Laboratory Investigation of Buried Pipes Using Geogrid and EPS Geofoam Block

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Abstract. This paper describes the results of laboratory tests conducted on flexible PVC pipes with diameter of 160 mm, buried in unreinforced and reinforced trench with geogrid layer and expanded polystyrene (EPS) geofoam block. The repeated load with amplitude of 450 kPa and frequency of 0.33 Hz was applied on the trench surface, using plate loading at a diameter of 150 mm to simulate the vehicle loads. Vertical diameter strain (VDS), strain at pipe's crown and transferred pressure on the pipe's crown were recorded throughout the test for up to 500 cycles of loading. The variables examined in the testing program include thickness of EPS block (30, 60 and 100 mm) and its density (10, 20 and 30 kg/cm^3). The pipes were embedded at depths 1.5 times their diameter and the width of EPS block was kept constant at 2.0 times the pipe diameter in all tests. The results show that the values of VDS and pipe strain increased rapidly during the initial loading cycles, thereafter the rate of deformation and strain reduced significantly as the number of load cycles increased. According to the results, the minimum VDS and pipe's crown strain were provided by 100 mm thickness and 30 kg/cm^3 of EPS block placed over the pipe with a geogrid layer giving values of, respectively, 0.15 and 0.10 times those obtained in the reinforced trench with a geogrid layer.

1. Introduction

Expanded polystyrene (EPS) geofoam as a lightweight material with the density about a hundreds of soil has been used in engineering applications since 1950s. EPS geofoam is utilized in (1) reducing settlement below embankments, (2) sound and vibration damping, (3) reducing lateral pressure on sub-structures, and (4) reducing stresses on buried conduits and related applications [1].

Improvement behaviour of buried pipes against applied loads have been studied by many researchers [2-8]. In all cases, EPS blocks or geogrid layers show significant improvement in the behaviour of buried pipes when use inside the soil mass above pipe. Kim et al. [2010] addressed the pressure reduction on the crown of buried pipe under the static loading, due to use of EPS blocks over the buried pipes. The model test shows that the width of EPS block influences the pressure acting on the pipe's crown. They reported the optimal width of EPS block approximately of 1.5 times the pipe diameter. Anil et al. (2015) investigated the performance, strength and energy absorption capability of EPS block over the buried pipes against impact forces. Their investigation is done by using drop weight impact testing apparatus. The results show all protective layers affected the behaviour of pipes positively. However, the best performance was obtained from the thickest EPS block. Hedge and Sitharam [2015] conducted experimental studies to explore the possibility of using combination geocell and geogrid reinforcement system in protecting a buried pipe. Their results show the use of both geocell and geogrid reinforcements have more significant reduction in the deformation of the pipe as compared with alone geocell or geogrid. Moghaddas Tafreshi and Khalaj, [2008] investigated the behaviour of buried flexible plastic pipes in geogrid reinforced sand under repeated loadings. They reported that the rate of pipe deformation decreases significantly as the loading cycles increase and the optimum embedded depth of the first reinforced layer is approximately 0.35 times of the loading surface width.

Given the potential of geosynthetic reinforcement and EPS geofoam block to provide the improved behaviour of buried pipe in the previous section, a series of tests were performed to evaluate the performance of buried pipes subjected to repeated loading, when supported by both geogrid reinforcement and EPS block, simultaneously.

2. Material Properties

2.1. Soil

The used soil in the trench (around and above the pipe) has a gradation curve as shown in 'Figure 1'. The maximum and average particles size of the soil was 9.8 mm and 2.2 mm, respectively. Note the size of the soil particles is based on the ASTM D 2321-08 standard which limited the grain size of soil around the pipe to be maximum 38 mm. The soil is classified as well-graded sand (symbolized as SW) in the Unified Soil Classification System (ASTM D 2487-11). According to the standard proctor compaction test (ASTM D 1557-12), maximum density and optimum moisture content of the soil were 21.5 kN/m^3 and 9.5%, respectively.

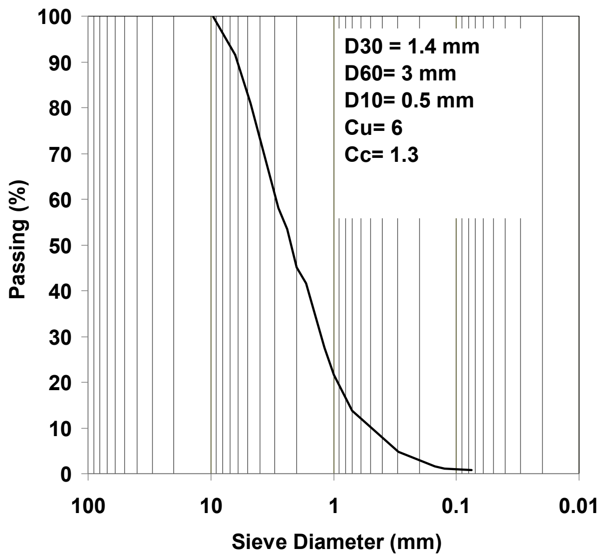


Figure 1. Gradation of trench soil

2.2. Geofoam

In order to take the advantage of EPS materials properties such as lightweight features and energy absorption capabilities, EPS blocks with a rectangular cross section at three densities of 10, 20 and 30 kg/m^3 were buried over the pipe. 'Figure 2' shows the stress-strain relation of three uniaxial tests on EPS blocks with three densities and with dimensions of 5*5*5 cm under strain controlled conditions. As seen in this figure, with increase in the strain level, the strain hardening behaviour would be visible (Ossa and Roma, 2009).

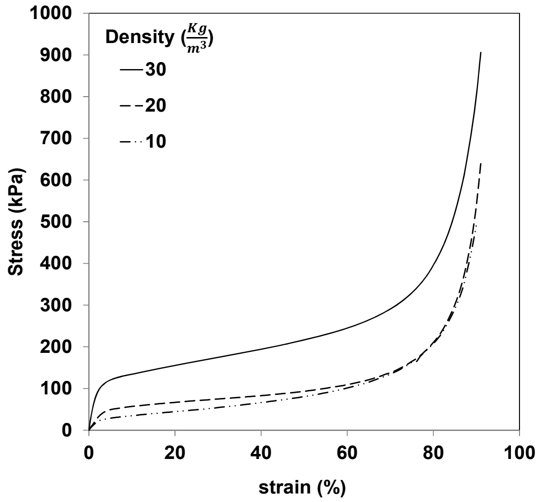


Figure 2. stress- strain behaviour of EPS blocks

'Figure 2' shows that the compressive strength of EPS blocks at 10% strain are 34, 57.1 and 134.3 kPa for three densities of 10, 20 and 30 kg/m^3, respectively. This shows that the compressive strength varies non-linearly with density of EPS blocks. This is in line with the ASTM C 578-95.

2.3. Geogrid

To investigate the effect of soil reinforcement on the behaviour of buried pipe, one layer of geogrid was used in the tests. The engineering properties of this geogrid are presented in Table 1.

Table 1. Engineering properties of geogrid

Aperture Figure	Thickness (mm)	Aperture Size (mm)	Mass Per Unit Area (gr/m^2)	Ultimate Tensile Strength (kN/m)
hexagonal	5.2	27*27	695	5.8

2.4. Pipe

The tests were conducted on PVC pipes with ratio of pipe diameter to thickness equal to 50. These pipes are practical for swage and drainage. In this study, the pipes had 160 mm external diameter, 3.2 mm wall thickness and 980 mm length. To prevent binding against the end walls of testing tank, the length of the pipe was 20 mm less than the length of the stiff tank.

3. Test apparatus

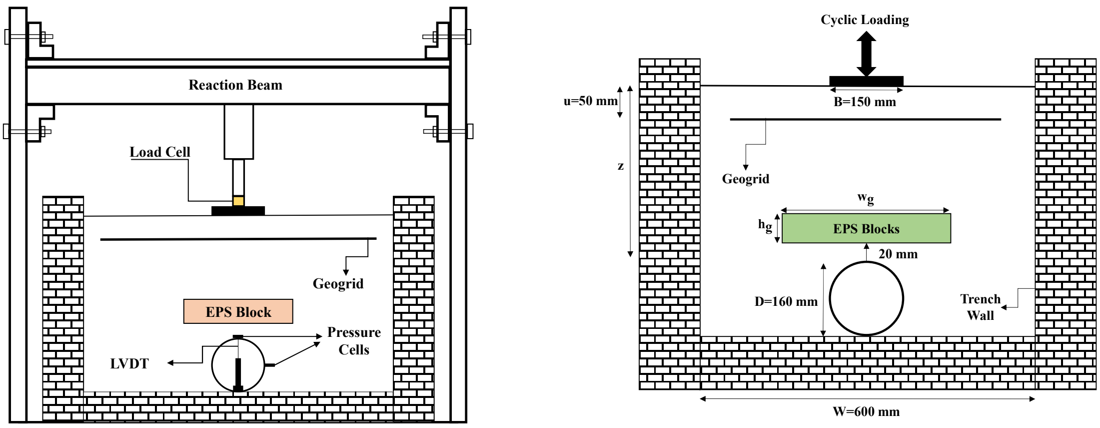
The test apparatus consists of three main parts, (1) test tank, (2) loading system and (3) data acquisition system. The test tank has the length, width and height of 1000 mm. To monitor the pipe behaviour, transparent glass (plexiglass) was used in one side of testing tank, perpendicular to the longitudinal pipe axis. Loading system consists of a hydraulic cylinder which can produce static and cyclic loading up to 10 kN. Data acquisition system controls the whole system within internal processor which records all the output data streams from different sensors (e.g. load cell, strain gauge, pressure cells and LVDTs). The trench contains the reinforced soil, EPS block and model pipe testing, was prepared in the testing tank. The trench has a width of 600 mm, length 1000 mm and its height varies depending on the embedment depth of the buried pipe.

Based on ASTM D 2321-08 recommendation, the width of the trench should be at least equal to (W=1.25D+300). According to AASHTO (2010) the minimum width of the trench should be greater than the values represented in Eqs. (1) and (2).

$$W = 1.5D + 305 \tag{1}$$

$$W = D + 406 \tag{2}$$

W and D are respectively the minimum trench width (in mm) and pipe diameter (in mm). Thus, to satisfy the minimum width defined by the Standards, trench width of 600 mm is selected. ‘Figure 3’ shows the schematic view of the experimental model setup and parameters were used in the experiments.



(a) (b)

Figure 3. (a) test setup (b) geometry and test parameters

4. Preparation of Testing Model

Soil density in trench was 18.5 kN/m^3 with 6% moisture. With regard to the uniform trench, soil pouring was compacted in several layers. Each layer had 20 mm thickness and they compacted uniformly by dropping weight of 5.5 pounds over a metal plate with dimensions of 300 × 100 mm (in direction of trench length). The density of the soil layers was controlled by weighing the amount of the required soil and flexible rulers were mounted on the walls of trench. It is notable that the density and moisture of the soil layers in trench (about 88% relative compaction) was according to ASTM D 2321-08 that limits the minimum relative compaction of SW soil in the buried pipe trench to 85%. In the reinforced trench, when the soil level was reached to the springline and crown of the pipe, the pressure cells were implemented. EPS blocks were also installed over a 20 mm soil layer which was compacted over the buried pipe crown. Geogrid layer was implemented at depth of 0.33B (B= diameter of loading plate) beneath the loading surface (Moghaddas Tafreshi and Khalaj; 2008). When the soil surface reached to the required level, a rigid loading plate with a diameter of 150 mm and thickness of 25 mm was placed over the center of trench and the related sensors were adjusted. In all the tests, the repeated loading with an amplitude of 450 kPa and frequency of 0.33 Hz was applied on the loading plate to simulate the vehicle loading.

5. Testing program
Table 2 shows the details of testing program. In all tests, the pipe was embedded at the depth of 1.5D (D= pipe diameter) and the width of EPS block was kept constant at 2.0D.

Table 2. Details of testing programs

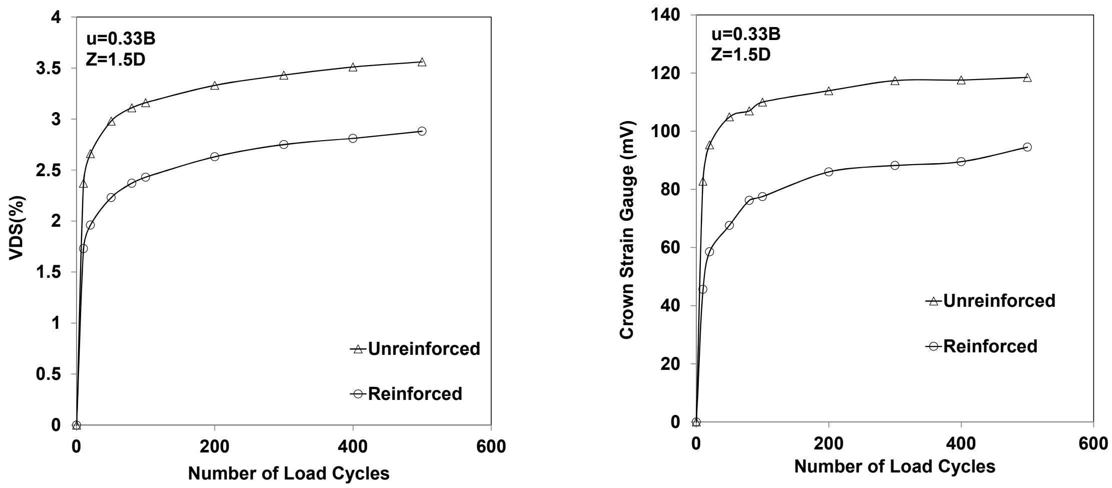
Test Condition	EPS Thickness (mm)	EPS Density (kg/m^3)	No of Test.
Unreinforced			1+1*
Geogrid reinforced	————	————	1+1*
EPS block in addition to geogrid layer	100 100 30,60,100	10 20 30	5+4*

*The tests which were performed two or three times to verify the repeatability of the test data

One of the important issues in laboratory studies is repeatability of results to ensure accuracy in measuring the input and output parameters. For this reason, some tests were repeated to monitor system performance and its accuracy. Repeated test results show the small difference (less than 6%) which is negligible in geotechnical applications.

6. Results and discussion
In this section the test results of the laboratory model are represented and discussions are made for determining the effect of different parameters on the buried pipes behaviour. Since the main criteria of the flexible pipes safety are their deformation (Moser and Folkman, 2001), the VDS of the pipe diameter is considered as the most significant and important factor.

6.1. The effect of geogrid layer
To reduce the pipe deformation, a layer of geogrid was laid at the optimum depth beneath the loading surface. The length and width of geogrid layer was equal to the trench proportions. The results in 'Figure 4' show that the values of VDS and pipe strain increases rapidly during the initial loading cycles, thereafter the rate of deformation and strain decrease significantly with increase in the number of load cycles. For the reinforced test with geogrid layer, maximum vertical diameter strain (VDS) of pipe at the end of the loading cycle has 19% reduction compared to the unreinforced condition. Reduction in the VDS of the buried pipes is originated from the geogrid effects such as membrane effect and stress redistribution which would reduce the transferred stress over the buried pipe. As seen in 'Figure 4', the reduction trend in the circumferential crown strain of the pipe is parallel to the VDS. Pipe buried in geogrid reinforced trench shows 20% reduction in maximum circumferential strain of pipe's crown compared to the unreinforced condition.



a) b)

Figure 4. Variation of the (a) maximum VDS and (b) maximum crown strain of the pipes buried in unreinforced and geogrid reinforced trench with number of load cycle

Table 3 shows the maximum vertical pressure acting on the crown and on the sides (springline) of the pipes at the end of cyclic loading for both unreinforced and reinforced installations. As seen with implementation of a geogrid layer, transferred vertical pressure on side and crown of the pipe decrease.

Table 3. Maximum transferred vertical pressure in the crown and side of the pipes at the end of the load cycle for unreinforced and reinforced trench with a geogrid layer conditions.

Test Condition	Pressure (kPa)	
	Springline	Crown
Unreinforced	20	45
Geogrid Reinforced	17	35

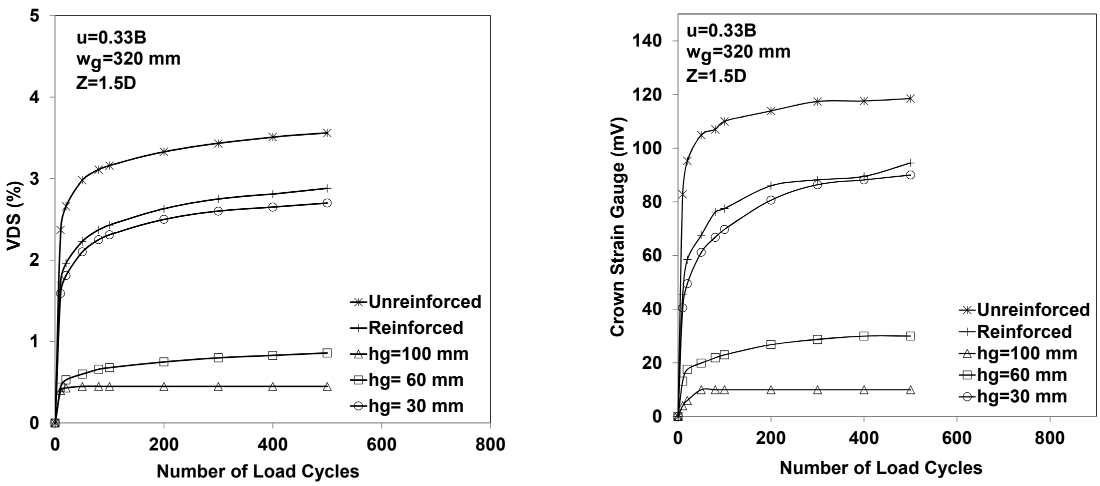
6.2. The effect of EPS block and geogrid layer

Due to the ultra-lightweight EPS blocks and its compressibility, arching phenomena could occur in the trench. Arching could cause a reduction of the exerted stress on the buried pipe and provides a better situation in aspect of pipe protection. In this section, the effect of the EPS blocks thickness and their density on behaviour of the buried pipes was examined.

6.2.1. The effect of EPS block thickness

'Figure 5' shows the variation of maximum VDS and maximum strain of pipe's crown with the number of load cycle for different installations of EPS block and geogrid layer.

This figure shows with increase in thickness of the EPS block, the VDS and crown strain values of the pipe increase. In the last cycle of loading, the minimum VDS and minimum pipe's crown strain are provided by 100 mm thickness of EPS block and geogrid layer giving 84.4% and 89% reduction respectively, in comparison with those obtained in the reinforced trench with a geogrid layer.



a) b)

Figure 5. Variation of the (a) maximum VDS and (b) maximum crown strain of the pipes buried in unreinforced, geogrid reinforced and EPS block plus geogrid reinforced trench with the number of load cycle

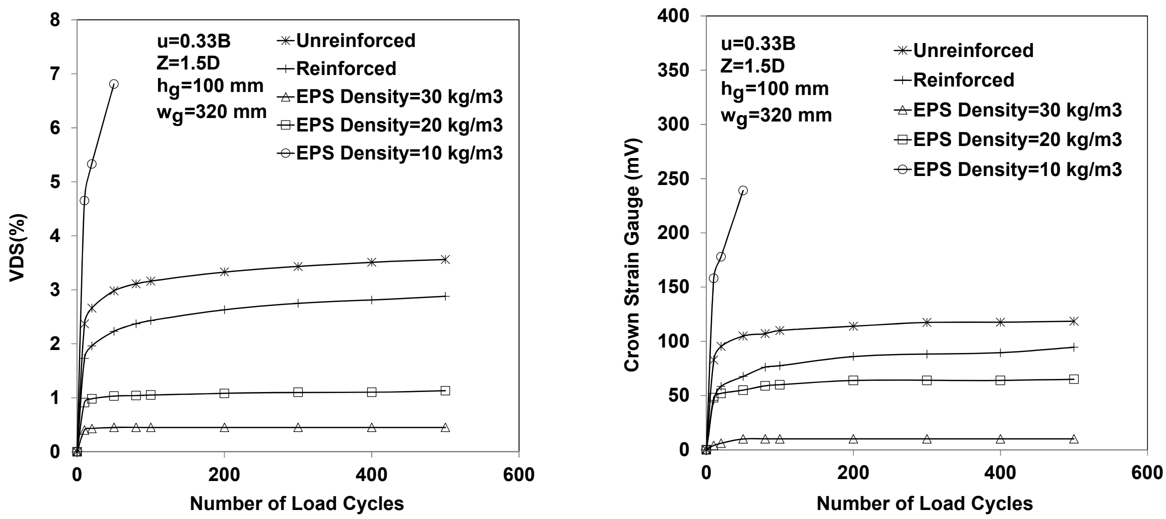
6.2.2. The effect of EPS block density

EPS blocks with a thickness of 100 mm and 320 mm width were used in three densities of 10, 20 and 30 kg/m^3. With increase in the density of EPS blocks the area under the strain–stress diagram (figure 2) increases, thus the growth in the block ability for energy absorption would be expected.

'Figure 6' shows the variation of the maximum VDS and pipe's crown strain with the number of loading cycles for different densities of EPS block. Table 4 shows the maximum reduction in the VDS and crown strain values of the pipes for the trench including EPS block and geogrid layer compared with those obtained for the reinforced trench by a geogrid layer. 'Figure 6' and Table 4 show that with increase in the density of the EPS block, the VDS and crown strain values of the pipe significantly decrease. For example, with decrease in the density of EPS block from 30 to 10 kg/m^3, the rupture was happened in the pipe. It could be attributed to the lack of sufficient resistance at low density of EPS block (10 kg/m^3), punching in EPS block and consequently large transferred stress on the pipe.

Table 4. Maximum percentage reduction in VDS and crown strain values of pipe for the trench including EPS block and geogrid layer compared with those obtained for the reinforced trench by a geogrid layer (hg=100 mm)

EPS Density (kg/m3)	VDS	Crown Strain
10	Pipe rupture	Pipe rupture
20	60.7%	57%
30	84.4%	89%



a) b)

Figure 6. Variation of the (a) maximum VDS and (b) maximum crown strain of the pipes buried in unreinforced, geogrid reinforced and EPS block plus geogrid reinforced trench with the number of load cycle

Table 5 shows the maximum vertical pressure acting on the crown and side of the pipes at the end of cyclic loading for different installation. As seen with increase in density of EPS block, the transferred pressure on the crown and side of the pipe decreases. Decrease in pressure acting on the pipe's crown has the same trend with pipe crown strain and VDS.

Table 5. Maximum transferred vertical pressure in the crown and side of the pipes at the end of the load cycle for different conditions

Test Condition		**Pressure (kPa)**	
		Springline	**Crown**
Geogrid Reinforced plus EPS block with density of	30 kg/m^3	4	8
	20 kg/m^3	15	-------
	10 kg/m^3	37	125

7. Conclusion

One of the practical advantage of Expanded Polystyrene (EPS) blocks are their performance in stress attenuation on buried conduits and pipes. This paper addressed the effect of EPS blocks and geogrid layer on the behaviour of the buried pipes subjected to the simulated traffic load. The results could be summarized as follow:

- In the geogrid reinforced system, the vertical diameter strain (VDS) and circumferential crown strain of the buried pipe at the end of the loading cycle have 19% and 20% reduction respectively, as compared with the unreinforced system.
- With increase in the thickness of the EPS block, the vertical diameter strain (VDS) and pipe crown strain decreases. For example, with increase in the thickness of EPS block from 30 mm to 100 mm, the VDS value have 83% reduction.
- With decrease in the density of the EPS block, the vertical diameter strain (VDS), pipe crown strain and vertical pressure in crown and side of the pipe increase. The results show that for the low density of the EPS blocks (e.g. 10 kg/m^3), rupture in the pipe would be anticipated.

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