Investigating the performance of EPS subgrades by laboratory tests

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ABSTRACT: EPS Geofoam is an appropriate material for reducing dead loads of road embankments and hence, mitigating settlements of pavements constructed over poor ground conditions. It has been used successfully in many projects since its appearance in 1960's, yet, there are still pitfalls regarding its application and design, requiring deeper investigations. A serious problem is related to insufficient functionality of such backfills in preventing ruts on the pavement surface. In this paper, results of a series of cyclic plate load tests are presented, describing the influence of soil thickness, as an influential factor, on the performance of these embankments. Nevertheless, this thickness is not an independent factor. It is also dependent on the density of EPS in the subsequent layers. In practical applications, two layers of EPS with different densities are used and the density of the bottom layer should be minimized in order to reduce overall cost of the pavement along the highway. It has been observed that improper thickness for soil layer (less than 40 cm) above subsequent EPS layers of 30 and 20 kg/m^3 (top and bottom layers respectively), significantly reduces the ability of such pavements to tolerate against rutting when a noticeable number of cycles of loading is applied.

Keywords: Cyclic Plate Load Tests, EPS Geofoam, Lightweight Material, Road Subgrades

1 INTRODUCTION

Roads and highways always require a challenging procedure in construction, especially when it comes to soft grounds. An engineer can either improve the bed resistance by driving piles, soil mixing or other treatment techniques, or as an alternative, use lightweight materials in the backfill to reduce pressures. The first category of techniques is usually time consuming and the result is greatly dependent on the quality of the implementation of the method. It is hard to ensure that the piles are installed thoroughly or the mixing is done with the specified requirements. On the other hand, lightweight materials are easier to be approved with regard to their properties. Furthermore, such materials are handled with least energy and do not include special equipment or man power for installation. Therefore, more designers are encouraged to incorporate such methods in the projects (Stark et al. 2004).

Most of the lightweight substances for road embankments weigh around 30-50% of the soil density. As a recently emerging lightweight material, EPS has a density of 1-2% of soil, which is far away lighter than other materials. The ultra-lightness of EPS geofoam introduces great benefits to the construction process, as well as its operation phase. The feasibility of EPS has been examined and approved in a great number of road projects. Several numbers of studies have also been performed to inspect different aspects of using EPS. Although, the extensiveness of EPS behavioral features, especially in combination with soil, makes it a complicated subject to comprehend in a complete manner (Stark et al. 2004).

One of the most intricate characteristic of EPS geofoam is related to its behavior under cyclic loading. A few studies have focused on this topic, which have not covered all of the desired attributes and vague points. For example, Zou et al. (2000) created a test section and examined EPS pavements and compared them to non-EPS ones. The results showed that EPS introduced larger permanent deformation on pavement surface due to larger elastic strains during cyclic loading. They examined effect of EPS block size, soil material and EPS density on the performance of pavement, but did not include effect of soil thickness or upper EPS thickness in their studies. Another similar study (but with a different target) by Tanyu et al. (2013), which also incorporates geocell reinforcement of soil over soft bed (EPS as soft bed) does not cover the mentioned points either.

A recent study by Mohajerani et al. (2017) has also indicated that there are still several areas of improvement for utilization of EPS geofoam in pavement construction. They have concluded that in addition to the research needed to find out about novel applications EPS geofoam in Geotechnical Engineering, lack of information about current usage of EPS has remained as serious obstacle in emerging this method as a standard around the world. They have emphasized that further tests have to be performed and new concepts should be developed in order to enrich existing guidelines and provide the designers with a more complete set of information. In addition to the mentioned studies, Moghaddas Tafreshi and Ghotbi Siabil (2017) and Ghotbi Siabil and Moghaddas Tafreshi (2018) have covered some of the aspect, but further studies are still required.

To cover one of the main shortages, this study has been intended to explore the effect of soil thickness on the rutting on the surface of EPS embankments under cyclic loading condition. To achieve this goal, a series of large scale cyclic plate load tests were planed and performed in a test box. Test setup and discussion on the result will be presented in the next sections.

2 TEST SETUP AND PREPARATION

Soil and EPS are the main materials used in this study, hence a brief description of their major characteristics is provided here, following with the introduction about test setup and measurement devices. Based on the Unified Soil Classification System (ASTM D 2487-09), the soil is a well-graded sand (SW) and in compliance with the requirements of ASTM D 2940-09 and therefore, a suitable material for highways and airports subbase. The soil had a maximum dry density of 20.6 kN/m^3 at 5% moisture content after being tested by Modified Proctor Method (ASTM D 1557-12). The grading diagram of soil is shown in Figure. 1. EPS geofoam blocks were provided by a regional molder in Iran and were cut into required dimensions by hot wire. As two layers of EPS with different densities are commonly used in practice, in this study EPS with density of 30 kg/m^3 was used in the upper layer as a protective agent and 20 kg/m^3 was used under this protective layer. Stiffness of EPS is approximately related to its density by a linear function and the higher the density, the more stiffness it will have. Elastic modulus of EPS 30 and EPS 20 were measured 2.16 MPa and 0.81 MPa respectively.

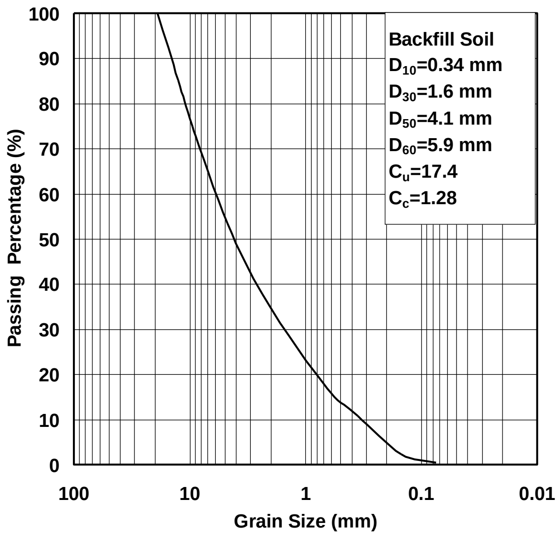

Figure 1. Soil grading diagram.

A series of plate load tests were conducted in a test box constructed in the “Laboratory of Physical Modeling in Geotechnics” at K.N. Toosi University of Technology. Dimension of the box was 2200×2200 mm in plan and 1200 mm in depth. EPS blocks with densities of 20 and 30 kg/m^3 were cut into 500×1000×200 mm blocks by using hot wire. The blocks were placed inside the pit, aligning the 200 mm dimension in vertical direction, forming layers with 200 mm depth. The blocks were placed with a tight arrangement in order to minimize gaps between them. Dimensions of the test box and variables are shown in Figure 2.

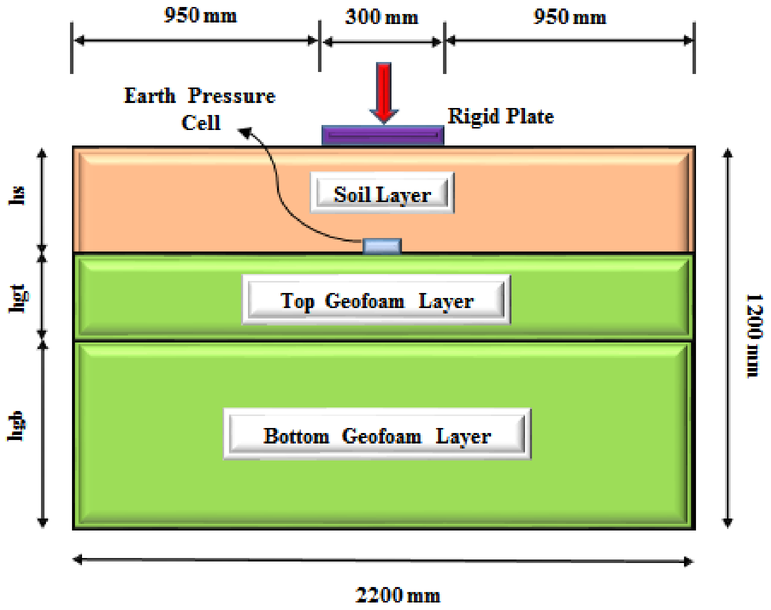

Figure 2. Test box dimensions and test variables.

The next step was placing geotextile layer above the final EPS level in order to protect EPS block from damage. A pressure sensor was also placed on the EPS to record variations of pressure applied on the uppermost EPS layer during cyclic test. Finally, soil was moved into the box using hand shovels and was compacted by a vibratory compactor. The depth of each layer was about 100 mm after compaction. The compaction procedure was performed until maximum achievable compaction was ensured (typically 5 passes of compactor). This procedure was repeated until the soil layer reached the desirable thickness. A picture of the prepared test backfill is shown in Figure 3.

Figure 3. Prepared test box before staring loading.

The main cyclic tests included application of 100 cycles of 275 kPa low cyclic pressure, succeeded by 400 cycles of high 550 kPa. These pressures were applied to the top of test backfill by using a rigid steel plate of 300 mm diameter. It has to be mentioned that these values are the reduced amplitudes from the original proposed case of loading, 400 and 800 kPa for light and heavy vehicles (Brito et al, 2009). For analyzing test results, thickness of the soil layer and amplitude of settlement were converted to dimensionless parameters by dividing them to the diameter of rigid loading plate and used in the result diagrams.

3 RESULTS AND DISCUSSION

In order to evaluate behavior of EPS under cyclic loading, cubic samples of EPS geofoam were tested under uniaxial cyclic loading condition using the pressure range resulted from main tests. Each sample was tested under 3 magnitude of cyclic pressure, representing high, low and medium applied pressure on EPS. Figure 4 and Figure 5 demonstrate the hysteresis curves for 20 kg/m^3 and 30 kg/m^3 EPS densities, respectively. It is evident that increasing the magnitude of cyclic pressure beyond a certain value, induces very large strains and causes unstable reaction in the EPS geofoam. For example, when EPS 20 is subjected to the cyclic pressure with amplitude of 100 kPa, 4% strain occurs in the sample after 100 cycle, and for 150 kPa, the sample strains very rapidly and in an unstable manner (see Figure 4). Therefore, a threshold pressure can be identified between 100 and 150 kPa pressure amplitudes, after which the unstable behavior appears. The threshold pressure is dependent on the density of EPS, as it can be observed on Figure 5, this critical value places between 150 and 250 kPa for EPS 30.

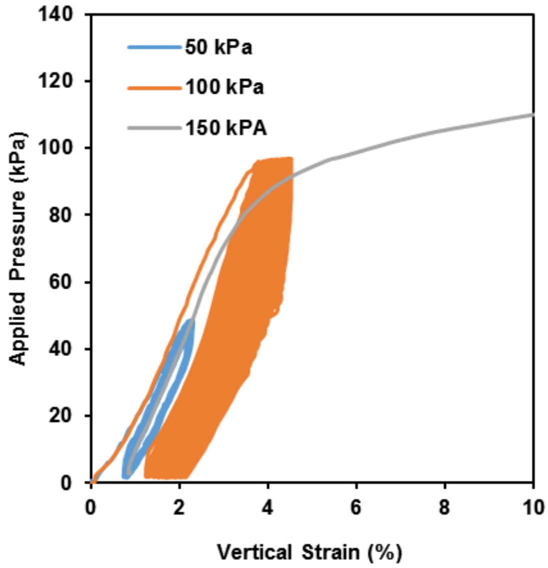

Figure 4. Uniaxial cyclic test on EPS 20 samples.

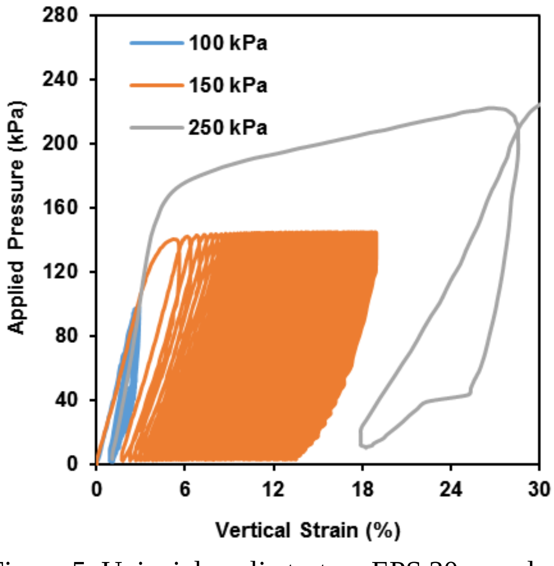

Figure 5. Uniaxial cyclic test on EPS 30 samples.

Effect of soil thickness was investigated on the total settlement of loading surface (rut depth). In all tests, the thickness of the bottom layer of EPS (with low density) was kept constant equal to h_{gb}=600 mm. The thickness of the upper EPS layer varies with the variation in soil thickness and the sum of thickness for these two layers was constant and equal to 800 mm. Figure 6 displays the result of main cyclic test performed on pavement sections introduced in Figure 2. Based on this figure and for the range of h_s values studied here, peak settlement of the pavement surface does not increase beyond 12 mm after application of 100 cycles of lower amplitude pressure (275 kPa). It is also evident that increasing number of load application does not generate a noticeable increase in the settlement value and it stays stable after a short while. This indicates that EPS subgrades are proper solution for using in highway embankments when larger trucks with higher pressure amplitude are not allowed.

For higher amplitude cyclic pressure (550 kPa), pavement behaves differently. When the soil thickness is 200 mm, the pressurized surface undergoes extreme deformation and the rut depths increase up to about

75 mm at the beginning of loading. For larger soil thicknesses, settlement increases gradually but with a varied intensity for various h_s values. For instance, total settlement increases up to 27 mm after 500 cycles for h_s=300 mm, and it remains below 12 mm for h_s=700 mm. Except for h_s=200 mm, all other trend lines show a nearly stable manner during 500 total applications of cyclic pressure. Despite the extreme displacements occurred at larger load amplitudes for soil thickness of 200 mm, such embankments can perform suitably under lower intensity cyclic pressure, and probably can improve under larger cyclic pressures when proper reinforcement measures are incorporated.

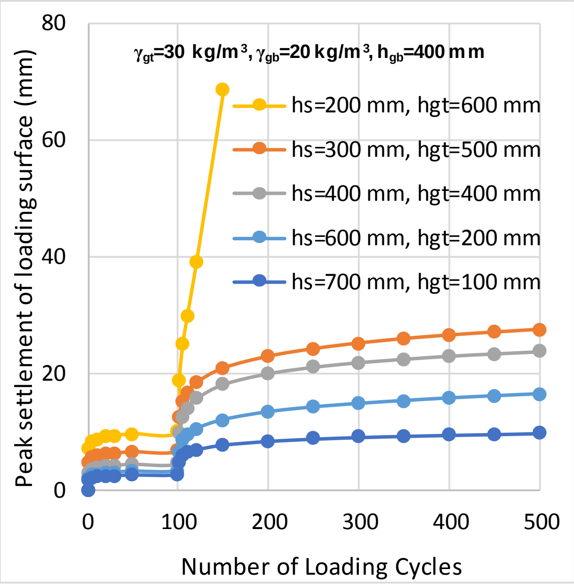

Figure 6. Effect of soil thickness on the total settlement pavement section.

The reason for the described behavior and the difference in the performance of pavement in low amplitude and high amplitude pressures can be addressed by Fig. 7. Variation of pressure was recorded above the EPS geofoam bed by using an Earth Pressure Cell (EPC) as shown in Figure 2, during main cyclic tests. When the low amplitude pressure is applied, the transferred pressure to the top of first EPS layer is below 100 kPa for all of the cases. Referring to Fig. 5, it is observed that when cyclic pressure on EPS 30 is 100 kPa, the strains are very low and does not increase quickly. When the applied pressure is 550 kPa, the transferred pressure reaches up to 150 kPa and higher. Fig. 7. demonstrates that EPS 30 shows a growing trend in strains when subjected to 150 kPa pressure. Therefore, thickness of the soil is greatly influencing factor based on the density of EPS and should be considered in design precisely.

4 CONCLUSION

This study has revealed that while EPS is a great material for a quick and safe construction of embankments over weak ground, its performance should be evaluated widely with sufficient consideration prior to the start of the project. Uniaxial cyclic test on EPS specimens demonstrated that each density of EPS has a specific range of pressure at which it displays a stabilized behavior. Cyclic plate load test showed that thickness of soil above EPS layer has an essential influence on the rut depth and its increase rate. For an embankment section with a 200 mm thick EPS 30 placed over an EPS 20 bed, thickness of soil less than 300 mm is inappropriate when the pavement is subjected to high amplitude pressure (550 kPa). Although larger values of h_s do not show an unstable trend in surface settlement, they still have a growing rate that needs mitigation methods to prevent failure at more loading repetitions. On the other hand, the pavement does not undergo intolerable surface settlement for lower amplitude cyclic pressure (275 kPa) and therefore, can be a proper choice when the maximum applied pressure is limited to those of lighter trucks.

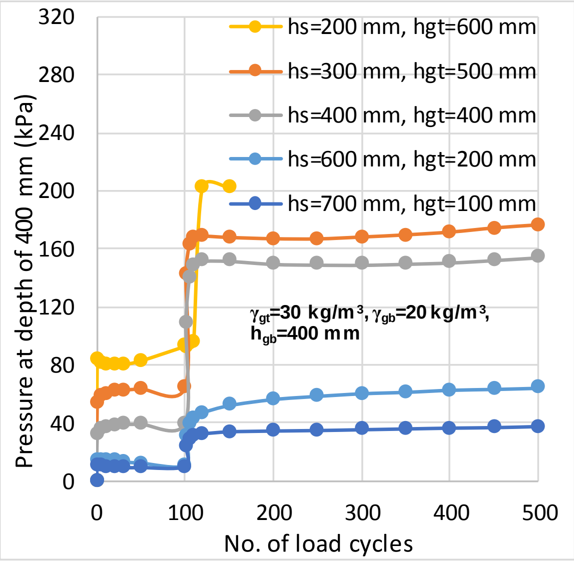

Figure 7. Measured pressure above geofoam bed and under soil layer.

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