Investigation of cyclic behavior of EPS-sand mixtures using large direct shear apparatus

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Abstract

Lightweight fill materials have been used in many civil engineering applications throughout the world. A lightweight fill was produced by blending expanded polystyrene (EPS) beads and sands. Such formed granular geomaterials , known as sand-EPS lightweight fills, have potential of being lightweight compared to traditional fills, thus are suitable for many infrastructure works where less overburdens are expected, e.g., utilities trench backfills. This paper examines the static and cyclic behavior of sand-EPS mixtures under direct shear test conditions. Large direct shear tests were conducted on the lightweight fills to observe materials' stress-strain relationships, specifically, the stress-strain variations associated with the mixing ratios of EPS beads. The behaviors of mixtures under cyclic loading are worth to pay much attention on, though there are few relative studies about this at present. Cyclic stress–strain relationships and stiffness degradation curves for sand-EPS mixtures with different mix ratios are also discussed. EPS beads were incorporated into the mixtures based on their mass ratios over sands, i.e., 0.15% and 0.35%. Monotonic Direct shear tests were conducted under 3 different vertical stresses (40, 80, 160kPa) and the cyclic shear behaviors of the sands was tested by considering the normal stress of 50 kPa. The results showed that the inclusion of EPS bead in sand will lead to a decreased shear modulus and damping ratio.

Key words: EPS-sand mixture, Dynamic properties, Cyclic direct shear, Shear modulus, Damping ratio

1. Introduction

As a non-conventional geo-material, EPS (expanded polystyrene) is used in two different ways, EPS blocks (also called EPS geofoam) and EPS beads mixed with soil and sometimes a binder like Portland cement. EPS block is being successfully used in many civil engineering applications, such as lightweight fill in roadway embankment over soft soils [1], seismic buffers (among others: Zarnani and Bathurst [2]; Trandafir et al. [3]; Athanasopoulos-Zekkos et al. [4]; Zarnani and Bathurst [5]); reduction of swelling pressure caused by expansive soils (among others: Aytekin [6]; Ikizler et al. [7]; Rocco and Luna [8]; Asha et al. [9]); slope stability [10].

In literature, there are some investigations about the evaluation of stress-strain behavior of EPS. It is found that some factors influence the stress-strain behavior of EPS such as its density, applied confining stresses, time effects, sample size and temperature (among others: Elragi et al. [11]; Hazarika [12]; Leo et al. [13]; Gnip et al. [14]). Furthermore, EPS wetting could affect its stress-strain behavior [15]. Chun et al. [16] and Hazarika [12] evaluate the influence of EPS density on its stress-strain response for static loading. Chun et al. [16] indicate that EPS compressive strength decreases with confining stress. Nowadays, EPS is currently used as a packaging or insulating material in various industrial fields in the world. A large quantity of EPS is consumed, and is disposed as a waste, whereas the availability of mechanical test results will extend the use of EPS geofoam to geotechnical applications, which will contribute to decreasing the amount of EPS ending up in landfills and will contribute to more sustainable infrastructure systems. [17]

Liu et al. [18], suggested EPS-bead instead of EPS-block because of some disadvantages. They mixed silty clay with EPS-beads and Portland cement. Miao et al. [19] Used standard Proctor tests, unconfined compression tests, California Bearing Ratio (CBR) tests, unconsolidated-undrained tests, and consolidated-undrained tests to investigate settlement problem associated with bridge approach embankments over soft soil. Padade and Mandal [20], proposed a geomaterial by blending fly ash instead of soil with EPS-beads and cement. Using compression tests showed that the compressive strength of EPGM (expanded polystyrene-based geomaterial) increases considerably if cement-to-fly ash ratios of 10, 15, and 20% are used. Compared with EPS block geofoam, EPS beads mixed geomaterial has higher density but higher compressive strength and higher stiffness so it can be used as a strong fill material with high strength.

Some researchers mixed EPS particulates with sand to create a lightweight fill and measured the stress-strain characteristics of the modified soils in the laboratory using direct shear and triaxial compression tests (among others: Liu et al. [18]; Miao et al. [19]; Zhu et al. [21]; Deng and Xiao [22]; Deng and Xiao [23]; Edincliler et al. [24]). Rocco and Luna [8], mixed EPS particulates into cohesive, swelling soils to discuss the effect of EPS content on the unit weight and void ratio using Standard Proctor and triaxial UU compression tests. However, EPS beads are inexpensive compared with EPS blocks (geo-foam), in order to save cost of cement and consequently gain a non-cementitious lightweight fill, Deng and Xiao [22,23] studied the stress-strain behavior of EPS-sand for a single type of EPS-bead-sand mixture. They showed a systematic decrease in drained strength with increasing EPS content.

So far previous studies for lightweight geo-materials are mainly about the monotonic behaviors. When used in practical engineering, lightweight soil may undergo various cyclic loads; so it is necessary to investigate its dynamic properties along with the mechanical and stress-strain behavior. The main aim of this study is to conduct some large direct shear tests on fine grained sand mixed with EPS beads with different weight contents to investigate their effect on mechanical properties of the proposed lightweight geo-material.

2. Experimental Study

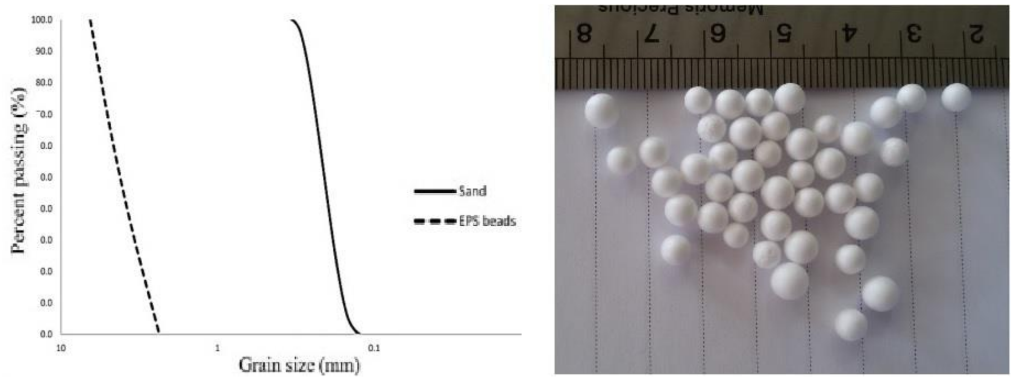
2.1. Materials

Materials used in this work included sand and EPS beads. The sand used in the EPS-sand mixture was “Chamkhaleh Sand”, supplied from Chamkhaleh beach located on *SW* of Caspian Sea. The index properties of the sand are presented in Table 1. Specific gravity of sand was 2.62. Fig.1 shows the sand gradation, which is classified as being poorly graded (SP) under the Unified Soil Classification System ($Cu=1.54$, $Cc=0.95$).

The *EPS* beads used in this study was obtained from a regional supplier of EPS materials for engineering, manufacturing, and packaging industries. The beads were white, even, and spherical, sizing between *2-7* mm (Fig. 1). The grain size distribution curves of EPS beads are given in Fig. 1 and index properties are presented in Table 1, respectively. The unit weight obtained for *EPS* beads was *0.08 KN/m3 according to* ASTM C 128 [25]. Specific gravity (Gs) of beads was also calculated by filling the voids between *EPS* beads with distilled water and then to calculate the net volume of beads and determine the specific gravity of beads, which was *0.013*.

Table 1. Physical properties of tested materials

Material	Specific gravity (Gs)	Dry unit weight ($kN/m3$)	Effective size D_{10} (mm)	Mean grain size D_{50} (mm)	Uniformity coefficient Cu	Coefficient of curvature Cc
Sand	2.63	14.2(min) 16.1(max)	0.17	0.21	1.54	0.95
EPS bead	0.013	0.08	2.60	4.00	1.70	0.90



(a) (b)

Figure 1. Materials specification ; a) Grain size distribution curves of *EPS* bead and sand used for mixtures ; b) Optical microscope photos of *EPS* beads

2.2. Large Direct Shear Testing Setup

This study uses a large scale direct shear device [26]. The general test arrangement of large-scale direct shear test is shown in Fig. 2. The shear box has the capability of sustaining lateral shearing force of up to *100 kN*. The inner length, width and height of the upper and lower shear box, is *300 mm×300 mm×100 mm*. During the directly shearing test, the upper box was fixed on the frame and was stationary and the lower half was driven by a horizontal loading system. The movement of the lower shear box in the horizontal direction is controlled by a horizontal servo motor that could slide smoothly in the horizontal direction. The system is capable of applying a constant strain rate from *0.1* to *60 mm/min*. A detachable steel load bearing is provided with the upper shear box for uniform distribution of normal stress. The vertical loading applied by a mechanical jack is transferred through the rigid reaction frame and adds on a rigid load plate which is placed on top of the soils in the upper shear box. The system is capable of applying a vertical stress of up to *200 kPa*. The horizontal movement of the lower shear box, vertical movement of rigid load plate and the shear force exerted during shearing testing are also recorded. These data are collected by using a load cells and two linear variable displacement transducers *(LVDT*). A load cell was connected between the servo piston and the steel frame of the lower box. The capacity for the load cells is *50 kN* and The capacities for vertical and horizontal *LVDT* are *50 mm*.

Figure 2. Large direct shear test apparatus

2.3. Specimen Preparation

EPS–sand samples were prepared by mixing EPS beads with sand with varying weight content , η. i.e., η=0, 0.15% and 0.35%. As EPS beads are lighter than the sand particles, they tend to float in the mixture when EPS beads and sand are mixed in dry conditions. Sufficient water added to provide bonding between the EPS beads and sand, which made it possible to mix without segregation. For each designated mixing ratio, the mass-based proportions of sand and *EPS* bead were determined beforehand. The proportioned materials were mixed thoroughly until the mixtures were homogenous enough.

Mixtures at a designated weight were placed in layers and compacted moderately by tamping efforts until the desired dry density (γ_d=15 kN/m3) was reached. It should be noted that the dry density was defined based on total solid constituents, namely *EPS* beads inclusions and sand particles. The target dry density of *EPS*-sand mixtures was achieved by quantifying the weight of proportioned *EPS* and sand mixtures to be placed within a volume. Consistent compaction was attained by controlling the feed quantity of the portion to be placed in an increment. The specimen preparation procedure used in this study was implemented to obtain a homogenous distribution, and no evidence of segregation was observed for any *EPS* content. A list of specimens and corresponding weight ratios is provided in Table 2 for *EPS*-sand mixtures. A total of *18* tests [i.e., *EPS* content $\eta=0$ (pure sand) and two different *EPS* contents respectively with 6 different displacement amplitudes] of large direct shear tests were performed in this investigation.

Table2. Summary of direct shear testing program on *EPS*-sand mixtures

Designation	Content by weight η *(%)*	Dry density *(kN/m^3)*	Overburden pressure *(kPa)*
Sand	0	15	50
EPS-Sand-1	0.15	15	50
EPS-Sand-2	0.35	15	50

2.4. Equipment Verification Using Sand

To verify that the large-scale direct shear device worked properly, control tests were first conducted using sand. To prevent the sand from falling out of the upper box when the two boxes were offset during shearing, a *3cm* wide angle iron flange was bolted to the side of the lower box. The shear strength of sand was also obtained using the standard direct shear test according to ASTM D3080-04 [27] using the same condition. The specimen dimensions on the standard direct shear device were *5×5* cm and *2.5* cm height.

Three vertical pressures were used: 40, 80, 160 kPa. For each normal load, the shear resistance versus shear displacement relationship was plotted; the maximum shear resistance for each normal load was derived from the curve. Then the Mohr-Coulomb failure envelope was obtained.
Duplicate tests were first conducted for pure sand model in both large and small. The results are shown in Figs. 3, 4 and 5. They proved to be qualitatively reproducible and comparable with the result of standard direct shear. The Mohr-Coulomb failure envelopes were obtained from shear stress versus shear displacement relationships Due to the good reproducibility, only the shear stress versus shear displacement curves from one set of tests are shown in Fig. 6. The three curves are labeled with their respective normal stresses. The results from the large scale shear tests and the standard direct shear tests are summarized in Table 3. both cohesion values are very small; therefore, the friction angle governs shear strength. Table 3 shows that the large-scale shear tests provided comparable and slightly lower (conservative) value for internal friction angle.

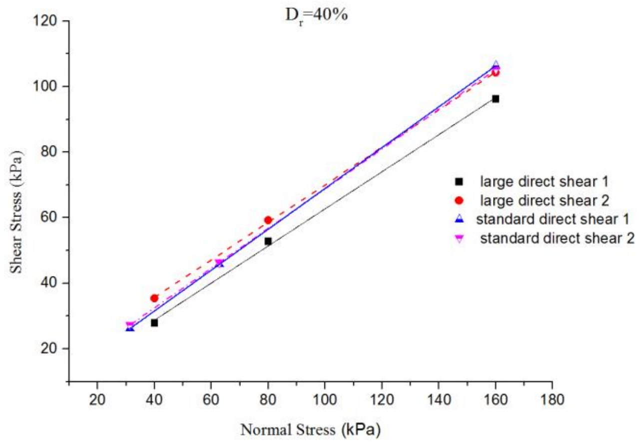


Figure 3. Failure envelopes of sand from standard and large-scale shear testing for relative density of 40%

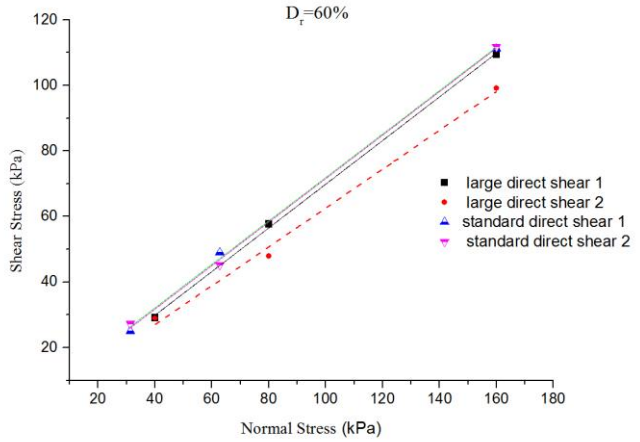


Figure 4. Failure envelopes of sand from standard and large-scale shear testing for relative density of 60%

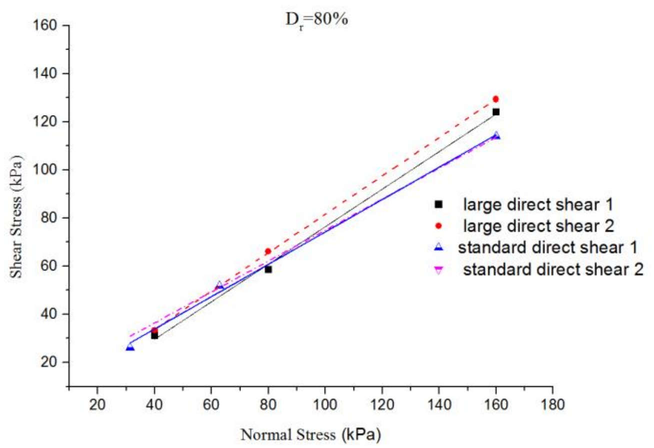


Figure 5. Failure envelopes of sand from standard and large-scale shear testing for relative density of 80%

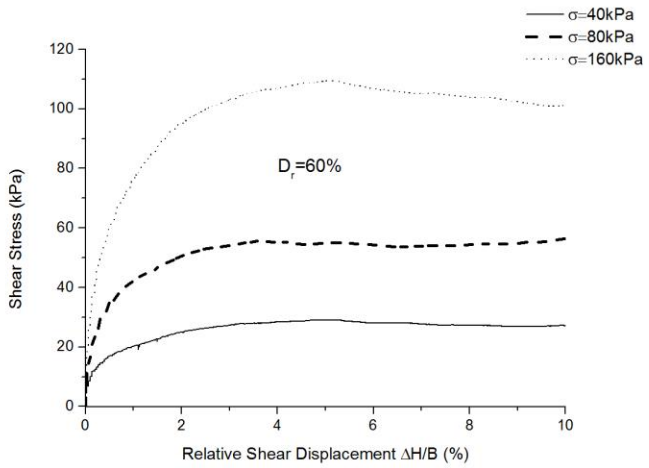


Figure 6. Shear stress versus displacement relationships of medium sand

Table 3. Shear strengths of sand obtained from Large-Scale and Standard Direct Shear Tests

D_r(%)	Strength Parameter	Large-Scale Direct Shear Test		Standard Direct Shear Test	
		Test1	Test2	Test1	Test2
40	c (kPa)	6.16	12.83	4.91	8.26
	Ø (°)	29.51	29.80	31.91	31.21
60	c (kPa)	3.22	3.27	2.72	5.21
	Ø (°)	33.67	30.66	33.52	33.56
80	c (kPa)	1.5	1.77	7.01	10.72
	Ø (°)	37.93	38.60	33.90	32.75

3. Result and Discussion

The large scale direct shear experiments were conducted under constant normal stress of 50 kPa. The cyclic loading were applied under strain controlled condition in 6 different amplitudes of 2 mm, 3 mm, 4 mm, 5 mm, 10 mm and 15 mm. The loading rate was 60 mm/min in the horizontal direction. Fig. 7 shows the hysteresis loops for pure sand model under cyclic loading condition. This plot clearly shows the effect of shear displacement amplitude on dynamic parameters of the material. It is observed that increasing the amplitude causes a reduction in dynamic shear modulus and increases the damping ratio which is reflected as wider loops and more gentle slopes.

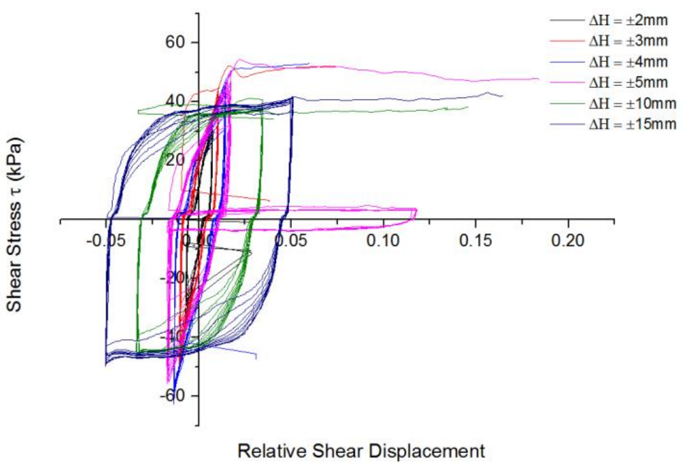


Figure 7. Cyclic direct shear tests on pure sand under 50 kPa normal stress

The EPS beads inclusion has influence on cyclic behavior of EPS-sand mixture. Fig. 8 demonstrates the hysteresis loops for two different EPS contents along with the pure sand model in different shear displacement amplitude. It is seen from the test results that EPS makes the hysteresis loops flatter and decreases shear stiffness of the mixtures. Also the shear modulus (slope of the loops) decreases with increase in shear strain amplitude as expected.

Furthermore, a decrease in the damping ratio with increasing EPS content is observed. This behavior is well exhibited by reduction in the area of the hysteresis loops (i.e., the dissipated energy) relative to the rebound elastic energy with increasing EPS content.It is clearly observed that EPS beads inclusion leads to softer mixture and more elastic material due to recoverable strain energy stored in deformable EPS beads.

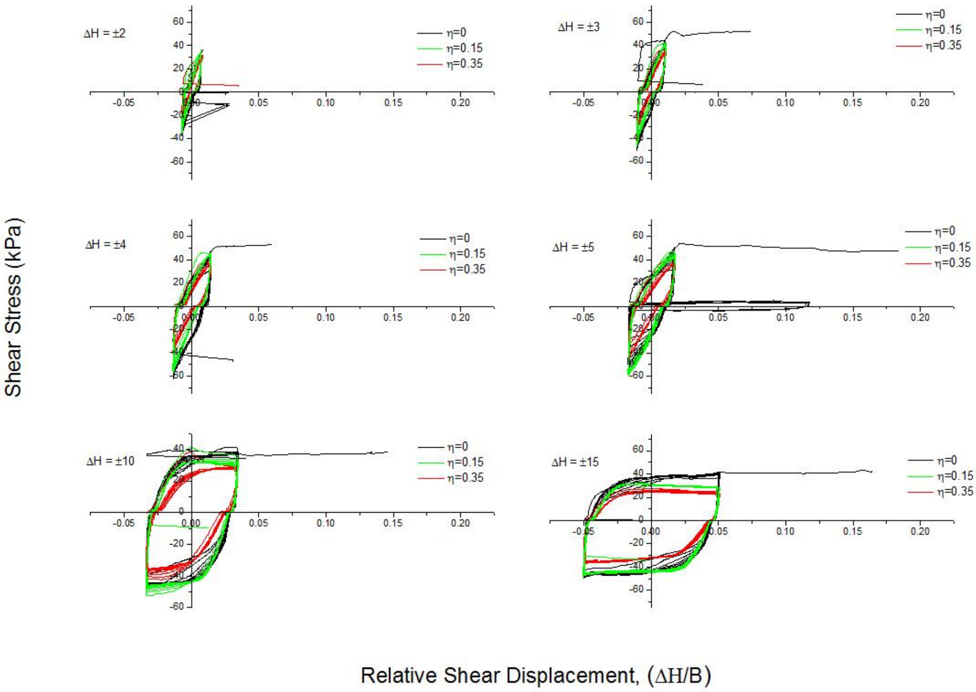


Figure. 8. Comparison between hysteresis loops of the mixtures in different EPS contents under cyclic loading

4. Conclusions

The objective of current experimental investigation is to understand the effects of EPS contents on the behavior of sand, and to have an understanding of the behavior of “Chamkhaleh sand” in cyclic direct shear testing apparatus. The tests reported in this paper show the followings:

1. The results showed that the inclusion of EPS bead in sand will lead to a decreased shear modulus and softer mixture indeed.
2. The results showed that the inclusion of EPS bead in sand will lead to a decreased damping ratio, due to more elastic behavior caused by deformable beads.
3. These observations lay the foundations toward the engineering design of these materials. However, further data are required to analyze the behavior of these sands under monotonic and cyclic tests. Low and high strain ranges need to be covered by other apparatuses to provide clear understanding of the behavior.

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