)	0.75	0.65
Foam- Cast in Place Concrete	2.36	1
Foam-Textured HDPE Membrane	1	~1
Foam- Smooth HDPE Membrane	0.29	0.23
Foam-Smooth PVC Membrane	0.70	0.40

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3.7 Thermal Resistance

EPS geofoam consists of approximately 98% air and 2% polystyrene (BASF Corp., 1997). The air entrapped within the geofoam is a poor heat conductor, there-fore, making EPS geofoam excellent for heat insulation. The R-value measures thermal resistance of substances. R-values for typical soil and concrete in general are much less than 0.1 m3 ?C/W. Figure 2-8 shows the R-values of EPS geofoam as given in ASTM C 578-95 and the range of 0.5- 0.8 m3 ?C/W for EPS geofoam is much higher than the R-values of typical soil and concrete. The R-value of geofoam increases with the density. The curves tend to level horizontally with increasing the density. Van Dorp, 1988 mentioned that it reaches its maximum around a foam density of 35kg/m3. The R-value tends to decrease with temperature increase as shown in the same figure. Another factor that will affect the thermal resistance of EPS geofoam is the amount of moisture absorption (Negussey, 1997). R-value degrades or de-creases with moisture absorption while aging has no effect on the R-value (Hunts-man, 1999i). This is because the closed cell structure of EPS contains only air.

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3.8 Ultraviolet Effect

Exposing the expanded polystyrene geofoam to ultraviolet will yellow the surface and a powder like texture will appear. Sheeley, (2000) tested the effect of this new surface on the interface friction between foam blocks and concluded that ultra-violet degradation diminished the peak interface strength between geofoam and cast in place concrete. Power washing removed with commercially available equipment effectively the degradation and improved the adhesion bond strength.

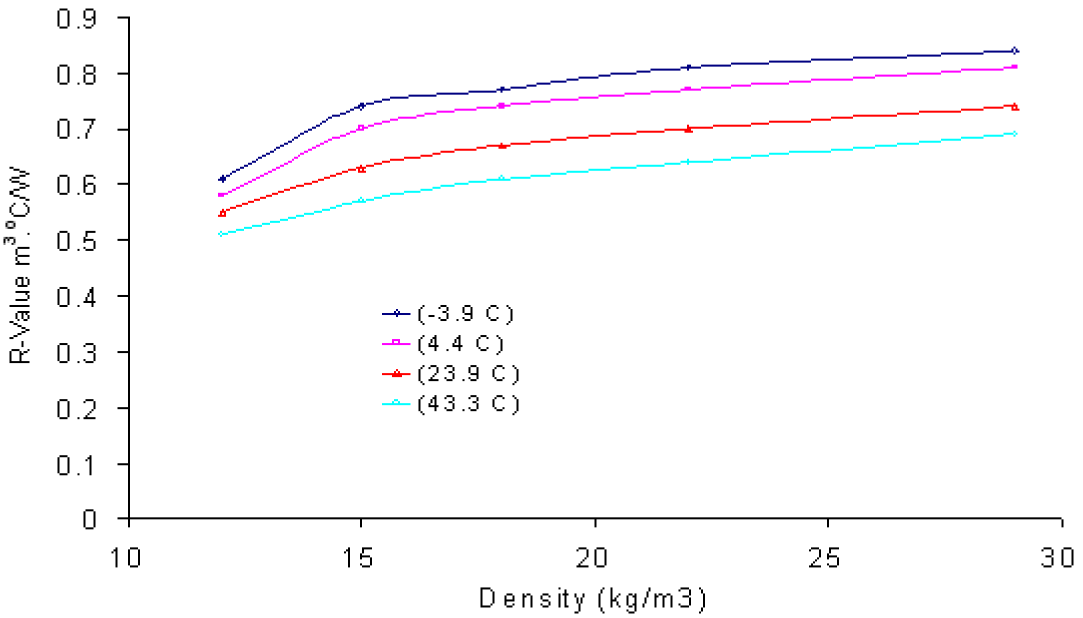

Figure 2-8 ASTM C 578-95 EPS R-Values

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3.9 Flammability

Expanded polystyrene geofoam is combustible and should not be exposed to open flame or other ignition sources. Combustion products are carbon monoxide, car-bon dioxide, water and soot. The manufacturer can include fire-retarding additives during production, which will increase cost by 5 – 10% if procedures generating heat and flame are required near geofoam (Sun, 1997). The fire retardant is mainly to de-crease the potential of fire spread from a small flame source. The melting temperature of polystyrene is 150^{0}C (Mandal, 1995).

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3.10 Water Absorption

The water absorption of expanded polystyrene is low. Although water absorption decreases as density increases as shown in table 2-9, fusion is the most important factor influencing the moisture resistance of expanded polystyrene. Good fusion reduces the amount of water absorption. For 9 –12 years of service, equilibrium values of 8-9 % volume have been found in EPS fills below the ground water table (van Dorp, 1988).

Table 2-9 % Volume of Water Absorption (German Specifications, after van Dorp, 1988)

Density, kg/m^3	After 7 Days	After 1 Year
15	3.0	5.0
20	2.3	4.0
25	2.2	3.8
30	2.0	3.5
35	1.9	3.3

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3.11 Resistance to Attacks

Chemical resistance of thermoplastic expanded polystyrene is dependent on time, temperature, and applied stress in functional use (Huntsman, 1999f). Chemical attack usually results in the softening and cracking of the plastics. Expanded Polystyrene has the same resistance to chemical reagents as general-purpose polystyrene. Most acids and their water solutions do not attack polystyrene; however strong oxidizing acids do. The thin cell walls and large exposed surface of expanded polystyrene make it sensitive to attack by solvents. Table 2-10 shows some of the chemical reagents and solvents and the corresponding EPS resistant.

Since it has no nutritional value, expanded polystyrene does not attract ants, termites, or rodents; however it is not resistant to them. Habitation by insects can be a problem for geofoam, as they can burrow through geofoam to reach food or to establish a comfortable home. Marine borers can also attack polystyrene as they do wood.

Fungal attack has not been observed on expanded polystyrene. EPS does not support bacterial growth as well. The main reason is that expanded polystyrene can-not supply nutrients for fungal or bacterial growth.

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3.12 Energy Absorption

EPS geofoam is utilized in packaging, as its energy absorption characteristics provide good protection. From the stress strain curves of EPS groom shown in figure 2-3 it can be seen that the area under the curve, which represents the strain energy absorbed by the material increases with density. Sliding between the EPS geofoam blocks is another way to produce damping (Kuroda, et al., 1996).

Table 2-10 Selected EPS Resistant Behavior (after BASF Corp., 1997 and van Dorp, 1988)

Source of Attack	Resistant Behavior
Salt Water (Sea Water)	Resistant
Alkali Solutions	Resistant
Soaps	Resistant
Caustic Soda Solutions	Resistant
Bitumen (Air Blown)	Resistant
Silicon Oils	Resistant
Alcohol	Resistant
Micro Organisms	Resistant
Paraffin Oil, Vaseline, Diesel Oil	Limited Resistance
Petrol (Super grade)	Non Resistant
Strong Oxidizing Acids	Non Resistant
Fuming Sulphuric Acid	Non Resistant
Organic Solvents	Non Resistant
Saturated Aliphatic Hydrocarbon	Non Resistant

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3.13 Inertness Properties

Polystyrene is completely inert. Any corrosion of metals in contact with expanded polystyrene will be caused by other factors (R-control, 1999a).

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3.14 Acoustical properties

Expanded polystyrene, when used in combination with other building materials effectively reduces the transmission of airborne sound through partitioned walls, ceilings and floors (Huntsman, 1999g). EPS has the advantage of being lightweight and effective in thicknesses as low as 0.625 cm it can replace thicker, heavier materials.

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3.15 Durability

No deficiency effects are to be expected from EPS fills placed in the ground for a normal life cycle of 100 years, Aab?e (2000). Aab?e added that this should hold true provided possible buoyancy forces resulting from fluctuating water levels are properly accounted for, the blocks are properly protected from accidental spills of dissolving agents and the applied stress level from dead loads is kept below 30-50% of the material strength.

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3.16 Environmental Effect

EPS geofoam is made of polystyrene beads and polystyrene is not biodegradable and chemically inert in both soil and water. Therefore EPS geofoam will not contaminate the ground or ground water. Adding to this, EPS is widely used for food containers. If EPS is burned either accidentally or intentionally as a part of a waste to energy program, the products of composition are primarily carbon dioxide and water. EPS is a recyclable material and 5% of volume of the manufactured geofoam is traditionally recycled geofoam. Raw beads, prepuffs, regrind and small molded parts can obstruct sewers and waterways. They have been found in the digestive tracts of fish (Huntsman, 1999a).

The plastic foam insulation producers faced a major set back issue for their industry because of ozone depletion caused by the use of low thermal conductivity blowing gases such as chlorofluorocarbon 11 and 12 (CFC-11 and CFC-12). Industry has obtained an acceptable immediate solution by using hydro chlorofluorocarbon (HCFCs) 141b and 142b for polyisocyanurate and polystyrene, respectively. The phase out of HCFCs may be required within the next 10 years, but other chemicals, such as hydro fluorocarbons (HFC-134a and HFC-245fa) exist and could become the next generation of blowing agents (McElroy, 1998).

An important benefit of EPS geofoam is that it now does not use CFC or HCFC in its manufacture as most other polymeric foam does. (Horvath, 1993 and GeoTech, 1999b). Extruded polystyrene, a member of the geofoam family, and the main competitor to EPS in insulation applications does have ozone-depleting gases as the blowing gas in its manufacturing. Huntsman, (1999a, 1999c, 1999e) provides a guide to clean air permitting for expandable polystyrene processors.

4. Design and Construction Considerations

Although geofoam has been utilized successfully in engineering applications failure is reported in very few of them. Fire, block flotation, differential icing of pavement are main causes of failure (Horvath, 1999a). Some potential items should be taken into account when utilizing geofoam in engineering applications. Engineers and technicians should be aware of such concerns when designing and during all construction phases. Design and construction considerations can be summarized in the following points:

4.1 Buoyancy

EPS geofoam is a super lightweight material, as was mentioned earlier with practical density ranges between 11 and 30 kg/m3. Uplift force due to buoyancy effect can be a reason of failure during or after construction. Enough surcharge can be pro-vided or the ground water table has to be controlled during and after construction to avoid instability against uplift. Utilizing uplift resisting anchors such as concrete slab anchored to the ground (Ninomiya and Makoto, 1996) or geotextiles (George, 2000) can be a useful alternative to solve the buoyancy problem. In all cases all design aspects such as the strength limit and the limiting strain must be checked to avoid creep while solving the buoyancy problem.

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4.2 Concentrated Loads

EPS geofoam is a material that punctures easily. Direct application of concentrated loads should be avoided. Placing of a concrete slab and providing an adequate thickness of the cover fill material are two solutions to avoid such problem. The better the load distribution is the less the strain will be. The cost and the time consumed while placing the concrete slab or the extra fill cover should be taken into consideration. Also, the heavier the dead load on the foam mass the more strain; hence the more creep will be faced. A good engineering judgment has to be taken.

Test results reported by Nishi, et al., (1996) show that the concrete slab on the top of the EPS geofoam mass has a high effect in load distribution. Angles equal 50~70 degrees with the vertical presents the load distribution within a concrete slab. In the foam it self, the angle is reduced to 20 degrees for the same applied load.

[TOP]

4.3 Chemical Attack

As was mentioned earlier, EPS geofoam show different resisting behavior to-wards organic and non-organic fluid and substances. Geofoam dissolves in gasoline and other fluids or their vapor that may exist during construction or while in service. Also the surrounding soils could be contaminated and contain EPS geofoam solvents. Utilizing a proper cover to the EPS geofoam mass will solve the problem. Solutions such as rapping the foam blocks in plastic sheets or covering with geotextiles or placing a concrete slab on the top of geofoam are engineering wise feasible (Negussey and Elragi, 2000a).

[TOP]

4.4 Flammability

As was mentioned earlier geofoam is a combustible material. Although fires is unlikely hazard in service it can be easily occur during construction or in storage. Since EPS geofoam is utilized in the construction site with other engineering materials such as steel, usage of open flame such as welding is likely to be occurred. Including the fire-retarding additive during production can be a solution against small ignition source (Huntsman, 1999h) but not complete fire prevention. In such case the cost of EPS geofoam block will be increased by 5 – 10%. If operations utilizing a source of ignition such as welding, fire watch procedures must be followed. In all cases all workers and incorporating persons in the site or using the storage area has to be aware of the flammability property of the substances they are dealing with (Negussey and Elragi, 2000a).

[TOP]

4.5 Ultraviolet Degradation

Construction conditions may require long storage duration of geofoam uncovered or foam can be exposed to sunlight after completing one construction phase and waiting for the other phase in schedule. As ultraviolet degradation has effects on the interface friction between EPS geofoam blocks and between some other engineering material and EPS geofoam blocks, it can be avoided by covering the geofoam mass with opaque sheeting during extended periods of open-air storage. As the affected surface is eroded or washed away a non-affected surface can be exposed and the adhesive bond strength is improved (Negussey and Elragi, 2000a).

[TOP]

4.6 Differential Icing

Having one portion of the road with icy condition while adjacent portions are ice-free is known as differential icing condition. Differential icing was first encountered in practice in the 1960s (Horvath, 1995c). This phenomenon normally occurs between typical grades supported pavement and bridge decks. Similar situation occurs between bad designed insulated pavements and pavement portions that are not insulated. Differential icing is considered to be a safety issue. On roads vehicles drivers do not expect to encounter sudden pavement icing when a road is elsewhere ice-free. Differential icing is somewhat recognizable by motor vehicles drivers for the case of bridge-deck icing, as the visual change between the two different surfaces is normally clear especially if proper warning signs are utilized. On the contrary, the sudden change in the icy condition for the case of insulated portions are totally unexpected by the drivers and can cause serious accidents.

EPS geofoam below pavements has a tendency to hinder frost penetration and restrict the upward flow of ground heat during slightly sub freezing temperature days. This can result in different ice formation rates and melting between areas that do and do not have EPS geofoam. Increasing the capability of the base and or the subbase material to provide some ground heat flow to the pavement surface can minimize the extent of differential icing on traveled roadways. One way to do so is to provide an adequate thickness for the base and/or the subbase taking in consideration that in-creasing the thickness above a certain amount can result in undesirable immediate or creep settlement.

[TOP]

4.7 Insect Infestation

EPS geofoam is non-nutritive to any living organism (Horvath 1999a). There-fore there is no potential that EPS placed on or in the ground will be consumed as a food source. On the other hand insects sometimes nest in foam. Carpenter ants and termites have been encountered around wood framed residential structures. EPS geo-foam used as thermal insulation is likely to be attacked by insects such as termites and while tunneling through or nesting on their way to wood structural elements. Projects located far from the existence of wood structural elements such as road insulation or Embankment fills have no known evidence of insect damage. Appropriate protection methods need to be determined based on project location and situation. Consultation with EPS geofoam manufacturers can result in solutions to avoid insect infestation such as utilizing additives to geofoam blocks while processing to make them resistant to such attacks (R-Control, 1999b, 1999d).

[TOP]

4.8 Moisture Absorption

As was mentioned earlier EPS geofoam tends to absorb a little amount of moisture over time. Practically less than 10% by volume is absorbed in the life of ser-vice for geofoam. A 10% value will increase the density of geofoam to approximately 100 kg/m3 for type VIII geofoam. In applications when geofoam is utilized as light-weight fill. It is important to take into account the increased density, as this will be on the conservative design side. It’s important to note that some degradation in thermal properties may occur with increased moisture absorption. (Negussey, 1997).

[TOP]

4.9 Gaps Between Blocks

During construction and while placing EPS geofoam blocks strong attention should be made to accurately place the blocks with the minimum amount of gaps between individual EPS geofoam blocks and successive EPS geofoam layers. The existence of gaps will create stress concentration in the area of contacts. Excessive immediate strains and large creep strains will result from such gaps. The resulting overall settlement may result in unsatisfactory situations such as decreasing the lifetime of a pavement structure (Negussey and Elragi, 2000a).

[TOP]

4.10 Immediate Deformation

The elastic modulus of EPS geofoam is small compared to the elastic modulus of some other engineering materials such as concrete, wood and steel. EPS geofoam working strains are normally between 0.4% and 1% strain. A 0.5% immediate strain was recorded for a 9.12 m EPS height backfill (Cho, et al., 1996). This 0.5% is considered both elastic strain and gap closing. For high fill of EPS geofoam, the immediate elastic deformation may be a considerable. Some projects have utilized more than 10m-fill height of EPS geofoam. In such cases, more than 0.1m of immediate deformation was measured. The designer has to take that in to account in calculations (Negussey and Elragi, 2000a).

[TOP]

4.11 Connections with Structural and Architectural Elements

According to the design of a project EPS geofoam may experience large settlements from either gap closure, immediate elastic deformations or creep deformations as previously mentioned. Adjacent structural or architectural connections such as fascia walls, which may be attached to an EPS geofoam embankment, e.g. may be damaged due to differential movement. The designer has to be aware of such a problem and detailed drawings have to provide solutions to such cases. Slotted or pinned connections may be a solution, where deformation can take place in the EPS geofoam structure without damaging the adjacent connections and elements (Negussey and Elragi, 2000a).

[TOP]

4.12 Sliding

The density of EPS geofoam is very low. Hence during construction the whole EPS geofoam mass can slide under the effect of any lateral force, if nothing is placed on top of it to increase the frictional normal force. This situation can happen in the case of backfilling while the foam layers are still uncovered. The construction sequence should take this into consideration (Negussey and Elragi, 2000a).

[TOP]

4.13 Blocks Alignment

To increase the integrity of the geofoam mass, blocks have to be aligned in such a way that the vertical and horizontal joints between the blocks must not be continuous. Traditionally if multiple layers of geofoam are required, successive block layers are placed perpendicular to the previous layer. Also offset vertical block joints between layers (Negussey and Elragi, 2000a).

[TOP]

4.14 Transition Zones

For designs that incorporate both expanded polystyrene fill and traditional fill materials, differential settlement can be a problem where the two types of constructions are transitioned (Thompsett, et. al., 1995). This can be overcome by reducing the number of EPS geofoam layers, layer by layer along the length of construction. The length of this transition zone depends on the structure and the calculated settlement rate. This type of construction detail is commonly used for geofoam approach ramps to bridges.

5. Standards and Design Manuals

Table 2-11 shows some of the existing ASTM standards for evaluation of rigid cellular plastic foam properties. Four committees have control and influence on foam standards: Committee C-16 (Thermal Insulation), Committee D-20 (Plastics), Committee E-5 (Fire Standards) and Committee F-7 (Aerospace Industry Methods). More specific standards for geofoam are now under development by a newly formed "Geofoam Task Group" within ASTM Committee D-35. Out side the United States such as in Norway, NRRL (1992) show example of the procedure to be followed when testing expanded polystyrene for use in road embankments.

In the United States, there are EPS geofoam design manuals and EPS applications manuals. Horvath (1995b, 1998a) and Negussey (1997), present analysis and design guidelines for some geofoam applications. Similarly some EPS geofoam products have their own conceptual guides to analysis and design (GeoTech, 1998). From other countries, the Public Works Research Institute of Ministry of Construction, and Construction Project Consultant, Inc., (1992), Duškov, M., (1999) and Draft European Standards, (1998) present specifications or design manuals for expanded polystyrene.

Table 2-11 Selected ASTM Standards Applicable to Geofoam (after Negussey 1997)

Property	Standard	Committee #	Committee	Volume
Density	C-303	C-16.32	Insulation	4.06
Density	D-1622	D-20.22	Plastics	8.01
Thermal Conductivity	C-177	C-16.30	Insulation	4.06
Thermal Conductivity	C-518	C-16.30	Insulation	4.06
Compressibility	D-1621	D-20.22	Plastics	8.01
Flexural	C-203	C-16.32	Insulation	4.06
Tensile/Adhesion	D-1623	D-20.22	Plastics	8.01
Vapor Transmission	E-96	C-16.33	Insulation	4.06
Absorption	C-272	C-16.33	Insulation	4.06
Thermal Expansion	D-696	D-20.30	Plastics	8.01
Combustion; O2 Index	D-2863	D-20.30	Plastics	8.02

Insulation Specification	C-578	C-16.22	Insulation	4.06

Tsukamoto (1996) presented guidelines for constructions using EPS geofoam in slope stability and widening embankments applications. In 1995 the highway and traffic research society (FGSV) in Germany published the code of practice for the use of rigid EPS foams in the construction of road embankments. Beinbrech (1996) presented the best summary and recommendations.

6. Applications

6.1 Introduction

Horvath (1992) classified the applications utilizing EPS geofoam blocks by "their function". The four functions of EPS geofoam are lightweight fill, compressible inclusion, thermal insulation and small amplitude wave damping (ground vibration and acoustic). Horvath (1999b) add two more functions, drainage and structural. Another way to classify the applications is by engineering properties.

Five EPS geofoam properties appear to be very useful when utilizing EPS geofoam. These properties are: density, compressibility, thermal resistance, vibration damping and self-supporting nature of the EPS geofoam. These properties can solve many important engineering problems such as settlement problems, slope stability problems and bearing capacity problems. Conventional geotechnical solutions for such problems (e.g., deep foundations, sheet piles, retaining walls or other solutions) may be economically unfeasible. Table 2-12 shows selected engineering applications and the corresponding EPS geofoam function to be utilized. The following concepts and schematic design figures are proposed to illustrate some of these applications and examples of actual installations.

Table 2-12 Selected EPS Geofoam Applications

Application	Density	Compres-	Damping	Insulation	Cohesion

		sibility			
Slope Stabilization					
Embankments					
Bridge Approaches					
Earth Retaining Structures					
Bridge Abutments					
Buried Pipes					
Flood Control Levees					
Landscape Architectural					
Plaza Decks					
Basement Insulation					
Railways					

[TOP]

6.2 Slope Stabilization

Geofoam can be utilized in slope stabilization as shown in figure 2-9. To re-duce the tendency of failure of portion of the soil the crest of the slope is excavated and replaced by the super lightweight material EPS geofoam. Alternative solutions may require the changing of the slope inclination, buttressing the toe of the embankment using soil nailing or any other solution that may affect the geometry of the slope or the surrounding land or may not be feasible for many reasons.

In Japan a road embankment on a steep hillside was constructed using 1834 cubic meter of EPS geofoam. The EPS was utilized in a section of the road of about 104 m long (Suzuki et. al., 1996). The total cost of stabilization efforts was reduced as a result of adopting EPS. The construction time was also reduced in this project.

In Colorado, a 61m section of US highway 160 failed and caused the east-bound lane of this heavily traveled highway to close. A 648 cubic meters of EPS geofoam was utilized as fill in the crest of the slope to increase the factor of safety. The total cost of the project was $160,000, which was much less than the $1,000,000 cost of the alternative a retaining wall solution (Yeh and Gilmore, 1989).

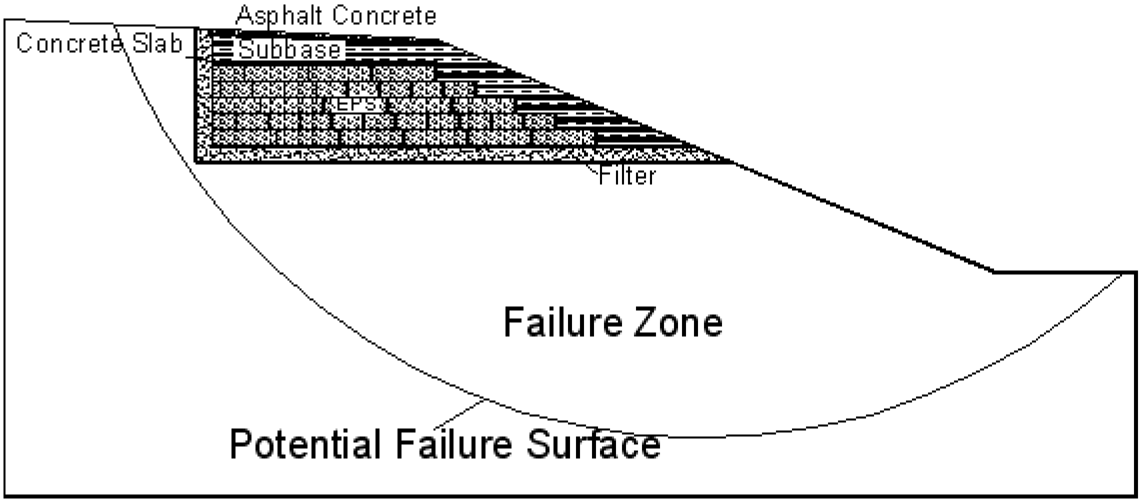

Figure 2-9 Slope Stabilization Utilizing EPS Geofoam

In 1994 EPS geofoam was utilized for construction of a 21m embankment for an emergency truck escape ramp in Hawaii (Mimura and Kimura, 1995). The project was originally designed as an earth fill embankment with extensive geotextile reinforcement and wick drains to overcome stability problems and to reduce settlement. During construction, actual subsurface conditions were observed to be worse than expected. About 13,500 cubic meters of geofoam was used as lightweight fill to replace the earthen embankment.

A segment of County Truck Highway "A" located within a remote region in Wisconsin required continuous maintenance of the pavement due to a creep landslide (Reuter, 2000). The slope was 4.9m height at a 14 degree angle with the horizontal. A well-defined scarp developed within the asphalt despite the frequent patching of the pavement. Instrumentation helped in defining a deep-seated slip surface, which was slowly creeping down slope. Replacing the soil in the slide mass with compacted granular fill was rejected as a solution. As this approach would have meant temporarily closing the highway and excavation would have to extend below the water table in order to reach the deep sliding surface. It was decided to reduce the up slope driving force of the slide by excavating the embankment fill from the head of the slide and replacing it with lightweight fill polystyrene geofoam. Both Extruded Polystyrene and type II Expanded Polystyrene were used. To reach a factor of safety of 1.5 three layers of 0.81m thick geofoam each of 7.3m width was required.

In New York, expanded polystyrene geofoam blocks were utilized to treat an unstable roadway embankment slope involving clayey soil (Jutkofsky, et al., 2000). The selection of the geofoam treatment was based upon its constructability and mini-mal impact to both the environment and adjacent homeowners. Potential traffic safety problems associated with differential icing of roadways from the presence of geofoam blocks beneath pavements was minimized by using a thicker subbase layer in the geo-foam treated area. Data from an instrumentation program consisting of an inclinometer, extensometers and thermistors showed that the use of geofoam to reduce the driving force of a slope has stabilized the slope. No slope movement has occurred since the treatment was completed in 1996. More details on this case history are shown in chapter 4.

[TOP]

6.3 Reducing Lateral Pressure on Retaining Structures

EPS Geofoam can be placed between the retaining structure and the soil. Two main geofoam configurations are used as shown in figure 2-10. Differences between the two configurations are shown in chapter 6.

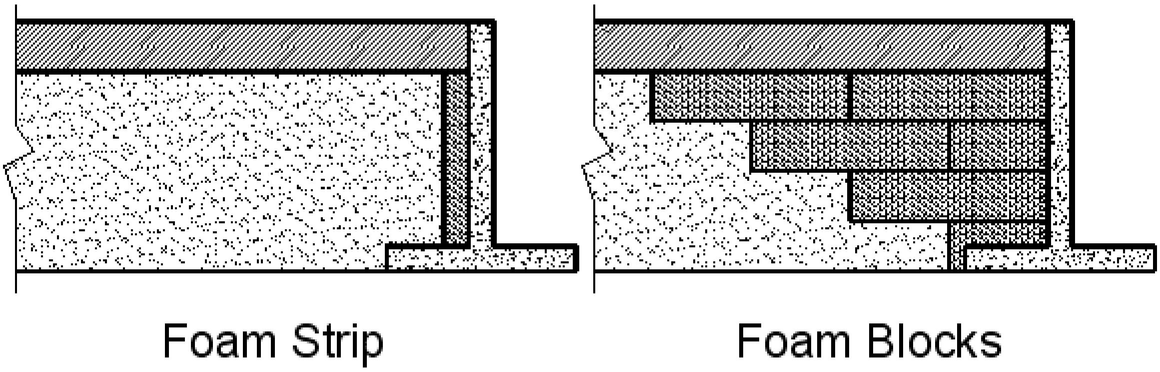

Figure 2-10 Lateral Stress Reduction Utilizing EPS Geofoam

To reduce the static earth pressure acting behind a 14 m height abutment during and after construction of the backfill and the dynamic earth pressure due to earth-quakes and traffic loads after the construction; 0.5m strip of EPS geofoam was utilized as a cushion between the abutment and the backfill (Matsuda et. al., 1996). Finite element analysis, showed 85% reduction in the overall bending moment during rolling compaction when utilizing 12kg/m3 EPS geofoam. The 20kg/m3 geofoam showed 70% reduction compared with the case of no geofoam. The geofoam blocks configuration is utilized in portions of the basement wall in the Syracuse Mall (Sun, 1997). Results are shown in chapter 6.

[TOP]

6.4 Embankment Fill to Reduce Settlement

Figure 2-11 shows a situation of constructing a new embankment on soft ground. In such a case large settlement can be experienced under the load of the conventional embankment fill. Also, soil may take years to achieve its full settlement. Any existing utility line will be damaged if it is not designed for large deflections. By excavating part of the soil and placing geofoam to reach the required embankment's height and placing the pavement structure on the top of the geofoam a fast lightweight solution is achieved. Zero net stress increase is reached if the amount of excavated soil is equal to the weight of the pavement structure.

In the city of Issaquah, Washington (Cole, 2000) predicted settlement from conventional bridge approach fill of 0.3~ 0.54m. Approximately 1.25-cm settlement was reported after 180 days of utilizing 1822 cubic meters of EPS geofoam as fill material.

In Salt Lake City, Utah, EPS geofoam was utilized as an embankment fill. The primary use of geofoam is to minimize settlement impacts to buried utility lines. These utilities were required to be in service during construction. In areas where conventional borrow is used for backfill, expected construction settlement of the clayey foundation soils is about 0.5 to 1.0 meter (UDOT, 1998). This large amount of settlement exceeds almost all strain tolerance for buried utilities. EPS geofoam reduced the settlement. More details on this case history are shown in chapter 5.

EPS was utilized as backfill of a bridge abutment to reduce the settlement of the approach (Ishihara, et al., 1996a). It was essential to complete the fill work in a short time, because further settlement may have occurred had conventional fill been used. A 1040 cubic meter volume of EPS geofoam was used with a height of 9m. Work was completed in the required time with minimum settlement.

A 139m section of a road in Solbotmoan, Norway experienced significant settlement. The road was flooded twice each year (Rygg and Sorlie, 1981). Each addition of new materials to compensate for settlement would cause a further settlement. The rate of settlement had been large and increasing. The subgrade condition was 5m of peat. Below the peat there is 13m of soft silty clay. In 1975 the road embankment was excavated and bark was added up to the ground water level. Foam of height 1.2m to 2.0m was utilized on the top of the bark. For the following five years (until the time of publishing the paper) the road has been subjected to traffic. The total settlement varies between 0 and 80mm with a reduced rate of settlement.

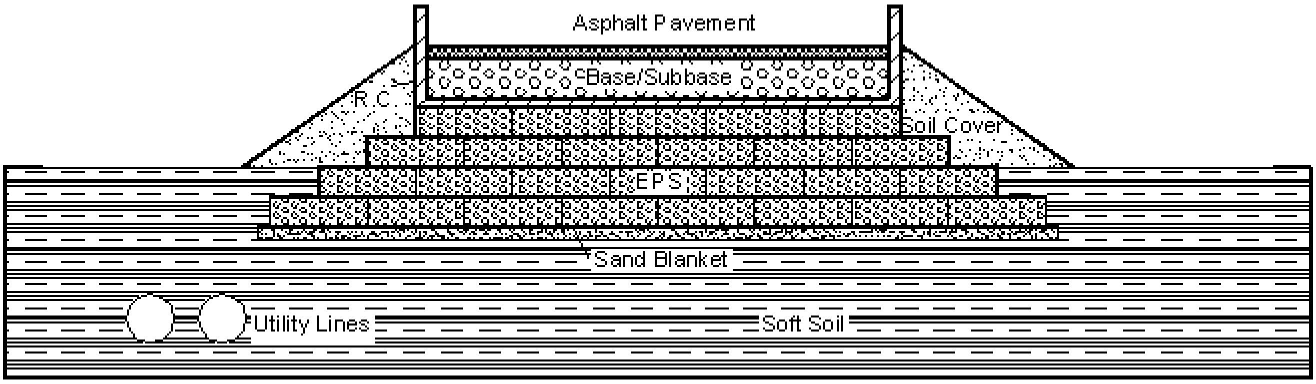

Figure 2-11 Settlement Reduction on Utility Pipes Utilizing EPS Geofoam

[TOP]

6.5 Widening Embankments

Another embankment application is shown in figure 2-12. For a limited right of way, widening of embankments can be easily achieved utilizing EPS geofoam. As shown in the figure the self-standing property will reduce the additional space without the need of a retaining wall. However a fascia wall will be required to protect the geo-foam face.

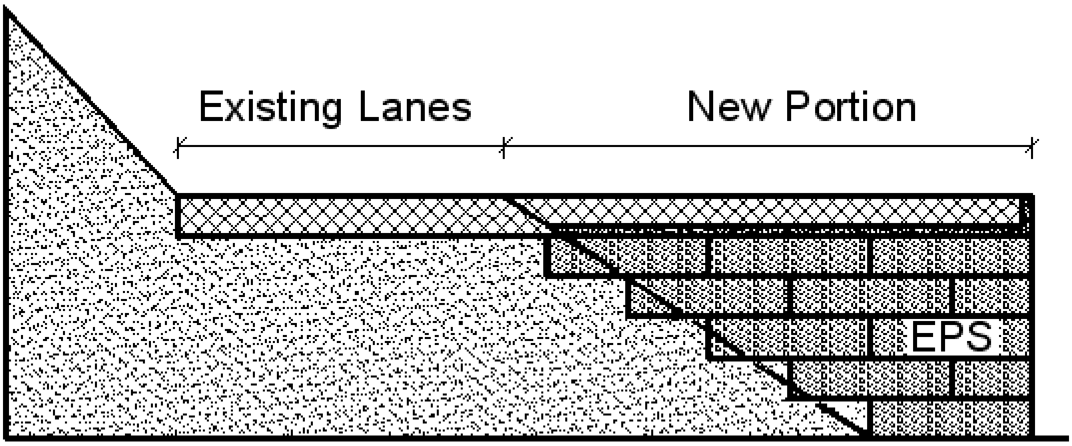

Figure 2-12 Widening Embankments Utilizing EPS Geofoam

[TOP]

6.6 Stress Reduction on Buried Pipes

The compressible inclusion of EPS geofoam may be utilized to reduce loading above rigid conduits (Vaslestad, 1990). Virtually all conduits can be designed to benefit from the effect of soil arching (GeoTech, 1999c). Figure 2-13 shows conduits of different cross sections and how thin layers of EPS geofoam are placed some 0.5m above the rigid conduit. The main point is to mobilize arch action for the soil above the foam.

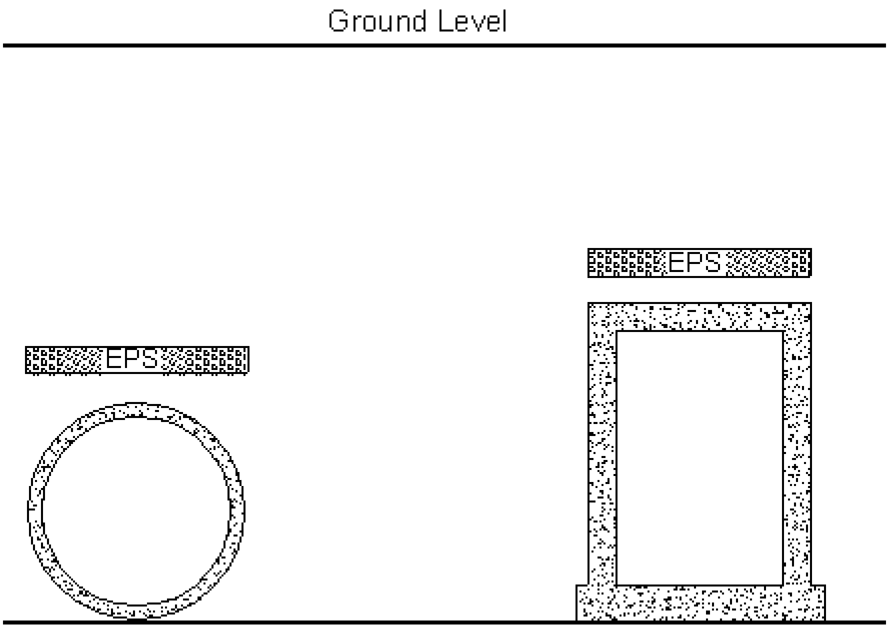

Figure 2-13 Stress Reduction on Pipes Utilizing EPS Geofoam

Vaslestad, et al., (1993) reported the results of three tests for concrete culverts with EPS geofoam placed above them. In the first test the instrumented culvert was a 1.95m diameter pipe beneath a 14m high rock fill embankment. In the second test a 1.71m diameter pipe was used beneath a 15m high rock fill. In the third test a 2 m width box culvert was used beneath

11m of silty clay. Reduction of the vertical stresses between 30% and 50% of the overburden stresses was reported in the three tests. Strains in the EPS geofoam were 27 to 42 percent. Use of the compressible inclusion above rigid culverts in Norway has resulted in cost reductions of the order of 30% and has made possible the use of concrete pipes beneath high fills.

[TOP]

6.7 Decreasing Foundations Depth in Cold Regions

Foundations in cold climate areas are usually placed below the anticipated frost penetration depths. Basements or crawl spaces are constructed to meet the required foundation depth. That means extra floor level to construct and more time and more money to spend. Figure 2-14 shows an alternative solution where EPS geofoam strips are placed in such a way to insulate the soil beneath in contact with the foundation. This insulation system has to surround the building. The wing part of the insulation is utilized to reduce the excavation depth for placing the geofoam (Negussey, 1997).

In 1990, a 180 square meter addition to an aircraft control tower was constructed at Galena, Alaska (Danyluk, 1997). Because of limited resources, a shallow insulated foundation was specified instead of traditional foundation. In other words, a 0.5m deep foundation was constructed instead of one at 3.6m depth. Insulation as in figure 2-14 was utilized. The wing side was 14.8 m length at a depth of 0.65m. The insulation utilizes heat from the building and surrounding soil, redirects it to the area around the foundation and thus reduces the frost penetration. Instrumentation was utilized to measure the temperature at various points. Results show the effectiveness of the insulation system, which was geofoam but not EPS.

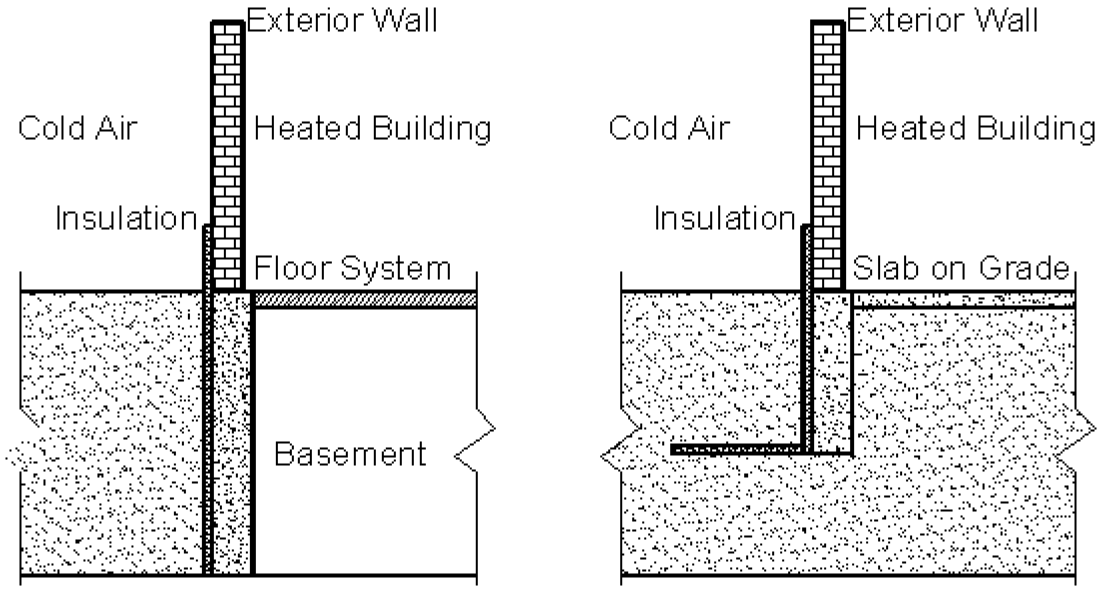

Figure 2-14 Building Insulation & Shallower Foundations Utilizing EPS Geofoam

[TOP]

6.8 Pavement and Railway Insulation

The cycle of winter freezing and spring thawing of soil can affect transportation facilities such as roads and railroads. This is because the ground surface heaves as a result of freezing and settles upon thawing. Thus the lifetime of the pavement section is reduced. The subgrade is weakened and this could be of safety concern for road, railways or airfields. The cross section in figure 2-15 shows the placement of EPS geofoam layers below a pavement section.

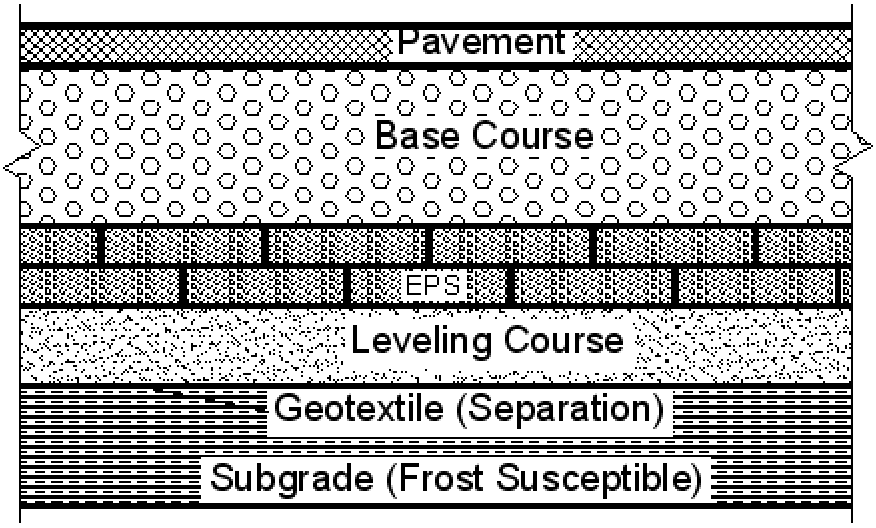

Figure 2-15 Pavement Insulation Utilizing EPS Geofoam

[TOP]

6.9 Bridge Support

Another application (Frydenlund and Aab?e, 1996) of EPS has been as a sup-port foundation for bridge abutments in Norway, as shown in figure 2-16. Higher strength EPS geofoam is required with some resultant increase in cost per unit volume. This solution has been used for both single span bridges with up to 5m high EPS geofoam fill and also for multi span bridges. In all cases the EPS material has per-formed satisfactorily with no adverse effects on the bridge.

An example of such application is Lakkeberg Bridge in Norway. It is a single lane steel bridge with one 36.8m span crossing road E6 close to the Swedish border. The bridge was built in 1989 directly on top of EPS fills (height equals to 4.5m and 5m on both sides) as an alternative to placing the bridge on pile foundations. After 10 years of operation field records show that the average deformation is slightly over 1% of the total fill height (Aab?e, 2000).

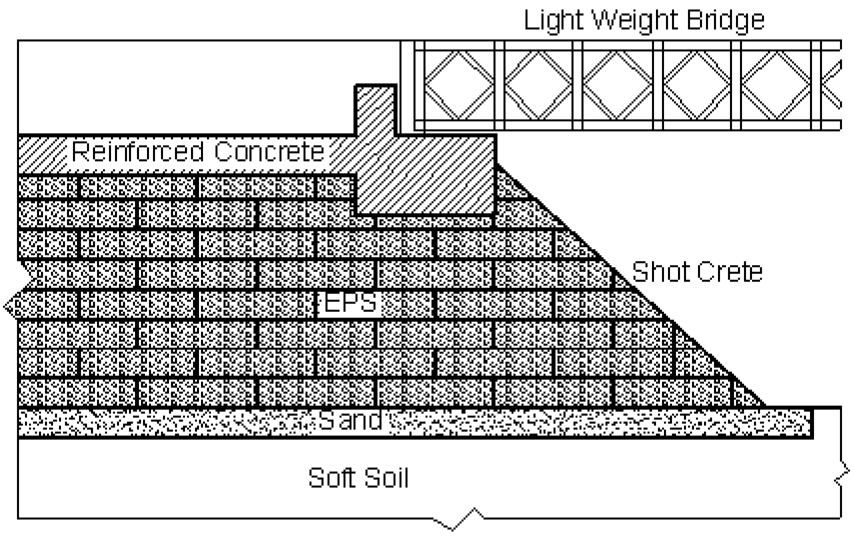

Figure 2-16 EPS Geofoam Bridge Abutments

[TOP]

6.10 Compressible Inclusion Against Expansive Soil

Another application for utilizing EPS geofoam is to use it as a compressible inclusion adjacent to a structural element when it is in contact with expansive soil (Horvath 1996). Expansive soils or swelling soils are those soils that have the tendency to increase in volume when water is available and to decrease in volume if water is removed (Ranjan and Rao, 1993). Figure 2-17 shows part of a structure on pile foundations. The compressible inclusion EPS geofoam is utilized below the structural slab. Upon soil heave EPS geofoam compresses according to its own stress strain relation as shown in figure 2-3. The stresses on the structural slab will be limited to a specified value depending on the density of the EPS geofoam. The geofoam will also act as a form for the slab.

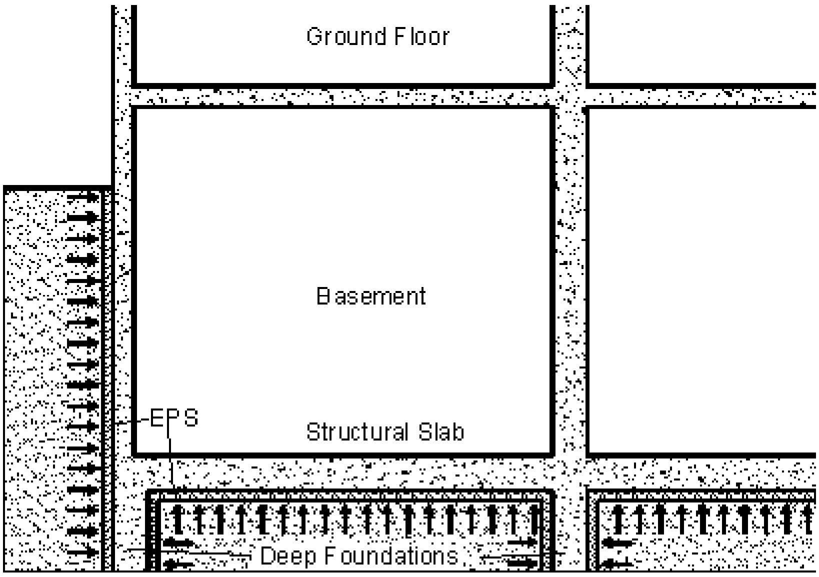

Figure 2-17 Soil Expansion Stress Reduction Utilizing EPS Geofoam

On the Channel Tunnel project in England EPS geofoam was utilized as a compressible inclusion (Horvath, 1995a). The purpose of utilizing EPS geofoam was to reduce heave pressure below the floor system of the channel tunnel.

[TOP]

6.11 Reducing Differential Settlement

In Syracuse, New York, 28,000 cubic meters of EPS geofoam are placed next to outside perimeter of the basement of the Carousel Mall (Stewart, et al, 1994). The purpose of utilizing the rectangular cross section collar of EPS geofoam is to reduce the settlement of the edge of the structure. Since it was necessary to raise grades up to 2.7m around the edge of the 65,000 square meter load compensated mat foundation structure over a deep soft soil, there would be a significant and abrupt changes in stress at the subgrade level at the mat edge had traditional fill is used.

[TOP]

6.12 Concrete Forms

EPS was utilized as buried form for a large concrete abutment (Yoshihara and Kawasaki, 1996). The traditional and alternative method to build such abutment is to use a sand form and the concrete was than placed. Finally the sand has to be with-drawn using a sand pump and the hole provided in the footing was filled with concrete to complete the structure. Saving construction time as a result of reduced material and labor required for form was one of the advantages of using geofoam instead of sand or wood forms.

Another application for EPS as a concrete form is reported by Miyamoto, et., al., 1996. Continuous footings made of EPS geofoam forms are studied. A shortened construction period, heat retention improvement and work saving was achieved.

[TOP]

6.13 Reducing Lateral Soil Flow on Existing Deep Foundations

Another application is reported by Wano, et al., (1996). A bridge abutment was constructed on soft ground utilizing EPS. The purpose is to reduce the lateral soil flow and the horizontal movement of the bridge substructure. Field observation over a considerable period of time showed that the horizontal movement of the bridge sub-structure had essentially stopped and was stable.

In Japan, 11,000 cubic meter of EPS geofoam are utilized as a lightweight fill nearby a pile foundation (Ishihara et al., 1996b). The soil layer to a depth of 30m was very soft. The 0.6m diameter piles with a 55m length are likely to be severely dam-aged resulting from lateral flow caused by the weak subsoil upon utilizing conventional fill.

A 2000 cubic meter of EPS geofoam was utilized in a similar application on a soft ground. EPS backfilling of the abutment on the Moriyama tollgate side of Grand Lake Biwa Bridge is utilized to reduce lateral displacement on pile foundations (Nishimura, 1996).

[TOP]

6.14 Stress Reduction on Buried Structures

In Tokyo, Japan, a pedestrian 150m long and 5m width access link was constructed to span an elevation difference of 8m (Nishizawa, 1996). The access link exists over an existing structure, which restricted the load both during and after construction. Disturbance to local residents had to be taken into account by reducing both the construction time and the noise during construction. 1430 cubic meter of EPS geofoam was utilized in this project.

[TOP]

6.15 Shallow Foundations

EPS geofoam was utilized in the foundations of an emergency staircase of an overpass (Ojima, et al., 1996). The ground at the site contains a layer of soft clay. Deep foundation was restricted by the existence of a four-meter diameter sewer pipe below the footing of the staircase. Load compensated foundation was the solution by utilizing 3m height of foam directly below the footing. No extra settlement occurred of the utility line occurred.

[TOP]

6.16 Load Bearing Walls

EPS geofoam is utilized in manufacturing load-bearing walls. EPS is used as the core of panels with oriented strand boards being the face of the panel (R-control, 1999c).

[TOP]

6.17 Frost Shielding for Buried Conduits

In climates that experience freezing temperatures, water and sewer pipes are normally buried below the depth of maximum frost. A shallower trench is desirable in many situations. Frost shielding methodology is the technique of placing insulation in some configuration around a pipe to protect the pipe from freezing (Coutermarsh and Carbee, 1998, Coutermarsh, 1997). Savings in time and money afforded by de-creased burial depth balance the increased cost of insulation and the time to install it.

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