Improvement of sand using Portland cement and polystyrene foam container waste

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Abstract

The goal of this study was investigating the application of a combination of polystyrene foam container waste and Portland cement in improvement of sand. For this purpose, Babolsar sand was used as the base soil. Strips of disposable polystyrene foam container waste in "chips" of 50 × 5 mm and 50 × 10 mm were added to the soil at 0.0%, 0.1%, 0.2% and 0.3% by weight along with 3% Portland cement at a relative density of 70%. All samples were cured for 7 days under saturated conditions and then tested using a large-scale direct shear apparatus. The results showed that, in both cemented and uncemented samples, the addition of foam chips increased the cohesion and internal friction angles, which increased the shear strength of the soil. At higher percentages and using larger-sized foam chips, the shear strength increased even more. In uncemented samples, the stiffness did not change with the addition of foam chips, yet the final dilation of the samples decreased. In cemented samples, the stiffness and the reduction in shear stress after the peak strength decreased. The final dilation of the cemented samples increased at higher foam chip contents and for the larger sized chips. The results of numerical analysis showed that the use of foam chips increased the safety factor of a slope improved in this manner. It also was found that the foam chips with a lower length-to-width ratio had a greater effect on increasing the safety factor of the sandy slopes.

Keywords: Soil improvement; Polystyrene foam waste; Cement; Stability.

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1. Introduction

One of the most important aspects of civil engineering projects is preparation of appropriate ground for construction of a building. The amount of land that is naturally suitable for construction of a structure is gradually decreasing as the population increases. In such a situation, development of innovative methods of ground improvement has become an important topic of research. The advantages of one method over another relate to engineering, economics, environmental parameters, performance conditions, availability of facilities and time and space constraints. Access to high-quality materials that are also economically available and can easily withstand the loads applied by a structure is the primary motivation behind research on the application of new materials to soil improvement.

Studies on application of plastic waste for soil reinforcement are sparse and depend on the type of waste. A number of researchers have used polyethylene, polyester and polypropylene waste and fibers while the others have used plastic waste from bottles, bags or sheets. Different tests have been used to determine the changes in soil behavior after the addition of these materials.

Consoli et al. (2002) conducted laboratory studies on uncemented and cemented sand reinforced with polyethylene plastic waste. They concluded that the stress-strain response of cemented and uncemented soil improved with the addition of the plastic waste. Consoli et al. (2004) studied the effect of polyester, polypropylene and glass fibers on the failure mode, maximum deviatoric stress, ductility and energy absorption of the soil by performing triaxial shear tests on sand reinforced with a combination of cement and fibers. They reported that the addition of fibers significantly changed the failure mode from brittle to ductile. The peak deviatoric stress of fiber-reinforced specimens also occurred at higher axial strains than for unreinforced soil.

Ahmed et al. (2011) considered the behavior of sandy soil reinforced with recycled gypsum, Portland cement and polystyrene plastic waste. They found that adding plastic waste increased the axial and tensile strengths of the soil. The optimum width of waste strips was

2.5 mm and the optimal length-to-width ratio was 3, while the optimum percentage of plastic waste by weight was about 0.7%.

Babu and Chouksey (2010) conducted consolidated undrained triaxial tests on sandy soil mixed with plastic waste from water bottles. They reported that adding such waste to the mixed soil increased the shear strength and decreased its stiffness. Babu and Chouksey (2011) investigated the effect of polyethylene terephthalate (PET) water bottle waste on clay, sand and gravely soils. Their results showed that the axial and shear strengths of the reinforced soil increased with the addition of plastic waste and the stiffness decreased. This was confirmed by Hafez et al. (2019) using consolidated drained triaxial shear tests. Their results showed that the elastic modulus of clay soil increased by 58% when it was reinforced with 0.6% bottle waste fibers. Economically, the results indicated that the use of this method to improve transportation infrastructures would reduce the cost of road construction projects by 8%.

Ruiz et al. (2013) studied on clay and locally mixed soil by adding PET plastic waste fibers to determine changes in the California bearing ratio (CBR). Their results showed that the CBR of clay did not change much after the addition of this type of fiber. But, the CBR of the mixed sandy soil decreased after addition of fiber at the beginning of test and then increased as the percentage of plastic fiber increased. This was not consistent with the results of Farah and Nalbantoglu (2019), who investigated the effects of plastic waste from recycled water bottles on the behavior of sandy soil using CBR and direct shear tests. They found that the inclusion of plastic waste increased both the CBR and shear strength of the sand. The optimum percentage of plastic waste by weight was 0.75%.

Chebet and Kalumba (2014) examined the effect of adding plastic bag waste (polyethylene) to sandy soil by performing direct shear and CBR tests. Their results showed that the addition of plastic fibers improved the soil strength characteristics. The optimum length, width, and thickness of the waste were determined as 15, 6, and 2 mm, respectively, while the best percentage of waste by weight was 0.1%.

Peddaiah et al. (2018) studied the behavior of silty sand reinforced with bottle-waste sheets and polyethylene bag waste. The effect of the waste content and its dimensions on the strength of the silty sand was investigated using direct shear and CBR tests. The results showed an optimum size of 15 × 15 mm for the plastic chips and an optimum content by weight as 0.4%.

Salimi and Ghazavi (2019) investigated the effect of inserting PET plastic waste sheets into sandy soil using triaxial shear tests. They found that the shear strength increased as the number of plastic sheet layers increased. The high tensile strength of the PET sheets increased the safety factor of the reinforced slopes.

Portland cement has been shown to be an effective material for improving granular soil. Consoli et al. (2007) performed uniaxial and triaxial tests on cemented sandy soil and introduced the porosity-to-cement ratio as the most effective parameter for explaining the mechanical behavior of such soil in place of the water-to-cement weight ratio. Hamidi and Soleimani (2012) investigated an increase in the rate of dilation and the friction angle using different types of cement mixed with sandy soil and presented equations for the estimation of these changes based on cement type and cement content.

Amini et al. (2014) confirmed an increase in the shear strength and stiffness of cemented sand improved with Portland cement by conducting large-scale direct shear tests. They found that the brittleness and final dilation increased with an increase in the cement content. This was confirmed by Amini and Hamidi (2014) with the use of triaxial shear experiments.

Wei and Ku (2020) conducted a laboratory study to investigate the effect of water-to-cement weight ratio on the performance of Portland cement as a granular soil stabilizer. The effects of the cement content and porosity ratio were considered in this study. They presented design curves to estimate the degree of soil improvement according to the cement content.

Consoli et al. (2020) tested the effects of porosity, cement content and the porosity-to-cement ratio on the behavior of silty sand by performing tensile strength and uniaxial compression tests. Their results showed that the ratio of porosity-to-cement content was the best parameter for explaining the tensile strength of such soil, as well as the uniaxial compressive strength.

Hamidi and Hooresfand (2013) and Dehghan and Hamidi (2016) investigated the use of polypropylene fibers to increase ductility of soil improved with cement. They reported that the fibers increased the strength, deformability and energy absorption of the improved soil.

Accordingly, granular soil reinforced with cement and fibers was introduced as a suitable and deformable material for construction projects.

Janalizadeh Choobbasti and Soleimani Kutanaei (2017) conducted uniaxial compression tests to investigate the effect of polyvinyl alcohol (PVA) fibers and Portland cement on the deformation characteristics of sand. They found that the addition of cement increased the uniaxial compressive strength of the soil and decreased its ductility. However, reinforcement of cemented sand with PVA fibers increased the uniaxial and residual strengths and decreased its brittle behavior. Ghadakpour et al. (2019) investigated the combined effect of PVA fiber and Portland cement on the shear strength and deformability of sandy soil. They found that the addition of cement increased the shear strength of the sand and changed its behavior from ductile to brittle. The addition of fibers to the cemented specimens also increased the ductility and energy absorption of the soil.

The results of previous studies have shown that Portland cement is an effective ingredient for increasing the strength of granular soil. On the other hand, adding cement decreases the ductility of the soil mass. The use of fibers has been recommended by several studies as a solution to decreasing the brittleness of soil improved with cement. The addition of plastic waste is an alternative to be considered as a step towards the recycling and reuse of such materials. One common form of plastic currently in use is disposable polystyrene foam containers. The high volume of production of these containers and their foam texture justifies the study of their application as an inexpensive material for soil improvement. Soil improvement using a combination of Portland cement and this type of waste is the topic of the present study. The soil strength parameters first have been determined by performing large-scale direct shear tests. The factor of safety of a slope improved by this material then has been investigated using stability analysis.

2. Testing program

2.1. Materials

Sand from the shores of the Caspian Sea near the city of Babolsar in northern Iran was used as the base soil. This sand has a uniform grain-size distribution with an average diameter of 0.23 mm and is classified as SP according to the Unified Soil Classification System. Its gradation curve and physical properties were determined by performing required testing according to ASTM (2009) and are presented in Fig. 1 and Table 1. The cementing material used was Portland cement type 5, which is typically applied in acidic and sulfate-bearing environments. Because the soil improved in this study was likely to be used in such environments. Table 2 presents the characteristics of the cement used for improvement according to ASTM (2007).

Table 1. Physical properties of the base soil

Parameter	Method	Value
Maximum dry density (kN/m^3)	ASTM-D4253	18.3
Minimum dry density (kN/m^3)	ASTM-D4254	15.7
Specific gravity (Gs)	ASTM-D854	2.74
Minimum void ratio (e_{min})	ASTM-D4253	0.5
Maximum void ratio (e_{max})	ASTM-D4254	0.75
Mean diameter (mm)	ASTM-D6913	0.23
Coefficient of uniformity	ASTM-D6913	1.75
Coefficient of curvature	ASTM-D6913	0.89

Table 2. Properties of Portland cement

<table>
<tr><th colspan="2">Parameter</th><th>Value</th></tr>
<tr><td colspan="2">Blaine (cm^2/gr)</td><td>3220</td></tr>
<tr><td colspan="2">Initial setting time (min)</td><td>155</td></tr>
<tr><td colspan="2">Final setting time (min)</td><td>220</td></tr>
<tr><td rowspan="3">Compressive strength (kg/cm^2)</td><td>3 days</td><td>230</td></tr>
<tr><td>7 days</td><td>320</td></tr>
<tr><td>28 days</td><td>460</td></tr>
<tr><td colspan="2">Autoclave Expansion (%)</td><td>0.07</td></tr>
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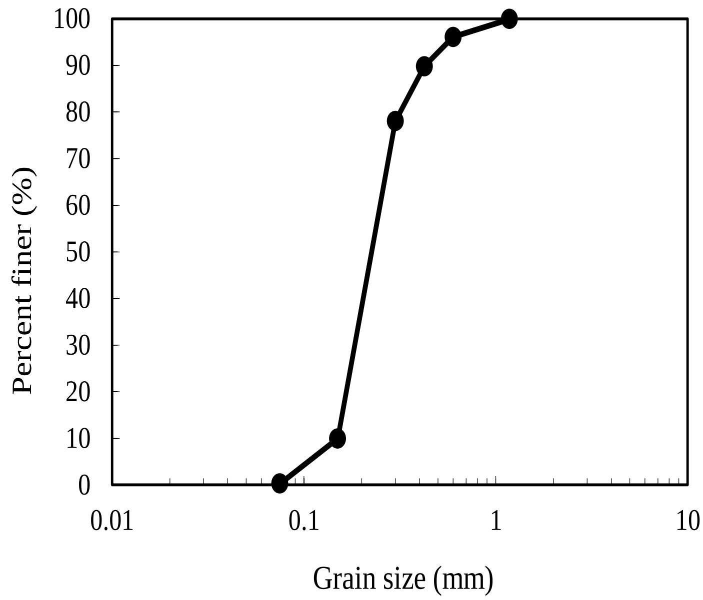


Fig. 1. Gradation curve of Babolsar sand

In the present study, the focus was on soil improvement with a combination of cement and foam container waste. The strips of foam from the containers have been denoted herein as “foam chips”. The thickness of the chips was 2 mm and the cut dimensions were either 50 × 5 mm or 50 × 10 mm; thus, the aspect ratios of the chips were 5 or 10, respectively. Table 3 presents the characteristics of the polystyrene foam materials used in the present study.

Table 3. Mechanical characteristics of polystyrene foam chips (Mills, 2007)

Parameter	Value
Unit weight (kg/m^3)	1030~1060
Bulk density (kg/m^3)	600~650
Water adsorption (%)	0.03~0.10
Young's modulus (kPa)	2.28×10^6~3.28×10^6
Tensile strength (kPa)	3.5×10^4~5.17×10^4

2.2. Sample preparation and testing method

Clean dry sand was combined with 3% Portland cement by weight of dry soil. A Similar value has been applied by Amini and Hamidi (2014) for improvement of sandy soil using cement and fiber. The percentage of foam chips was 0.0%, 0.1%, 0.2%, 0.3% (total weight of the dry sand and cement). In order to start the hydration process, 5% water (total weight of dry sand, cement and waste) was added to the samples, same as Amini et al. (2014). After blending the materials to produce a homogeneous mixture, the soil was poured into a shear box measuring 180 × 300 × 300 mm. Each sample was prepared in three layers, each having a relative density of 70%. The maximum diameter of the soil grains was limited to one-sixth of the height of the box and one-tenth of its width. Cemented samples were kept in the mold at 25±3°C in a room with >90% relative humidity for 48 h to reach their initial strength. After that, the specimens were covered with a wet cloth and were saturated with low water head to prevent bond degradation for another five days to reach their 7-day strength before shearing. Fig. 2 shows the Babolsar sand, a sample disposable polystyrene foam container, foam chips, and the mixture of sand, cement, foam chips and water.

Large-scale direct shear tests (300 × 300 × 180 mm) were performed on the prepared samples. To prevent excess pore pressure generation in the samples, the loading rate was chosen as 0.1 mm/min. The samples were subjected to large-scale direct shear tests under surcharge pressures of 100, 200 and 300 kPa to determine the shear strength parameters. The horizontal and vertical deformations, as well as the horizontal forces were measured accurately at regular intervals. Table 4 depicts the variables in direct shear tests.

Table 4. Variables in direct shear tests

Sample type	**Cement content (%)**	**Foam content (%)**	**Fiber size (mm)**	**Surcharge pressure (kPa)**	**Number of tests**
Unreinforced sand	0	0	0	100,200,300	3
Reinforced sand with foam	0	0.2	50*5, 50*10	100,200,300	6
Reinforced sand with cement	3	0	0	100,200,300	3
Reinforced sand with cement and foam	3	0.1,0.2,0.3	50*5, 50*10	100,200,300	18

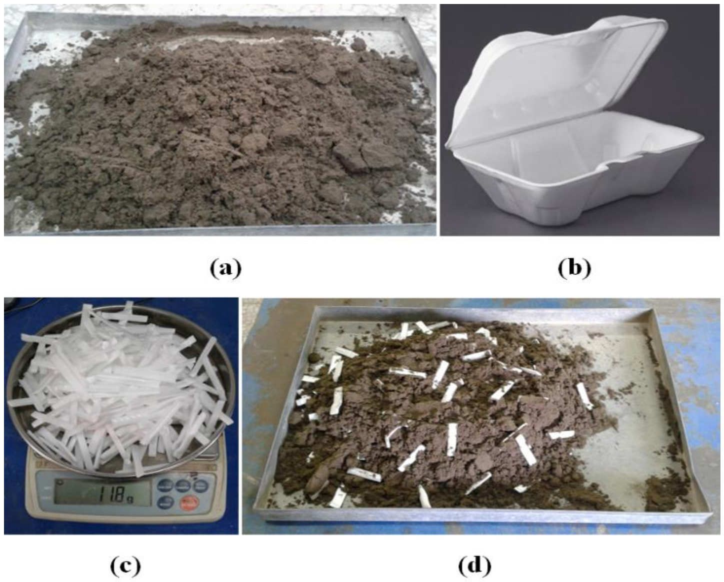


Fig. 2. Images of: (a) Babolsar sand; (b) disposable foam container; (c) foam chips; (d) mixture of soil, foam chips, cement and water.

3. Results

Fig. 3(a) shows the shear stress-horizontal displacement curves of the unreinforced and reinforced sand with 0.2% 50 × 5 mm and 50 × 10 mm foam chips subjected to a surcharge pressure of 100 kPa. Fig. 3(a) shows that an increase in the foam chips content increased the shear strength of the sand. Despite the slight increase in horizontal displacement associated with the maximum shear strength, the initial slopes of the curves for unreinforced sand and sand reinforced with foam chips (of both sizes) showed no significant change in stiffness.

Fig. 3(b) reveals that dilation of the sandy soil strongly decreased with the addition of the waste. This was due to the compressive characteristics of the foam chips that reduced dilation of the sandy soil at larger displacements. When shear stress is applied, the sand particles roll and topple on each other which increases dilation value. However, existence of foam and its compressible behavior reduces this type of behavior. For this reason, the final dilation of foam reinforced specimens are lower than unreinforced ones. Similar results have been reported for plastic waste mixed sandy soil by Babo & Chouksey (2011).

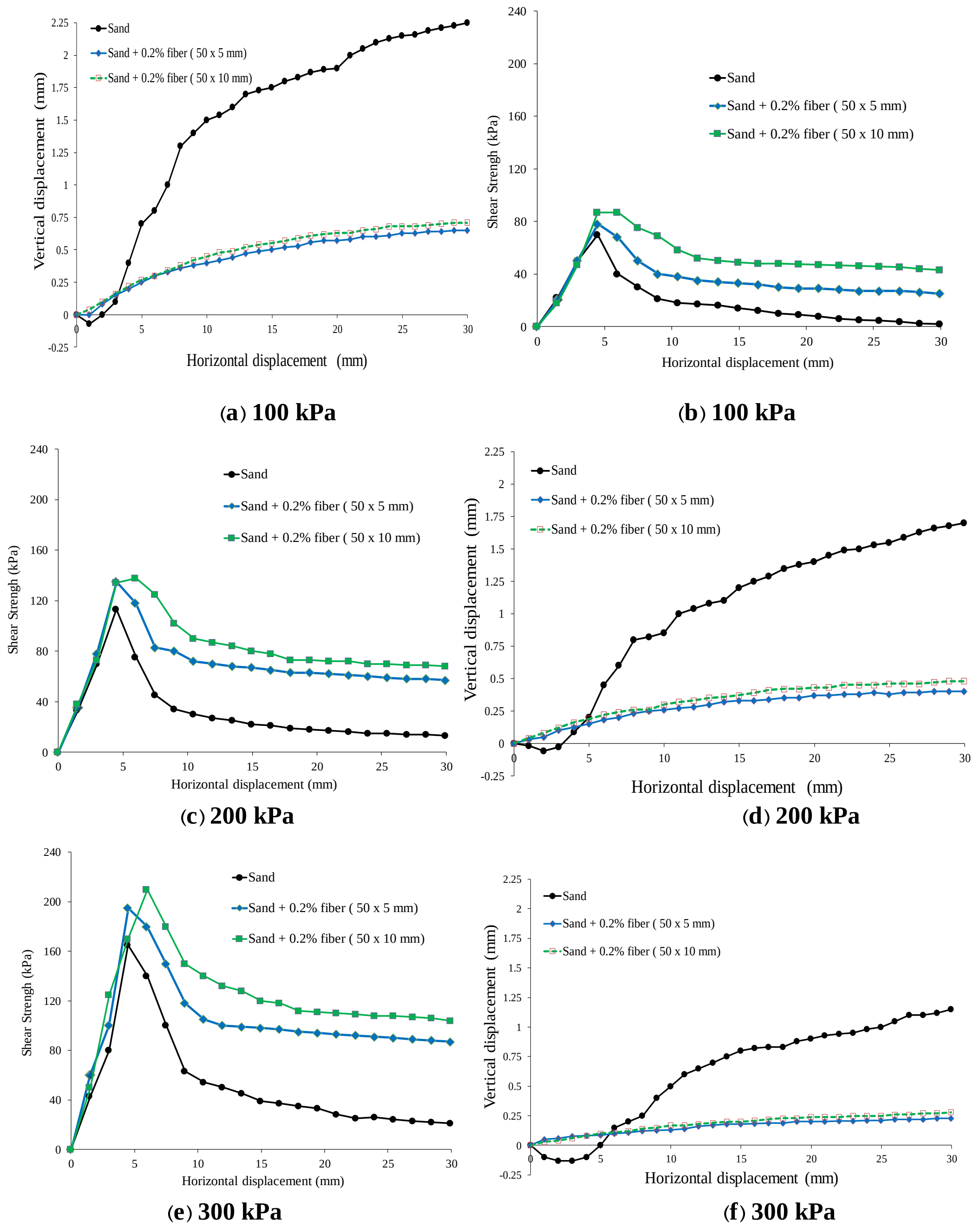
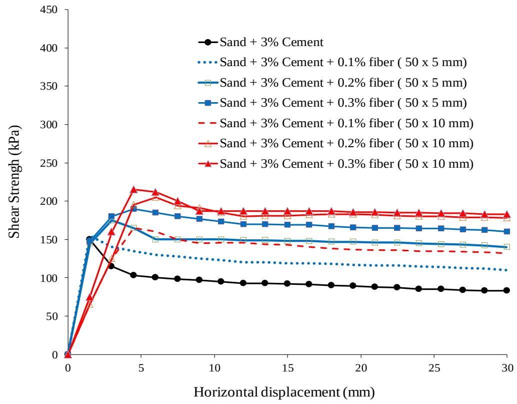


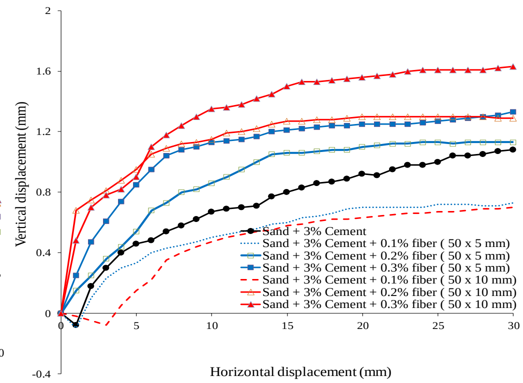
Fig. 3. (a) Shear stress-horizontal displacement curves of sandy soil and sand reinforced with 0.2% 50 × 5 mm and 50 × 10 mm foam chips at surcharge pressure of 100 kPa; (b) vertical displacement-horizontal displacement curves at surcharge pressure of 100 kPa; (c) shear stress-horizontal displacement curves of sandy soil and sand reinforced with 0.2% 50 × 5 mm and 50 × 10 mm chips at surcharge pressure of 200 kPa; (d) vertical displacement-horizontal displacement curves at surcharge pressure of 200 kPa; (e) shear stress-horizontal displacement curves of sandy soil and sand reinforced with 0.2% 50 × 5 mm and 50 × 10 mm chips at surcharge pressure of 300 kPa; (f) vertical displacement-horizontal displacement at surcharge pressure of 300 kPa.

Figs. 3(c) and 3(e) show that an increase in surcharge pressure caused an increase in shear strength of the specimens for overburden stresses of 200 and 300 kPa, respectively. Figs. 3(d) and 3(f) show that the final dilation in the unreinforced and reinforced sand, respectively, decreased with an increase in the surcharge pressure. The increase in strength can be attributed to the increased friction between the soil and foamy waste. Also according Ahmed et al (2011), the increase in strength can be related to the increased contact surface between the waste and the solid particles. The values of dilation for unreinforced samples also consist well with reported values in other researches for Babolsar sand (Amini et al. 2014).

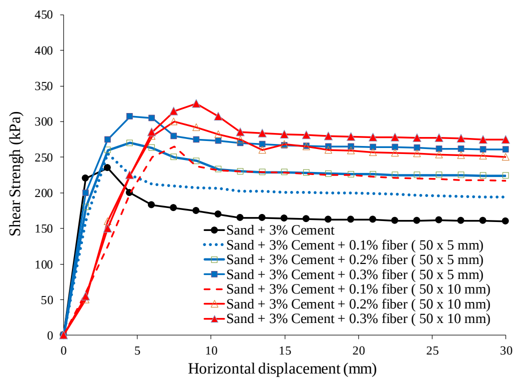
Fig. 4 shows the effects of foam chips on the results of direct shear tests on cemented sand. Fig. 4(a) displays the shear stress-horizontal displacement curves for cemented sandy soil (3% cement content) and cemented samples reinforced with different amounts of 50 × 5 mm and 50 × 10 mm foam chips at a surcharge pressure of 100 kPa. Fig. 4(a) indicates an increase in the peak shear strength with the addition of cement to the soil. In this case, the initial stiffness and the reduction in shear stress after the peak strength also increased. With the addition of foam chips to the cemented soil, the initial stiffness decreased and the reduction in shear stress after the peak strength decreased. In other words, the ductility of the cemented samples was improved by the addition of the foam chips. This is in line with the results of Dehghan and Hamidi (2015, 2016) and Ghadakpour et al. (2019) for fiber-reinforced cemented sands. Figs. 4(c) and 4(e) show the changes in shear strength at 200 and 300 kPa of surcharge pressure, respectively. In all cases, the increase in the foam chip content in cemented soil increased the shear strength. This increase is mainly due to the increase in friction between soil and foamy waste, increase in contact area and development of tensile stress in the foamy waste. The same reasons have been emphasized by babu & Chouksey (2011). It was observed that the increase in shear strength for the 50 × 10 mm foam chips was greater than for the 50 × 5 mm chips. This can be related to the increased conract area between soil and waste which has been also considered by Hataf and Rahimi (2005) to provide the optimal value for tire length chips in soil reinforcement.



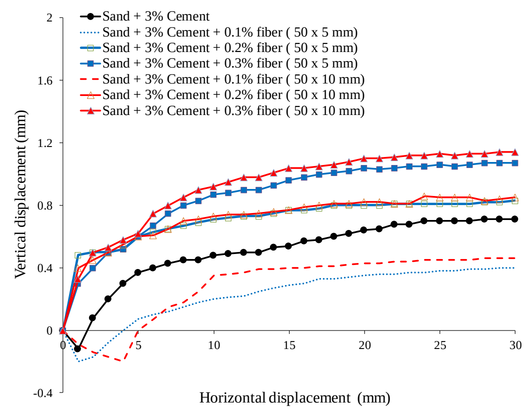
(a) 100 kPa



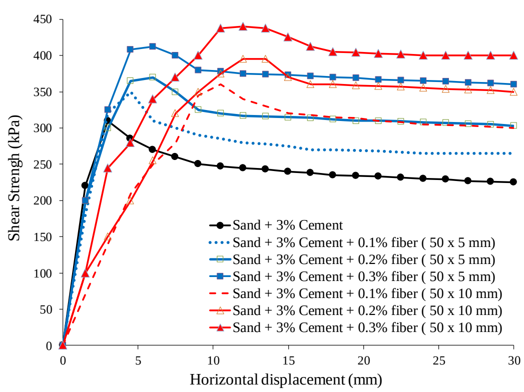
(b) 100 kPa



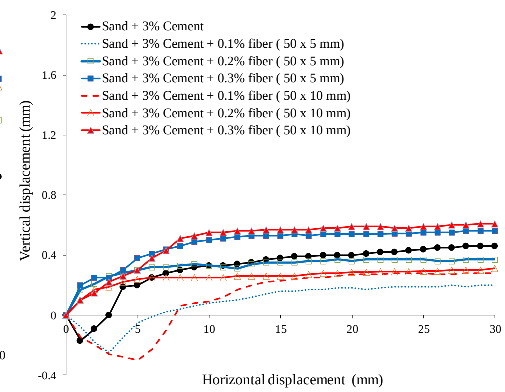
(c) 200 kPa



(d) 200 kPa



(e) 300 kPa



(f) 300 kPa

Fig. 4. (a) Shear stress-horizontal displacement curves of cemented sand and cemented sand reinforced with different percentages of 50 × 5 mm and 50 × 10 mm chips at 100 kPa; (b) vertical displacement-horizontal displacement curves for the same soils at surcharge pressure of 100 kPa; (c) shear stress-horizontal displacement curves of cemented sand and cemented sand reinforced with different percentages of 50 × 5 mm and 50 × 10 mm chips at 200 kPa; (d) vertical displacement-horizontal displacement curves of the same soil at surcharge pressure of 200 kPa; (e) shear stress-horizontal displacement curves of cemented sand and cemented sand reinforced with different percentages of 50 × 5 mm and 50 × 10 mm chips at surcharge pressure of 300 kPa; (f) vertical displacement-horizontal displacement curves for the same soils at surcharge pressure of 300 kPa.

Fig.4(b) shows the vertical displacement-horizontal displacement curves for the specimens under the100 kPa surcharge pressure. The addition of Portland cement increased the rate of dilation in the samples. As illustrated by Lade and Overton (1989), when cement is added to the sandy soil, the resulted bonding between the grains cause larger particles which are more interlocked and induce more dilation during shear loading. The addition of 0.1% of 50 × 5 mm or 50 × 10 mm foam chips to the cemented soil decreased the final dilation of the samples. This was also observed for surcharge pressures of 200 and 300 kPa, as shown in Figs. 4(d) and 4(f), respectively. Again, an increase in surcharge pressure increased the shear strength of cemented soil.

A further increase in the waste content to 0.2% increased the final dilation of the cement-reinforced soil. However, it was observed that, for the uncemented samples in Fig. 3, the final dilation decreased after the addition of 0.2% foam chips. This occurred because compression of the foam chips is more likely in uncemented sand during shear deformation, which will decrease dilation. In cemented soil, the bonding and strongly cemented structure prevented the foam chips from easily compacting and decreased the final dilation. This was especially true at higher chip contents (above 0.1%) and for the larger foam chips (50 ×10 mm). The greatest dilation observed was related to the cemented samples containing 0.3% of 50 × 10 mm foam chips.

Fig. 5 shows the change in the ratio of shear strength of sand reinforced with foam chips (S_f) to the shear strength of the sand (S) for different percentages of 50 × 5 mm and 50 × 10 mm foam chips. It can be seen that the addition of 0.2% of 50 × 5 mm foam chips increased the shear strength of the sand 18% to 24%. The addition of 0.2% of the 50 × 10 mm chips caused an increase in shear strength of 26% to 35%. These results also show that an increase in the surcharge pressure decreased the effect of the foam chips on the strength ratio.

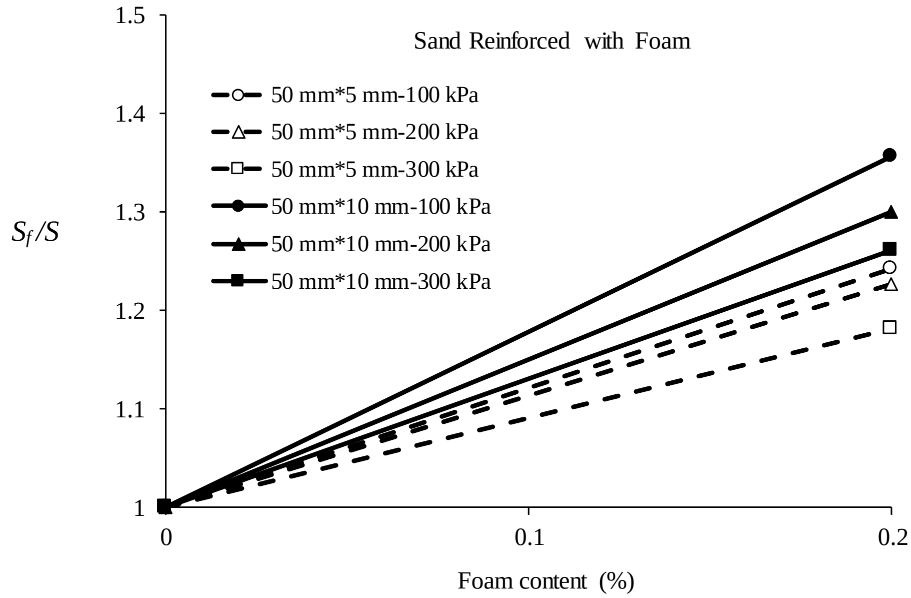


Fig. 5. Change in ratio of shear strength of reinforced sand to shear strength of unreinforced sand with foam chips content.

In the cemented samples, the shear strength increased with addition of foam chips. Fig. 6 shows the ratio of shear strength of the cemented specimens reinforced with foam chips (S_{f+c}) to the shear strength of the cemented sand (S_c). The results indicate that the larger chips (with a smaller length-to-width ratio) caused a greater increase in the shear strength of the cemented sand. In fact, as the area of the chips increased, the tensile force (as the product of tensile strength in foam area) increased at the failure surface. Fig. 6 shows that the addition of 0.2% of 50 × 5 mm foam chips increased the shear strength from 16% to 20%. This increase for 0.2% 50 × 10 mm foam chips was 24% to 28%. Comparing with calculated values for uncemented sand, it is clear that, in equal proportions, the effect of the foam chips on the strength of uncemented sand was greater than the effect on cemented sand. The rates of increase in strength for cemented samples increased 29% to 33% for 0.3% of the smaller chips and from 39% to 43% for the same amount of larger chips. Unlike the uncemented samples, the increase in the surcharge pressure in the cemented samples caused an increase in the strength ratio. This indicates that reinforcement of the cemented soil at a greater depth (which will increase the overburden pressure) will be useful by using the presented method.

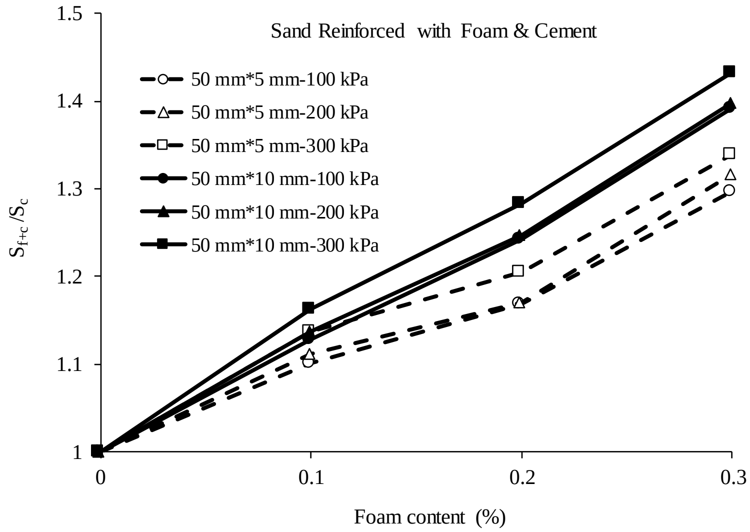


Fig. 6. Change in ratio of shear strength of reinforced cemented sand to shear strength of cemented sand with foam chips content.

The Mohr-Coulomb failure envelope was plotted for the tested soils using the failure points in the tests and the results are shown in Fig. 7. Accordingly, the cohesion and internal friction angles of the cemented sand increased as the foam chip content increased. These increases related to the tensile strength of the foam at the failure surface. The tension induced in the foam chips increased the shear strength of the reinforced soil at the horizontal failure surface in the direct shear test. The cohesion and friction angle for the sand reinforced with a combination of 3% cement and different percentages of foam chips are shown in Figs. 8 and 9, respectively. The addition of 0.3% 50 × 5 mm foam chips caused a 20% increase in the cohesion of the cemented sand. The increase in cohesion for the larger foam chips was about 30%. Note that 0.3% of the smaller foam chips, having an aspect ratio of 10, increased the friction angle of the cemented soil by about 20%. However, this increase was about 25% for the same amount of the larger chips with an aspect ratio of 5.

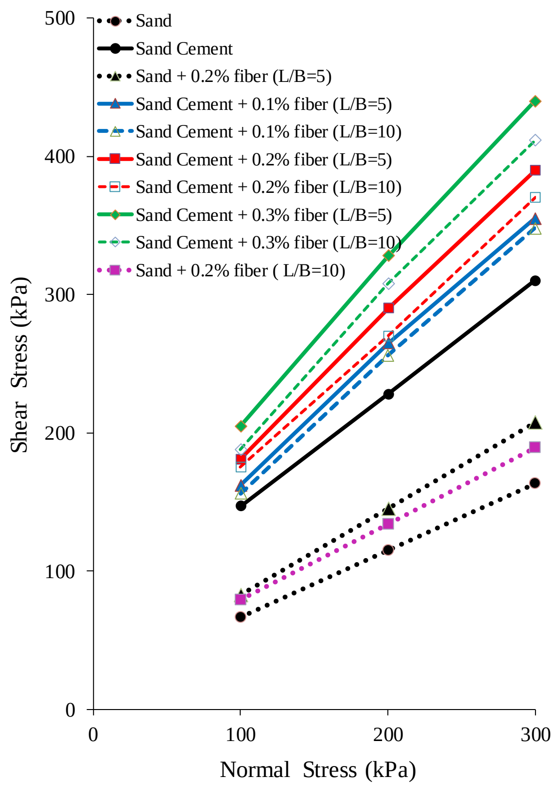


Fig 7. Failure envelopes of soils with different percentages of cement and foam chips.

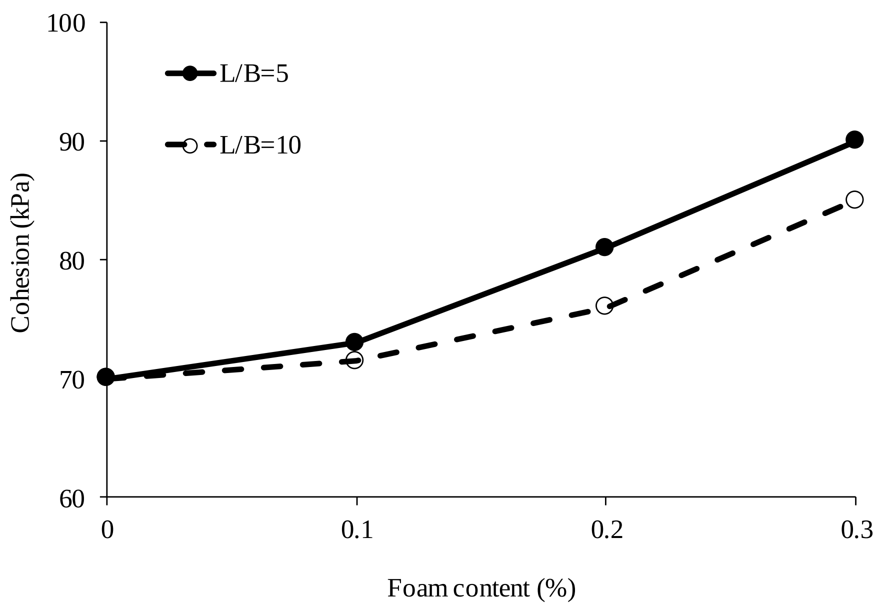


Fig. 8. Change in cohesion intercept of cemented sand after inclusion of 50 × 5 mm and 50 × 10 mm foam chips.

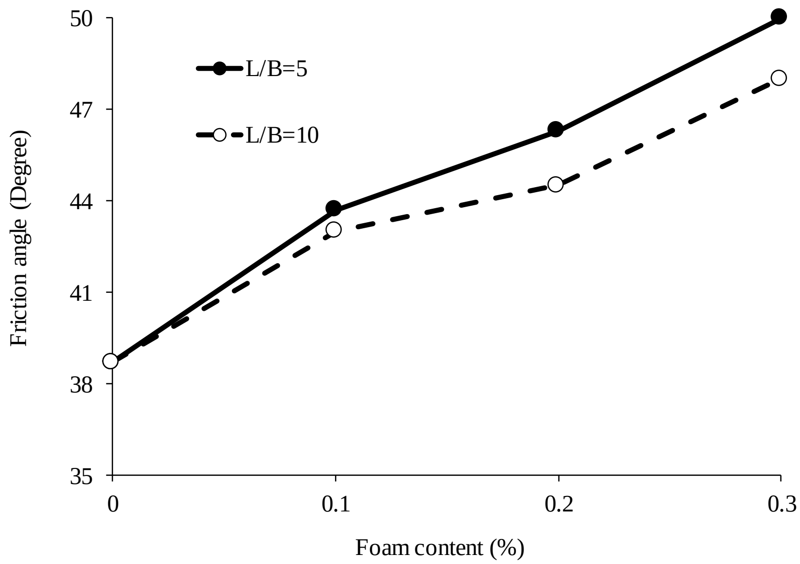


Fig. 9. Change in internal friction angle of cemented sand due to the addition of 50 × 5 mm and 50 × 10 mm foam chips.

4. Stability analysis of reinforced slope

SLOPE/W is a subset of Geo-Studio and was used to investigate the effect of the addition of foam chips on slope stability. The modeled slope had a height of 30 m and a 45° angle from the horizontal surface. The Morgenstern-Price method was used to analyze the slope stability. This method is preferred because it considers all available forces and uses more equations to perform the analysis. The depth of the soil under the slope was 30 m. Seismic acceleration of 0.25g was applied to investigate the horizontal force of an earthquake. All analyses were performed under dry soil condition. The Mohr-Coulomb failure criterion with the cohesion intercepts and friction angles from Figs. 8 and 9, respectively, were used to model the unreinforced and reinforced sandy soil with foam chips.

Analysis showed that the factor of safety of the cemented sandy slope was 1.444. This value increased to 1.665 with the addition of 50 × 5 mm foam chips, and to 1.774 and 1.988 for weight contents of 0.1%, 0.2% and 0.3%, respectively. It also was found that reinforcement of the cemented sand with the 50 × 10 mm chips at percentages of 0.1%, 0.2% and 0.3%, increased the factor of safety to 1.708, 1.890 and 2.141, respectively.

Fig. 10 shows the critical failure surfaces obtained from slope stability analysis for cemented sand and reinforced cemented sand with 0.3% 50 × 10 mm foam chips. Fig. 11 shows the changes in safety factor with a change in the content of the foam chips of different sizes. It can be seen that the increase in the foam chips content increased the safety factors and the stability of the cemented slope. It also was found that the foam chips with lower aspect ratios is caused a greater increase in the safety factor.

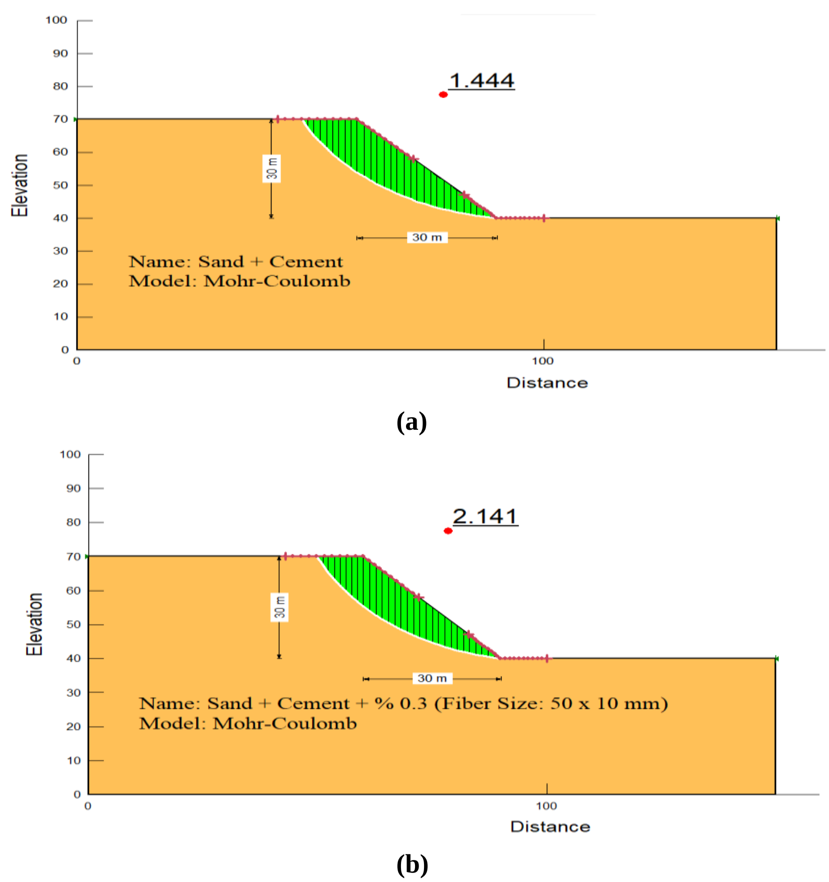


Fig. 10. The critical failure surfaces obtained from stability analysis and factors of safety for slopes: (a) sand with 3% cement; (b) sand with 3% cement and 0.3% 50 × 10 mm foam chips.

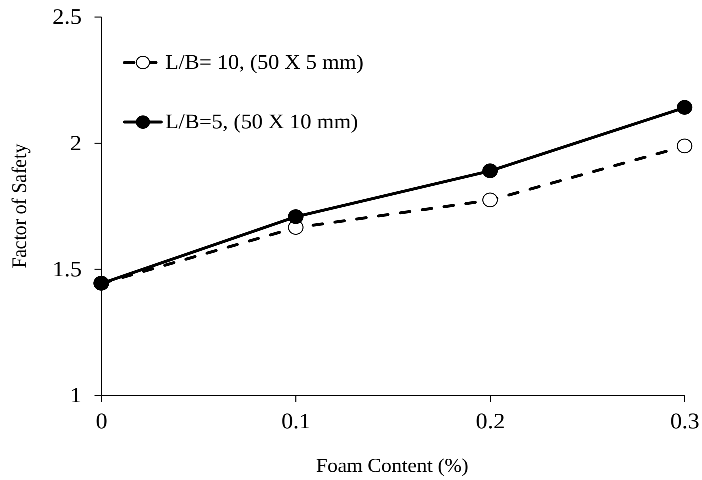


Fig. 11. Safety factor of cemented sandy slope vs. changes in the size and content of disposable foam chips.

5. Conclusions

- The results of large-scale direct shear tests (300 × 300 × 180 mm) revealed that 0.2% disposable polystyrene foam chips increased the maximum shear strength of uncemented samples by 24% to 35% and of cemented samples by 20% to 28%. At similar foam chip contents, the increase in strength of the uncemented sandy soil was greater than of cemented sand.
- Foam chips with lower aspect ratios (or larger chips) caused greater increases in the shear strength of the soil. The effect of reinforcement with foam chips increased with an increase in the surcharge pressure for the cemented samples. However, the level of reinforcement was greater for uncemented soil at lower surcharge pressures.
- The inclusion of foam chips in uncemented samples decreased the final dilation of the soil. In the cemented samples, especially at higher chip contents (0.2% and 0.3%) and a larger chip size (50 × 10 mm), dilation of the samples increased.
- The initial stiffness of the uncemented samples did not change with the addition of foam chips, although in the cemented samples, the initial stiffness and the reduction

in shear stress after the peak shear strength decreased with the addition of foam chips. This means an increase in ductility of the cemented sand.

- The use of foam chips from disposable containers increased the cohesion and internal friction angle of cemented soil. The cohesion intercept of cemented sand increased by 20% to 30% with the addition of 0.3% foam chips and the internal friction angle increased by 20% to 25%.
- The results of stability analysis showed that an increase in the foam chip content increased the safety factor and the stability of cemented sandy slope. It was found that the larger chips with lower aspect ratios caused a greater increase in the factor of safety.
- Due to the increase in shear strength and ductility of the cemented soil and the increase in the safety factor of slopes reinforced with a combination of cement and foam chips, the use of this recycled and inexpensive material is recommended for the improvement of man-made sandy slopes and trenches.

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