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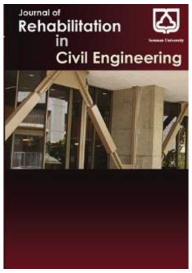

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Effects of Geofoam Particles on Geotechnical Properties of Clay-dune Sand

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ABSTRACT

Nowadays, new materials are widely used for improving the bearing capacity of the soils and geosynthetics include the type of these materials which are utilized in this regard. In addition, the geofoam panel type of geosyntethic materials is useful and an alternative for backfill in retaining wall or pavement layers. The present research mainly aimed to investigate sthe effects of geofoam particles (0.2, 0.5, & 1%) on improving the bearing capacity of the clay-sand mixture. To this end, dune sandy soil (passed from sieve No.30 and residue on sieve No.50) was provided from Shore of the Lake Urmia and mixed with kaoline industrial clay at 15, 30, and 50 percentages. Then, compaction, uniaxial in three loading speed (0.5, 1, & 1.5 mm/min), direct shear (in vertical stresses 1, 2, & 3 kg/cm^2), and falling head permeability tests were performed to evaluate the influence of geofoam particles on geotechnical properties of the mixed soil. The results showed that maximum dry density and elastic modulus increased by a 0.5% increase in the geofoam in the soil mixture. Meanwhile, the shear strength of the specimens increased as well. Finally, permeability and the drainage condition improved by adding geofoam to the specimens.

1. Introduction

Geofoam is a type of geosynthetic material that contains foam. In addition, it is highly used in geotechnical engineering owing to its low density as compared with the density of the soil, as well as its high compressibility, rapid and easy implementation, heat insulation, and water absorption resistance [1]. Therefore, geofoam can be utilized in retaining walls, pavement construction projects as a lightweight filler, and the

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reduction of stresses caused by vertical loads in the lower layers [1, 2].

Considering that gasoline can dissolve geofoam, in projects of this concern, geofoam must be covered with impervious plastic membranes such as polyvinyl chloride and geomembrane in order to cope with such fluids [3, 4].

Generally, the stress and strain behavior of geofoam blocks can be divided into four regions. In the first region, the linear behavior can be observed in the strain lower than 0.8%. In the second region, the curve has an inflection up to a strain of about 10%. In the third region, geofoam has linear behavior up to a strain of about 50% while geofoam hardens in the fourth area that is associated with the strain higher than 50% [4].

Extensive studies have focused on geofoam application in granular or block form in order to improve the soil and geotechnical buildings. The first use of geofoam as a light embankment in Japan dates back to 1985 and this country has assigned almost 50% of the total consumption worldwide. Further, geofoam light-weight embankment materials have been applied as an option for subgrade soil modification since 1990 due to some reasons. First, the short construction time of lightweight embankments as compared to other subgrade stabilization methods, as well as a decrease in subgrade settlement and an increase in its load-bearing capacity as compared to the use of other materials for the construction of embankments [5].

Horvath conducted one of the most important studies in this field. He divided the stress-strain behavior of geofoam materials into linear and elastic, plastic with a specific yielding compressive strength, linear and hardening, as well as nonlinear and hardening parts based on the results of the laboratory tests [3]. In the investigation of the behavior of geofoams with different densities, sizes and shapes, Elragi showed that by increasing the size of the geofoam blocks, its elastic modulus increases and the behavior of larger specimens is more resistant than the smaller ones [6]. Furthermore, Hazarika observed that increasing the size of the geofoam block with the same density leads to an increase in its compressive strength [7]. Saradhi et al. testing the lightweight concretes, found that, the compressive strength in concrete containing geofoam aggregates increases by increasing the density of geofoam [8]. In another study, Negussey concluded that the strength and modulus of the geofoamal blocks increases in unconfined pressure testing through increasing the density of geofoams [9]. Moreover, Illuri evaluated the mechanical behavior of geofoam-soil mixture and its effect on reducing the swelling potential and the volume of swollen soils through a series of direct and three-axis shear tests. These studies were conducted on sand and bentonite with different mixing ratios, and crude geofoam was added to the soil with a weight mixing percentage of 0.3, 0.6, and 0.9%. The results of direct shear tests revealed that, increasing the weight percentages of geofoam mass in mixtures with less bentonite led to an increase in the maximum shear stress. However, the opposite condition was observed in more plastic soils [10].

Likewise, Aytekin et al. tested a geofoam-free expanding soil and the same soil with different amounts of geofoam rolls and then evaluated the pressure of lateral and vertical swelling [11]. Deng and Xiao also studied the stress-strain properties of sand-geophomic mixture by performing direct and three-axial static shear tests. They evaluated the effect of mixing ratio and confining pressure on grain and geofoam soil mixture behavior. The results of three-axial tests on three different mixing ratios (i.e., 0.5, 1.5, & 2.5%) demonstrated that increasing the mixing percentage of geofoam decreased shear strength while it increased the volume of the strains. The confining pressure was directly correlated with the strength of the mixture as well. Finally, a percentage of 0.5% was suggested as the optimal mixing ratio [12]. Similarly, Necmeddin and Canakci examined the effect of adding modified expanded polystyrene geofoams to the soil on density indices such as optimal moisture content and maximum dry density [13]. The thermal modification of geofoams is considered as a new method proposed by Kan and Demirboga to achieve stable and high-density foams with higher strength. The results showed that the maximum dry weight in both density experiments linearly reduced by increasing the weight percentage of geofoam [14].

Various studies have addressed the application of geofoam in the improvement of soil materials in Iran. For example, Heydarian et al. added geofoam particles at the weight percentage of 0.25, 0.4, and 0.5 to sandy soils, as well as 0.02 and 0.03% to the clay. Based on their results, the angle of internal friction decreased while the apparent adhesion increased by increasing the percentage of geofoam in the sandy soil. Additionally, uniaxial compressive strength exhibited an incremental trend in the clay soil by increasing the geofoam [15]. In addition, Nejad Shirazi et al. evaluated the effect of geofoam particles on coarse (residue on screen 4) and fine grained material (passing through screen 4) and found that the angle of internal friction decreases whereas the apparent adhesion increases by increasing the percentage of geofoam in the sandy soil. Further, the uniaxial compressive strength in the clay soil demonstrated an incremental trend by increasing the geofoam [16]. Likewise, Hasanpouri and Dabiri performed several studies to evaluate the impact of thickness, density, height, and the number of geofoam blocks on the lateral pressure applied on the stone and wood retaining walls under static loading conditions. Their results showed that the placement of geofoam blocks can significantly reduce the lateral pressure of the soil mass on the wall. The present study sought to investigate the possibility of using geofoam particles in clay-sand soils to build the retaining wall embankment or road pavement layers. Furthermore, it was attempted to evaluate the effect of geofoam particles on the grain structure and their placement beside each other, as well as the load-bearing capacity of the clay-sand mixture [17, 18].

2. Materials and Methods

2.1. Materials

In this research, kaolinite clay soil with the commercial name (ZMK2) was used, which is produced in Iran-China Company [19]. Moreover, fine dune sand was prepared from the shores of Lake Urmia. The particle size distribution of dune sand was selected between sieves No.40 and No.50. Dune sand mixed with clay in 15, 30 and percentage (by weight) as well (Figure 1). Similarly, the particle size distribution of materials was determined according to ASTM D421 [20] and ASTM D422 [21] (Figure 2). Based on the diagrams and according to unified soil category system, dune sand was uniformity graded (SP) and subangular. Additionally, the clay had low plasticity (i.e., PI=10 and SL=18). Plasticity index was (PI) evaluated based on ASTM D4318-95A [22]. In addition, the specific gravity (Gs) of materials was assessed based on ASTM D854 [23] (Table 1). Further, geofoam particles were prepared from EPCO Company [24] with the commercial name EPS12. The properties of geofoam particles are presented in Table 2. Concerning mechanical properties of geofoam and the particle size (less than 3 mm diameter), the rate of 0.2, 0.5, and 1% (by weight) was added to clay-sand mixture specimens, respectively.

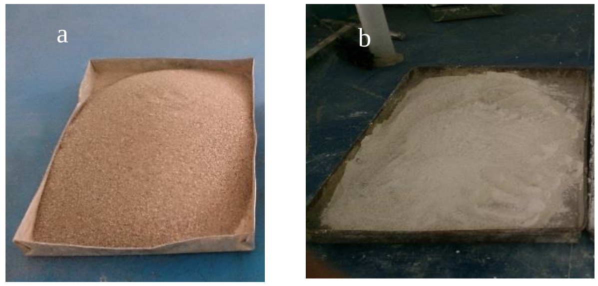


Fig. 1. Materials of the study, (a) dune sand and (b) kaolinite clay.

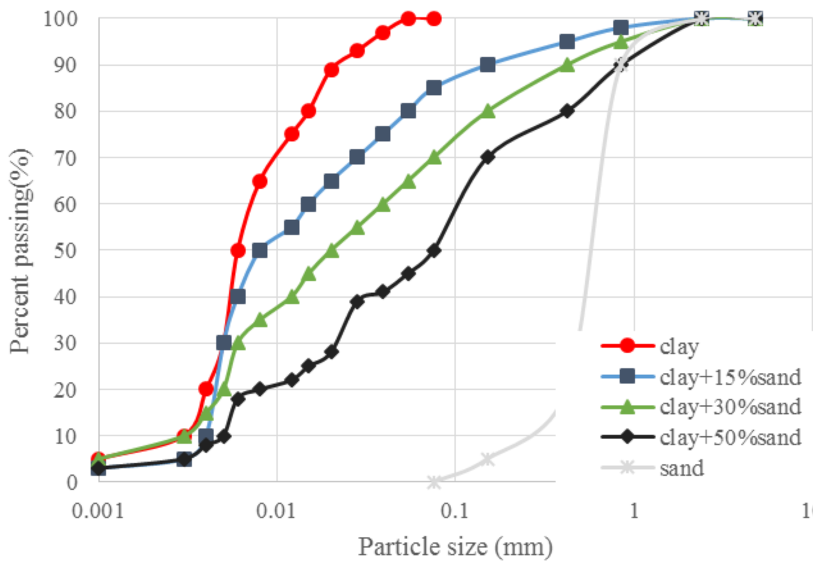


Fig. 2. The curve for grain size distribution of materials

Table 1. Specific Gravity Values of Materials.

Clay	Clay+15% Sand	Clay+30% Sand	Clay+50% Sand	Sand
2.647	2.665	2.681	2.695	2.65

Table 2. Mechanical Properties of EPS 12 Geofoam Particles [24].

EPS12	Unit	Properties
11.2	kg/m^3	Unit weight
15	kPa	Compressive strength
1500	kPa	Elastic modulus
69	kPa	Flexural strength

Note. ESP: Expanded polystyrene

2.2. Experimental Program

As mentioned earlier, the present study mainly aimed to evaluate the effects of geofoam particles on geotechnical properties of clay-dune sand mixtures. For this purpose, the compaction test was performed according to ASTM D4253 [26] and ASTM D4254 [27] in order to determine the minimum (e_{min}) and maximum (e_{max}) void ratios. Furthermore, the ASTM C305-14 [28] was used to prepare uniform and homogeneous mixed specimens. Accordingly, geofoam particles and water (by considering the optimum water content) were blended in a mixer. Then, the mixture was rested for a while so that geofoam particles absorb water and stick to soil particles properly. Next, the soil aggregates were quietly added to geofoam particles in a dry condition. Based on the standard, the 30-second mixed operation was stopped so that the materials absorb the moisture. Finally, the mixing operation was performed in 15 and 60 seconds with slow and moderate round speeds, respectively. Moreover, uniaxial compression test was conducted based on ASTM D2166-16 [29] in order to determine the geotechnical properties of the improved and unimproved mixed specimens. To consider the effects of loading speed in material behavior, this test was performed in three speeds equal to 0.5, 1, and 1.5 mm/min (Figure 3). Then, the direct shear test was conducted according to ASTM D3080-11 [30] in 10×10 cm mold with slow loading speed equal to 1 mm/min and vertical stress of 1, 2, and 3 kg/cm^2 (Figure 4). Finally, head falling permeability test was run according to ASTM D5084 [31] in order to investigate the effects of geofoam particles in the drainage and filtering of materials. Tests programming is provided in Table 3.

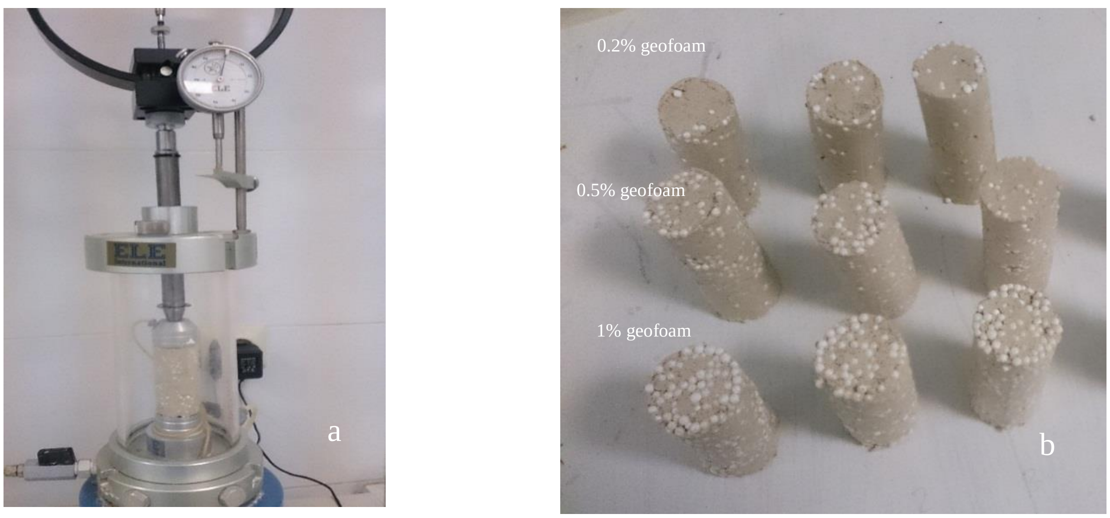


Fig. 3. Uniaxial compression test apparatus, (a) A specimen under loading and (b) improved clayey specimens with geofoam.

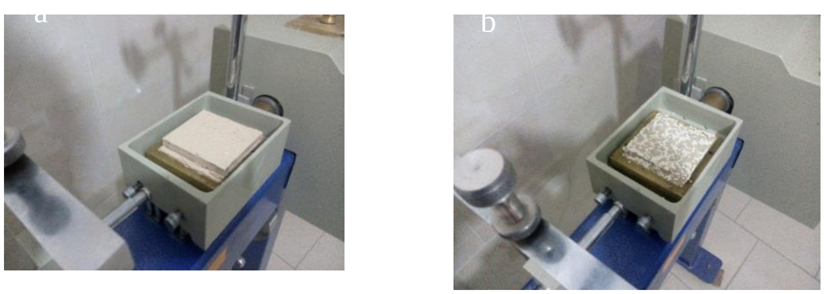


Figure 4. Direct shear test apparatus, (a) Clay+15% sand+0.2% geofoam, and (b) Clay+15% sand+1% geofoam.

Table 3. Experimental Program of the Study.

Specimen	**Geofoam (%)**				**Test Program**			
	0	**0.2**	**0.5**	**1**	**Compaction Test**	**Uniaxial Compressive Strength Test**	**Direct Shear Test**	**Head Falling Permeability Test**
C-0	*	*	*	*	*	*	*	*
C-15S	*	*	*	*	*	*	*	*
C-30S	*	*	*	*	*	*	*	*
C-50S	*	*	*	*	*	*	*	*

Note. C: Clay; S: Sand.

3. Results

The results from the compaction test are displayed in Figure 5a-b. As shown, in the absence of geofoam particles in the soil samples, the maximum dry density of the clay soils increases by increasing the sand percentage to 30% and then decreases by increasing the clayey soil percentage. In addition, the optimum moisture content, which was maximum in the clay, shows a slight downward movement by increasing the sandy soil percentage. Based on the results, the maximum dry density increased while the optimum water content decreased when the geofoam particles of 0.5% (by weight) were added to the specimens. Then, in all studied samples, contrary to the previous state, the maximum dry density decreased whereas the optimum moisture content increased by increasing the percentage of geofoam particles. Given that geofoam particles are flexible, the soil mixture leads to a reduction in the voids of the inter particles while increasing the contacts when 0.5% of these particles are between the sand and clay (with low plasticity). Nonetheless, the subangularity of the sandy soil is more effective in these conditions. As a result, the maximum dry density increases whereas water absorption shows a decrease, which is in line with the findings of Heydarian et al. [15] and Nejad Shirazi et al. [16].

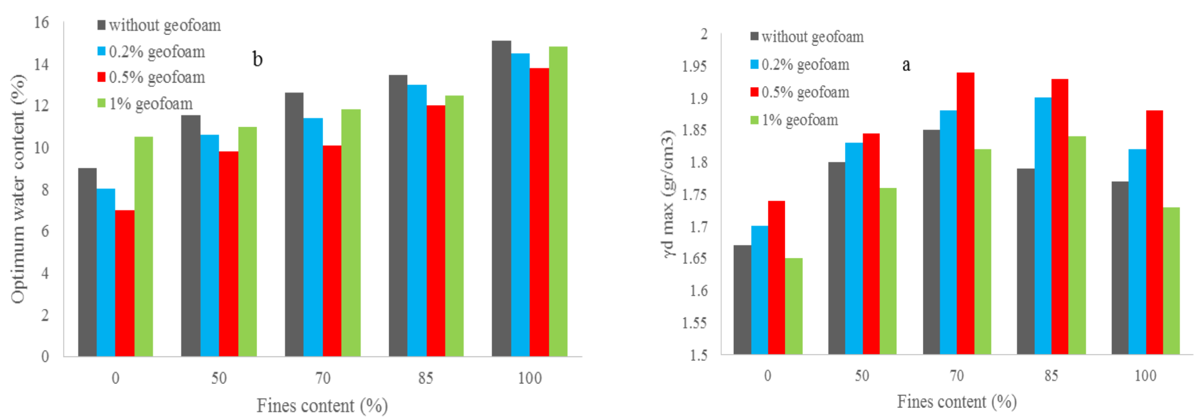


Fig. 5. Effects of geofoam particles on compaction test results, (a) Maximum dry unit weight and (b) Optimum water content.

These conditions can be explained based on the minimum void ratio (e_{min}) shown in Figure 6. The minimum void ratio is associated with sandy soils in the absence of geofoam in the soil samples. Then, the e_{min} parameter reaches a minimum value, or in other words, the free space between the particles reduces and it increases slightly in the clay by increasing the clay content in the samples to about 85% (15% of the sand). When geofoam particles were added to the studied soil samples, the void ratio reached the lowest level in all studied samples at 0.5% by the weight of the geofoam. This represents a relative improvement in the density. Further, the void between the particles increased and discontinuity was created in the structure of the particles of the soil samples by increasing the percentage of geofoam particles in the soil samples. Accordingly, the void ratio between the soil particles increased while the maximum dry density reduced, and finally, the optimal moisture content demonstrated an increase.

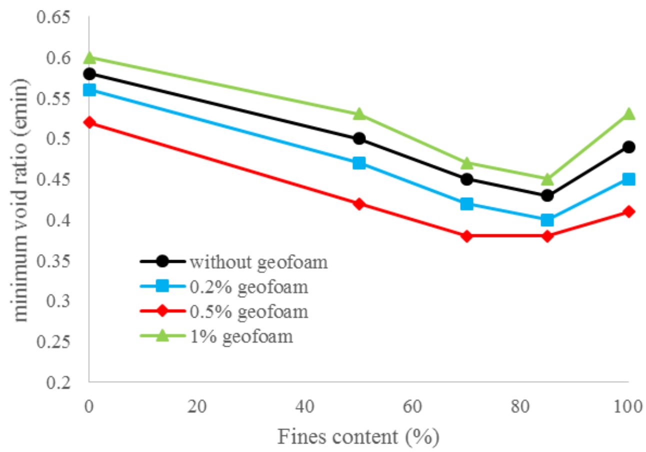


Fig. 6. Effects of geofoam particles on the variation of the minimum void ratio (e_{min}) in specimens.

Uniaxial compressive strength test was performed to investigate the effect of geofoam particles on the bearing capacity and ductility of the specimens. Furthermore, the velocity values of loading 0.5, 1, and 1.5 mm/min were considered for applying the obtained results in pavement layer improvement and geotechnical constructions under dynamic loading in a special condition. Figure 7a-b-c illustrates the compressive strength values of the specimens at the failure moment in different loading rates. Based on the data in the diagrams, in the case, the geofoam particles were not added to the soil, the compressive strength of the sample increased by increasing the percentage of the sand to 30% in the clay, which corroborates with the findings of Heydarian et al. [15] and Nejad Shirazi et al. [16]. When the sand content in the clay reached 50%, the uniaxial compressive strength decreased due to changes in the structure and skeleton of the soil. In the case of addition of geofoam to the specimens, the uniaxial compressive strength of the samples was at its maximum level when the geofoam content was 0.5% by weight. This increase was 2.02 times higher than the non-improved state in the clay soil on average (at three loading rates). In the mixture samples of the clay-sand at percentages of 15, 30, and 50, the increase in the strength was 1.35, 1.1, and 1.8 times on average, respectively, as compared to the unimproved state (at three loading rates). On the other hand, increasing the geofoam particle content in the samples reduced the amount of the bearing capacity due to a discontinuity in the soil structure and matrix of the particles. Based on Figures 6 and 7-a-b-c, the void ratio represents the minimum value in the clay with 30% sand mixture specimen when adding 0.5% geofoam particles. Therefore, strength demonstrates an increase by increasing the contact areas between the particles. Thus, by increasing the loading rate, the uniaxial compressive strength of the studied samples increased slightly because of the flexibility of geofaom particles. This situation is suitable for pavement layer improvement. Similarly, the settlement and deformation behavior of the studied samples, as well as the effect of the geofoam particles on the values of elastic modulus and deformation at the moment of failure were investigated and related results are depicted in in Figures 8a-b-c, and 9a-b-c, respectively.

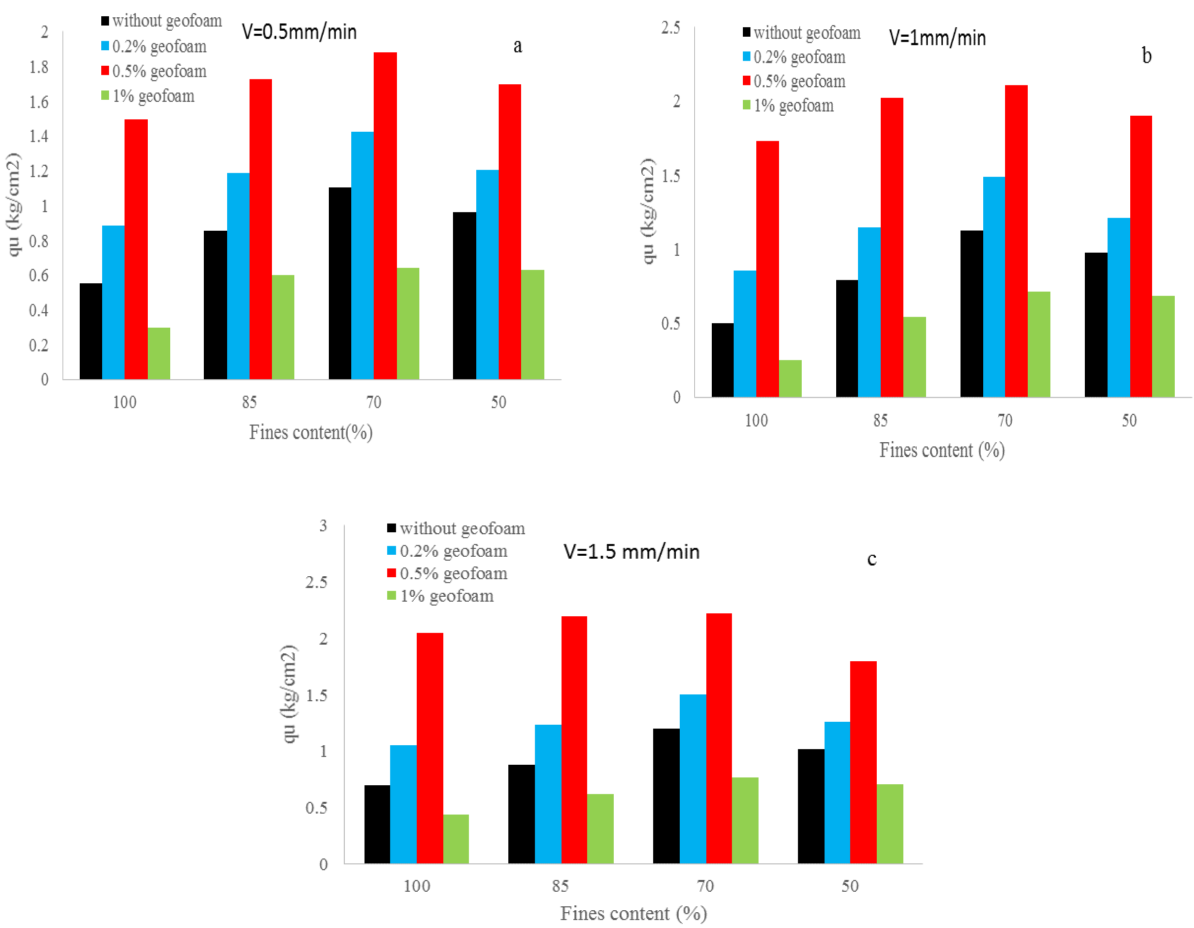


Fig. 7. Effects of geofoam particles on uniaxial compression strength in different speed loadings (i.e., 0.5, 1, & 1.5 mm/min).

As shown in Figure 8, the elastic modulus in the samples of the clay-sand mixture increases at all loading rates in the unimproved state by increasing the percentage of the sand in the clay. The addition of geofoam particles to the samples leads to 0.5% by the weight of geofoam. This increase in clay soil samples at three loading rates was 95.9% on average. By adding the sand particles of 15, 30, and 50% to the clay samples at three loading rates, the average increase in the elastic modulus is 97.3, 58.6, and 57.6%, respectively. However, the elastic modulus represents a sudden decrease when the content of geofoam particle content reaches 1%. Moreover, the elastic modulus increase due to flexibility and locating between the particles produced the maximum elastic modulus by increasing the loading rate. These conditions became more suitable for samples containing 0.5% geofoam. Therefore, this combination is effective for decreasing the value of the settlement in pavement layers and soils under foundation.

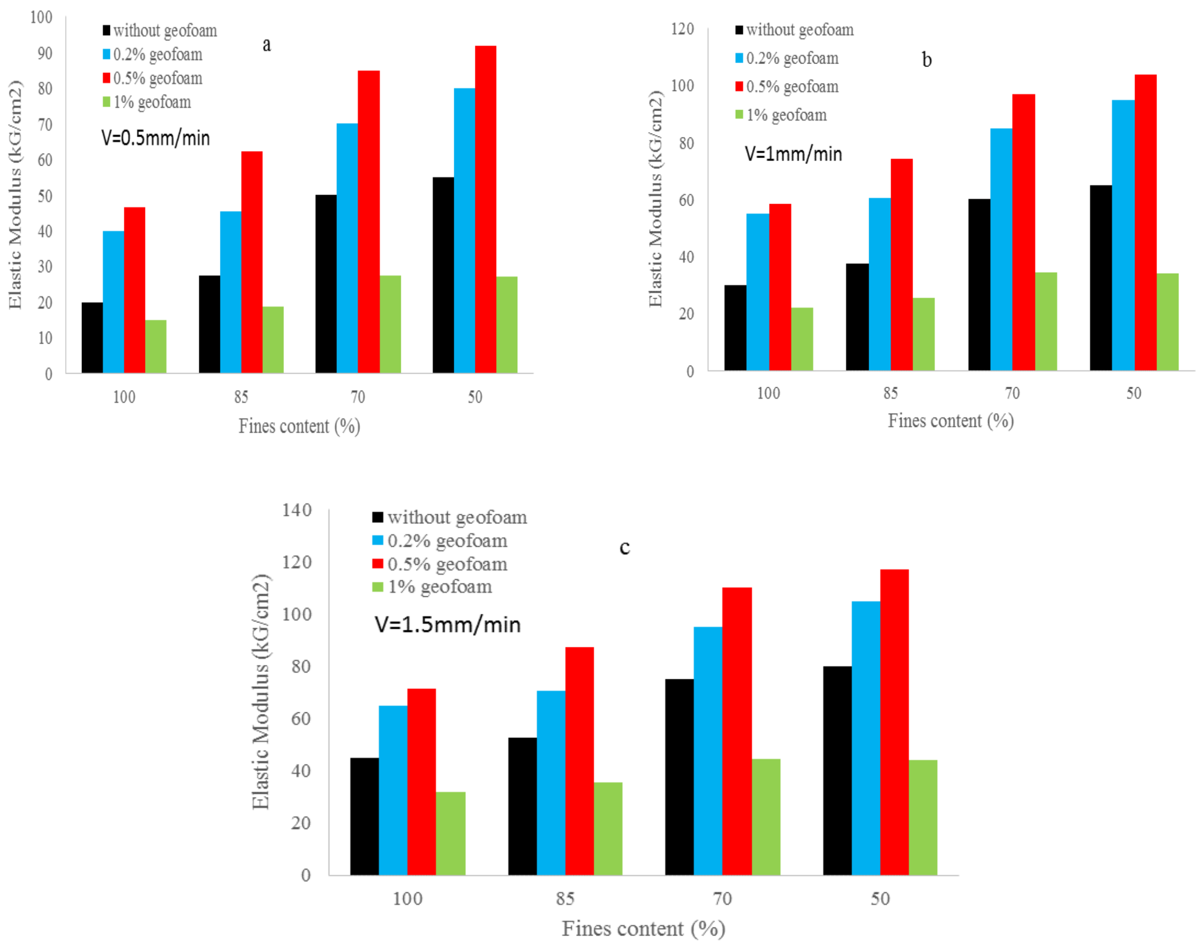


Fig. 8. Effects of geofoam particles on elastic modulus in different speed loadings (i.e., 0.5, 1, & 1.5 mm/min).

Based on the data in Figure 9, by increasing the percentage of sandy soil, the axial strain rate at the moment of failure reduces at all loading rates in the samples that contain no geofoam particles. However, by adding 0.5% of the geofoam to the soil samples, an average of 31.3% increase is observed in ductility in a sample containing clay at three loading rates. Contrarily, sand particles at three loading rates represent an increase by 39.8, 58.6, and 86.6% by considering the existence of 0.5% of geofoam particles in the clay samples containing 15, 30, and 50%, respectively. Although 0.5% geofoam particles in the clay with 30% sand mixture can increase the elastic modulus, t soil improvement has brittle behavior based on the obtained results regarding the axial strain rate.

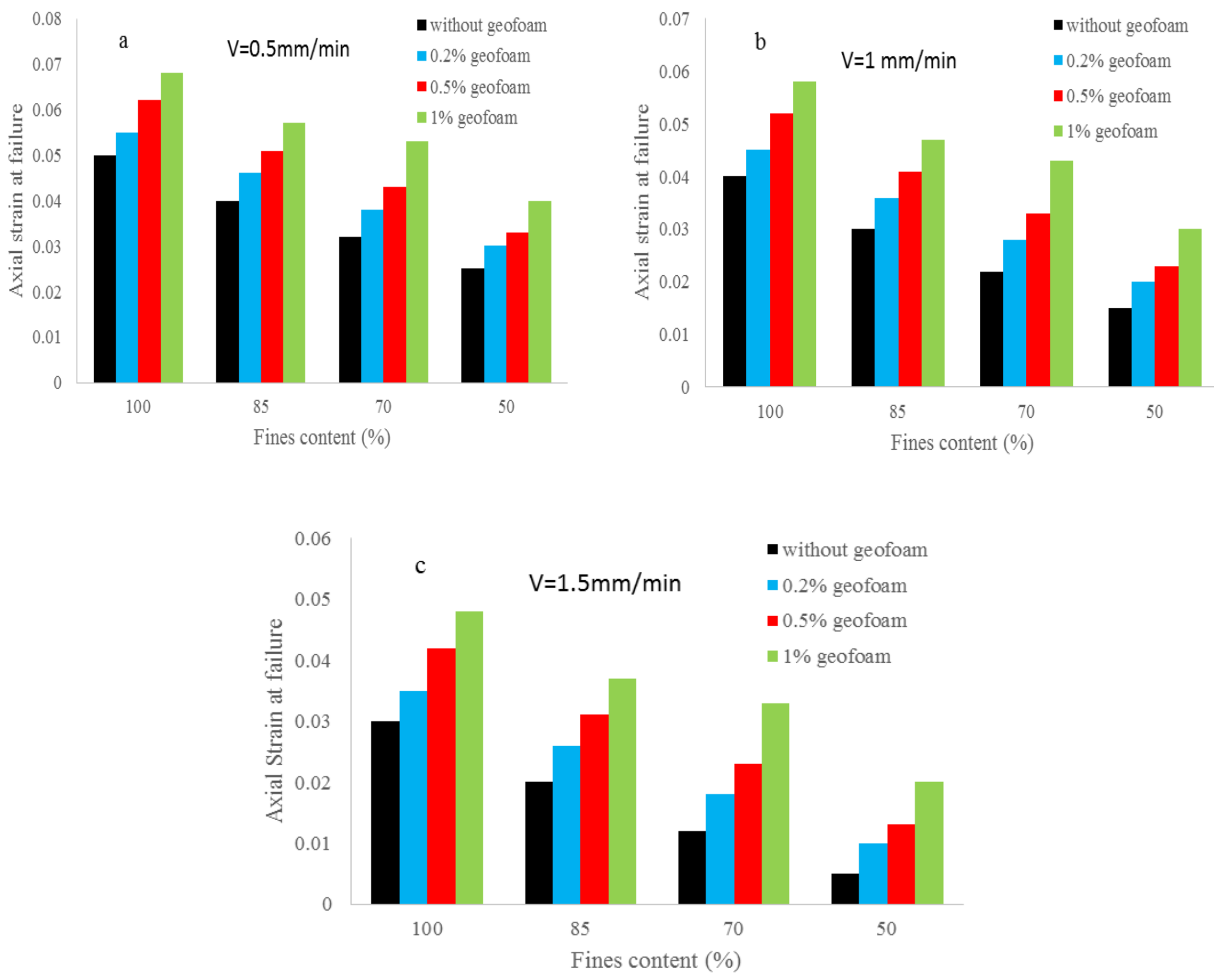


Fig. 9. Effects of geofoam particles on the axial strain at failure in different speed loading (0.5, 1, and 1.5 mm/min).

The study also investigated the effect of geofoam particles on the bearing capacity and shear strength of the studied samples, the direct shear test was under vertical stresses of 1, 2, and 3 kg/cm^2. The variations in the angle of friction and the cohesion of the soil samples are depicted in Figure 10a-b. The internal friction angle (φ) in the clay samples increases in the absence of the added geofoam particles and by increasing the percentage of sand, which is due to an increase in the contact between the particles in the mixed soil samples (Figure 10a). In addition, the internal friction angle in clay soil samples increases by 5.04 and 14.7% through adding the geofoam particles to the samples at 0.2 and 0.5%, respectively. Further, the internal friction angle at 0.2 and 0.5% of the geofoam indicates an increase of 12.6 and 13%, 4.24 and 8.9%, as well as 5.7 and 11.6% in clay samples containing sand particles at 15, 30, and 50 percentages, respectively. These conditions show that this amount of geofoam in the studied soil samples leads to proper friction between the soil particles of the clay-sand mixture. Moreover, a discontinued structure and matrix among the particles of the studied soil samples can be created by increasing the percentage of the geofoam particles, which is found to reduce the contact between the particles and thus decrease the internal friction angle. As displayed in Figure 10b, the cohesion of the studied soil samples in the absence of geofoam particles has a decreasing trend by increasing the percentage of the sand particles. However, it increases in the clay soil sample by 14.7 and 57.1% when adding 0.2 and 0.5% of geofoam to the samples, respectively. Additionally, at 0.2 and 0.5% of geofoam, cohesion rates increase by 23.8 and 76%, 25 and 75%, as well as 29 and 64% in the clay samples with sand particles at 15, 30, and 50%, respectively. In general, due to the flexibility of geofoam particles and the subangularity of the sandy soil, geotechnical parameters (e.g., cohesion and internal friction) in clay-sand soil mixtures reduce the void ratio while they increase interaction contacts between the surfaces of the particles in the clayey soil, by adding geofoam particles up to 1%.

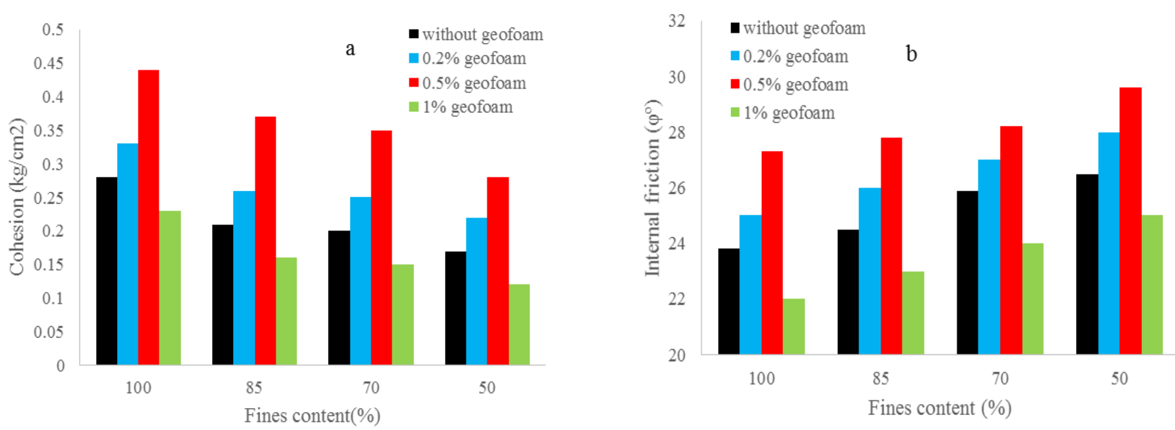


Fig. 10. Effects of geofoam particles on direct shear test results, (a) Cohesion, (b) internal friction angle.

Figures 11 and 12 illustrate the shear strength and shear strain variations at the failure moment of the studied soil samples under the influence of geofoam particles, respectively. As shown, the shear strength in samples without geofoam particles represents an increase by increasing the sand percentage in the clay soils. Similarly, the shear strain rate at the failure moment increases by an increase in the soil sand percentage. Likewise, the shear strength in all samples reaches its maximum level in 0.5% of the weight of geofoam when adding geofoam particles to the studied soil samples and this amount is also observed by increasing the vertical stresses. Based on the shear strain diagrams at the moment of failure in Figure 12, the ductility demonstrates an increase by adding geofoam particles to the studied soil samples.

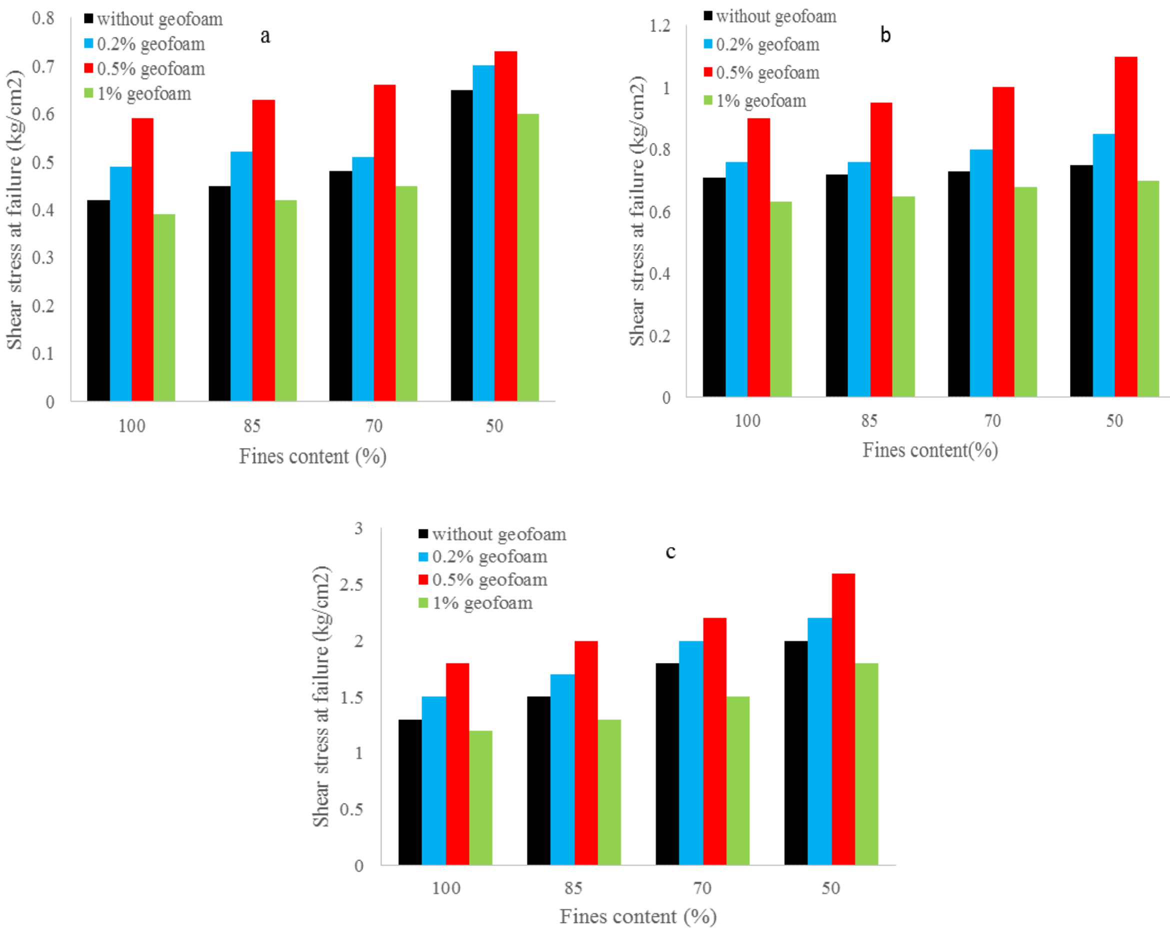
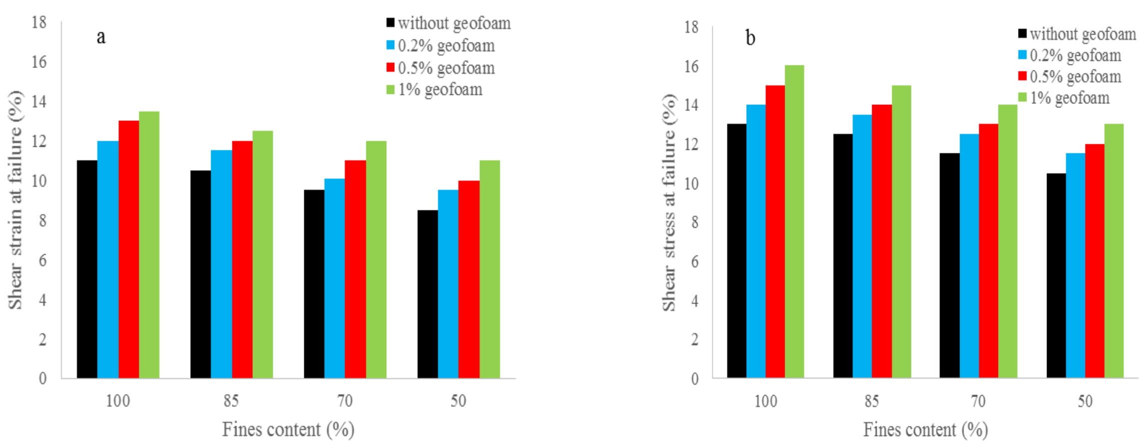


Fig. 11. Effects of geofoam particles on shear strength at failure.

Note. σv=1 kg/cm^2 (a), σv=2 kg/cm^2 (b), and σv=3 kg/cm^2 (c)



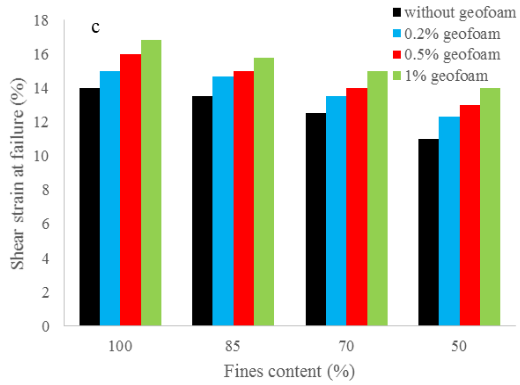


Fig. 12. Effects of geofoam particles on shear strain at failure.

Note. σv=1 kg/cm^2 (a), σv=2 kg/cm^2 (b), and σv=3 kg/cm^2 (c)

As represented in Table 4, the effect of geofoam particles on shear strength can be observed quantitatively at the failure moment of the studied soil samples. Based on the obtained results, the shear strength increases by 11.51 and 32.6%, on average, when adding 0.2 and 0.5% of the weight of geofoam to the studied samples at the vertical stress of 1 kg/cm^2 in all samples as compared with non-added geofoam which has the greatest effect on clay and increases the strength by 16.6 and 40.5%, respectively. However, this trend decreases by increasing the vertical stresses on the studied soil samples containing 0.2% of geofoam. In addition, the shear strength in the soil samples increases by 10.64% on average. Meanwhile, the shear strength shows an average increase of 33.3% by increasing the percentage of geofoam particles to 0.5% in the soil samples in higher vertical stresses. Further, an increase of up to 1% in the percentage of geofoam particles in the soil samples negatively affects the samples and reduces the shear strength in the soil mass in all vertical stresses, leading to a decrease in the load-bearing ability by 9.15% on average. Based on the data, 0.5% geofoam particles have optimum effects on the rate of shear strength at the failure of all studied specimens. Furthermore, the greatest effect is observed in medium vertical stress loading (i.e., 2 kg/cm^2) although subangularity in sandy soil can be observed in the improved clayey soil.

Table 4. Effects of Geofoam Particles on the Variations of Shear Strength Rate at Failure in Improved Specimens.

Specimen	**Geofoam (0.2%)**			**Geofoam (0.5%)**			**Geofoam (1%)**		
Vertical stress (kg/cm^2)	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Clay	16.6%	7.04%	15.3%	40.5%	26.7%	38.4%	-7.14%	-11.3%	-7.7%
Clay +15% sand	15.5%	5.5%	13.3%	40%	32%	33.3%	-6.66%	-9.72%	-13.3%
Clay +30% sand	6.25%	9.6%	11.1%	37.5%	37%	22.2%	-6.25%	-6.84%	-16.6%
Clay +50% sand	7.7%	13.3%	10%	12.3%	46.6%	30%	-7.69%	-6.66%	-10%

As mentioned in previous sections, a falling head test was performed to investigate the effect of geofoam particles on the drainage and permeability of the soil samples. The results are illustrated in Figure 13. As shown, in the absence of geofoam particles in the studied soil samples, the permeability in the soil samples decreases by increasing the clay content. However, by adding geofoam particles to the soil samples, permeability increases as compared with the unimproved state. These conditions indicate that geofoam particles with sandy soil can be effective in increasing the drainage property of the soil.

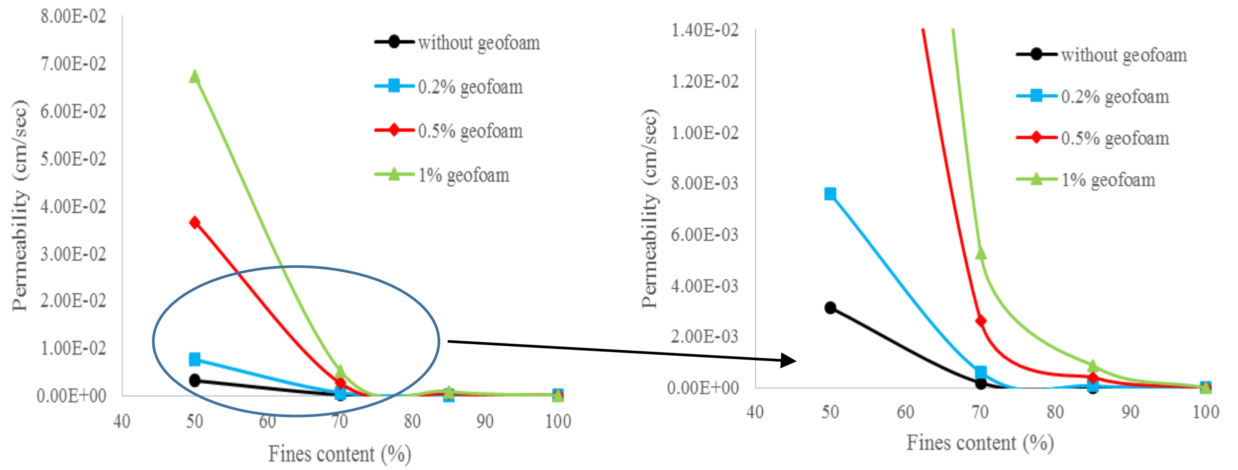


Fig. 13. Effects of geofoam particles on permeability in specimens.

4. Discussion

The results are justifiable according to the study conducted by Thevanayagam [32]. In other words, adding clay or sand at different percentages can essentially change the behavior of the sand and clay matrix. As displayed in Figure 14, void percentage changes can be observed in terms of fine grain size. In part A, fine grains are zero and sand grains are in good contact with each other and can transfer the force. When the percentage of fine particles increases from point A to B, fine grains fill the gap between the sand grains and reduce the void ratio and relative density without contributing to the load bearing, until point B, where fine grains completely fill the empty space between the sand grains. This amount of fine grain is called "critical fine grain". By increasing the amount of fine grained material and reaching point C, the sand grains are separated from each other and the fine-grained particles play an important role until the fine particles form the sample at point C. It should be noted that the critical fine grain relies on the grain size of the main soil and fine-grained properties. For example, well-graded soils have a lower void ratio than badly-graded soils. As a result, a smaller amount of fine grained material can completely separate the sand grains. Moreover, clay particles have a higher void ratio than the particles and can participate more effectively in filling the empty space between the sand grains.

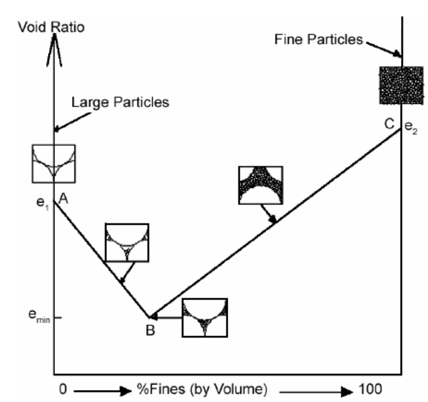


Fig. 14. Variation of void ratio in sand and clay mixtures based on the clay contents [32].

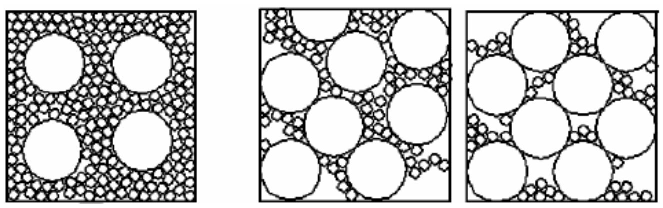
The fine grains are entirely in the empty spaces between the sand grains and reduce the total porosity of the sample while they have no active participation in the load bearing. Additionally, the clay particles gradually split a number of sand grains by increasing the amount of the fine grains. This is depicted in Figure 15a. Considering the size of the fine grains (fc) as the free space, the grain void ratio (e_s) can be determined as follows:

$$e_s = \frac{e + fc}{1 - fc} \qquad (1)$$

In the above relation, e_s is a granular void ratio. The fine grains completely occupy the empty spaces between the coarse grains so that the coarse grains have no contact with each other. In other words, coarse grains are immersed in the fine grains and cannot contribute in matrix bearing while they only function as a force transmitter between the surrounding fine grains.

These conditions are shown in Figure 15b. Contrary to (a), where the volume of the fine grains are considered as empty spaces, the volume of coarse grains is considered to be zero in this case and the void ratio between the fine grains is determined as follows:

In the above-mentioned equation, e_f denotes the intergrain void ratio. However, if the fine grains in the soil are clay-based, the texture is more integrated by adhering to the soil in addition to acting as the filler. The values of the above parameters are provided in Table 5.



(b) (a)

Fig. 15. Effects of fines content on soil skeleton [32].

Note. Fines content less than the limit value (a) and fines content more than the limit value (b).

Table 5. Effects of Fines Content and Geofoam Particles on Granular (e_s) and Intergrain (e_f) Void Ratios

Specimen	Without Geofoam			Geofoam (0.2%)			Geofoam (0.5%)			Geofoam (1%)		
Void ratio	e_{min}	e_s	e_f	e_{min}	e_s	e_f	e_{min}	e_s	e_f	e_{min}	e_s	e_f
Clay	0.49	-	0.49	0.45	-	0.45	0.41	-	0.41	0.53	-	0.53
Clay+15% sand	0.43	-	0.5	0.4	-	0.47	0.38	-	0.44	0.45	-	0.53
Clay+30% sand	0.45	-	0.64	0.42	-	0.6	0.39	-	0.56	0.47	-	0.67
Clay+50% sand	0.5	-	1	0.47	-	0.94	0.42	-	0.84	0.53	-	1.06
Sand	0.58	0.58	-	0.56	0.56	-	0.52	0.52	-	0.6		-

The obtained results from uniaxial and direct shear tests can be expressed in terms of granular (e_s) and intergrain (e_f) void ratios. Based on the results, e_f parameter reached its minimum when the amount of geofoam particles in the clay was equal to 0.5%. This indicated the movement of particles toward each other, the increasing contact with each other, and a reduction in space between these particles. However, the intergrain void ratio increased by an increase in the percentage of geofoam particles in clay 1% by weight, demonstrating an increase in the free space and a greater discontinuity between the clay particles. Similarly, the amount of intergrain void ratio showed an incremental trend in the unimproved condition when the sand particles were added to the clay. However, the intergrain void ratio reduced by adding the geofoam particles to the clay-sand mixture up to a concentration of 0.5% by weight, representing that the placement of geofoam particles to that extent between clay and sand particles causes more contact in the soil structure and matrix leading to a reduction in the free space between the particles. Given the above-mentioned discussions, the addition of 0.5% weight of geofoam in the clay-sand mixture improved the load bearing capacity.

5. Conclusion

Under normal conditions, soil has a lower bearing capacity considering that it is a non-integrated and non-cemented skeleton and since the void between the particles has a compressible and ductile form. Nowadays, modern materials are extensively utilized to increase soil bearing capacity. Geofoam from the family of geosynthetics is considered as one of the most widely used materials in this field with a very important performance in science and industry including serving as embankments behind the retaining walls or in the construction of pavement layers. The present study investigated the effect of 0.1, 0.5, and 1% of geofoam particles on shear strength, bearing capacity, and permeability of the clay-mixed soils (15, 30, & 50%). Some of the most suitable parameters for behavioral evaluation in mixture materials under the influence of loads include changes in the void ratios (e_s) and intergrain (e_f) in the structure and particle matrix. In general, the following results were obtained in this study:

1. It was observed that when no geofoam particles were added to the studied soil samples, the bearing capacity and shear strength increased by increasing the percentage of the sandy soil to about 30% in the clayey soil. This was due to the formation of a relatively stable structure and according to the intergrain void ratio which showed the process of reducing the empty space.

2. The optimal amount of geofoam particles in the soil samples, which improved the geotechnical parameters of the clay-sand mixture based on the results of the present study, was 0.5% by weight.

3. In addition, the maximum dry weight improved because of adding 0.5% geofoam particles to the specimens, indicating increased mixed soil compressibility due to the proper structure and cohesion between the particles.

4. When this amount of geofoam was added to the studied soil samples, it reduced the amount of the void space and the minimum void ratio based on the interaction between soil materials and geofoam particles. Therefore, the shear strength increased by an average of 44% relative to the unimproved state in all samples and vertical stresses (Table 5), as well as the clay by 35.2%.

5. The observed behavior was obtained from a uniaxial compressive strength test so that the presence of 15-30% of sandy soil in the clay increased the uniaxial compressive strength and the elastic modulus. Further, the uniaxial compressive strength of the samples increased on an average of 1.43, 1.45, and 1.26 times, respectively, at three loading rates (i.e., 0.5, 1, & 1.5 mm/min) and this amount was 1.69, 2.44, and 1.94 times in the clay, respectively. By observing the values of elastic modulus in the fixed samples, the geofoam content was found to increase ductility.

6. Moreover, based on the investigation of the effect of geofoam particles on the

permeability of the studied soil samples, geofoam is an appropriate soil additive that can improve drainage and permeability. It was also observed that increasing the percentage of geofoam in the samples leads to an increase in the permeability coefficient.

Therefore, improving geotechnical parameters in the clay soils with sandy particles is possible at the presence of geofoam particles. Thus, geofoam can be used to improve the embankment behind reinforced soil walls, retaining walls, and pavement layers. Finally, future studies are suggested to evaluate their dynamic behavior in order to accurately study the effect of the size of the dimensions and the density of the geofoam particles on the soil materials, as well as the damping ratio and shear modulus of soil particles which are fixed with the geofoam.

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