Effectiveness of EPS Bead Size and Cement Proportions on the Strength and Deformation of Light-Weighted Soil

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Abstract-The current study investigates the deformation and strength of Light-Weighted Soil (LWS) comprised of silt, Expanded Polystyrene (EPS) beads, cement, and water. The EPS bead sizes employed in this study are 4, 5, and 6mm in diameter with densities of 0.011, 0.009, and 0.006g/cm^3 and cement concentrations of 10% and 15%. The effects of different EPS bead sizes and cement proportions on the mechanical properties (strength and deformation) of LWS are evaluated by Unconfined Compression Strength (UCS) tests. The findings show that the EPS bead sizes significantly impact the strength and deformations of the LWS. The smaller the EPS bead size, the higher the observed strength, but, on the other hand, bigger EPS bead sizes have lower strength and higher ductility. It was also revealed that the strength of LSW is entirely dependent on the cement concentration. High cement content in the LWS has more strength and brittleness, but it is more prone to deformation. The cost can be decreased by increasing the EPS bead size, and thus the prescription of mixed soil can be enhanced. The use of EPS beads with a diameter of 4-6mm is recommended in the construction process, especially in backfill for retaining walls. Each EPS bead size provides advantages in different context, depending on engineering applications and field conditions.

Keywords-strength and deformation; expanded polystyrene beads; unconfined compression test; cement

I. INTRODUCTION

Light-Weighted Soil (LWS) comprises of silt, EPS beads, cement, and water and it has lower density than the ordinary soil. LWS has good independence, hardness, flowability, strength, ductility, heat resistance, and water resistance. The disposal of EPS is a problem that many cities face. On its own, EPS does not harm or contaminate the soil, but because it takes hundreds of years to break down, it takes up too much space in landfills and reduces the usable area. Its lightweight nature and low density have impeded efforts to recycle EPS. Lightweight fill materials are utilized in a variety of ways. They can be used as fill over poor soils, backfill for retaining walls to minimize lateral loads, fill materials for slopes to decrease driving forces, and seismic buffers, among other applications. These solutions have tremendous engineering merits and can significantly cut project costs.

Authors in [1] simulated the mechanical properties of mixed LWS using indoor tests and ABAQUS finite element software and assessed its strength characteristics and deformation law. Authors in [2] reported that when the size of EPS particles was in the range of 1–5 mm, the permeability of the water increased as the EPS particle size rose, while the UCS of spherical EPS 1–3mm particles was higher than that of fractured and flaky EPS particles [2]. EPS soil combinations' compressive strength, unit weight, permeability, dynamic properties, creep qualities, and water absorption properties were examined in [3]. Authors in [4] reported that when the size of the EPS beads increases, the unconfined compressive strength of LWS is reduced. To reduce project expenses, the impact of EPS beads with a particle size bigger than 3mm on the shear strength of LWS was explored in [5]. The stress-

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strain properties of EPS sand mixture specimens were investigated using Consolidated Drained (CD) triaxle compression trials, and it was revealed that increasing EPS content resulted in lower shear strength and increased volumetric strain [6]. Authors in [7] reported that the compressive strength of LWS decreases as the EPS increases. Furthermore, increasing the amount of EPS particles lowers the strength of LWS [7, 8]. The deformation of LWS is quick at the top of the sample and progressively declines to the bottom, according to the cyclic loading test and ABAQUS simulations of different blends of EPS and silty soil under varying confining pressure and cement contents [9, 10]. When the cement mixing ratio is increased, the mixed soil shear strength characteristics are comparable to those of general soil laboratory uniaxial and triaxle compression tests used to determine the relationship between stress and strain strengths. The triaxle test findings demonstrate that mixed soil's shear strength characteristics are very similar to ordinary soil only when the cement mixture is high [8]. Authors in [11] studied lightweight fill's unconfined compressive and shear strength and stiffness with regard to the cement-to-soil ratio. The compression strength of a lightweight blend is reduced by the formation of EPS particles. The most likely explanation is that the enlarged EPS beads have taken the place of the hydrate. In terms of composition, the porosity of the light mixture increases and the strength decreases as the percentage of light particles grows. When the cement percentage is reduced, the lightweight's compressive strength with various EPS sections varies only slightly [12]. Authors in [13] conducted triaxle and direct shear tests to investigate the shear strength characteristics. The soil friction angle was enhanced by combining 1mm EPS beads with fly ash.

The effect of various EPS geofoam densities and geofoam cell heights on the compressive strength was studied in [14, 15]. The density of EPS geofoam improves its compressive strength, whereas the compressive strength of EPS geofoam falls along with the cell height [16]. Light materials, such as EPS particles, are frequently used for mixing in a variety of earthworks in order to minimize the composite weight and reduce self-weight [15, 16]. The addition of cement solidification improves the engineering characteristics of waste soil, and the lightweight treatment reduces embankment settling [17, 18]. Additionally, the mechanical constitutive model of the lightweight mixture may be developed, and engineering applications can employ the calculated strengths and deformation of these lightweight additions [15, 21–24]. EPS is a type of plastic foam with several features, including light weight, pressure resistance, durability, and thermal insulation. It may be used to make LWS and is frequently employed in engineering constructions [20, 21]. Strength and deformability features are essential engineering properties of solidified soil as filling soil. Thus, focus is given on studying the basic mechanisms of artificially modified soil, such as compression deformability and shear strength. Many studies on LWS with EPS diameters up to 3mm have been reported, however, the mechanical properties of the mixed soil with EPS with diameters bigger than 3mm mixed with silty soil have yet to be thoroughly investigated. In the current investigation, laboratory experiments were conducted on silty soil mixed with different sizes of EPS beads and cement proportions. This study aimed to discover silty soil blends with various EPS bead sizes employed in civil engineering applications such as backfilling.

II. MATERIALS AND METHODS

A. *Silty Soil*

Silt soil was collected from the Yellow River Beach, which is adjacent to Zhengzhou City, Henan Province, China, as shown in Figure 1(a). The particles have a light-yellow color and uniform shape, as shown in Figure 1(b). The index characteristics and the gradation of silty soil are shown in Tables II and III. All particles passed through US standard sieve No. 40 (425μm). A total of 89.69% of the particles passed through the No. 200 (0.075mm) sieve. The gradation curve of silty soil is shown in Figure 1(c). According to the Unified Soil Classification System (USCS), this silt is classified as High Plasticity silt (MH). Its liquid limit is 52.63, which is greater than 50%, and the plasticity index (Ip) is 22.31 (greater than 7), and lies below the A-line in the plasticity chart.

(a)

(b)

(c)

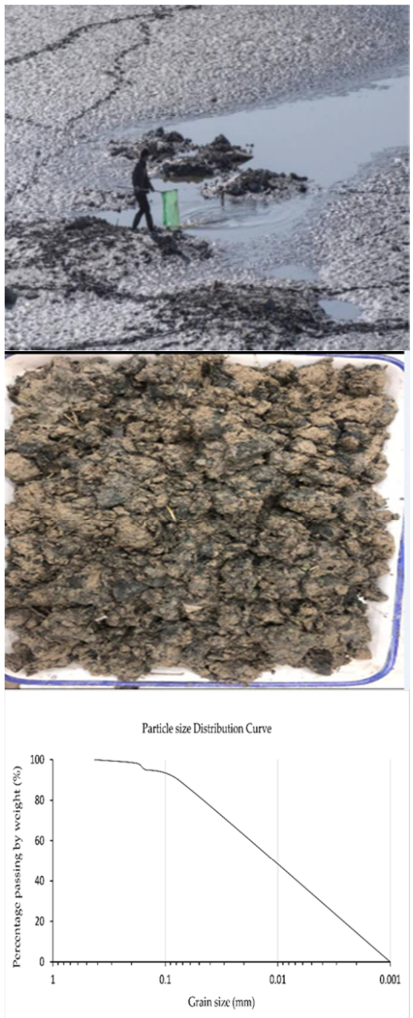

Fig. 1. (a) Yellow river sample collection site, (b) collected sample (silty soil), (c) grain size distribution curve.

B. EPS Beads

Lightweight EPS insulation is created from solid polystyrene particles. Polystyrene, which makes up 90 to 96% of its makeup, is the main gradient. Three different sizes of EPS beads, i.e. 4, 5, and 6mm, were employed in this study. The beads are round and white. Table I displays the densities and sizes of the EPS beads. In [22] images of the EPS beads taken using Scanning Electron Microscopy (SEM) can be seen.

TABLE I. SIZE OF EPS BEADS AND DENSITIES

Size of EPS beads (mm)	**Density (g/cm^3)**
4mm	0.011
5mm	0.009
6mm	0.006

C. Ordinary Portland Cement (OPC)

The curing agent used in this experiment is 32.5 composite OPC, which has a consistent quality, high strength, and quick-setting characteristics.

D. Sample Preparation and Mixed Ratio

The silty soil samples were first dried for 24h at 105°C in an oven. The following day, the dried samples were taken from the oven and were spread in a tray. They were carefully broken into pieces with a rubber hammer so that the structure of the silty soil could not be destroyed. Then, the pieces passed through a sieve and debris and unwanted materials were removed. Then, the cement was mixed into the dry silty soil. The silty soil's and cement's particles sizes are similar. Ordinary tap water was poured into the silt cement powder and they were mixed properly with a spatula for 2min until the admixture became homogenous. EPS beads of different sizes were put into the cement silt slurry and the admixture was mixed again for 5min. The mixture became non-homogenous because EPS beads are bigger than silt and cement particles [22]. The mixture was then sampled and the light-weighted samples were left for curing for 28 days. The specimens were ready for testing after the curing period. The mixing ratios are shown in Table IV.

TABLE II. INDEX PROPERTIES OF SILTY SOIL

Properties	**Values**
Density (g/cm^3)	1.49
Specific gravity G_s	2.72
Water content ω	99.5
Liquid limit w_L	52.63
Plastic limit w_p	30.32
Plasticity index I_P	22.31
Liquidity index I_L	3.10
Volumetric weight (r/KN/m^3)	14.90
Pore ratio (e)	2.64

TABLE III. SIEVE ANALYSIS

Particle percentage (%)			
0.425-0.18mm	0.18-0.15mm	0.15-0.075mm	0.075-0.001mm
1.76	3.19	5.36	89.69

E. Test Plan

The UCS is commonly used in engineering applications and tests. Different mixing ratios were chosen and 3 samples were made for each mixing ratio. The sample size dimensions for the UCS test were 40mm diameter and 80mm height, with applied loading pressures of different stresses. The impact of several parameters on the deformation and strength of silt LWS were investigated, including EPS particle size, cement blending ratios, and EPS content. The ultimate axial strength without lateral pressure resistance was measured using unconfined compressive strength. A dial gauge and a proving ring are typically employed to check the compressive strength, as shown in Figure 2(a). The UCS test was performed, and the test technique was controlled by strain. The device can directly detect the stress and determine the strain based on the sample's height change. The axial stress and strain data were obtained for 2 cement mixing ratios (10% and 15%) and the effect of EPS bead diameter on LWS's deformation and strength properties was examined.

(a)

(b)

Fig. 2. (a) View of the large-size unconfined compression test apparatus, (b) specimen after the test.

III. RESULTS AND DISCUSSION

A. The Effects of Cement and EPS Bead Size on Stress and Strain Curves of Light-Weighted Soil

The stress-strain curves of samples with various EPS bead sizes are shown in Figures 3-4. The stress-strain curve swings to the right and downward with increasing cement and EPS content. This demonstrates that the production of LWS follows a distinct pattern. The samples with 4mm EPS bead, 15% cement content, and 1% EPS content had more strength and lower ductility than the samples with 5mm and 6mm EPS bead size with the same percentage of cement and EPS. Besides, EPS beads of bigger sizes have lower shear strength and higher ductility. When the mixing ratio is 15% and 10% cement, and

1% and 2% EPS, the density of 4mm is higher than that of other EPS beads. Due to the small size of the sample, the EPS beads and silty particles have close contact with each other, which enhances shear strength. On the other hand, the tiny holes in the EPS beads of 4mm particles make movement more difficult. When the shear stress exceeds the sample's strength, the 4mm samples are easily destroyed quickly due to energy dissipation, which explains the sample's reduced ductility. Furthermore, when the size and composition of EPS beads grow more significant, the strength falls, and the ductility increases. Moreover, when EPS, a material with lower strength and better ductility, substitutes silty soil in blends, the strength and ductility of the EPS-silt blends drop. Another factor contributing to the weakening of EPS-silty blends is the failure of EPS beads to connect with soil particles.

The stress-strain relationship curve comprises three phases. Before reaching the yield stress, the early load period expands with the strain, stress rises, and the stress-strain relationship gets closer to a linear connection. The linear relationship demonstrates that samples in an elastic state with no discernible breaks can theoretically be restored. As the load increases in the material plastic yield stage, new cracks are formed, and the existing cracks are improved. The strain growth rate is greater than the stress growth rate as the soil shrinks and expands. The stress-strain relationship fits the curve, and the stress rises to its maximum value. The third step is the fracture stage, in which the stress lowers dramatically, and the curve's slope becomes negative. Stress-strain curves of different EPS bead sizes and cement mixing are shown in Figures 3-5.

TABLE IV. MIXING RATIOS

Specimen	Serial number	Cement content (a_c) %	EPS content (a_e)%	EPS beads	Water content	Curing time
LWS	1	10%	1%, 2%	4mm	40	28
		10%	1%, 2%	5mm	40	
		10%	1%, 2%	6mm	40	
LWS	2	15%	1%, 2%	4mm	40	28
		15%	1%, 2%	5mm	40	
		15%	1%, 2%	6mm	40	
Silt					99.5	28

B. *UCS of LWS and EPS Bead Size*

The UCS comparison for different EPS particle sizes is shown in Figure 5. The UCS for the 4mm group is larger for a given additive content than it is for the other EPS bead sizes. It is evident that when the EPS particle size increases, the UCS of EPS-silty blends diminishes. For instance, the UCS of the 4, 5, and 6mm groups is 550.30kPa, 320.51kPa, and 221.41kPa respectively, when the EPS content is 1% and the cement percentage is 15%. As a result, samples with 4mm EPS particle size should have a denser microstructure than samples with other EPS sizes, resulting in increased strength. Furthermore, the UCS difference between the 5mm and 6mm groups is less than that between the 4mm and 5mm groups. The soil structure of the 4mm group is smaller due to the relatively tinier particle size. The soil particles in the 5mm and 6mm groups cannot be closely mixed with the EPS particles because the EPS particles are substantially more significant than the soil particles. Furthermore, the EPS with particle sizes of 5 and 6mm had the most significant specific surface area and smooth surface, which reduced the effects of occlusion between soil particles, resulting in the weakest strength of all groups. The cost can be reduced by increasing the EPS size. Structural strength and prices drop as the EPS size increases. To reduce cost, practical projects should employ EPS beads with a diameter of 4-6mm, and material prescription can be adjusted.

C. *Deformation of LWS with Different Cement Proportions and EPS Bead Sizes*

LWS's confined stress-strain curve is comparable to other traditional soils. As the load and the size of the EPS beads grow larger, the modulus of deformation increases. The rate of development of light soil increased slowly at first and steadily dropped as stress increased, forming a curved dome shape. The turning point of the curve represents the strength of soil, particularly its ultimate strength.

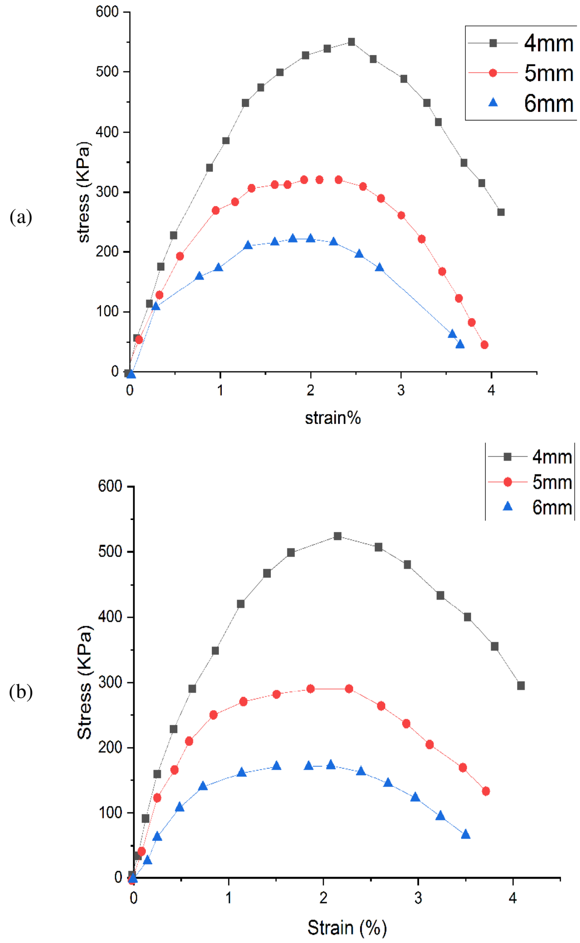

Fig. 3. 15% cement mixed with (a) 1% (b) 2% EPS content.

The bigger the EPS particle size, the lower the strength of the mix. The strength of a mixed soil containing a significant amount of cement is superior to that of a mixed soil containing less cement. The LWS's strength was improved however, if the stress exceeds the mixed soil's strength, the mixed soil's structure will eventually disintegrate and collapse. The ratio of

EPS particle volume deformation to the total volumetric deformation decreased as the EPS particle size rose from 4 to 6mm, due to the fact that when EPS particle size increases, fewer EPS particles are incorporated into the system as a whole, which lowers the EPS particle deformation ratio.

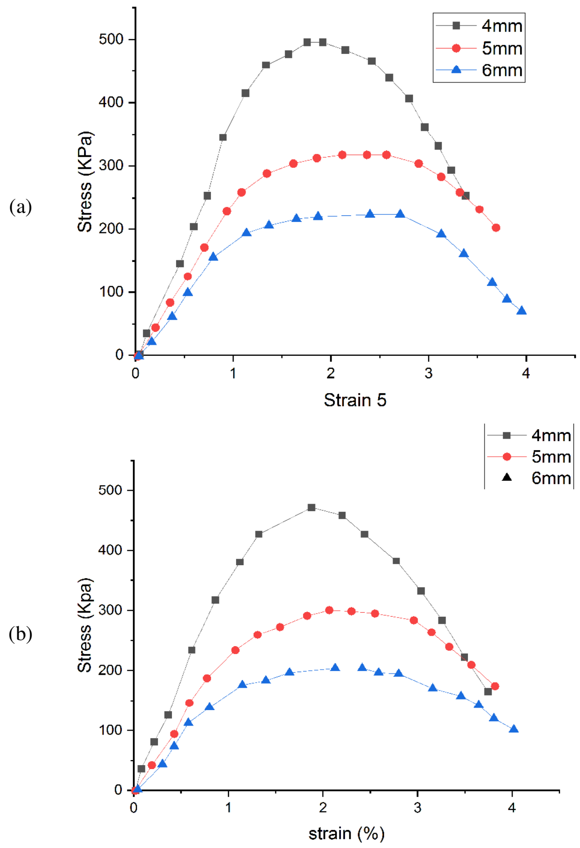

Fig. 4. 10% cement mixed with (a) 1%, (b) 2% EPS content.

The number of EPS particles in a structure significantly impacts structural deformation. With more EPS content in the sample, the particular surface area grows greater, reducing the sample's consolidation strength. Under different stress conditions, increased EPS sizes dramatically increase soil deformation. The structural deformation of lightweight silt soil is significantly affected by the added EPS particles. The experiment revealed that the added EPS particles of various sizes significantly impact the silt LWS's shear strength and deformation characteristics. The strength and deformation variation characteristics of LWS with varied EPS bead sizes are diverse. For instance, the samples with 15% cement and 1% EPS contents of 4mm size have the highest shear strength and the lowest ductility. On the other hand, the samples with 10% cement and 2% EPS of 6mm have the lowest shear strength and the highest ductility as shown in Figures 3 and 4, and they all display multi-stage changes. The failure strain value increased dramatically as the size and quantity of the EPS particle content increased, the plastic zone expanded, but the strength decreased. Additionally, the changing rate of stress intensity decreased as the EPS size increased, resulting in the extension of the elastoplastic range.

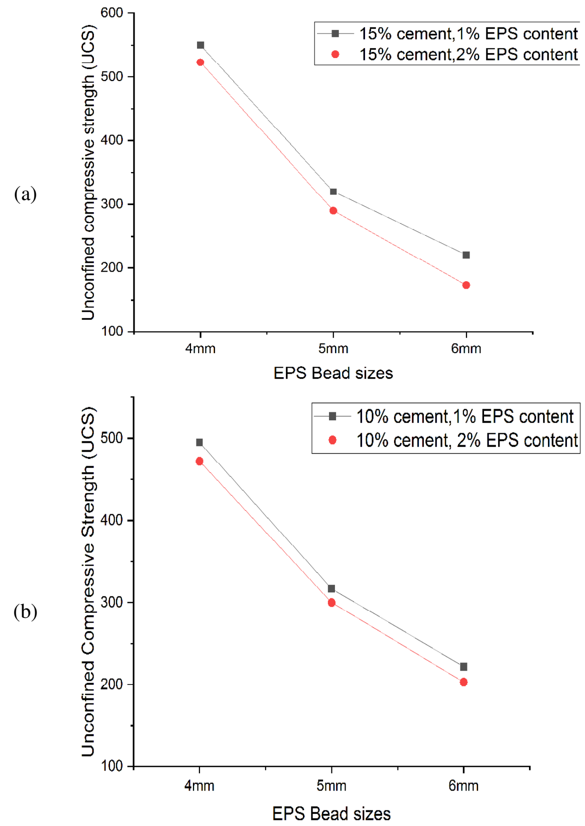

Fig. 5. Unconfined compressive strength and EPS beads size of (a) 15% and (b) 10% cement with 1% and 2% EPS content.

According to the analysis of Figures 3-5, cement concentration has little impact on the failure strain of light silt soil, and the strain value difference between them at different mixing ratios is small. As a result, the effect of cement amount on the strain value of light silt soil can be ignored within a limited range of cement contents. The strength of the cementation created between the EPS particles and the consolidated soil in the lightweight silt soil is quite robust under high cement content conditions. Moreover, when the stress level rises, a brittle fracture is more likely to occur.

IV. CONCLUSIONS

Unconfined Compressive Strength (UCS) test was utilized in this study to investigate the strength and deformation characteristics of Light Weighted Soil (LWS) comprised of EPS beads of various sizes, silty soil, cement, and water. From the experimental results, the following conclusions can be drawn:

- As the EPS particle size rises, the strength of LWS does not. EPS beads easily adhere to silty particles to create an elastic body in the case of 4mm EPS size because there are more pores between the particles and they are closer in size. The silty particles and EPS beads are in close contact due to their small diameter, thus increasing shear strength.
- The engineering features of EPS-silty blends, such as ductility and deformation, increase with high loads and EPS

size. When the EPS particle size approaches 6mm, the UCS results drop. The UCS of EPS-silt mixes with 4mm EPS size is greater than all the other groups for a given additive concentration, but their ductility is lower.

- The dome shape of LWS has confined stress-strain relation curves that differ from typically modified silt, indicating that LWS is structural soil. When stress is less than strength, very minor deformation occurs. However, the soil structure rapidly degrades and collapses when stress exceeds strength.
- The cost can be reduced by using higher EPS bead size. Strength and price drop as the EPS size increases. To save money, practical projects like wall retaining should employ EPS beads with a diameter of 4 to 6mm, while material prescription can be adjusted.

REFERENCES

[1] W. Q. Dai, X. Chen, and H. Q. Zhang, "Experiment and numerical simulation of dynamic behavior for cohesive soils," *Journal of Jilin University*, vol. 38, pp. 831–836, 2008.

[2] S. Yamada, Y. Nagasaka, and N. Nishida, "Foamed particle light-weight soil with sand," *Soils and Foundations*, vol. 37, pp. 25–30, 1989.

[3] H. Gao, J. Liu, and H. Liu, "Geotechnical properties of EPS composite soil," *International Journal of Geotechnical Engineering*, vol. 5, no. 1, pp. 69–77, Jan. 2011, https://doi.org/10.3328/IJGE.2011.05.01.69-77.

[4] A. Kan and R. Demirboga, "Effect of cement and EPS beads ratios on compressive strength and density of lightweight concrete," *Indian Journal of Engineering and Materials Sciences*, vol. 14, no. 2, pp. 158–162, Apr. 2007.

[5] T. Hou and G.-L. Xu, "Influence law of EPS size on shear strength of light weight soil," *Yantu Gongcheng Xuebao/Chinese Journal of Geotechnical Engineering*, vol. 33, pp. 1634–1641, Oct. 2011.

[6] A. Deng and Y. Xiao, "Measuring and Modeling Proportion-Dependent Stress-Strain Behavior of EPS-Sand Mixture," *International Journal of Geomechanics*, vol. 10, no. 6, pp. 214–222, Dec. 2010, https://doi.org/10.1061/(ASCE)GM.1943-5622.0000062.

[7] Y. Feng, "Experimental research on the compressive strength influencing factors of expanded polystyrene sheet silt mixed lightweight soil material," *Materials Research Innovations*, vol. 19, no. sup10, pp. S10-64, Dec. 2015, https://doi.org/10.1179/1432891715Z.0000000002089.

[8] A. A. H. Bhutto, S. Zardari, G. S. Bhurgri, M. A. Zardari, R. Bhanbhro, and B. A. Memon, "Post Construction and Long Term Settlement of an Embankment Dam Computed with Two Constitutive Models," *Engineering, Technology & Applied Science Research*, vol. 9, no. 5, pp. 4750–4754, Oct. 2019, https://doi.org/10.48084/etasr.3070.

[9] Y. Feng, Y. Chao, and P. Zhang, "Meso-Structure Deformation Mechanism of EPS Silt Mixed Lightweight Soil Material under Cyclic Loading," *Soil Mechanics and Foundation Engineering*, vol. 57, no. 3, pp. 237–243, Jul. 2020, https://doi.org/10.1007/s11204-020-09660-5.

[10] A. H. Bhutto, G. S. Bhurgri, S. Zardari, M. A. Zardari, R. Bhanbhro, and B. A. Memon, "Numerical Analysis of Rapid Drawdown of an Embankment Dam," *Engineering, Technology & Applied Science Research*, vol. 10, no. 2, pp. 5496–5500, Apr. 2020, https://doi.org/10.48084/etasr.3211.

[11] Y. Feng and Y. B. Pei, "Study on the Stress and Strain of EPS Silt Light-Weight Soil by Laboratory Test," *Applied Mechanics and Materials*, vol. 580–583, pp. 499–502, 2014, https://doi.org/10.4028/www.scientific.net/AMM.580-583.499.

[12] H. Liu, A. Deng, and J. Chu, "Effect of different mixing ratios of polystyrene pre-puff beads and cement on the mechanical behaviour of lightweight fill," *Geotextiles and Geomembranes*, vol. 24, no. 6, pp. 331–338, Dec. 2006, https://doi.org/10.1016/j.geotexmem.2006.05.002.

[13] W. Lu, J. Wang, and Y. Zhang, "Strength Characteristics of Cement Treated and Expanded Polystyrene Mixed Lightweight of Waste Soil from the Construction Site of a Yangtze River Bridge in China," *Advances in Civil Engineering*, vol. 2020, May 2020, Art. no. e3640510, https://doi.org/10.1155/2020/3640510.

[14] S. M. Nawghare and J. N. Mandal, "Effectiveness of Expanded Polystyrene (EPS) Beads Size on Fly Ash Properties," *International Journal of Geosynthetics and Ground Engineering*, vol. 6, no. 1, Mar. 2020, Art. no. 6, https://doi.org/10.1007/s40891-020-0189-3.

[15] A. H. Padade, S. Dutta, M. B. Nadaf, B. Ram Rathan Lal, and J. N. Mandal, "Expanded Polystyrene (EPS) Geofoam Unit Cells with Fly Ash," in *Geo-Chicago*, Chicago, IL, USA, Aug. 2016, pp. 35–43, https://doi.org/10.1061/9780784480144.004.

[16] E. Vitale *et al.*, "Chemo-mechanical behaviour of lightweight cemented soils," *Acta Geotechnica*, vol. 15, no. 4, pp. 933–945, Apr. 2020, https://doi.org/10.1007/s11440-019-00797-8.

[17] X. Zhao, G. Zhao, J. Li, and P. Zhang, "Unconfined compressive strength property and its mechanism of construction waste stabilized lightweight soil," *Geomechanics and Engineering*, vol. 19, no. 4, pp. 307–314, 2019, https://doi.org/10.12989/gae.2019.19.4.307.

[18] W. Lu, L. Miao, J. Zhang, Y. Zhang, and J. Li, "Characteristics of Deformation and Damping of Cement Treated and Expanded Polystyrene Mixed Lightweight Subgrade Fill under Cyclic Load," *Applied Sciences*, vol. 9, no. 1, Jan. 2019, Art. no. 167, https://doi.org/10.3390/app9010167.

[19] A. J. Puppala, P. Ruttanaporamakul, and S. S. C. Congress, "Design and construction of lightweight EPS geofoam embedded geomaterial embankment system for control of settlements," *Geotextiles and Geomembranes*, vol. 47, no. 3, pp. 295–305, Jun. 2019, https://doi.org/10.1016/j.geotexmem.2019.01.015.

[20] H. M. Gao, X. Li, Z. H. Wang, A. W. Stuedlein, and Y. Wang, "Dynamic shear modulus and damping of expanded polystyrene composite soils at low strains," *Geosynthetics International*, vol. 26, no. 4, pp. 436–450, Aug. 2019, https://doi.org/10.1680/jgein.19.00029.

[21] W. Lu, Y. Zhang, W. Liu, C. Liu, and H. Wang, "Evaluation of Geomembrane Effect Based on Mobilized Shear Stress due to Localized Sinking," *Advances in Civil Engineering*, vol. 2019, May 2019, Art. no. e4942578, https://doi.org/10.1155/2019/4942578.

[22] M. V. Silveira, A. V. Calheiros, and M. D. T. Casagrande, "Applicability of the Expanded Polystyrene as a Soil Improvement Tool," *Journal of Materials in Civil Engineering*, vol. 30, no. 6, Jun. 2018, Art. no. 06018006, https://doi.org/10.1061/(ASCE)MT.1943-5533.0002276.

[23] E. O. Ogunsona, K. L. Dagnon, and N. A. D'Souza, "Multi-Fold Enhancement in Compressive Properties of Polystyrene Foam Using Pre-delaminated Stearate Functionalized Layer Double Hydroxides," *Polymers*, vol. 12, no. 1, Jan. 2020, Art. no. 8, https://doi.org/10.3390/polym12010008.

[24] X. Ni, Z. Wu, W. Zhang, K. Lu, Y. Ding, and S. Mao, "Energy Utilization of Building Insulation Waste Expanded Polystyrene: Pyrolysis Kinetic Estimation by a New Comprehensive Method," *Polymers*, vol. 12, no. 8, Aug. 2020, Art. no. 1744, https://doi.org/10.3390/polym12081744.