Experimental Investigation on The Efficiency of Expanded Polystyrene (EPS) Geofoam and Geogrid in Protection of Buried Pipes under Static Loading

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Abstract— **Underground utility pipes form a complex network in urban areas. These buried structures are often subjected to damage and deformation due to repeated traffic loads. The aim of the study is to evaluate the efficiency of Expanded Polystyrene (EPS) Geofoam and combination of EPS with geogrid in protecting the buried pipes i.e., the suitability of the reinforcements to offer significant load bearing capacity and in reducing the strain on the pipes. A series of plate load tests were conducted on PVC pipes buried in unreinforced condition and reinforced with EPS of varying densities (15, 20 and 30 kg/m^3) and a combination of both EPS and geogrid. The vehicle tyre contact pressure was simulated by applying pressure on top of the bed with the help of a steel plate. The depth of placement of pipe was varied between 1B to 2B (B is the width of the steel plate). The load carrying capacity increased from 50% to 90% with an increase in density of EPS from 15 to 30 kN/m^3. The maximum load carrying capacity was observed with the combination of EPS and geogrid with an increase of 20% when compared to using EPS reinforcement only. As the depth of the pipe increases, the settlement increases and the bearing capacity decreases in all the cases. Compared to unreinforced condition, 34% reduction in strain was obtained when the bed was reinforced with EPS 30 and a reduction of 48% when the combination of EPS with geogrid was used as reinforcement.**

Keywords—utility pipes, Expanded Polystyrene Geofoam, Geogrid, plate load test, strain

I. INTRODUCTION

Pipelines are the safest and most economical means to transport gas, water, sewage and other fluids. The design of the pipelines depends upon the flow requirements and operating pressures. These pipelines or conduits are usually buried at shallow depths in trenches below the pavements with the help of flowable fills. The buried structures are often deformed and damaged due to the application of repeated traffic or heavy static vehicle loads. The damage of the buried pipes may cause significant material loss and destruction of the pipeline which leads to the discomfort of consumers of the utility and also to the travelers on the road. Nowadays, protecting the buried pipes and underground utilities using geosynthetic reinforcement is gaining popularity in geotechnical engineering. Moghaddas Tafreshi and Khalaj (2008) conducted laboratory model tests on small diameter pipes reinforced with geogrid in sand under repeated loading. Researchers observed that the usage of geogrid instantly reduced the deformation of the buried pipes.

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Palmeira and Andrade (2010) used the combination of geotextile and geogrid in the protection of buried pipes against accidental damages. It was observed by the researchers that the reinforcement offered significant resistance to sharp, penetrating objects and abruptly helped in the protection of the buried pipes.

In the modern years, EPS geofoam is been used in several geotechnical applications (Steven Floyd and Bret N Lingwall, 2014; Masood Abdollahi and Moghaddas Tafreshi., 2018). EPS is a cellular geosynthetic material which serves various functions like thermal insulation, lightweight fill, compressible inclusion and wave damping. The use of EPS has been extended in underground applications, mainly due to two reasons. Firstly, due to its very low mass density about 10 to 40 kg/m^3 which instantly reduces the vertical and horizontal loads on buried structures, underground utilities, retaining walls etc. Secondly, due to its relatively uniform compressibility, it can be used as 'compressible inclusion' in geosynthetic under static, monotonic and cyclic loading. In this technique 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 upon application of external stresses, the geofoam compresses to reduce static and dynamic loadings exerted against buried structure.

In the present study, contrary to the previous papers, the combination of EPS and geogrid was used to protect the underground utilities and buried pipelines. The model tests were carried out on EPS geofoam samples of varying density. Depth of placement of pipe was varied and the corresponding effect was observed.

II. MATERIALS USED

A. Sand

Sand used in the experiment was river sand which was collected from Pathanamthitta district with specific gravity 2.78, effective particle size (D_{10}) 0.45 mm, coefficient of uniformity (C_u) 4, coefficient of curvature (C_c) 1, maximum void ratio (e_{max}) 0.81 and minimum void ratio (e_{min}) of 0.51. According to Indian Standard Classification (ISC) the sand was classified as well graded with symbol SW. Figure.1 represents the grain size distribution of sand used in the study. The sand was obtained as medium dense sand with relative density of 50%. To achieve the desired relative density, the height of fall of sand was 35 cm.

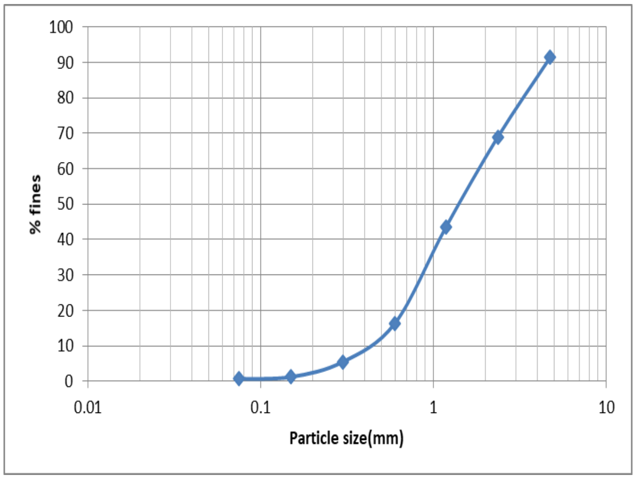

Fig 1. Grain size distribution curve of sand

B. EPS Geofoam

EPS block purchased from is shown in Figure 2. EPS geofoam density being a determinate index of EPS block plays a vital role in the value of compression strength, flexural strength, stiffness, and other mechanical properties of EPS. Therefore, three densities of EPS (15, 20 and 30 kg/m^3) are used to study the effect of geofoam density on reinforcing the buried utility. The physical properties of EPS with varying densities according to AS 1366, Part 3-1992 are given in Table 1.

TABLE I PROPERTIES OF EPS

Property	***Unit***	***EPS15***	***EPS20***	***EPS30***
Density	kg/m^3	15	20	30
Compression at 10% deformation	kPa	60	100	165
Shear strength	kPa	190	270	460
Tensile strength	kPa	200	280	440
Co-efficient of friction	-	0.5	0.5	0.5
Young's modulus	kPa	4000	6000	10000

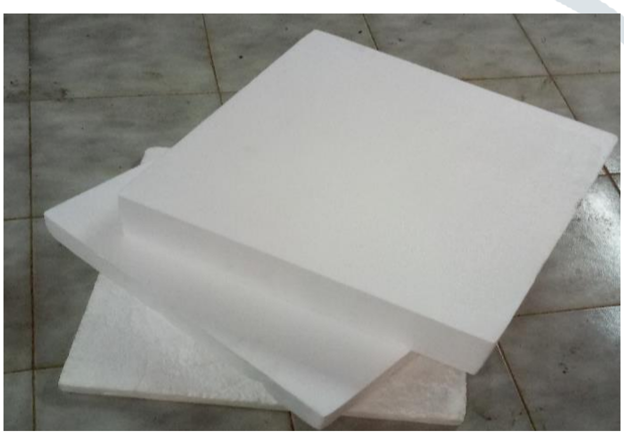

Fig 2. EPS geofoam of various densities

C. Geogrid

The biaxial polypropylene geogrid used as soil reinforcement in the study was collected from Ernakulam and is shown in Figure 3. The properties of geogrid as provided by the manufacturer is summarized in Table 2

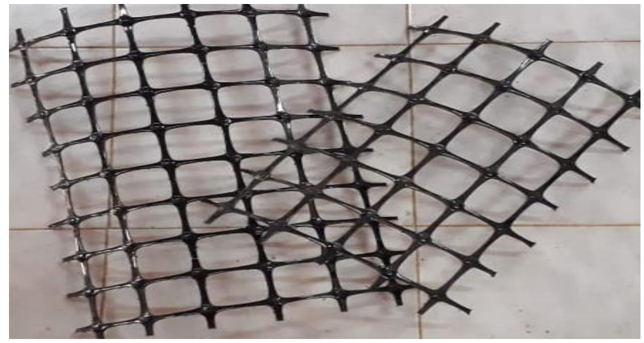

Fig 3.The photograph of the geogrid

TABLE 2 ENGINEERING PROPERTIES OF GEOGRID

Description	***Value***
Material	polypropylene
Material thickness (mm)	5.2
Ultimate tensile strength (kN/m)	5.8
Aperture size (mm)	20 x 20

D. Flexible PVC Pipe

The pipe used in the model test was made up of PVC (Polyvinyl Chloride) with external diameter 0.5 B i.e. 50 mm and thickness 1.2 mm.

III. TEST PROGRAM

A. Preparation of the Sand Bed

The sides of the test tank were covered with polythene sheets to avoid side friction. Prior to the start of the actual test, a series of trials were conducted to determine the height of fall required to achieve relative density. A calibration chart was prepared by obtaining the maximum and minimum void ratios of sand. All the tests were conducted at a relative density of 50%. The height of fall required to achieve 50% relative density was directly obtained from the chart. The pipe and the reinforcements were placed at predetermined depths during the preparation of the test bed. The pipe was placed at full width and covered with cap at both ends to prevent the entering of the sand. After attaining the desired height of the bed, the fill was levelled using a trowel without disturbing the density of the bed.

B. Experimental Setup

The experiments were conducted in test tank of 50 cm length, 50 cm in width and 60 cm in height made up of mild steel. The vehicle tire contact pressure was simulated by applying the pressure on the top of the bed with the help of a steel plate. The steel plate used for the purpose was square shaped with thickness 10 mm and 100 mm sides. The load was applied manually. A pre-calibrated proving ring was used to measure the applied load. Dial gauges were placed on either side of the steel plate to measure the plate settlement. Loading was continued for 10 mm (10% of width of steel plate) settlement of plate. Loading arrangement is shown in Figure 4.

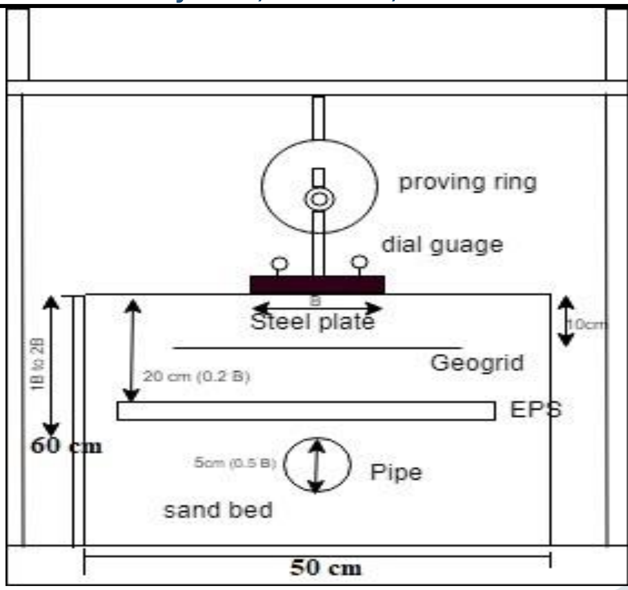

Fig 4. Schematic representation of the test setup

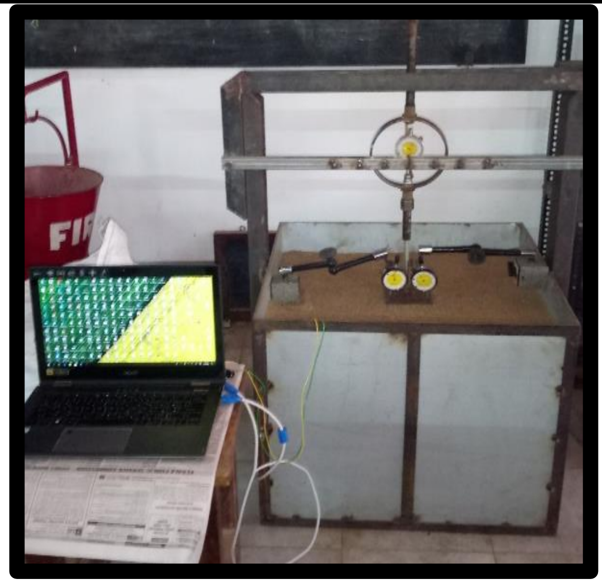

Fig 5. Loading with strain guage installation

C. Installation of Strain Guage

Strain gauge was mounted on the top surface of the pipe using commercial adhesives and insulation tape. Strain gauges had a normal resistance of 120 ohm, 10 mm guage length and maximum measuring capacity upto 1.5% strain. In the setup, Arduino Uno model was used as a microcontroller. The strain sensor with 5 volt supply was connected directly to the Arduino board and the communication with Arduino board is done through a serial data transfer. The code for Arduino is written in C++ language. The Arduino board acts as a voltage divider and helps in displaying the variation of strain on pipe. The values of strain on application of load are displayed on the monitor screen. Mounting of strain guage on pipe is shown in Figure 5 and loading arrangement with strain guage installation is shown in Figure 6.

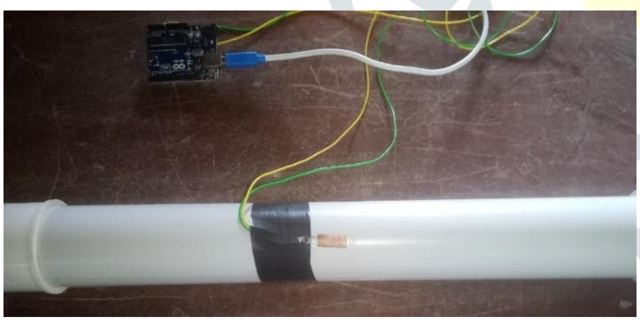

Fig 4 Mounting of strain guage on the pipe

D. Laboratory Plate Load Tests

A series of plate load tests were conducted in the unreinforced condition, then reinforcing the bed with different densities of EPS (15, 20 and 30 kg/m^3) and for a combination of EPS block and geogrid at a constant depth of pipe burial (1.5 B). The trial was then repeated by varying the depth of placement of the pipe from 1B to 2B, where B is the width of the steel plate. EPS geofoam was placed at constant depth of 0.2 B i.e. 20 cm and geogrid at 10 cm from the top of the sand bed.

IV. Results And Discussions

The efficacy of different densities of EPS, combination of EPS and geogrid reinforcements and burial depth of the pipe in the protection of the pipe are investigated in this particular section.

A. Effect of Reinforcements

The model study is conducted for both reinforced and unreinforced cases. The observing parameters are plate settlement and strain on pipe for different loading, under different reinforcement conditions. Figure 6 shows the load carrying capacity of soil for different reinforcement conditions and unreinforced condition.

The ultimate load carrying capacity of sand in unreinforced condition was obtained as 88 kPa. More than 50% increase in load carrying capacity was obtained when the bed was reinforced with EPS. The EPS being an inclusive compression material, upon application of external stresses, the geofoam compresses to reduce the load exerted against the buried pipe. The load carrying capacity increased by 45% with an increase in density of EPS from 15 to 30 kN/m^3. The higher density of EPS geofoam develops a high compressive strength. Flexural strength of EPS geofoam increases with increase in density.

The maximum load carrying capacity was observed when the bed was reinforced with the combination of EPS and geogrid with an increase of 20% when compared to EPS only. The inclusion of geogrid in addition to EPS contributes in improving the overall performance of the bed by resisting the downward movement of soil due to loading by virtue of membrane mechanism, providing confinement effect to the soil, thereby increasing the strength of soil.

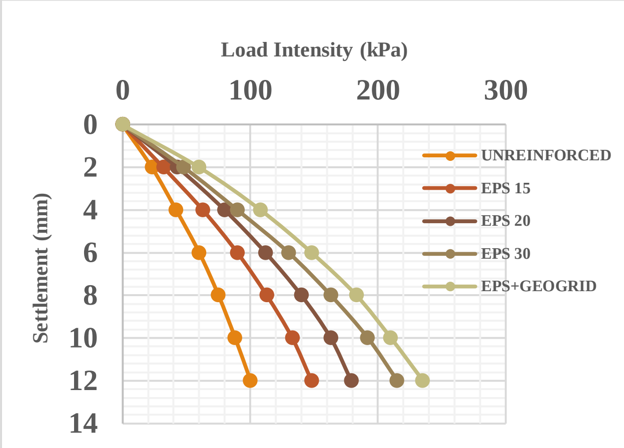

Fig 6. Variation of load carrying capacity with plate settlement for different types of reinforcement

Strain acting on pipe for different conditions were compared for the same load intensity (load carrying capacity of unreinforced load). A reduction in strain was observed as the pipe was reinforced with EPS. The strain values kept on decreasing as the density of EPS increased. Compared to unreinforced condition, 34% reduction in strain was obtained when the bed was reinforced with EPS 30. The least strain on pipe was observed when the combination of eps with geogrid was used as reinforcement. Compared to the unreinforced condition, 48% reduction in strain was obtained when the combination of EPS and geogrid was used. Figure 7 shows the variation of strain on pipe with loading for the various cases.

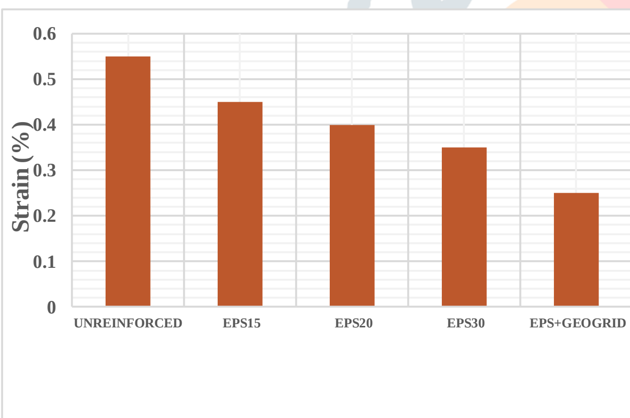

Fig 7. Comparison of strain on pipe for different loading conditions

B. Effect of Depth of Pipe Burial

The EPS geofoam with additional geogrid found to provide better protection to buried pipe as compared to other type of reinforcements. Hence, in this section the burial depth of pipe was varied between 1B, 1.5B and 2B in the presence of EPS 30 and geogrid. The objective of the depth variation was to understand and compare the load intensity and strain values experienced by the pipe at different depths. Figure 8 represents the variation of load intensity with plate settlement at different depth of placement of pipe. The performance of the sand bed was found to be influenced by the position of the pipe even in the presence of relatively stiff reinforcement. As the depth of the pipe increases, the load intensity for the required settlement also decreases in all cases. As the pipe stiffness is relatively higher than that of the reinforcement system, the pipe itself acts as a reinforcement along with the use of geosynthetics. Figure 8 represents the measured load intensity of the plate at different depth of placement.

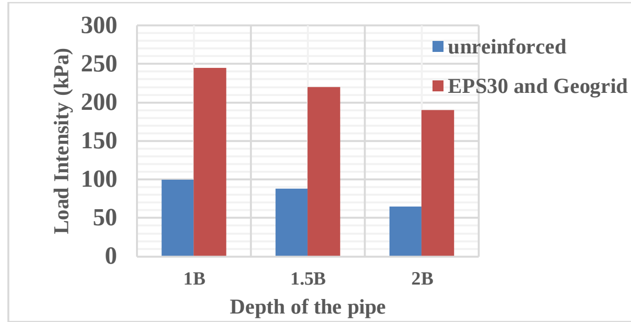

Fig 8. Load carrying capacity for different depth of placement

The measured strain values are corresponding to the applied load of 88 kPa, which is nothing but the ultimate load carrying capacity of the unreinforced bed. The strain values was found to have a small decrease from 0.6 to 0.45 % for different depths for the unreinforced case and 0.27 to 0.23 % for the reinforced case. Figure 9 shows the strain values at the top of the pipe for different depth of placement of pipe.

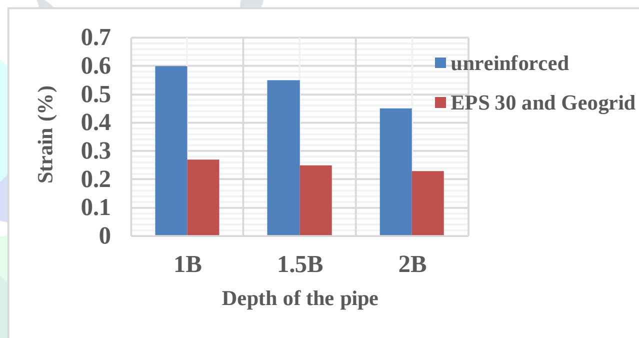

Fig 9. Strain values for different depth of placement of pipe

The observed load intensity and strain values indicate that the provision of the EPS with geogrid significantly reduces the depth of placement of the pipe. In the broader aspect, the study have a wide implications in reducing the installation costs of the buried pipe in large projects where pipelines are laid along several kilometers.

VI. CONCLUSIONS

This paper presented a laboratory model study to explore the possibility of using the ground reinforcements such as EPS and geogrid reinforcements in protecting the underground utilities. The main conclusions obtained are summarised as follows.

- The presence of EPS geofoam reinforcement significantly increased the load carrying capacity. The load carrying capacity was also found to increase with an increase in density of the geofoam. The maximum bearing capacity was obtained when the bed was reinforced with a combination of EPS and geogrid.

- The measured strain values in the reinforced cases were compared with the strain values measured at the same depth for the unreinforced case. A reduction in strain values were observed as the pipe was reinforced with EPS. The values kept on decreasing as the density of geofoam increased. The least strain on pipe was observed when the combination of EPS 30 with geogrid was used as reinforcement.

- Further, the depth of placement of pipe was varied between 1B to 2B below the loading plate in the presence of EPS and geogrid. The results suggested that the bearing pressure values decreased in all cases. The observed strain values indicate that the provision of EPS and geogrid reinforcements significantly reduced the depth of placement of pipe. The installation costs of buried pipes can be reduced in large projects, where the pipelines are laid along several hundreds of kilometers.

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