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Performance Evaluation of Pavements Constructed on EPS Geofoam Backfill Using Repeated Plate Load

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Abstract. EPS Geofoam is introduced as a suitable material for reducing dead loads and alleviation of settlements in road 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 upper EPS layer (less than 200 mm) significantly reduces the ability of such pavements to tolerate against rutting when a noticeable number of cycles of loading is applied.

1. Introduction

Construction of roads and highways always encompass challenging issuers, especially when soft ground is encountered. An engineer can deliver the design, either by improving the bed resistance using driven piles, soil mixing or other treatment techniques, or as an alternative, use lightweight materials in the backfill to reduce the surcharge pressures. Application of the first category is generally time consuming and the final result is greatly dependent on the quality of the implementation of the method. It is difficult to make sure if the piles have been installed thoroughly, or the mixing is done with the specified requirements. On the other hand, lightweight materials would be much easier to be approved with regard to their properties and installation as they are more accessible compare to the mentioned methods. Furthermore, such materials are handled with least energy and do not include special equipment or man power for installation. Consequently, more designers are encouraged to incorporate such methods in the projects [1].

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 behavioural features, especially in combination with soil, makes it a complicated subject to comprehend in a complete manner [1].

One of the most intricate characteristic of EPS geofoam is related to its behaviour 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 [2] 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 [3], 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 [4] 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 [5] and Ghotbi Siabil and Moghaddas Tafreshi [6-10] 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/m3 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 moulder 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/m3 was used in the upper layer as a protective agent and 20 kg/m3 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.

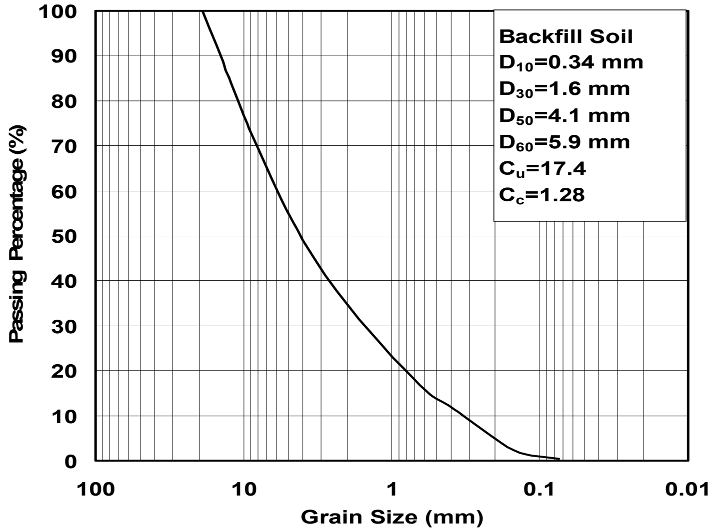

Figure 1. Soil grading diagram.

A series of plate load tests were conducted in a test box constructed in the “Laboratory of Physical Modelling 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/m3 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.

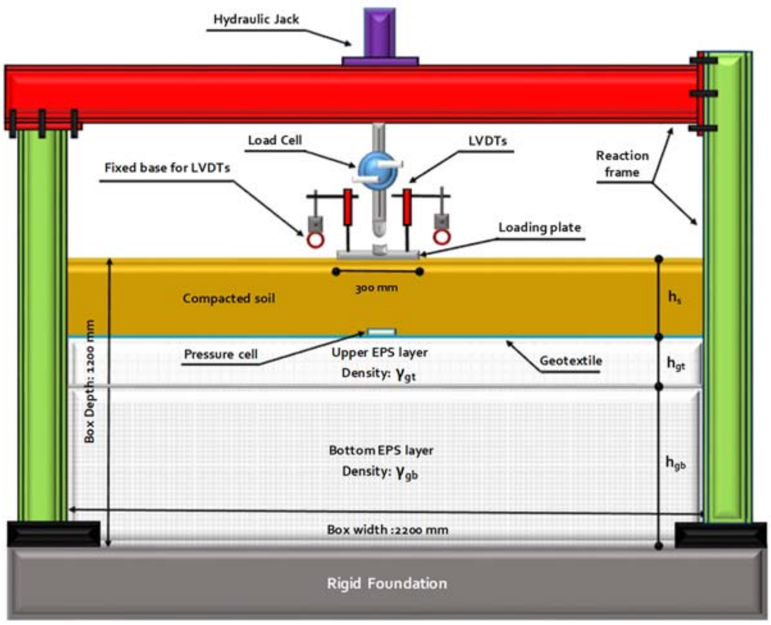

Figure 2. Test box dimensions and test variables

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 analysing 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 behaviour 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/m3 and 30 kg/m3 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 behaviour 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.

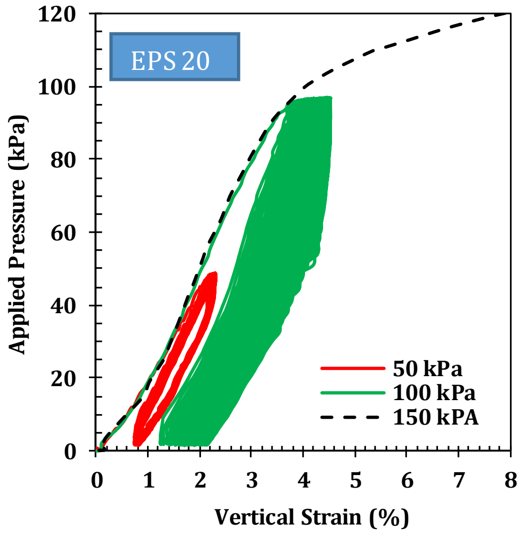

Figure 4. Uniaxial cyclic test on EPS 20 samples

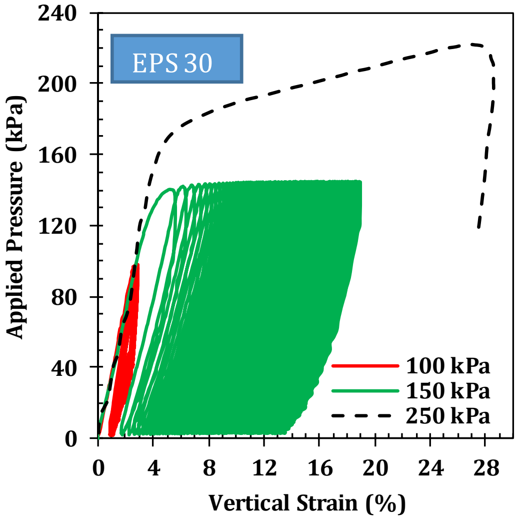

Figure 5. Uniaxial cyclic test on EPS 30 samples

Effect of EPS layers' thickness on the peak deformation of loading surface (rut depth) was investigated. In all tests, the thickness of the soil layer was kept constant equal to h_s=400 mm. Thicknesses of the upper and bottom EPS layer were varied, while the sum of thickness for these two layers was constant and equal to 800 mm (see Figure 2). The surface settlement of the described pavements from main cyclic plate load tests is displayed on Figure 6. According to this plot for the typical thicknesses of the upper and bottom EPS layers studied here, peak deformation of the pavement surface does not grow dramatically during application of the lower applied cyclic pressure (275 kPa). The variation in the pavement surface settlement is stabilizing at this stage. For h_{gt}>=200 mm, the peak settlement remains around 5 mm and for h_{gt} =100 mm, peak settlement has increased to about 7.5 mm, but still showing a stabilizing trend. Therefore, when the pavement is subjected to 275 kPa cyclic pressure, it shows an acceptable behavior in terms of pavement surface settlement. It can be concluded that a pavement with soil thickness of 400 mm and a minimum upper EPS thickness of 100 mm would behave sufficiently under the described condition and further increase in the thickness of high density EPS at the upper layer can be prohibited.

While a stabilized behavior is observed for lower applied pressure, the increase in surface settlement is somehow unstable for large applied pressure. On the first cycle of this pressure amplitude, the amount of peak surface deformation double for all of the cases. With increase in the number of load cycles, surface settlement increases significantly during the initial cycles of this loading stage. However, for upper EPS layer thickness of 100 mm, the increase in surface settlement is so severe (40 mm) that the pavement fails upon application of about 50 cycles. After completion of this test and deployment of the test section, it was seen that the upper EPS layer was ruptured due to significant bending. The other cases however, have undergone settlements which do not vary meaningfully. Therefore, it is concluded that with a soil thickness of 400 mm and EPS 30 as the upper EPS layer, the thickness of this EPS layer must not be selected less than 200 mm. Increasing the thickness of upper EPS layer beyond this values does not cause a considerable reduction on the surface settlement, thus can be selected as a base thickness for upper EPS layers for these pavements.

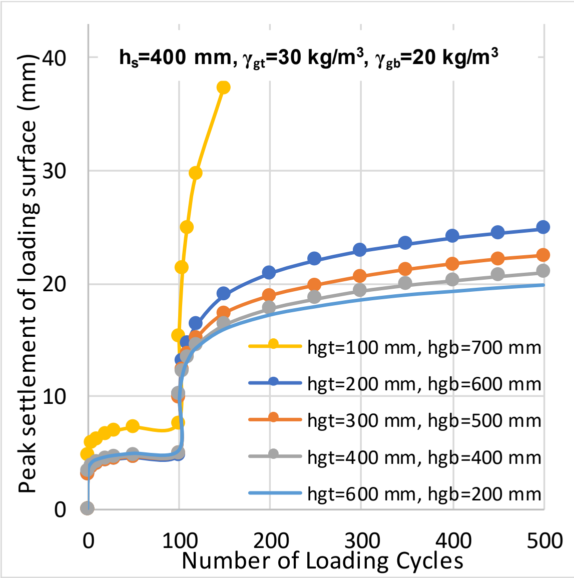

Figure 6. Effect of EPS layers' thickness on the total settlement pavement section.

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 behaviour. Cyclic plate load test showed that thickness of upper EPS layer has an essential influence on the rut depth and its increase rate. When the applied pressure is 275 kPa, the minimum thickness can be selected as the upper high density EPS layer and the pavements will show an appropriate behaviour. For the larger applied pressure amplitude (550 kPa), when the thickness of soil is 400 mm, the thickness of upper EPS layer must not be lower than 200 mm as it induces large settlements with insignificant number of load cycles and results in the failure of the pavement surface. However, increasing this thickness further would not affect the settlement to decrease meaningfully. Therefore, a proper thickness in terms of stability and economic must be selected based on the amplitude of the applied pressure.

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