Assessment the Role of Expanded-Polysterene Block and Grogrid Layer on Behavior of Buried Pipeline

Omid Khalaj 1, Naser Joz Darabi 2, Seyed Naser Moghaddas Tafreshi 2, Hana Jirková 1

1 Regional Technological Institute, University of West Bohemia, Plzen, Czech Republic
2 Department of Civil Engineering, K.N. Toosi University of Technology, Tehran, Iran

khalaj@rti.zcu.cz

Abstract. Geogrid layers and expanded polystyrene blocks have widely been implemented in geotechnical projects, recently. This paper investigates the behaviour of buried pipelines through experimental and numerical analyses by implementing an expanded polystyrene (EPS or geofoam) block and a geogrid layer over the buried pipe rested in a trench and imposed by trench surface loading. In this regard, a 3-D finite element model was created using ABAQUS software which verification and material characteristics have been derived from experimental results. The results indicate that the behaviour of buried pipelines can be ameliorated by employing EPS geofoam blocks; however, the compressible inclusion character of EPS blocks has a side effect of more surface subsidence of buried pipe trenches. In addition, reinforced soil covers with geogrid and geofoam has a considerable impression on amending the maximum surface settlement and maximum pipe crown displacement values.

1. Introduction

The reinforced soil has been broadly implemented in geotechnical engineering applications thanks to the long-time profitability of geosynthetics (i.e., Expanded polystyrene (EPS), geotextile, geogrid, and geocell). One of this practical solution, which is recently using in this area, is Expanded polystyrene (EPS). Expanded polystyrene (EPS) or geofoam as a lightweight material with a density of about a hundred of soil which has been used in engineering applications since the 1950s [1]. Buried pipes are one of the most vital parts of urban facilities, and their performance has a direct link with their serviceability. Owing to this fact, the performance and durability of these vital substructures depend on the safe and proper design, which should be proficient to persevere the safety and operation of them. One of the approved practical advantages of geosynthetics is their performance in stress attenuation on buried conduits and pipes. Owing to this phenomenon, so many researchers have scrutinized their performances [2-6]. Abdollahi et al. [5] conducted two series of laboratory large-scale model tests of the EPS blocks over buried structures under both unreinforced and geogrid-reinforced soil cover to explore the effect of geofoam blocks on system deformations and stress distributions. Their experimental results showed that the EPS performance was most pronounced when higher geofoam density and geogrid reinforcement were implemented. Moghaddas Tafreshi et al., [7] described full-scale experimental tests on high-density polyethylene (HDPE) flexible pipes buried at shallow depth, under simulated traffic loading. Their results indicate that the use of a geocell...
reinforcement beneath the loading surface not only reduces the pressure transferred to the pipe and decreases its deformation but also significantly negates the tendency of the EPS block to increase the soil surface settlement.

The literature above indicated the potential use of EPS blocks on buried pipes, by means of numerical and experimental approaches, but there is yet a lack of practical numerical investigation into the protection of pipes buried in trenches by the combined use both of EPS block and geogrid or geocell reinforcement. That’s why the main goal of this paper to address this combination under a specified approach.

2. Experimental study specifications and results

Experimental analyses were performed by the authors to investigate the effect of EPS geofoam on the behavior of buried pipes. Two experimental analyses were done to form a solid base for the inspection the verification and accurateness of the numerical analyses. A granular soil with maximum grain size and mean grain size of 20 mm and 4.3 mm, which classified as SW according to the Unified Soil Classification System ASTM D 2487-11 [8] with the maximum dry unit weight and the optimum moisture content about 20.42 kN/m³ and 5.1% (ASTM D 1557-12 [9]), respectively, were used. The EPS geofoam block with thickness and width (as a ratio of pipe diameter, D) equals to 0.6D and 1.5D, with a nominal density of 30 kg/m³ implemented in the experimental test. It should be mentioned that the optimum width value has been by some researchers equal to 1.5D [6, 10, 11], and the EPS blocks laid over the buried pipe. A high-density polyethylene pipe (HDPE 100), designed to withstand a pressure of 4 bar, having an outer diameter (D) of 250 mm, a wall thickness (t) of 4 mm and, thus, a Standard Dimension Ratio (SDR) = D/t =40 was selected. The data measurement system was developed to read and record the applied load, loading plate settlement, and pipe deformation automatically. An S-shaped load cell, with an accuracy of ±0.01% and a full-scale capacity of 100 kN, was placed between the hydraulic jack and loading plate to precisely measure the applied repeated load. To measure the average settlement of the loading plate during loading two linear variable differential transducers (LVDTs) with an accuracy of 0.01% of the full range (100 mm) were attached to opposite edges of the loading plate.

To measure the pipe deformation during the test, one LVDT with an accuracy of 0.01% of the full range (75 mm) was installed inside the pipe and under the crown of it. In order to simulate a part of the loads imposed by traffic loading, a load that could replicate that a heavy vehicle half-axle (40 kN) as a common heavy trailer (mean tire pressure 792 kPa) as recommended by Brito et al., 2009 [12] (figure 1) has imposed over a rigid plate with a diameter of 250 mm (equals to pipe outer diameter) placed at the center of the trench.

![Figure 1. The diagram of the applied stress](image-url)
Since compressible inclusion and low volume density are the intrinsic characters of EPS blocks, lessening the applied loads and arching occurrences could happen in the trench. Arching could cause a lessening of the employed stress on the buried pipe and afford a better condition in the feature of pipe protection. Figure 2 shows the maximum pipe crown displacement and soil surface settlement under the proposed load. As shown in the figures, by employing the EPS block in the trench of the buried pipe, the maximum crown settlement of the pipe has a 27.9% reduction. This phenomenon backs to the energy absorption of EPS blocks through their compressible inclusion character. Owing to this fact, the settlement of the loading surface showed an increase that is an indication of the compressible inclusion of the EPS block, which highlights the role of other reinforcement elements for ameliorating this phenomenon. These two experimental analyses employed as a robust basis for numerical analyses, which will discuss in the following section.

![Graphs showing pipe crown displacement and soil surface settlement](image)

**Figure 2.** (a) Pipe crown displacement, (b) Soil surface settlement in front of the imposed load.

3. **Numerical Analysis**

In order to perform the numerical analysis, ABAQUS software selected for our analyses. In this study, material properties and dimensions of models derived from the experimental tests that are done for incipient analyses and verifications.

The numerical models have the same dimension of the physical model. The experimental mentioned load imposed numerically to the soil surface with a diameter of 250 mm representing the area of vehicle tires with the trench surface. The placement of geofoam is modeled according to the predefined tests and proposed numerical analyses, and the dimensions of the trench are sufficient for modeling a large scale pipe that is imposed on a real load from the surface. In the numerical model, sides were immovable in the horizontal direction and set free in the perpendicular direction. Figure 3 (a) and (b) show the typical geometry parameters of the model and full-scale 3D model generated by the software, respectively. In regard to mesh generation, Hexahedral linear elements with reduced integration formulation (C3D8R) were used for soil, EPS block, and geogrid layer. Embedded interaction was utilized between soil and geogrid since embedded interaction provides a situation in which the host region and embedded structure act as a singular unit. Meanwhile, the pipe was modeled with a total number of 2730 elements with a linear Four-node shell element (S4R). The frictional coefficient between the EPS block with trench soils considered as 0.6 [13]. Friction angle value
between the pipe and soil considered as was set to equal to half of the peak frictional angle of soil [14].

![Diagram](image)

**Figure 3.** (a) Typical geometry parameters of the model, (b) Full scale 3D model and its ingredients.

A linear Drucker-Pager model available in ABAQUS was used to simulate the elastic and plastic behavior of the soil. In numerical analyses, Pipe considered as an elastic material, and table 1 shows the values of different parameters for soil, geogrid, and considered pipe. Pipe parameters declared by its production factory. Meanwhile, soil and geogrid parameters were kept in close reliability with the other researches [5, 7]. The geogrid layer has a hexagonal shape with 27 mm × 27 mm and 5.2 mm aperture size and thickness, respectively [5].

**Table 1. Material Properties.**

| material   | Density (kg/m³) | Young’s Modulus (MPa) | Poisson’s Ratio | Friction Angle | Cohesion (kPa) | Dilation Angle | Yield Stress (MPa) |
|------------|-----------------|-----------------------|----------------|---------------|----------------|----------------|--------------------|
| Soil       | 2062            | 45                    | 0.3            | 59.86         | 0              | 12             | ---                |
| Geogrid    | 0.85            | 260                   | 0.3            | ---           | ---            | ---            | 10                 |
| Pipe       | 560             | 1000                  | 0.45           | ---           | ---            | ---            | ---                |
In the Experimental analysis, EPS blocks with a thickness of 0.6D and 1.5D width were used in a density of 30 kg/m$^3$. The elastic limits (under 1% strain) and compressive strengths (10% strain) of EPS geofoam were gained from unconfined uniaxial compressive tests [15] on 200-mm cubic specimen. From the stress-strain figure and its values, the elastic-plastic behaviour converted from the nominal test data into its true values and then decompose the total strain values into elastic and plastic strain components to allow for direct data input into ABAQUS, this approach utilized by the algorithm mentioned by Meguid and Hussein, 2017 [4]. Table 2 shows the values of EPS blocks employed in numerical analyses.

**Table 2. EPS block properties**

| EPS Type | Density (kg/m$^3$) | Modulus of Elasticity (kPa) | Poison’s Ratio | Strength at 10% Plastic Strain (kPa) |
|----------|-------------------|---------------------------|---------------|-------------------------------------|
| EPS 30   | 28.5              | 50                        | 0.3           | 200                                 |

4. Numerical Results

The explicit solver was selected for scrutinizing the system and gaining the results. The gravity is implemented besides the surface loading to have more accurate results. Figure 4 shows the verification of experimental test in which the combination behaviour of soil and pipe in front of the mentioned load has been examined. The results of the numerical analysis have a little discrepancy with the experimental ones. In addition, the behaviour of the EPS block (density 30 kg/m$^3$) has been scrutinized in the situation that the buried pipe is protected by an EPS block laid over the buried pipe. The results of this analysis have a rational trend with experimental ones (figure 5). These results show the numerical procedure, parameters and behaviour of materials have dependable and approached properly.

![Figure 4](image)

**Figure 4.** Verification of the experimental test in the unreinforced condition

5. Effect of a Geogrid Layer

In this section, the effect of a geogrid layer in ameliorating the behavior of the buried pipe will be discussed. In this case, the geogrid layer was used with an EPS geofoam block (30 kg/m$^3$) with a width of 1.5D and a thickness of 0.6D. The geogrid layer with a size of 4.5B (B diameter of the loading plate) dimensions on all sides, was placed at depth of 0.35B beneath the loading surface [16].
The results of this analysis illustrate the role of a geogrid layer in improving the response of buried pipes reinforced by a single geofoam layer. Figure 6 (a) shows the effect of the geogrid layer on the behavior of the pipes and EPS blocks reinforced with a geofoam block and a geogrid layer simultaneously. As it is known, by using the geofoam block, the maximum pipe crown displacement experienced a reduction of about 28%. This amount increases by about 40% by utilizing the geogrid layer. This decrease reflects the effective efficiency of the geogrid layer on the improvement of buried pipes. Meanwhile, figure 6 (b) shows the maximum deformations in the up and down faces of the EPS blocks over their lengths. Owing to this figure, by implementing a geogrid layer over the embedded EPS blocks, the maximum settlement values decreased about 35%, and with this mind, the embedded EPS block has more aptitude to take part in the pipe behavior amelioration. Figure 7 shows the level of surface settlement in the presence of a single geofoam block and geofoam block with a geogrid layer. In this case, the geogrid layer managed to reduce the maximum loading settlement by 33%. Thus, the competent performance of the geogrid reinforced system in reducing the pipe deformation is evidenced as well as that in decreasing the soil surface settlement.

Figure 5. Verification of the experimental test in the reinforced condition
Figure 7. The level of surface settlement in the presence of a single geofoam block, a geofoam block with a geogrid layer, and unreinforced situation

6. Conclusions
Understanding the behavior of buried pipes and ameliorating has been an ongoing subject of debate between researchers since buried pipes have a direct link by every society because of their importance. In this regard, amendment and inspection of buried pipe responses and behaviors are so important. In the of amelioration, geosynthetics materials are so recognized and accepted approach for amending buried pipe responses under versatile loading conditions having sufficient potential to make a damage in buried-pipe serviceability. This paper following the method of numerical and experimental analyses by implementing a geofoam EPS block and a geogrid layer in a buried pipe trench under a specified trench surface loading. The results indicate:

- With employing a geofoam EPS block in the trench of the buried pipe, the crown of the pipe showed a 27.9% settlement reduction under the trench surface loading,
- With employing a geofoam EPS block in the trench of the buried pipe, the settlement of the loading surface showed an increase that is an indication of the compressible inclusion of the EPS block.
- By using a geogrid layer in the optimum depth and dimensions, the maximum pipe crown displacement experienced an increase of about 40%.
- By implementing a geogrid layer over the embedded EPS blocks, the maximum settlement values decreased about 35% than the situation in which the EPS block is the only reinforcement element.

Acknowledgment
The present contribution has been prepared under project LO1502 “Development of the Regional Technological Institute” under the auspices of the National Sustainability Program I of the Ministry of Education of the Czech Republic aimed to support research, experimental development and innovation.

References
[1] A. F. Elragi, "Selected engineering properties and applications of EPS geofoam," ed: State University of New York. College of Environmental Science and Forestry …., 2000.
[2] S. N. Moghaddas Tafreshi and O. Khalaj, "Laboratory tests of buried plastic pipes in sand under repeated-load," in *International Conference on Geomechanics and Geotechnics of Particulate Media*, 2006.

[3] O. Khalaj, N. J. Darabi, S. M. Tafreshi, and B. Mašek, "Protection of Buried Pipe under Repeated Loading by Geocell Reinforcement," in *IOP Conference Series: Earth and Environmental Science*, 2017, vol. 95, no. 2, p. 022030: IOP Publishing.

[4] M. Meguid, M. J. I. J. o. G. Hussein, and G. Engineering, "A numerical procedure for the assessment of contact pressures on buried structures overlain by EPS geofoam inclusion," vol. 3, no. 1, p. 2, 2017.

[5] M. Abdollahi, S. Moghaddas Tafreshi, and B. J. G. I. Leshchinsky, "Experimental-numerical assessment of geogrid-EPS systems for protecting buried utilities," vol. 26, no. 4, pp. 333-353, 2019.

[6] M. Azizian, S. M. Tafreshi, N. J. J. S. D. Darabi, and E. Engineering, "Experimental evaluation of an expanded polystyrene (EPS) block-geogrid system to protect buried pipes," vol. 129, p. 105965, 2020.

[7] S. Moghaddas Tafreshi, N. Joz Darabi, A. Dawson, and M. J. I. J. o. G. Azizian, "Experimental Evaluation of Geocell and EPS Geofoam as Means of Protecting Pipes at the Bottom of Repeatedly Loaded Trenches," vol. 20, no. 4, p. 04020023, 2020.

[8] D. J. A. B. o. A. S. Astm, "2487, Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)," vol. 4, pp. 206-215, 2011.

[9] D. J. W. C. Astm, USA, "1557. Standard test methods for laboratory compaction characteristics of soil using modified effort," 2012.

[10] H. Kim, B. Choi, and J. J. G. T. J. Kim, "Reduction of earth pressure on buried pipes by EPS geofoam inclusions," vol. 33, no. 4, pp. 304-313, 2010.

[11] O. Khalaj, S. N. M. Tafreshi, B. Masek, and A. R. Dawson, "Improvement of pavement foundation response with multi-layers of geocell reinforcement: Cyclic plate load test," (in English), *Geomechanics and Engineering*, vol. 9, no. 3, pp. 373-395, Sep 2015.

[12] L. Brito, A. R. Dawson, P. J. P. o. t. t. I. o. t. B. C. o. R. Kolisoja, Railways,, and C. I. Airfields , USA, "Analytical evaluation of unbound granular layers in regard to permanent deformation," pp. 187-196, 2009.

[13] V. Xenaki and G. J. G. I. Athanasopoulou, "Experimental investigation of the interaction mechanism at the EPS geofoam-sand interface by direct shear testing," vol. 8, no. 6, pp. 471-499, 2001.

[14] S. Yimsiri, K. Soga, K. Yoshizaki, G. Dasari, T. J. J. o. g. O’Rourke, and g. engineering, "Lateral and upward soil-pipeline interactions in sand for deep embedment conditions," vol. 130, no. 8, pp. 830-842, 2004.

[15] D. J. A. S. f. T. ASTM and N. Y. Materials, "1621, Standard Test Method for Compressive Properties Of Rigid Cellular Plastics," 2010.

[16] S. Moghaddas Tafreshi, O. Khalaj, and A. J. G. I. Dawson, "Pilot-scale load tests of a combined multilayered geocell and rubber-reinforced foundation," vol. 20, no. 3, pp. 143-161, 2013.