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The experimental investigation of behaviour of expanded polystyrene (EPS)

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Abstract. Low-strength substrates and anthropogenic soils are always an issue in civil engineering. Based on the soil layer types, several methods could be used to improve the basic/foundation layer however it would be difficult to make sure if the specified requirements are achieved. Nowadays, Expandable Polystyrene (EPS) as a lightweight material found as a substitution for traditional methods like soil replacement, soil mixing, using piles driving and other treatment techniques. This paper will demonstrate the static properties of EPS foams in a view point of construction material which will be a key for the future study of these materials. A series of compression tests were carried out on different types of EPS foam to study the effect of EPS geofoam density on the mechanical behaviour of these materials.

1. Introduction

Expanded Polystyrene (EPS) geofoam is a type of cellular polymeric material with a history of successful applications in civil engineering. It is used in different applications wherever it is exposed to various kinds of stresses [1]. In the 1960s, Norway started to use the EPS as a lightweight material to build the new reads on a low strength subgrades. Since then, other characteristics of EPS have made it ideal material to substitute other improvement method in different aspects of construction which need to reduce vertical and lateral stresses with acceptable compression strength. This meant a rapid increase in the use of EPS civil projects such as embankment construction [2-11], slope stability [12-14], retaining structures [15], bridge abutments [16-18], buried pipes and culvert [19-23].

Recently, increased work has been done on the compressible inclusion function of EPS geofoam. The high compressibility specification of EPS makes it an ideal material for reducing vertical and horizontal stress within its porous microstructure while there is almost no side deformation. Continuing investigation on this role of EPS has shown that the compressive strength of EPS geofoam is highly depend on material density, strain rate and the confining stress [24] which is still under the investigation of researchers. This study is intended to provide an understanding of the mechanical behavior of EPS geofoam subjected to monotonic compression loading with different strain rates. A series of uniaxial tests were carried out on cylindrical EPS geofoam specimens with different densities varying from 14.4 kg/m^3 to 28.8 kg/m^3. In addition, a laser sensor was used to measure the side deflection of the EPS samples to obtain a better understanding of the behavior of EPS geofoam.

2. Experimental procedure

The EPS blocks used in this study were produced by the company IZOPOL Dvořák, s.r.o. (a local manufacturer in the Czech Republic) with 4 different densities (Table 1) which were cut into cylinders using a water-jet cutting system.

Table 1. Material properties.

Properties	**EPS 70**	**EPS 100**	**EPS 150**	**EPS 200**
Density (kg/m^3)	13.5	18.0	23.0	28.0
Initial elastic modulus, E_i (MPa)	2.5	4	5	7.5
Compressive resistance@10% axial strain (KPa)	70	110	135	200

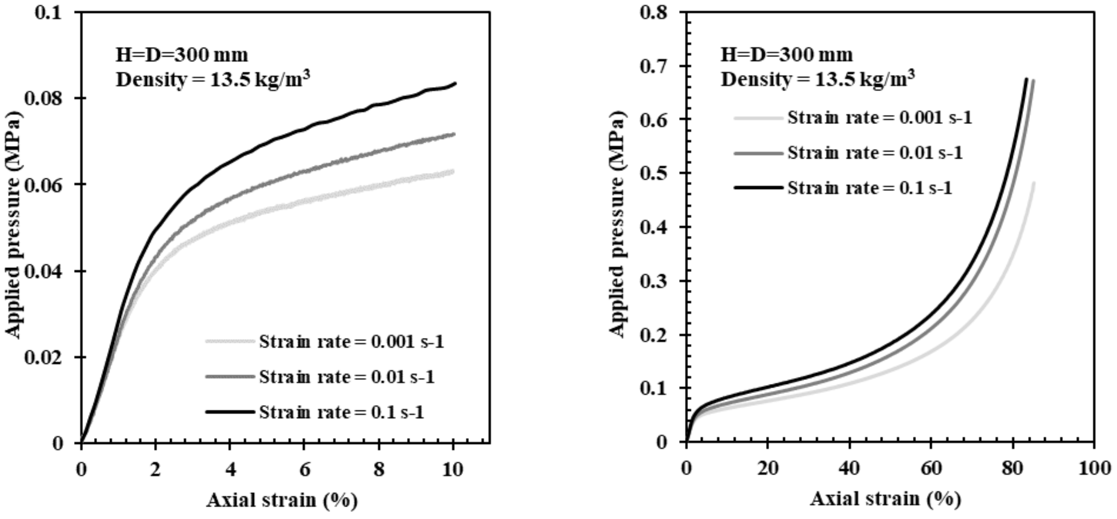
A universal hydraulic loading system equipped with high speed precise data acquisition was used to apply the uniaxial vertical loading. The applied load was measured by an inline load transducer with a capacity and accuracy of 100 kN and 0.02% which was double checked by an oil pressure sensor inside the hydraulic cylinder. The vertical movement of the hydraulic cylinder is controlled by an internal displacement transducer which can control the movement of the hydraulic piston with an accuracy of 0.01%. In order to monitor the side deformation of EPS samples, two laser scanners with measurement span and accuracy of 10 mm and 640 points/profile were installed on the side of the sample, free from the frame movement, to obtain the precise side measurement of the middle part of the samples. The whole system is controlled by the central data acquisition system with a sampling rate of 25 Hz - which covers the precise measurement for static tests. Figure 1 shows the real view of the testing system.

Figure 1. Testing equipment.

The first series of tests were carried out to check the performance of the loading system, loading frame, all the transducers, measuring and control system in addition of repeatability of the tests. The repeatability of the tests shows less than 2% difference, which confirms that the whole loading and measuring system works properly. The second group of tests were carried out to investigate the effect of strain rate on the behavior of the stress-strain curves of EPS. The loading was applied with different strain rates of 0.001, 0.01 and 0.1 s^{-1} up to the maximum available span/load capacity of the hydraulic loading system. The sample height and diameter was 30 cm (H/D = 1) with various densities of EPS so at the same time, the effect of EPS density on the mechanical behavior of EPS geofoams was also investigated.

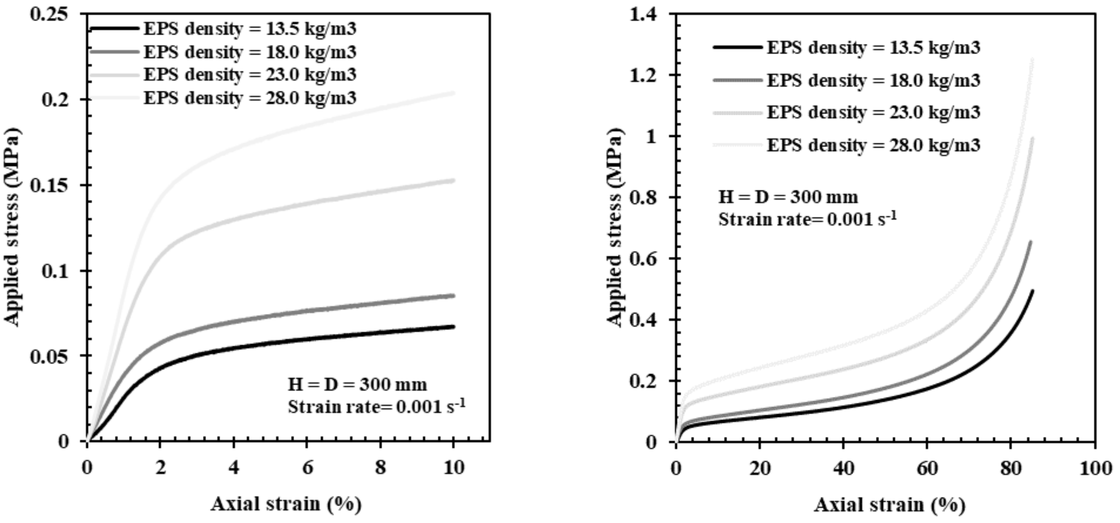
3. Results and discussion

Three strain rates of 0.1, 0.01 and 0.001 s^{-1} were selected to evaluate the effect of loading speed. The samples' height and diameter were 300 mm and the EPS density was varied from 13.5 to 28.0 kg/m^3. Figure 2 shows the stress-strain curve for different strain rates for first 10% strain and up to maximum compression stress. According to figure, EPS geofoam exhibits larger compressive strength with increasing strain rate and the difference in the compressive strength between the selected rates increases with increasing strain amplitude. It can be understood that, as the strain rate increases, the increment of increase in the compressive strength of EPS samples gradually decreases. When the rate of applied pressure is slow, EPS bubbles have enough time to deform and eventually destruct under pressure. As the loading rate increases, the bubbles are forced to contract evenly under the confinement and a smaller number of them might become damaged (comparable to what happens to saturated soil during consolidation). Thus when pressure is applied in a gentle manner, more EPS bubbles are destroyed and therefore a lower compressive strength is observed. The described mechanism seems to be more valid for lower density EPS geofoam, as the bubbles are larger. The structure of denser EPS geofoam consists of less air and thus might be less sensitive to the loading rate, but this requires further investigation.



(a) (b)

Figure 2. Stress-strain curve for different strain rates (a) up to 10% strain, (b) up to maximum compression



(a) (b)

Figure 3. Stress-strain curve for different densities (a) up to 10% strain, (b) up to maximum compression

Figure 3 shows the overall stress-strain curves for various densities of EPS geofoam. As expected, the compressive strength of EPS geofoam increases with increasing EPS density. EPS with densities 13.5 and 18.0 kg/m^3 show nearly close compression resistance rather than the other densities in lower strain however at higher strain (over 50%), the difference in properties became clearer. The maximum compressive strength are approximately 0.5, 0.65, 0.95 and 1.3 MPa for EPS with densities 13.5, 18.0, 23.0 and 28.0 kg/m^3 respectively.

Figure 4 displays the variation of Young’s modulus (Elastic modulus) for different densities of EPS geofoam with different strain rates. It’s clear that the larger elastic modulus achieved at highest density EPS, while by increasing the strain rate, the elastic modulus increased. On the other hand, the influence of the strain rate on the Young’s modulus of the EPS samples increases with increasing EPS density. The reason could be the elastic moduli which obtained from the elastic region of the plots that are not affected by the bubbles interaction phenomena on the overall plots (Fig. 2 and 3). When the EPS material is elastic (1% strain), the governing influential factor depends on the EPS material itself.

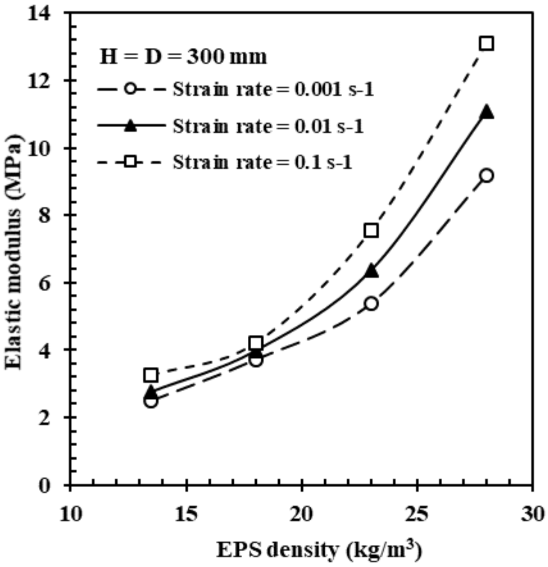


Figure 4. Variation of EPS geofoam elastic modulus with EPS density at various strain rates.

4. Conclusion

Different series of tests was performed on EPS geofoam samples to investigate the effect of sample density and strain rate on the stress-strain behaviour and elastic modulus of EPS geofoam. All the tests were performed on one type of EPS geofoam purchased from a regional producer in the Czech Republic, so there would be slight change if the other production from other producers will use. However, the general trend of behaviour was in good agreement with previous research. The results show that with increasing strain rate, both elastic modulus and compressive strength of the EPS sample increase. The elastic modulus is more sensitive to the strain rate for denser EPS, while the overall sample strength over the plastic strain region is more sensitive to the strain rate for lighter EPS, which can be attributed to the damage to air bubbles as the applied pressure increases. On the other hand, the elastic modulus of the EPS samples increases with increasing density of EPS geofoam, and can be related to it using a simple linear function.

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