Available online at www.CivileJournal.org

**Civil Engineering Journal**

Vol. 3, No. 8, August, 2017


# Deformation Characteristics of Sand Geofoam Blocks using Large-Scale Oedometer Apparatus

Reza Jamshidi Chenari [a*], Alireza Firoozfar [b], Shekofeh Attari [c], Ardavan Izadi [d], Seyed Ebrahim Shafiei [e]

[a] *Associate Professor, Department of Civil Engineering, Faculty of Engineering, The University of Guilan.*

[b] *Assistant Professor, Department of Civil Engineering, Faculty of Engineering, The University of Zanjan.*

[c] *M.Sc. Student, Department of Civil Engineering, Faculty of Engineering, The University of Zanjan.*

[d] *Ph.D. Student, Department of Civil Engineering, Faculty of Engineering, The University of Guilan.*

[e] *M.Sc. Graduate, Department of Civil Engineering, Faculty of Pardis, The University of Guilan.*

Received 24 May 2017; Accepted 05 August 2017

**Abstract**

As a lightweight fill material, expanded polystyrene (EPS) geofoam block has been successfully utilized in geotechnical applications due to its low density and high compressive strength. Understanding the modulus of elasticity and compressibility coefficient of sand-EPS is an aspect that has not been fully understood which may have a significant effect on the design and construction of geotechnical structures. In this study, an attempt has been made to understand the behavior of deformation characteristic parameters of sand-geofoam block combinations with different patterns, using a newly designed and fabricated large-scale oedometer apparatus. The influence of both different combinations of sand-EPS geofoam and relative densities of soil, on the stress-strain behavior and coefficient of volume compressibility under controlled conditions, are experimentally studied. Specimens of EPS geofoam with a density of 8 kg/m3 were tested in relative densities of 35% and 70% of sand under six different overburden pressures of 50 kPa, 100 kPa, 150 kPa, 200 kPa, 250 kPa, and 300 kPa. From the experimental results, it is observed that the settlement and volume compressibility coefficient substantially increased, as the thickness of EPS geofoam increases. Furthermore, utilization of thinner EPS layers with the constant volume fraction ratio of EPS led to the greater settlement.

*Keywords:* Geofoam Block; Large-Scale Oedometer; Volume Compressibility Coefficient; Stress-Strain Behavior.

## 1. Introduction

Development of urban communities and consequently increasing population growth and demand of sites for construction made intense pressure on the agility and responsiveness of civil engineers. Designers must identify innovative materials and construction techniques to address the problem of construction over soft soils. As an alternative geomaterial, the use of expanded polystyrene (EPS) geofoam block in engineering construction as a lightweight fill material is furiously growing over the last several decades. Expanded polystyrene (EPS) geofoam has been used as a geotechnical material since the 1960s, while the manufacture of EPS dates back to the early 1930's by a German company called I.G. Farben. The first insulation project with EPS geofoam and the first road embankment utilizing EPS were conducted in 1965 and 1972 in Norway, respectively. The first documented geotechnical project in North America was the installation of the Alaska Pipeline, where EPS geofoam was used for both utility protection and utility insulation simultaneously. In 1985, more than 470 m3 of EPS geofoam were used as embankment fill material in Japan. In

* Corresponding author: Jamshidi_reza@guilan.ac.ir

Germany, the EPS geofoam was used to minimize the differential settlement along the highway and to protect the fill material against frost [1].

Expanded polystyrene (EPS) geofoam is a closed cellular plastic foam and geosynthetic material which is used in a wide variety of civil engineering applications including rapid construction of embankment over compressible soils [2, 3], slope stabilization [4], reduction of static and dynamic thrust on retaining walls, bridge abutments and piles [5-12], as a sub-base fill material [13-16] and as isolation against dynamic loading [17]. In fact, the application of EPS geofoam can be classified by its function including lightweight fill (density), compressible inclusion, thermal insulation and vibration damper. Table 1. demonstrates the application of EPS and the corresponding EPS geofoam function [1, 6, 7].

**Table 1. Application of EPS geofoam with its corresponding function [1]**

| Application | Density | Compressibility | Insulation | Damping |
|---|---|---|---|---|
| Slopes and embankments | ✓ | ✓ | ✓ | ✓ |
| Bridges | ✓ | ✓ | ✓ | ✓ |
| Earth retaining structures | ✓ | ✓ | ✓ | ✓ |
| Buried pipe | - | ✓ | ✓ | ✓ |
| Railway | - | - | - | ✓ |
| Basement Insulation | - | - | ✓ | - |

Nevertheless, some weaknesses were reported by Deng in 2001 for the applications of ESP which include prefabrication of EPS block and transportation cost, the lack of controlling stiffness and properties of EPS in-situ, block floatation, and poor flame resistance [6, 18]. Also, there are so many design and construction considerations reported for application of EPS including, buoyancy, chemical attack, degradation, moisture absorption, instant settlement, sliding and etc.

The engineering properties of expanded polystyrene (EPS) have been looked into by Negussey and Jahanandish [19]. Stress-strain behavior and coefficients of lateral earth pressure of soils and EPS were compared in stress-controlled conditions. The results indicated that the engineering properties of EPS can be quantified in a manner similar to that of earth materials. Ikizler et al. [20] investigated the reduction of transmitting lateral swelling pressures on retaining structures constructed on expansive soils. Several hypothetical cases were presented to demonstrate the reduction of lateral swelling pressure of expansive soils by using different thicknesses of EPS geofoam. The results denoted that lateral and vertical swelling pressure reduces as EPS geofoam thickness increases. Hazarika [21] described a stress–strain behavior of EPS geofoam in the case of large-strain applications based on the theory of plasticity. In the derivation of the constitutive law, the geofoam was taken as a Von-Mises material, and it was postulated that the hardening regime follows a hyperbolic curve. The material parameters of the constitutive model were determined from a series of unconfined compression tests performed on EPS specimens of various sizes, shapes, and densities. Constitutive model parameters were found as a function of the absolute dimensions of the tested specimens as well as the density of EPS.

Pandade and Mandal [22] conducted a series of triaxial tests on EPS geofoam specimen of size 75 mm diameter and 150 mm height to obtain the shear strength parameters. Shear strength parameters were calculated for three different confining pressures of 50, 100 and 150 kPa. The tests were carried out up to 15% of axial strain. Results showed that the value of cohesion increase with the increase in density of EPS geofoam, while the trend of increase in the angle of internal friction was negligible.

Ertugrul and Trandafir [23] explored the potential application of geofoam in the reduction of lateral earth pressures on a flexible cantilever retaining walls. The effect of relative flexibility of the walls as well as the characteristics of the cohesion less backfill and geofoam on the active earth pressures was investigated. Experimental results indicated that the shape of the active pressure distribution diagram behind a cantilever retaining walls was non-linear. Also, the results illustrated that geofoam inclusions provided a reduction in lateral earth pressures. Based on the results of the parametric analyses, design charts and regression models were proposed to predict the active lateral earth pressure coefficients and the point of application of the lateral load on the flexible cantilever earth retaining walls with or without deformable geofoam layers.

In view of the fact that endeavors have been made over the years to analysis the stress-strain behaviors of sand-EPS mixture, understanding the modulus of elasticity and compressibility coefficient is of special importance in modeling the overall response of a particulate combination, soil density, geofoam blocks thickness, stiffness of the geofoam material and configuration of specimen. A laboratory study on the formation of lightweight material by blending sand with polystyrene (EPS) was conducted to understand the behavior of the deformation characteristics of sand-geofoam block combinations with large-scale Oedometer apparatus.

# 2. Experimental study

## 2.1. Materials Properties

The experiments were carried out on “Chamkhaleh Sand” collected from Chamkhaleh beach, a coastal area of Guilan Province, located on SW of Caspian Sea [24]. The specific gravity (Gs) was determined according to ASTM D 854 [25] as 2.63 with a maximum dry unit weight of 16.1 kN/m$^3$ based on ASTM D 4253 and a minimum dry unit weight of 14.2 kN/m$^3$ [26]. Figure 1. shows the particle size analysis of the soil based on ASTM-D422-63 [27]. The average particle size of sand was 0.21$^{mm}$. The uniformity coefficient and coefficient of curvature of the soil were calculated 1.54 and 0.95, respectively. Therefore, the soil was classified as poorly graded sand (SP) under the Unified Soil Classification System. The properties of sand utilized in this study are given in Table 2.

**Table 2. Physical properties of sand**

| Material | Specific gravity (Gs) | Dry unit weight ( kN/m$^3$) | Effective size D10 (mm) | Mean grain size D50 (mm) | Uniformity coefficient (Cu) | Coefficient of curvature (Cc) |
|---|---|---|---|---|---|---|
| Sand | 2.63 | 14.2 (min)<br>16.1 (max) | 0.17 | 0.21 | 1.54 | 0.95 |

The intended EPS geofoam was pre-puffed from polystyrene resin with a chemical composition of $C_8H_8$ and manufactured by a local EPS block company. The ability of EPS geofoam blocks to cut into various shapes and sizes makes it a common lightweight fill material on a project, which further reduces site job challenges. The selected geofoam was cut into 5$^{cm}$, 10$^{cm}$, and 15$^{cm}$ thick plates with a diameter of 50$^{cm}$ with a measured density (ρ) of 8 kg/m$^3$ subjected to oedometer tests. Figure 2. shows the oedometer test specimen of EPS geofoam used in this experimental study.

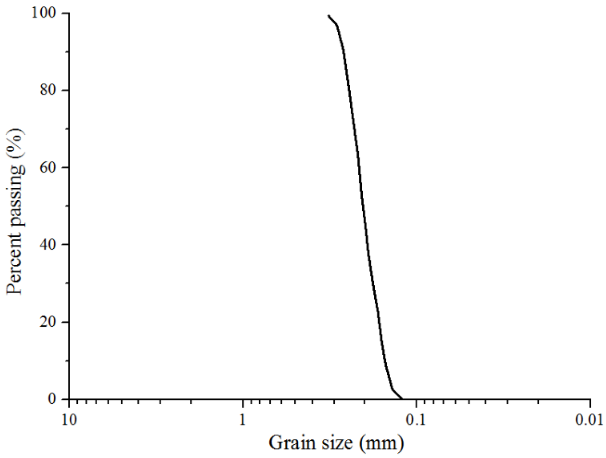



**Figure 1. Grain size distribution curves of sand**

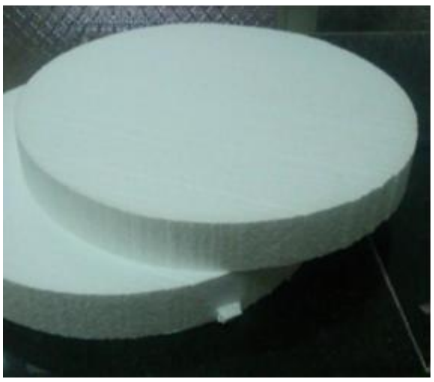


**Figure 2. Oedometer test specimen of EPS geofoam**

## 2.2. Specimen Preparation

In this study, the amounts of 35% and 70% for the relative densities of sand were chosen to investigate the soil-EPS deformation characteristics. Geofoam specimens with an outer diameter equal to oedometer tank size and heights of 5$^{cm}$, 10$^{cm}$ and 15$^{cm}$ were used. To investigate the influence of various parameters on test results, 22 large oedometer tests were conducted. EPS geofoam blocks are often arranged in layered configurations when used in geotechnical applications. A list of specimens with volume fractions and thicknesses of EPS layers is provided in Table 3. Several patterns have been used to study the effect of a single layer or multi-layer combination of EPS geofoam for different volume fractions. Each combination was tested at six different overburden pressures, including 50 kPa, 100 kPa, 150 kPa, 200 kPa, 250 kPa, and 300 kPa.

For conducting tests, dry sand was molded into the chamber of the oedometer apparatus at a designated relative density. A hand tamper was employed to reach the desired density of the soil. EPS plates were placed on the soil layer, and again sand was poured and compacted. Finally, a plastic plate with a diameter equal to the inner diameter of the tank was put on top to apply the load to the specimen uniformly and compact it to the target height. The test involved applying increments of vertical static load to the sample and recording the corresponding settlement. The duration of the application of each load increment depends on the soil and its compressibility characteristics. Once equilibrium reached for a loading step, the next increment was applied. The normal pressure was applied with loading actuator from zero to a final value of 300 kPa stepwise with an increment of 50 kPa. From the changes in thickness at the end of each loading stage, the compressibility of the soil may be observed and parameters such as coefficient of volume compressibility ($m_v$) were measured. This process was carried out for all different combinations of sand and geofoam.

**Table 3. Summary of oedometer testing program on geofoam-sand layers combinations.**

| Designation | Volume fraction $V_f$ (%) | | Layers of EPS (cm) | Pattern | Overburden pressure (kPa ) |
|---|---|---|---|---|---|
| | $V_{f\ sand}$ | $V_{f\ EPS}$ | | | |
| Sand | 100 | 0 | 0 | Sand | 50-300 (@50) |
| Sand+5$^{cm}$ EPS | 87.5 | 12.5 | 5 | Pattern “a” | 50-300 (@50) |
| Sand+10$^{cm}$ EPS | 75 | 25 | 5-5<br>10 | Pattern “b”<br>Pattern “e” | 50-300 (@50) |
| Sand+15$^{cm}$ EPS | 62.5 | 37.5 | 5-5-5<br>10-5<br>15 | Pattern “c”<br>Pattern “g”<br>Pattern “i” | 50-300 (@50) |
| Sand+20$^{cm}$ EPS | 50 | 50 | 5-5-5-5<br>10-5-5<br>10-10<br>5-15 | Pattern “d”<br>Pattern “h”<br>Pattern “f”<br>Pattern “j” | 50-300 (@50) |

## 2.3. Large Oedometer Apparatus

The standard oedometer test, also referred to as one-dimensional compression test is a classical laboratory test that allows characterizing the soil stress-strain behavior during one-dimensional compression or swelling. The most well-known apparatus which has been utilized to investigate the load−deformation characteristics of homogeneous fine-grained soils is a Casagrande-type Oedometer. A typical Casagrande Oedometer cell has an internal diameter of 76 mm and a height of 19 mm. However, the dimensions of this kind of apparatus do not meet the requirements of some civil engineering applications, like studying load−deformation characteristics of specimens with larger diameter particles such as granular materials or municipal solid waste materials. Another common apparatus, called hydraulic oedometer developed by Rowe and Barden [28], is available for specimens of 75−254 mm in diameter [28]. Although the hydraulic oedometer is able to use specimens of larger sizes, its dimensions are still inadequate for many applications in geotechnical engineering.

In order to measure the load-deformation behavior of geomaterials under a vertically applied stress up to 1.5 Mpa, a large cylindrical oedometer with a diameter of 492 mm and height of 550 mm has been designed and fabricated at faculty of engineering of the University of Guilan. The ability of the large odometer apparatus to evaluate the hydraulic and mechanical properties of non-conventional materials makes it pioneer especially in the case of EPS geofoam, tire shreds, tire chips, etc [29]. The complete setup of the apparatus can be seen in the Figures 3 and 4.

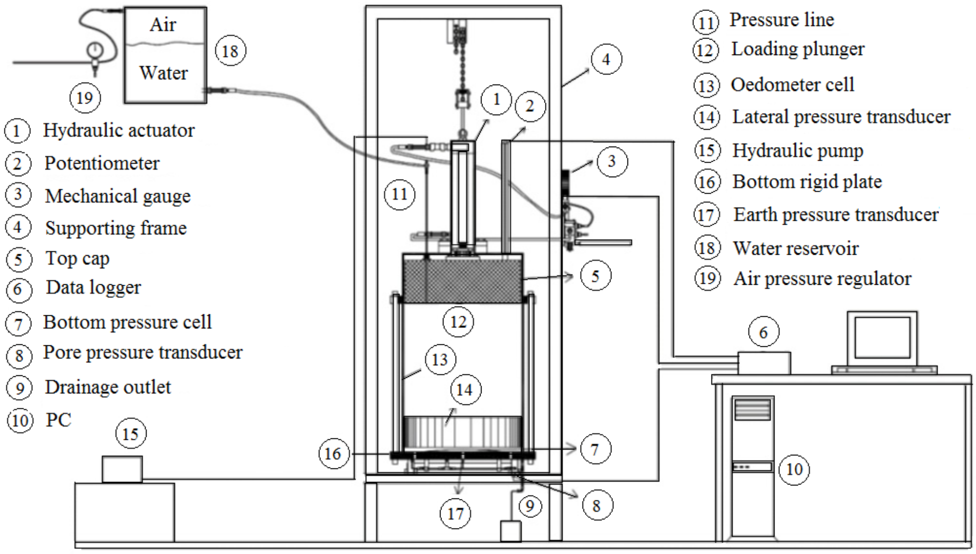



**Figure 3. Details of the large Oedometer cell [29]**

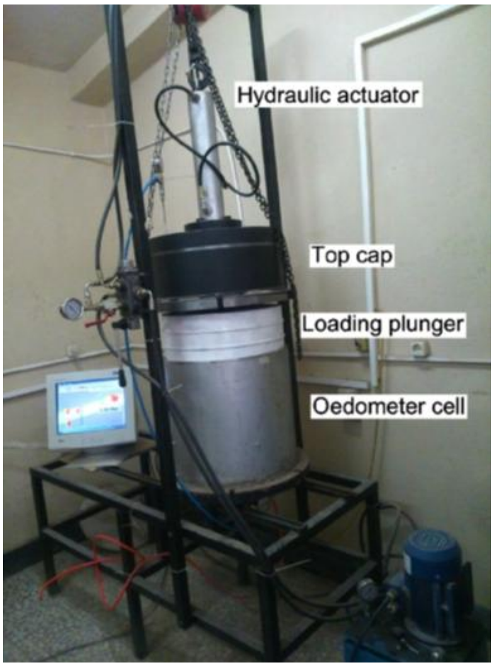



**Figure 4. Large Oedometer testing apparatus [29]**

## 3. Results and Discussion

### 3.1. Stress-Strain Behavior of Specimens

Figure 5. demonstrates the variation of the axial strain of pure sand versus the applied normal stress for two relative densities. The graphs show that there is a continuous increase in the value of axial strain with respect to increase in normal stress for both densities. Obviously, the stiffer the specimen, the less axial constrained strain. Vertical stress-strain behaviors of EPS-sand specimens under different overburden pressures and volume fractions are shown in Figure 6. By adding an EPS layer, the vertical strain increased quickly for each relative density, i.e. for Dr=35%, the vertical strain in pattern “a” increased 1.55, 1.55, 1.69, 1.4, 1.35, and 1.30 times in comparison to the pure sand model for different applied stresses, while for Dr=70%, the vertical strain in pattern “a” increased 2.85, 3.12, 3.17, 2.93, 2.75, and 2.71 times in comparison to the pure sand for different overburden pressures. It was also observed that the axial strain increases with the increase in the volume fractions of EPS geofoam material. It is clear from different graphs that the volume compressibility coefficient which is the slope of strain- stress curves, increases with EPS geofoam volume fractions. Another observation is that for overburden pressures higher than 150 kPa, the volume compressibility drops due to the fact that the EPS geofoam stops deformation when the overburden pressure is higher than 150 kPa.

Most studies have found the extent of the initial linear-elastic portion of the curve to be up to 2% strain, however some researchers have reported slight downward concavity of the curve in a range of up to 1% [6]. The elastic limit stress decreases with increasing the volume fractions EPS and increases with the density of the soil.

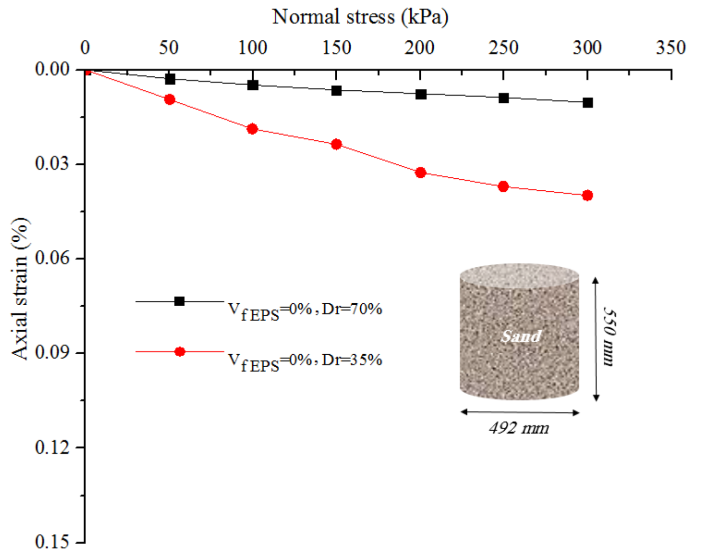
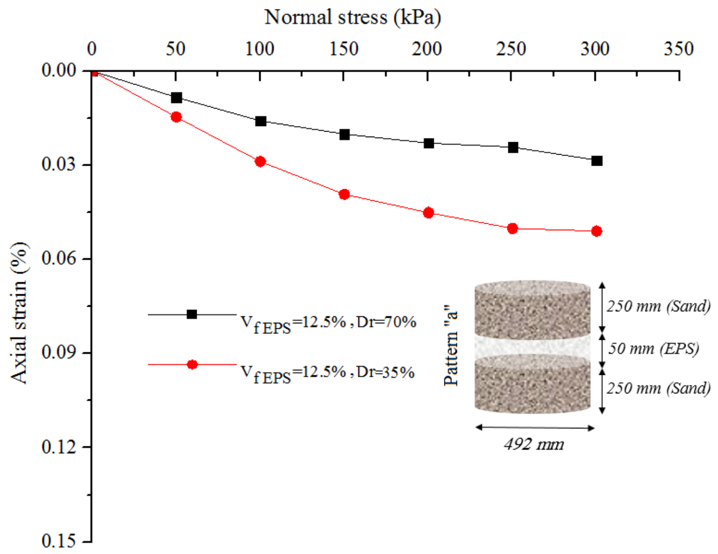
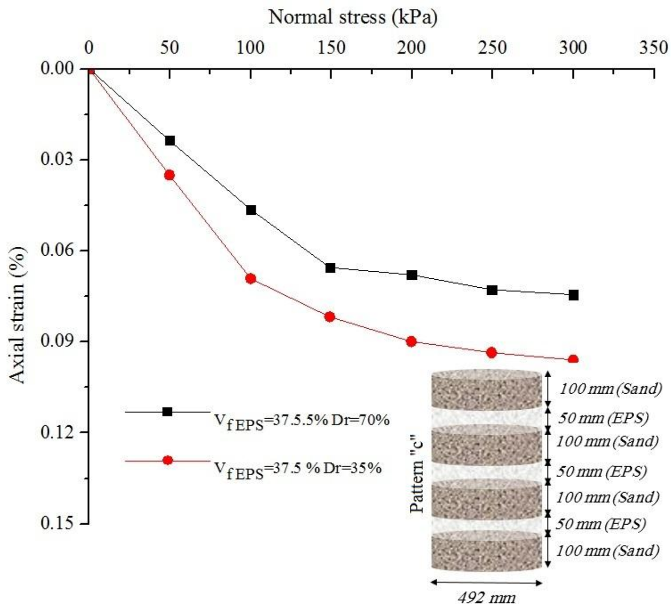



**Figure 5. Stress-strain behavior of sand.**




**(a)**




**(b)**

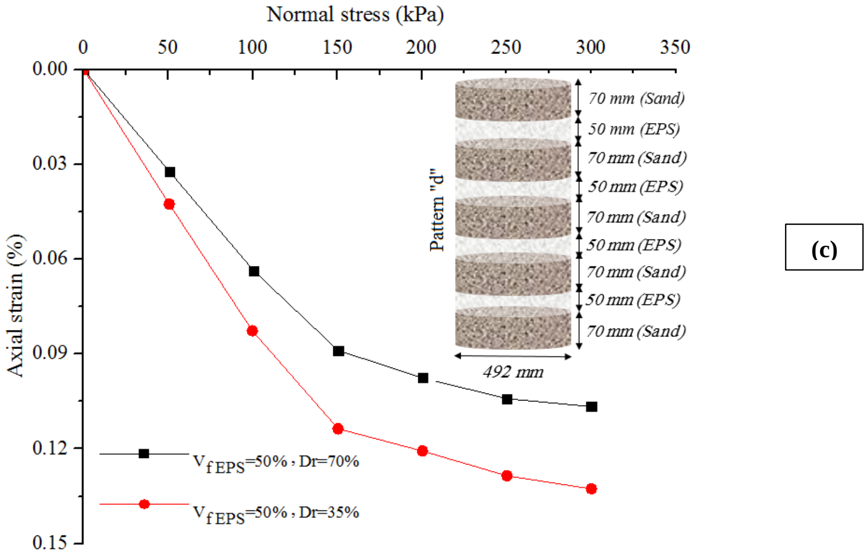



**Figure 6. Effect of EPS content on the stress-strain behavior of layered composite;**
**a) $V_{f\,EPS}$=12.5%; b) $V_{f\,EPS}$=37.5%; and c) $V_{f\,EPS}$=50%**

Figure 7. illustrates a comparison between the amounts of axial strain for the various combinations in the case of applied pressure of 300 kPa. As seen in this figure, the axial strain increased by the increase of EPS content for both relative densities. Each rectangle shows a particular volume fraction of EPS. With a constant EPS content, the higher thickness of the EPS layer, the less axial strain happened in the specimens. For instance, in Sand+15$^{cm}$ EPS, the case of pattern "i" sustained less axial strain. The reason for this phenomenon may be due to better transfers of stress in thin layers. The results showed that the thickness of EPS layer and therefore the layering scheme of EPS-sand composite has a significant influence on the settlement. The results also indicated that the impact of layering is reduced with the increase in the sand relative density.

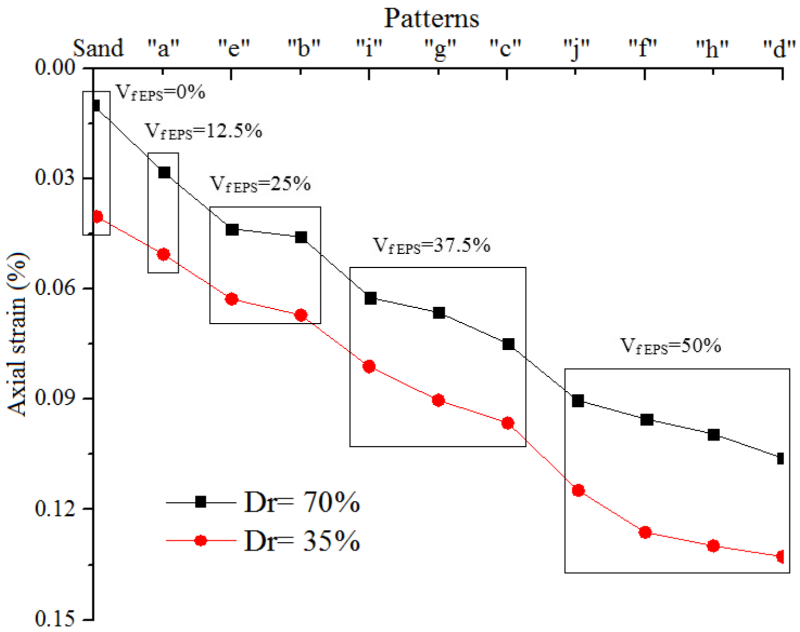



**Figure 7. The effect of layering scheme on the constraint deformations of EPS-sand composites, $\sigma_v$=300 kPa**

## 3.2. Variation of Compressibility Coefficient

The variations of the volume compressibility coefficient ($m_v$) for all EPS-sand composites are presented in Figure 8. The coefficient of compressibility in EPS-sand composites decreased with an increase in overburden pressure. The rate of its changes is a function of EPS layers thickness in the specimen. There are many differences between the values of ($m_v$) in two relative densities at lower stress levels, but the coefficients of compressibility in both specimens get closer to each other with increasing vertical stress. These discrepancies indicated the decreasing effect of sand and significant contribution of EPS behavior in combinations.

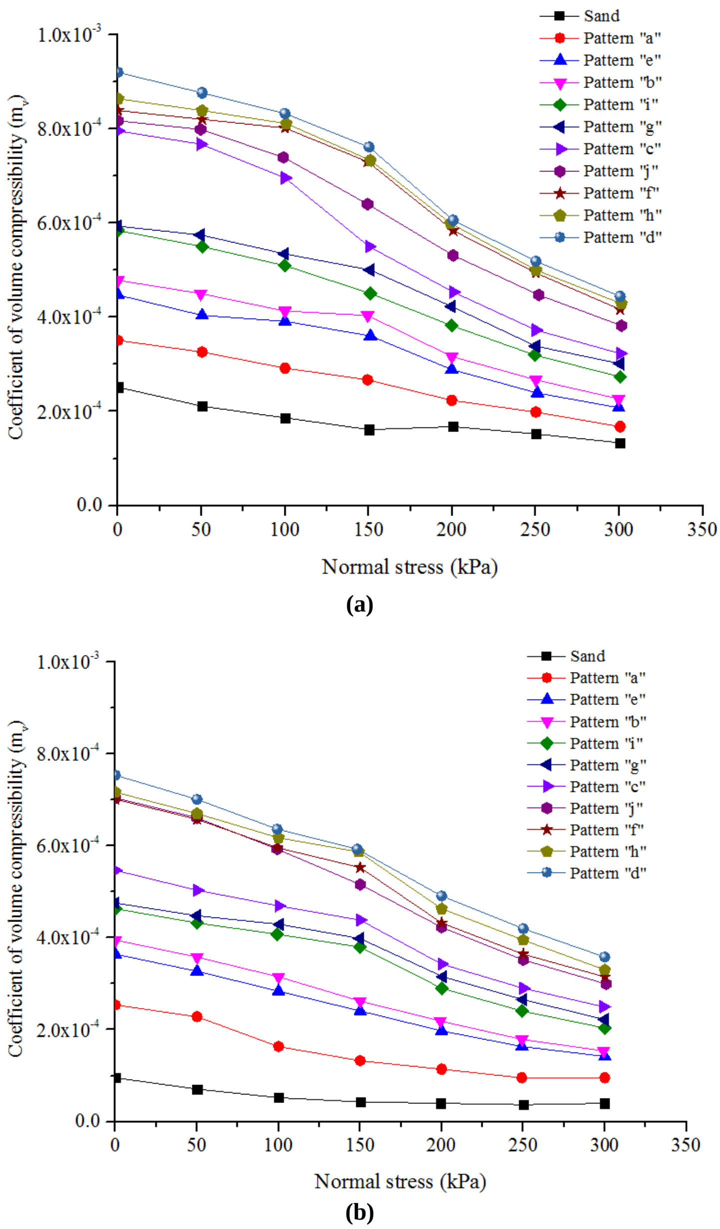



**Figure 8. Effect of vertical stress on the volume compressibility coefficient in various relative densities; a) Dr=35%; b) Dr=70%**

## 4. Conclusion

A series of experimental study has been carried out on geofoam block-sand composites in different volumetric contents, using a newly fabricated large-scale oedometer apparatus. Axial strain and volume compressibility coefficient of different combinations were measured. The results of this study showed that the application of EPS blocks needs special attention to calculate settlement and coefficient of compressibility.

The axial strain decreased by increasing the relative density i.e. the stiffer the soil, the less axial sustained strain. The results showed that adding an EPS layer induces the higher level of vertical strain and coefficient of compressibility. For instance, when Dr=35%, the vertical strain in pattern "a" increased 1.55, 1.55, 1.69, 1.4, 1.35, and 1.30 times in comparison to the pure sand specimen for different applied stresses, while for Dr=70%, the vertical strain in pattern "a" increased 2.85, 3.12, 3.17, 2.93, 2.75, and 2.71 times in comparison to the pure sand specimen for overburden pressures of 50 kPa, 100 kPa, 150 kPa, 200 kPa, 250 kPa, and 300 kPa respectively. It is worth noting that, the rates of increment in axial strain have increased up to the vertical stress of around 150 kPa, while these increment rates decrease after the axial stress of around 150 kPa. Using multi-layers of EPS geofoam induces more axial strain when the same thickness of EPS separates into more layers. The thickness of EPS layer and pattern of EPS have a significant influence on deformation characteristics of specimens. The results also indicated that the impact of layering is reduced with an increase in the soil density. Certainly, these results should be investigated along with other results of deformability and shear strength of composite and optimum thickness and volume fractions of EPS to be selected.

## 5. References

[1] Elragi, A. F., "Selected engineering properties and applications of EPS geofoam", State University of New York College of Environmental Science and Forestry, ProQuest Dissertations and Theses, (2000).

[2] Mandal, J.N. and Nimbalkar, S.S., "Reduction of lateral earth pressure by compressible inclusion by centrifuge modeling", In Proceeding of Indian Geotechnical Conference, (1999): 63-67.

[3] Farnsworth, C. B., Bartlett, S. F., Negussey, D., and Stuedlein, A. W., "Rapid construction and settlement behavior of embankment systems on soft foundation soils", Journal of geotechnical and geo-environmental engineering, 134(3), (2008): 289-301.

[4] Jutkofsky, W., Sung, J. and Negussey, D., "Stabilization of embankment slope with geofoam", Transportation Research Record: Journal of the Transportation Research Board, 1736, (2000):94-102.

[5] Horvath, J.S., "Using geosynthetics to reduce earth loads on rigid retaining structures", In Geosynthetics, Conference, Atlanta, Georgia, USA, (1991).

[6] Horvath, J.S., "The compressible inclusion function of EPS geofoam", Geotextiles and Geomembranes, 15(3), (1997): 77-120.

[7] Horvath, J.S., "Geofoam compressible inclusions: the new frontier in earth retaining structures", In Geotechnical Engineering for Transportation Projects, (2004): 1925-1934.

[8] Mandal, J.N. and Nimbalkar, S.S., "Centrifuge tests for bearing capacity of EPS on soft soils", Foundation Problems and Case Studies, 1st IGS Indore Chapter, (2000): 60-74.

[9] Bathurst, R.J., Zarnani, S. and Gaskin, A., "Shaking table testing of geofoam seismic buffers", Soil Dynamics and Earthquake Engineering, 27(4), (2007): 324-332.

[10] Hatami, K. and Witthoeft, A.F., "A numerical study on the use of geofoam to increase the external stability of reinforced soil walls", Geosynthetics International, 15(6), (2008): 452-470.

[11] Zarnani, S. and Bathurst, R.J., "Numerical modeling of EPS seismic buffer shaking table tests", Geotextiles and Geomembranes, 26(5), (2008): 371-383.

[12] Zarnani, S. and Bathurst, R.J., "Influence of constitutive model on numerical simulation of EPS seismic buffer shaking table tests", Geotextiles and Geomembranes, 27(4), (2009): 308-312.

[13] Duškov, M., "Materials research on EPS20 and EPS15 under representative conditions in pavement structures", Geotextiles and Geomembranes, 15(1), (1997): 147-181.

[14] Duškov, M. and Scarpas, A., "Three-dimensional finite element analysis of flexible pavements with an (open joint in the) EPS sub-base", Geotextiles and Geomembranes, 15(1), (1997): 29-38.

[15] Stark, T.D., Arellano, D., Horvath, J.S. and Leshchinsky, D., "Geofoam applications in the design and construction of highway embankments", No. NCHRP Project 24-11, (2004).

[16] Huang, X. and Negussey, D., "EPS Geofoam Design Parameters for Pavement Structures", In Geo-Frontiers 2011: Advances in Geotechnical Engineering, (2011): 4544-4554.

[17] Ossa, A. and Romo, M.P., "Dynamic characterization of EPS geofoam", Geotextiles and Geomembranes, 29(1), (2011): 40-50.

[18] Deng, A., "The influence of different soils properties on stabilization behavior of reinforced soil", Soil Engineering & Foundation, 15 (2), (2001): 31-34.

[19] Negussey, D. and Jahanandish, M., "Comparison of some engineering properties of expanded polystyrene with those of soils", Transportation Research Record, 1418, (1993): 43-50.

[20] Ikizler, S.B., Aytekin, M. and Nas, E., (2008), "Laboratory study of expanded polystyrene (EPS) geofoam used with expansive soils", Geotextiles and Geomembranes, 26(2), (2008):189-195.

[21] Hazarika, H., "Stress–strain modeling of EPS geofoam for large strain applications", Geotextiles and Geomembranes, 24(2), (2006): 79-90.

[22] Padade, A. H., and Mandal, J., "Behavior of expanded polystyrene (EPS) geofoam under triaxial loading conditions", Electronic Journal of Geotechnical Engineering, (17), (2012): 2542-2553.

[23] Ertugrul, O.L. and Trandafir, A.C., "Lateral earth pressures on flexible cantilever retaining walls with deformable geofoam inclusions", Engineering Geology, 158, (2013): 23-33.

[24] Karimpour Fard, M., Jamshid Chenari, R., and Soheili, F., "Shear strength characteristics of sand mixed with EPS beads using large direct shear apparatus" Electronic Journal of Geotechnical Engineering, 20(8), (2015): 2205-2220.

[25] ASTM D854, (2014), "Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer", ASTM International, West Conshohocken.

[26] ASTM D 4253, (2006), "Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table", ASTM International, West Conshohocken.

[27] ASTM D422-63, (2007), "Standard Test Method for Particle-Size Analysis of Soils", ASTM International, West Conshohocken.

[28] Rowe, P.W. and Barden, L., "A new consolidation cell", Geotechnique, 16(2), (1966): 162-170.

[29] Jamshid Chenari, R., Karimpour Fard, M., Maghfarati, S.P., Pishgar, F. and Machado, S.L., (2016), "An investigation on the geotechnical properties of sand–EPS mixture using large oedometer apparatus", Construction and Building Materials, 113, (2016): 773-782.