Experimental Investigation on the Efficiency of Expanded Polystyrene Geofoam Post and Beam System in Protecting Lifelines

Masood Abdollahi, Seyed Naser Moghaddas Tafreshi

Abstract**—**Expanded polystyrene (EPS) geofoam is a cellular geosynthetic material that can be used to protect lifelines (e.g. pipelines, electricity cables, etc.) below ground. Post and beam system is the most recent configuration of EPS blocks which can be implemented for this purpose. It provides a void space atop lifelines which allows settlement of the loading surface with imposing no pressure on the lifelines system. This paper investigates the efficiency of the configuration of post-beam system subjected to static loading. To evaluate the soil surface settlement, beam deformation and transferred pressure over the beam, laboratory tests using two different densities for EPS blocks are conducted. The effect of geogrid-reinforcing the cover soil on system response is also investigated. The experimental results show favorable performance of EPS post and beam configuration in protecting underground lifelines.

Keywords**—**Beam deformation, EPS block, laboratory test, post-beam system, soil surface settlement.

I. Introduction

EPS is a geosynthetic material which can be used in civil engineering applications. Based on its functions like thermal insulation, lightweight fill, compressible inclusion, and wave damping [1], the use of EPS has been extended in road construction, retaining walls, bridge abutments, and building foundation [2]. Because of EPS lightweight and compressible quality [3], [4], it can be used as soft zone materials above the pipeline [5]-[7]. In this method, known as imperfect trench, the center prism above the pipe undergoes more deformation than its adjunct soil prisms, which results in negative arching and therefore reduces the imposed load on the buried structure [8]. Recently, a new configuration of EPS geofoam blocks called post and beam was used in a Utah roadway to protect gas pipelines from extreme soil settlement [9]. In this configuration EPS blocks are placed on each side of the pipe (posts) and the capping beam is put atop (beam). By varying post height, desirable void space above the pipe can be achieved. So, soil can settle without imposing stress to the pipeline. EPS post and beam configuration was simulated using a 2D finite difference model and reported its functionality under traffic loading [9]. The effect of different parameters such as EPS density, soil cover thickness, and beam thickness on the response of the system under static loading using a 3D model was investigated [10].

In this paper, the efficiency of EPS block as post and beam system in sustaining the imposed monotonic load and protecting the underlying pipeline is investigated. Since an excessive subsidence in soil cover, due to compressive behavior of EPS blocks would be expected, thus soil reinforcement using geogrid is also considered in number of tests. The specific aims of the paper are to determine the influence of the EPS block density and geogrid-reinforcement on the variation of soil surface settlement, beam deflection, and pressure distribution over the EPS beam.

Masood Abdollahi is with the K. N. Toosi University of Technology, Iran, Islamic Republic Of (e-mail: masood.abdollahi91@gmail.com).

S. N. Moghaddas Tafreshi is Professor of Geotechnical Eng., CivilEngineering Department, K. N. Toosi University of Technology, Tehran, Iran (e-mail: nas_moghaddas@kntu.ac.ir).

II. Test Materials

A. Backfill Soil Cover

Granular soil passing through the 20-mm sieve with a specific gravity of 2.66 (G_s=2.66) was used as backfill soil cover in the testing program. The grain size distribution of this soil is shown in Fig. 1. According to Unified Soil Classification System (ASTM D 2487-11), the soil is classified as well-graded sand (SW). The angle of internal friction (φ) of the soil, obtained by consolidated undrained triaxial compression tests at a wet density of 19.72 kN/m^3 (corresponding to 92% of maximum dry density (20.42 kN/m^3) with moisture content of 5%, similar to the compacted density of the backfill soil cover) of specimens was 40.5°.

B. Geogrid

A high-density polyethylene (HDPE) geogrid was used as soil reinforcement in the tests. A series of index tests involving uniaxial-tensile loading were performed to measure the load-displacement response of the biaxial geogrid samples. The geogrid properties as provided by the manufacturer are summarized in Table I. The tests are conducted according to the ASTM standard D6637-11 (2011) on multi-rib geogrid specimens. In these index tests, one of the clamps is fixed, while the other is allowed to move and pull the geogrid specimen with constant strain rate of 10% strain/minute. The photograph and load-strain response of the geogrid are presented in Fig. 2.

C. EPS Blocks

EPS geofoam density is the main index of EPS block as it plays a key role in the value of compression strength, flexural strength, stiffness, and other mechanical properties of EPS [11]. Therefore, two densities of EPS (20 and 25 kg/m^3) are used to study the effect of geofoam density on system response. To evaluate the behavior of EPS geofoam used in the current study, static tests on EPS cubic specimens with dimension of 200× 200 mm in plan and 100 mm in height were performed. To obtain the condition of fully static loading as proposed by [12], the loading with a rate of 1 kPa/s is applied on the EPS surface. Test result is shown in Fig. 3. As it can be seen, compressive strength of EPS block considerably increase as denser block is used.

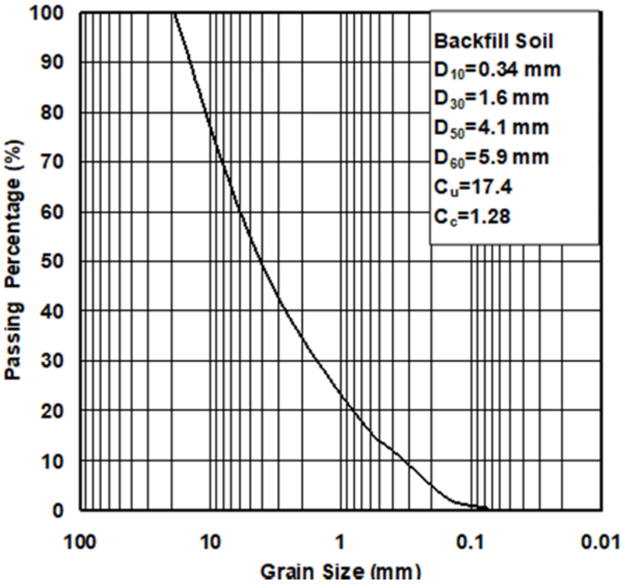
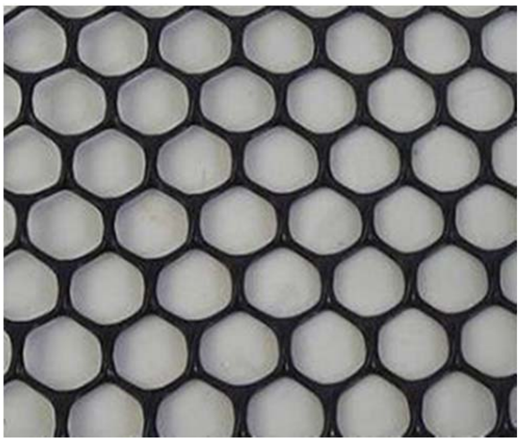


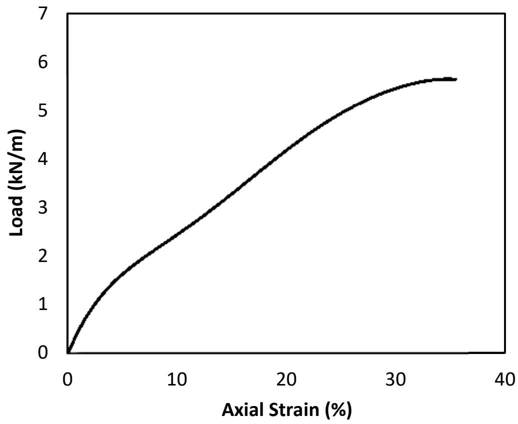
Fig. 1 Grain size distribution curves for backfill soil (ASTM D 2487-11)

TABLE I
ENGINEERING PROPERTIES OF GEOGRID

Description	Value
Material	HDPE
Material thickness (mm)	5.2
Mass per unit area (kg/m^2)	0.695
Ultimate tensile strength (kN/m)	5.8
Aperture size (mm)	27×27



(a)



(b)

Fig. 2 (a) The photograph of the geogrid (b) The load-strain response of the geogrid

III. LARGE SCALE MODEL TEST

To evaluate the performance of EPS post and beam system, two series of large scale tests are performed. The layout of test pit, post and beam geofoam blocks, reinforcement layer, soil cover, loading plate, data acquisition system (LVDTs and pressure cell), and the geometry of the test configuration are displayed in Fig. 4.

The test pit consists of lower part measuring 1200×1200 mm in plan and 550 mm in height where geofoam blocks and backfill soil were placed and upper part with dimension of 1200×1200 mm in plan and 300 mm in height for soil cover. The whole post and beam system and soil cover are well restricted in plan and can only displace perpendicular to the plan. The load system is a hydraulic jack that is well supported by a strong steel beam spanning the width of test pit. A circular steel rigid plate with diameter of 200 mm and thickness of 20 mm as a loading plate was put on the surface of soil cover at the center of backfill and then the monotonic loading with a rate of 1 kPa/s was applied on the surface of loading plate. To measure the settlement of loading plate, two LVDTs with accuracy of 0.01% and a full range of 80 mm were attached to the reference beam and their tips were placed on the loading plate. To measure the transferred pressure on the EPS beam surface, a pressure cell with an accuracy of 0.1% and full range of 1000 kPa was placed on the middle of beam span where it was expected to experience the highest pressure within a block. In order to evaluate the beam deformation, a LVDT (0.01% accuracy and 80 mm full range) was placed beneath the EPS beam in the middle of free span between two posts.

To compact the layers of soil cover, a Hitachi walk-behind vibrating plate compacter with plate dimension of 400×600 mm was used. In the absence of reinforcement layer, the cover soil was compacted in three levels of 0, 100, 200 mm from the level of the loading plate base. For the geogrid-reinforced backfill, the compaction was performed in four layers, 0, 50 (the embedment depth of geogrid layer), 100, 200 mm from the base of loading plate. The soil moisture during the tests was kept at 5%. The soil density after compaction was measured using sand cone tests in different level of backfill soil, in accordance with ASTM D 1557-12.

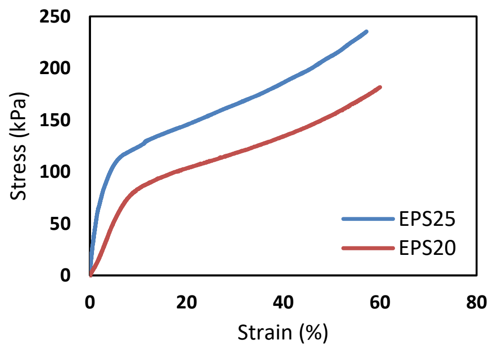


Fig. 3 Stress-strain behavior of EPS geofoam

IV. Test Program

To assess the post and beam system performance in protecting underground lifelines, eight tests including four independent tests plus four replicates were conducted. Details for each test are summarized in Table II. Since EPS densities in practical civil applications range between 10 and 30 kg/m^3 [11], so the effect of EPS Density on system response was investigated trough using EPS20 and EPS25 respectively abbreviated to EPS block with density of 20 kg/m^3 and 25 kg/m^3 as posts and beam blocks. To evaluate the beneficial effect of geogrid reinforcement on soil settlement, beam deflection, and developed pressure in beam block two independent test are performed for two EPS densities. In both tests, similar geogrid with a dimension of 1000 mm×1000 mm was placed in the center of soil cover and 60 mm below the bearing plate.

In order to assess the utility of the apparatus, the accuracy of the measurements, the repeatability of the system, the reliability of the results and finally to verify the consistency of the test data, the tests described in Table II were repeated twice.

V. Results and Discussion

The results of tests are presented for the variation of EPS beam deflection, soil surface settlement and transferred pressure on EPS beam for two EPS densities in unreinforced and geogrid-reinforced installations.

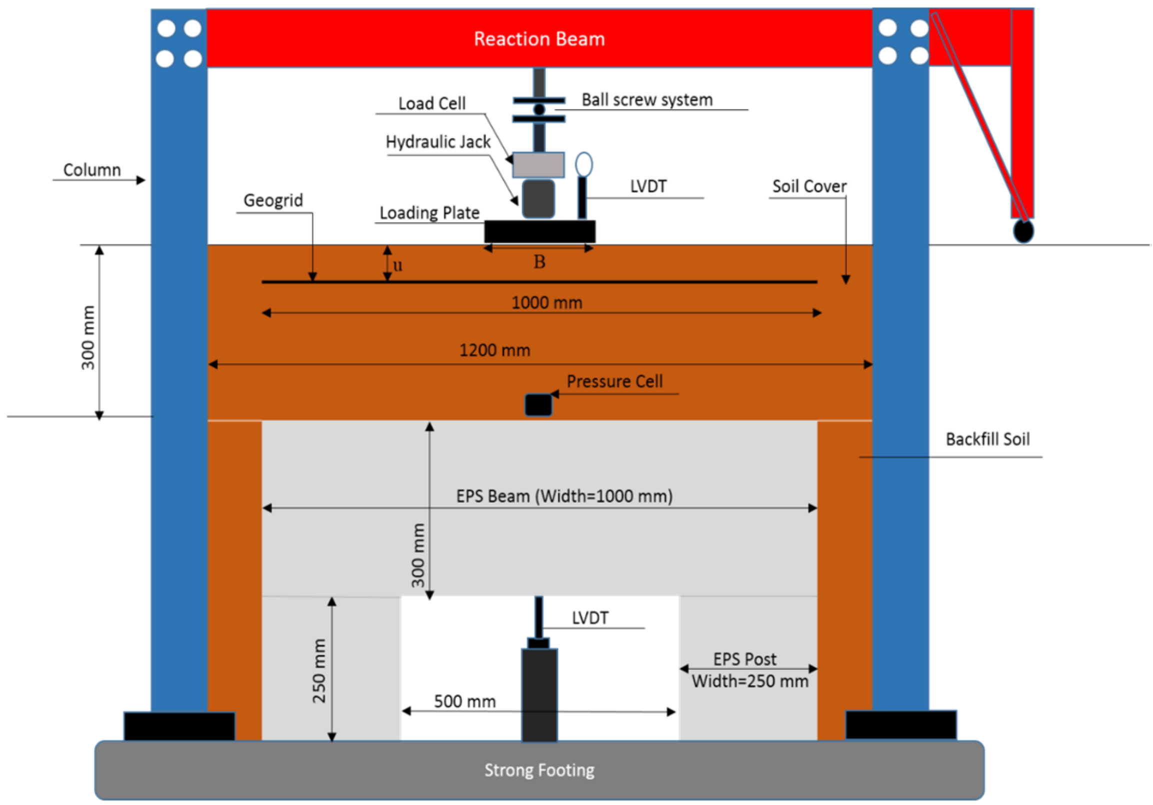


Fig. 4 Schematic representation of the test setup, geometry and layout of the test configuration

TABLE II
SCHEME OF THE TESTS ON EPS POST AND BEAM SYSTEM IN UNREINFORCED AND GEOGRID-REINFORCED BACKFILLS

Test Symbol	Description	u/B	EPS Density	Constant Parameters
D25U	Unreinforced	0.3	25 kg/m^3	Soil cover thickness: 300 mm
D20U	Unreinforced	0.3	20 kg/m^3	Beam thickness: 300 mm
D25R	Reinforced	0.3	25 kg/m^3	Span: 500 mm
D20R	Reinforced	0.3	20 kg/m^3	Post's height to width ratio: 1

A. Beam Deflection

Variation of EPS beam deflection with applied pressure on loading plate is shown in Fig. 5 for two EPS densities in unreinforced and reinforced systems. As seen, beam deflection decreases when higher EPS density is used. This figure indicates that higher modulus of elasticity of heavier EPS block (corresponding to higher density) delivers less deformation as compared with lighter EPS block (corresponding to lower density) under same applied pressure on the soil surface. It is also obvious that using a layer of geogrid reinforcement beneath the loading surface decreases the beam deflection due to membrane effect of geogrid layer and less transferred pressure to the beam block. For example, at the applied load of 500 kPa and EPS block with density of 25 kg/m^3, the beam deflection is about 5.4 mm and 4.0 mm, respectively for unreinforced and reinforced backfill.

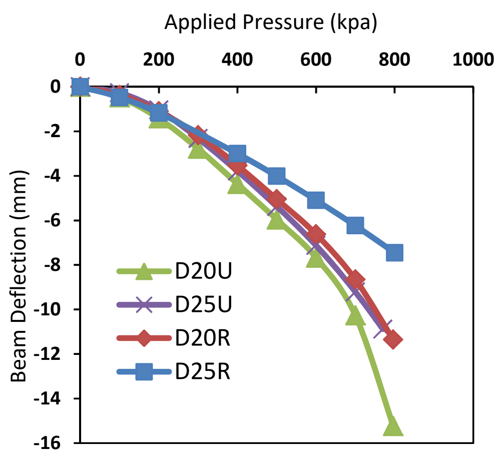


Fig. 5 Variation of beam deflection with applied pressure for two EPS densities in unreinforced and reinforced installations

B. Soil Settlement

Fig. 6 presents the variation of the loading plate settlement against the applied pressure. This figure is evidence of beneficial effect of the EPS with higher density and geogrid reinforcement installation owing to much stiffer and less surface settlement. The soil settlement highly depends on beam deformation as they act altogether as a system. So less deformation in denser beam block results in lower plate displacement. As seen in Fig. 6, the soil surface settlement of the backfill at applied load of 600 kPa is decreased about 27% using heavier EPS density compared to lighter density. Fig. 6 also shows that the use of geogrid noticeably reduces the loading plate settlement as it confines the soil, preventing lateral spreading and also lowers the transferred pressure in depth backfill soil and over EPS beam. For example, the soil surface settlement of the reinforced installation at applied pressure of 600 kPa reduces about 37% for installation with EPS block density of 25 kg/cm^3. Generally, the settlement reduction demonstrates that the geogrid reinforcement performed well in reducing the settlement of loading surface.

C. Pressure Distribution over EPS Beam

Fig. 7 illustrates the transferred stress in beam versus imposed pressure. It shows that EPS density has no major effect on the stress distribution, particularly for applied pressure of less than 400 kPa. However, the use of lighter blocks insignificantly reduces the transferred stress in beam. As seen in this figure, geogrid-reinforcement decreases the transferred stress over beam block, due to membrane effect and mobilizing tension force in geogrid. The vertical component of the tension force in the reinforcement layer could reduce the pressure on the EPS block and subgrade soil.

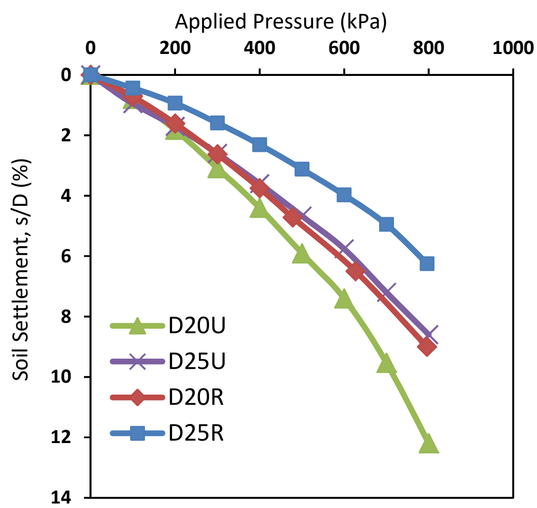


Fig. 6 Variation soil settlement with applied pressure for two EPS densities in unreinforced and reinforced installations

D. System Efficiency in Protecting Pipelines

When the backfill soil cover is reinforced, deflection in EPS beam is small (about 7 mm and 11 mm, respectively EPS25 and EPS20 in pressure of 800 kPa) to the system dimensions and thus the EPS material could be considered in its elastic range. Also, the maximum vertical stress that develops in the EPS beam is about 101 kPa in density of 25 kg/m^3 and 82 kPa in density of 20 kg/m^3. These values are within the acceptable limits for EPS Blocks with density of 25 kg/m^3 and 20 kg/m^3 and less than their compressive strength obtained by uniaxial test as shown in Fig. 3.

VI. Conclusion

In this study, a series of laboratory tests under static load carried out on the EPS post and beam system in unreinforced and reinforced backfill soil cover. The test results evaluated the EPS and reinforcement performance in terms of EPS beam, soil surface settlement and transferred pressure on EPS beam. Based on the results obtained, the following conclusions are derived:

1. Use of denser blocks significantly lowers both the beam deflection and soil surface settlement. The EPS density has no major effect in transferred stress over beam.
2. Backfill soil-reinforcement over EPS beam beneficially reduces deformations of beam block and backfill surface settlement. It also lowers transferred stress over EPS beam and so protects EPS post and beam system.
3. When the soil cover is reinforced, beam deflection is considered small to its dimension and transferred stress on beam is less than its compressive strength. So, EPS post and beam system can practically be used to protect buried pipelines.

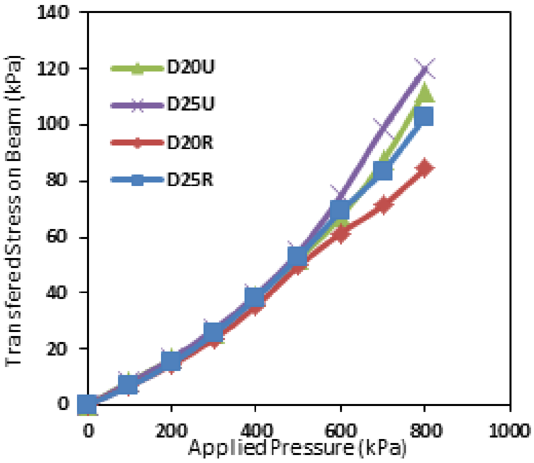


Fig. 7 Variation of transferred stress on EPS beam with applied pressure for two EPS densities in unreinforced and reinforced installations

References

[1] Horvath J. S., Expanded polystyrene (EPS) geofoam: an introduction to material behavior. Geotext Geomembr 1994, pp. 263-280.

[2] Stark, T. D., Bartlett, S. F., Arellano, D., Expanded Polystyrene (EPS) Geofoam Applications and Technical Data, 2012.

[3] Horvath, J.S., New developments in geosynthetics; 'Lite' products come of age. *Standardization News* (ASTM), 1992, 20(9), pp. 50-53.

[4] Horvath, J. S., The compressible inclusion function of EPS geofoam: an overview. In: Proc. Intl. Sym. On EPS Construction Method, Tokyo, Japan, 1996, pp. 71-81.

[5] Zhang, W., Liu, B., Xie, Y., Field test and numerical simulation study on the load reducing effect of EPS on the highly filled culvert, J. Highw. Transp. Res. Dev, China, 2006, vol. 23, pp. 54-57.

[6] Kang, J., Parker, F., and Yoo, C. H., Soil-structure interaction and imperfect trench installations for deeply buried concrete pipes." J. Geotech. Geoenviron. Eng., 2007, 133(3), pp. 277–285.

[7] Kim, H., Choi, B. & Kim, J., Reduction of earth pressure on buried pipes by EPS geofoam inclusions, Geotechnical Testing Journal, 2010, vol. 33, number. 4, pp. 1–10.

[8] Marston, A., The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments: Bulletin 96, Iowa Engineering Experiment Station, Iowa State College, Ames, IA, 1930.

[9] Bartlett, S. F., Lingwall, B. N., and Vaslestad, J., Methods of protecting buried pipelines and culverts in transportation infrastructure using EPS Geofoam. Geotext Geomembr, 2015, vol. 43, pp. 450-461.

[10] M. Abdollahi, S. N. Moghaddas Tafreshi, Numerical Investigation on Performance of Expanded Polystyrene Geofoam Block in Protecting Buried Lifeline Structures, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:11, No:9, 2017 model for EPS geofoam. Geotext Geomembr, 2006, vol. 24, pp. 299-310

[11] Ahmed Fouad Elragi, Selected Engineering Properties and Applications of EPS Geofoam, 2000.

[12] S. N. Moghaddas Tfreshi, A. R. Dawson, Behaviour of footings on reinforced sand subjected to repeated loading – Comparing use of 3D and planar geotextile, Geotextile and Geomembrane 434-447, 2010.