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Reducing Dynamic Lateral Loads on Earth Retaining Structures Utilizing EPS Geofoam

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ABSTRACT. Expanded polystyrene (EPS) geofoam is a lightweight material that has been used in engineering applications long time ago. Its density is about a hundredth of that of normal weight soil. Its thermal insulation properties are excellent with stiffness and compression strength comparable to medium clay. It has been utilized in several engineering applications such as in reducing settlement below embankments, sound and vibration damping, reducing lateral pressure on substructures, reducing stresses on rigid buried conduits and several others.

A new application for EPS in civil engineering is provided in the study as an example for the potential use of EPS in the civil engineering profession. Reducing the dynamic loads on earth retaining structures utilizing EPS-Geofoam is analyzed.

The results of this study point towards the main conclusion that EPS geofoam is the future material of promise in various civil engineering applications. SABIC polystyrene has comparable densities and stiffness such that it can be used in all such applications.

Keywords: EPS, Geofoam, Applications, Civil, and Engineering.

1. Introduction

Expanded Polystyrene, EPS, geofoam is a plastic/polymeric material. Plastic materials are commonly derived from coal or oil refining. Plastics can be molded by the influence of heat and pressure. Commonly used EPS geofoam has a density of 15- 30 kg/m^3 with stiffness and strength comparable to medium clay. It is self-supporting when stacked and has good heat insulation properties.

Introduced in the 1950s (BASF Corp., 1997) Expanded Polystyrene, EPS, geofoam has played an innovative role in solving a number of engineering problems as a lightweight construction material. In the geotechnical-engineering field, EPS geofoam is used as backfill to reduce lateral pressure behind retaining structures. EPS geofoam reduces settlement experienced by utility lines when used in constructing embankments. Bridge approaches fills experience less settlement when built of EPS geofoam with reduced differential settlement between bridge deck and approach fill (bridge bump). Stabilization of slopes with geofoam can maintain original slope angle, and reduces environmental damage on the site while increasing the factor of safety of the slope at the same time.

Use of EPS geofoam compressible inclusion can reduce the pressures induced by seismic loading. The technique of compressible inclusion can also be used for soil interaction problems. Heave problems are common and economically important in those parts of the world with arid regions, e.g. Egypt and Southwestern United States (Lambe & Whitman, 1969) as well as the kingdom of Saudi Arabia (Saudi Building Code SBC 303, 2006). Creating arch action above buried utility line by using compressible inclusion reduces stresses on the utility lines hence permitting the use of rigid concrete pipes beneath high fills.

The study presents an over view about this important material and its potential applications in the civil engineering profession. Discussion about the engineering properties of the material as well as its behavior under loading is presented. Finally the results and discussion of civil engineering problems where EPS geofoam shows to be good alternative solutions compared to the typical one are presented. This include; reducing lateral pressure behind retaining structures by using geofoam, slope stabilization by using geofoam, and reducing the vertical pressure on utility lines by using geofoam

2. Literature Review

Expanded Polystyrene, EPS, geofoam is a super-lightweight, closed cell, rigid, plastic foam, which is invented in 1950 (BASF, 1997). The EPS geofoam light unit weight puts it in a separate category compared to other types of engineering lightweight materials as shown in Table (1). The literature review covers two titles; review of the EPS geofoam physical/engineering properties and review of the engineering applications utilizing the EPS geofoam.

Table (1). Types of Lightweight Materials (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

3. Material Properties

EPS geofoam is a lightweight material with a good insulation and energy absorption characteristics. On the other hand, its strength and stiffness are comparable to some types of soils. EPS densities for practical civil applications range between 11 and 30 kg/m^3. 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. Table (2) shows 5 EPS types, which are categorized by ASTM C 578-95.

Figure (1) 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.

Table (2). ASTM C 578-95 EPS Densities

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

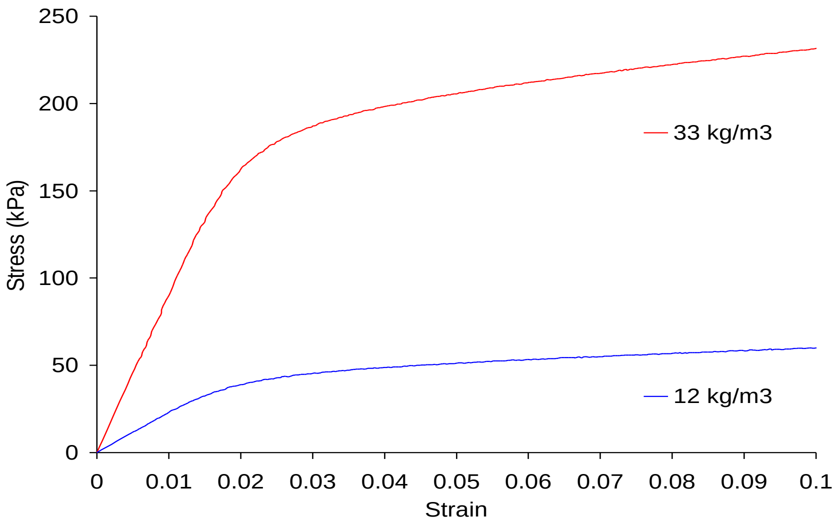

Fig. (1). EPS Uniaxial Compression Stress Strain Curves (after Negussey and Elragi, 2000)

There is no defined shear rupture for EPS geofoam under compression. 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 3 shows the compressive strength of EPS geofoam as given by ASTM C578-95.

Table (3). ASTM C 578-95 EPS Compressive Strength

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

Figure (1) shows that 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 (1). 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/m^3 density the initial modulus ranges between 5 Mpa and 7.75 Mpa, which means a 55% difference. The relation is linear for some researchers (Horvath, 1995 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. Duskov (1997) after testing 20kg/m^3 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. Poisson’s ratio value range between 0.05 and 0.5 are found in the literature for EPS geofoam. 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). The compression behavior of EPS geofoam is strain rate dependent (Negussey, 1997). Higher strain rates result in higher initial modulus and higher compression strength.

EPS geofoam may experience cyclic loading in a number of engineering applications; such as in traffic loading and earthquake loading. The majority of laboratory testing and field observations suggest that the cyclic load behavior of block molded EPS geofoam 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 that 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.

Tensile strength of EPS material can be an indication of the quality of fusion of the pre-puffs and any recycled EPS geofoam used in the process (Horvath, 1995). The literature shows that its tensile strength increases with the density (ElRagi et al., 2000). The material fails in tension as a crack on the tension side appears at the moment of failure and the flexural strength increases with density of the material (ElRagi et al. 2000). EPS geofoam is susceptible to time dependent creep deformation when a constant stress level is applied. Creep deformations decrease with density increase (Sun, 1997).

Sheeley (2000) showed that the effect of density on interface strength of geofoam was negligible. Values of both peak and residual friction factor are shown in Table (4). 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.

Table (4). EPS Geofoam Interface Friction Factors (Sheeley, 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

The water absorption of expanded polystyrene is low. Although water absorption decreases as density increases as shown in table (5), fusion is the most important factor influencing the moisture resistance of the EPS geofoam.

Table (5). % Volume of Water Absorption (German Specifications, 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

3.1 Engineering Applications

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 (Aaboe, 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 3.0 m thick layer of peat above 10.0 m 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).

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 (Newman, 2009).

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 15.0 m 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). Experience in Japan with EPS geofoam showed that EPS geofoam structures performed well under seismic loading as well as under static loading. During the years of 1993 to 1995 strong earthquakes occurred in various parts in Japan. Hotta, et al., (1996) reported 5 earthquakes of magnitudes range 6.6 to 8.1. Although some damage occurred to EPS sites, Hotta et al., considered that EPS embankments were highly stable during earthquakes.

4. Methodology

4.1 Reducing Dynamic Loads on Retaining Structures

Another application is the use of EPS geofoam for reducing the induced seismic loads against rigid non-yielding retaining structures. EPS geofoam seismic buffers can be used to reduce earthquake-induced loads acting on rigid retaining wall structures. The numerical simulations were carried out using the FLAC code software. The influence of the buffer zone was examined by computing the natural frequency of the retaining wall for the various examined cases. In general this is determined through a numerical study in which an investigation of the influence of using seismic buffer zone made of EPS geofoam on the natural periods of retaining walls is conducted. A model of a retaining wall with a seismic buffer zone made of EPS geofoam is developed and several cases were analyzed that took into consideration the position and thickness of the buffer zone and on the seismic performance of the retaining wall.

4.2 Numerical Analysis

A numerical model utilizing *FLAC* software is established with the cohesion, friction, dilation and tensile strength of the Mohr-Coulomb model those properties are assumed to remain constant. The reinforced retaining wall model with the assumed dimensions is shown in Figure (2).

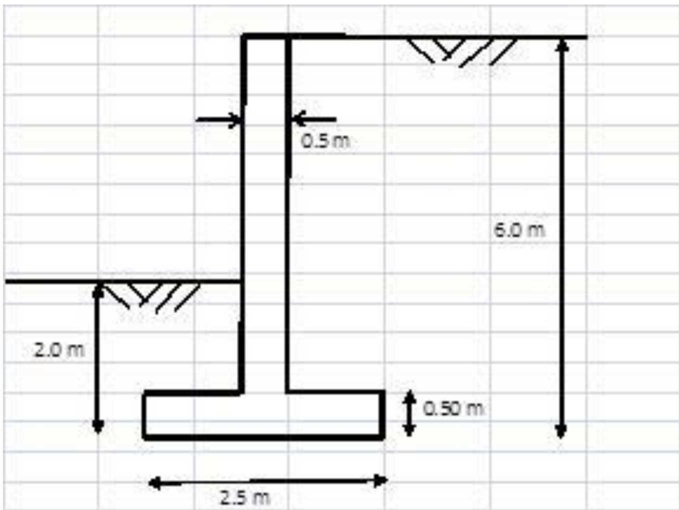

Fig. (2). Wall configuration considered for the study

The soil material is simulated as a strain-softening soil; the cohesion weakens as a function of plastic strain.

Mesh 0.1m

Total length=17m

Depth 6m

Wall 2.5m x0.5 base

Wall web 0.5m x5.5m

Total back fill= 6m

Front fill 2m

E-modulus of concrete = 2xe10   p-ratio = 0.15

E-modulus of foam = 5xe6   p-ratio = 0.25

Shear modulus sand=400.0e6

Bulk modulus=666.67e6

Density=1700 kg/m^3

Friction angle = 40^o

Cohesion =1.0xe5

Concrete density = 2400 kN/m^3

Foam density = 20 kg/m^3

Three cases were analyzed to investigate the effect of using the EPS geofoam on reducing the seismic loads on the rigid non-yielding retaining structures.

5. Results and Discussion

The Figures (3) – (8) show the results from numerical analysis of the wall using computer software. The results are presented in the form of developed natural frequency of the wall in response to horizontal acceleration.

i. Using a 10cm-cushion in front of the wall

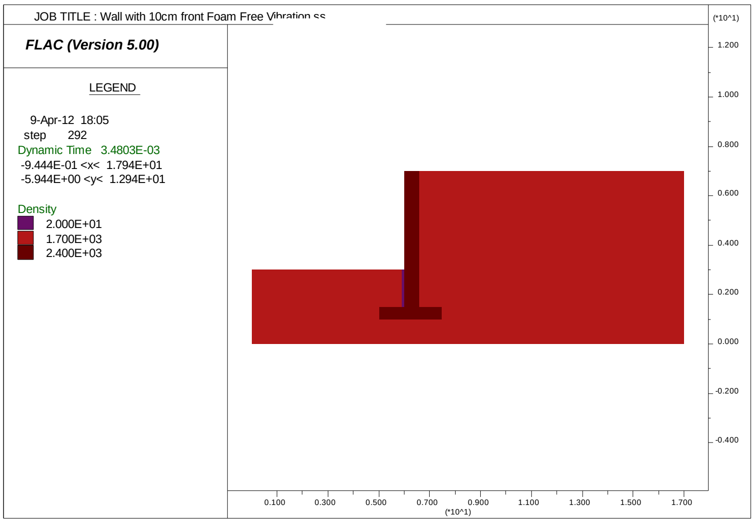

Fig. (3). Model of RW with the EPS front cushion

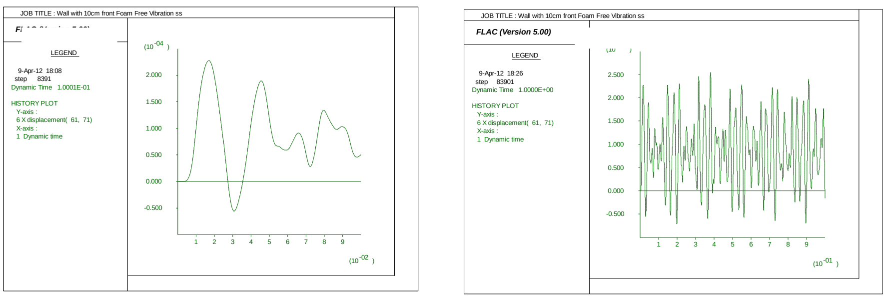

Fig. (4). Developed wall natural frequency without and with the cushion

ii. Using a 20cm-cushion in the backfill of the wall

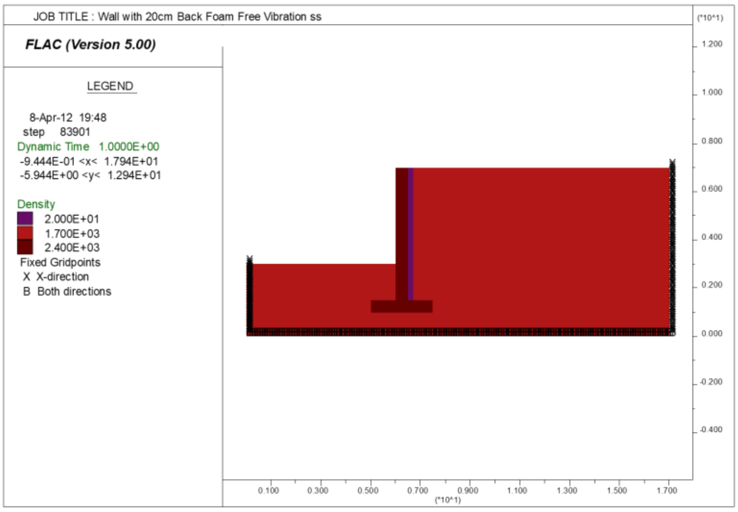

Fig. (5). Model of RW with the EPS back cushion

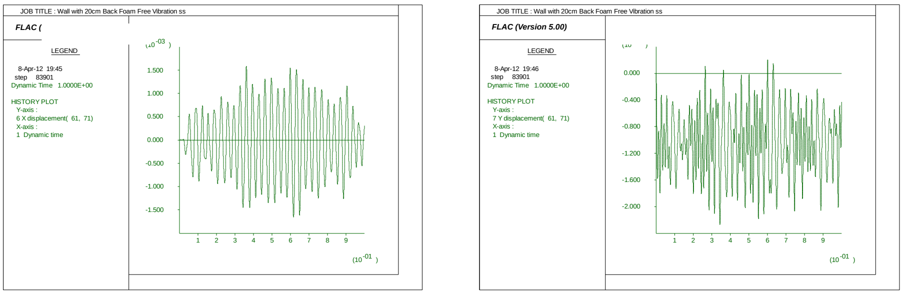

Fig. (6). Developed natural wall frequency without and with the cushion

iii. Using 10cm-double cushion in the wall

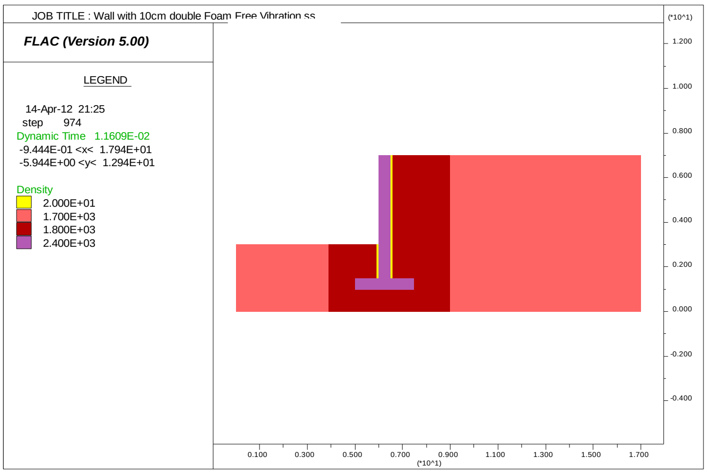

Fig. (7). Model of RW with the EPS front and back cushion

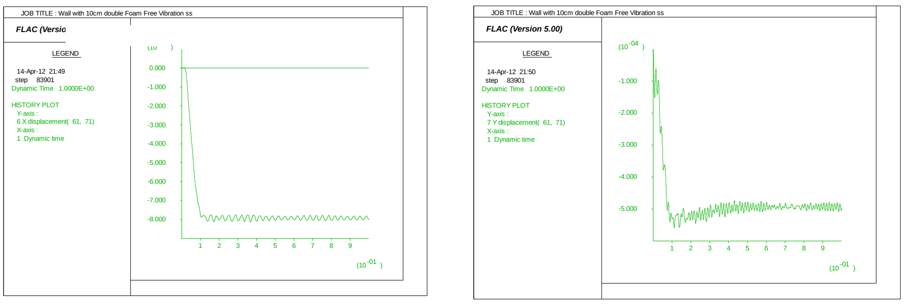

Fig. (8). Developed natural wall frequency without and with the cushions

The above shown results show that the existence of the foam cushion reduced the lateral dynamic pressure on the wall, hence reducing lateral displacement. The reduction of the value of displacement depends on the amount and position of the compressible inclusion

Another important result is that the fundamental natural period of the retaining wall varies depending on the position of the compressible cushion. Hence this can reduce the effect of the dynamic force by avoiding resonance between the structure and earthquakes.

6. Conclusions and Recommendations

The presented study shows that the light-weight material; EPS Geofoam has a great potential for use in the civil engineering profession which may be summarized as follows:

1- Expanded polystyrene (EPS) geofoam is a lightweight material that has been used in engineering applications long time ago

2- Expended polystyrene can be used as a compressible sheet for all types of underground structures against those faces in contact with earth.

3- Expanded polystyrene can change the overall fundamental frequency of contact structure hence reducing seismic effect

4- Expended polystyrene can reduce pressure by converting passive earth pressure into active earth pressure utilizing the compressibility of the polystyrene

5- Expended polystyrene can be utilized in several applications such as in reducing settlement below embankments, sound and vibration damping, reducing lateral pressure on substructures, reducing stresses on rigid buried conduits and several other related civil engineering applications

It is recommended that:

1- Extra studies have to be performed using the various types of SABIC polystyrene to refine the results.

2- Experimental testing has to be performed in order to better verify the results of the numerical studies.

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تخفيض الأحمال الديناميكية الجانبية على الحوائط الساندة باستخدام البوليسترين الجيوفوم

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ملخص البحث. مادة البوليستيرين جيوفوم هى مادة خفيفة الوزن تستخدم في التطبيقات الهندسية منذ وقت طويل. الجيوفوم له كثافته تبلغ حوالي واحد في المئة من تلك الخاصة بالتربة الطبيعية. خصائص العزل الحراري للجيوفوم ممتازة مع صلابة وقوة ضغط مماثلة للطين المتوسط. وقد استخدمت في العديد من التطبيقات الهندسية مثل في الحد من الهبوط أسفل السدود والجسور، الحد من تأثير الصوت والاهتزازات، والحد من الضغط على الأساسات، والحد من الضغوط على المنشأت المدفونة تحت الأرض والعديد غيرها.

تقدم الدراسة الحالية تطبيق أخر فى الهندسة المدنية والمتمثل في دراسة الاستخدام محتمل للجيوفوم فى تخفيض الأحمال الديناميكية الجانبية على الحوائط الساندة. أظهرت الدراسة نتائج مشجعة في هذا المجال من الناحية التحليلية والتي يمكن تدعيمها ببعض النتائج المعملية لنصل نحو الاستنتاج الرئيسي أن الجيوفوم الذى تنتجه شركة سابك السعودية يمكن أن يفيد في هذا المجال والعديد غيرها مما يشير إلى أن هذه المادة واعدة الاستخدام في مختلف التطبيقات الهندسية المدنية.