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Swelling Soil Improved with Geofoam and Sand

Mohamed A. Sakr[1], Ashraf K. Nazir[2] and khloud M. Ali[3]

[1]Professor, Faculty of Engineering, Tanta University, Egypt.
[2]Professor, Faculty of Engineering, Tanta University, Egypt.
[3]M.Sc. Research Student, Faculty of Engineering, Tanta University, Egypt.

Abstract

This paper presents a study of the swelling soil and its recurrent volume changes with the variation of moisture content. This soil has a unique shrink-swell behavior which changes along with variation in soil water content reducing the strength that can damage a structure. Controlling the swelling potential of soil is one of the important criteria to the civil engineers. Several attempts are being made all over the world to improve the swell-shrink phenomenon of swelling soil. The present paper attempts to study the improvement of the swelling soil with EPS geofoam layer and with sand as a layer and as soil-sand mixture. Various tests have been performed such as sieve analysis, standard proctor test, Atterberg limits, one- dimensional oedometer, and free swell index in the laboratory on both natural and improved soil. These tests were performed at the geotechnical engineering research laboratory, Tanta University. From the obtained results of the experimental testing program, it has been observed that the engineering properties of the swelling soil are improved effectively and the swelling pressure is substantially reduced, as the percent of sand, thickness and density of EPS geofoam increased. Also, from the test results it was found that adding sand could considerably decrease the swelling pressure of the swelling soil from 520 kN/m^2 to nearly 320 kN/m^2.While the tested soil with a swelling pressure of about 520 kN/m^2 was changed to nearly non expansive soil when improved with EPS geofoam.

Keywords: Swelling soil, improvement, sand, EPS geofoam, swelling pressure.

1. Introduction

Swelling soil is considered to be one of the most problematic soils and it causes damage to various civil engineering structures because of its swelling and shrinking potential when it comes into contact with water. In U.S. alone, the damage causes approximately 15 billion dollars per year [1]. Swelling soils behave differently from other normal soils due to their tendency to swell and shrink. Because of this swelling and shrinking behavior, swelling soils may cause many problems in structures or construction projects like: structural damage to lightweight structures such as sidewalks and driveways, cracks in walls and ceilings, damage to pipelines and other public utilities, lateral movement of foundations and retaining walls due to pressure exerted on vertical walls. The problem of the swelling soil can be improved by using various methods such as pozzolanic stabilization using rice husk ash and fly ash, chemical soil stabilization, cement and lime stabilization, and stabilization using sand as stated by many investigators [2], [3], [4], [5] [6].

Preventative practices include excavation and replacement of swelling soil with non–swelling soil, soil isolation and installation of subsurface drains [4], [7]. Sand is a non-swelling soil having minimum plasticity and doesn't have any kind of charges on its surface. Swelling soil possesses charge on its surface which gives them Cation Exchange Capacity (CEC). Hence the addition of sand to the swelling soil helps to balance the electrical charges in the swelling soil and consequently reducing the expansion [1], [8], [9], [10]. The present study mainly focuses on studying the swelling characteristics of one commercially available swelling soil known as bentonite clay with the addition of two of the most economical stabilization non-swelling materials; sand and expanded polystyrene (EPS) geofoam.

The addition of sand was in two forms of sand layer over the swelling soil and in the form of sand-swelling soil mixture with different percentages of (0, 10, 20, 30, 40, and 50 %) by weight. The EPS geofoam was used as a layer above the swelling soil with a thickness of (0, 2, 6, 10, and14) mm. Various tests of index properties (specific gravity, liquid limit, and plastic limit) and engineering properties (compaction, free swell and swelling pressure) were performed on the swelling soil with and without improvement. Also, to study the consolidation behavior of the swelling soil improved with sand and EPS geofoam, one dimensional consolidation (Odometer) tests were conducted.

2. Experimental work, Materials used and Sample preparation

1. Swelling Soil

It is purely artificial clay soil known as bentonite and was obtained from Bentonite and Derivatives Company in Borg Al-Arab; Alexandria, Egypt. This material is yellow and comes in the form of finely ground powder. The physical characteristics of this bentonite are shown in Table 1.

2. Sand

For the stabilization of swelling soil, yellow clean medium sand which passes through 4.75mm sieve was used in this study. This sand was oven dried for 24 hours to remove its moisture before testing. The main properties of the used sand are illustrated in Table 2 and the Grain size distribution analysis is introduced in Table 3.

3. Expanded Polystyrene (EPS) geofoam

The EPS geofoam is produced from petrol by expanding polystyrene particles and mixing them with each other. It is thermoplastic foam with closed pores and usually white in color [11].

4. Sample Preparation

In this paper, different laboratory tests were performed on untreated soil (bentonite) to determine its properties. The initial moisture content of bentonite is found to be 9.8%.

Table 1: properties of used bentonite

Property	**value**
Specific gravity	2.58
Liquid limit (%)	342
Plastic limit (%)	53
Plasticity index (%)	289
Optimum moisture content, OMC (%)	29.3
Initial water content, Wc %	9.8
Maximum dry unit weight, γ_{dmax} (kN/m^3)	14.3
Free swell index (%)	800

Table 2: properties of used sand

Property	**value**
Specific gravity, G_S	2.6
Optimum moisture content, OMC (%)	9.0
Maximum dry unit weight, γ_{dmax} (kN/m^3)	18.4

Table 3: grain size distribution analysis

Description	**Value (%)**
Coarse sand	9
Medium sand	79
Fine sand	12

Before testing, the soil samples were kept in oven for 24h at 110°c. EPS geofoam densities for practical civil applications range between about 11 and 30 kg/m^3. For compressible inclusion applications, the lowest density is generally desirable [12]. The EPS geofoam of nominal density of 10 and 20 kg/m^3 are chosen in this study. Table 4 shows different series of tests which were performed on bentonite without additives and with sand and EPS geofoam additives.

For the case of sand and bentonite, in the first group the sand was mixed with soil as a mixture and in the second group the sand was used as a layer above bentonite. In the first group of tests, bentonite was mixed with sand under controlled conditions. The mixture was prepared by hand mixing and then compacted in the odometer cell with dry unit weight equals 85% of the obtained maximum value of the dry unit weight from the modified proctor test [13]. The sand-bentonite mixture is compacted in three layers with the same energy (15blows/layer) for five percentages of sand (10%, 20%, 30%, 40% and 50 %). In the second group, the same percentages of sand as those used in the first group were employed but the sand was placed as a layer above bentonite and then compacted in the odometer cell. In this group of tests, the weights of bentonite and sand in the cell for each percentage of sand were equal to the weights of bentonite and sand used in the first group.

In the same Table 4, another two groups of tests were performed on bentonite improved with EPS geofoam. The EPS geofoam was placed as a layer above bentonite and the tests were performed using different thickness of EPS geofoam (0, 2, 6, 10, and14 mm) and with two densities (10 and 20 kg/m^3). These thicknesses were equal to the same percent (10, 30, and 50) of sand that was placed above bentonite in the first case of soil improved with sand. The soil was compacted inside the odometer cell using a hand compaction tool which is shown in Figure 1.

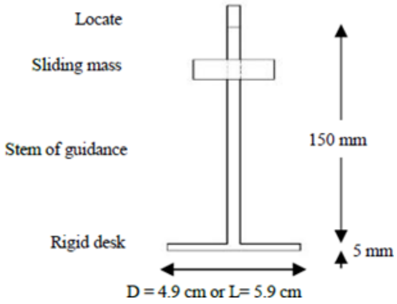

Figure 1. Sketch of the hand compaction tool as used by [13].

Different tests of basic index properties, Liquid limit (LL), plastic limit (PL), compaction, specific gravity (Gs), swelling pressure (SP), and free swell tests were also conducted on bentonite and bentonite soil mixed with sand, as per ASTM standards.

Table 4: Experimental testing programme

Test series	**Bentonite with and without additives**	
1	Bentonite without additives	
Bentonite and sand		
Test series	First group	Second group
	Bentonite (B)-sand (S) mixture	Sand placed above bentonite as a layer
2	90%B+10%S	90%B+10%S (2mm)
3	80%B+20%S	80%B+20%S (4mm)
4	70%B+30%S	70%B+30%S (6mm)
5	60%B+40%S	60%B+40%S (8mm)
6	50%B+50%S	50%B+50%S (10mm)
Bentonite and EPS geofoam		
Test series	First group	Second group
	EPS geofoam layer (γ=10kg/m^3)	EPS geofoam layer (γ=20kg/m^3)
7	B+2mm EPS	B+2mm EPS
8	B+6mm EPS	B+6mm EPS
9	B+10mm EPS	B+10mm EPS
10	B+14mm EPS	B+14mm EPS
No. of tests		19

3. Results and discussion

3.1 Effect of additives content on the swelling pressure

Relationship between vertical displacement and loads on the oedometer cell for the case of bentonite improved with sand (mixture and layer above bentonite) are shown in Figures (2 and 3). From these two figures, it can be seen that the swelling pressure of bentonite is found to be decreased with increasing the percentage of sand added (mixing or as a layer) as shown in the two Figures (4 and 5).

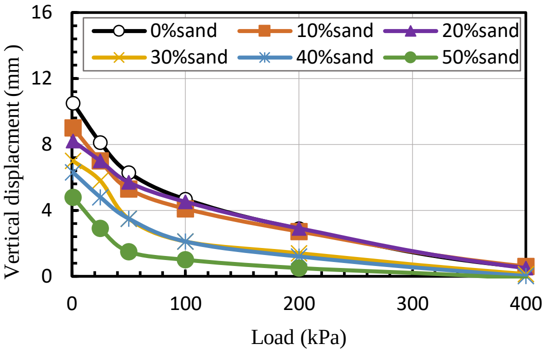

Figure 2. Relationship between vertical displacement and loads in the odometer test for the case of sand-bentonite mixture.

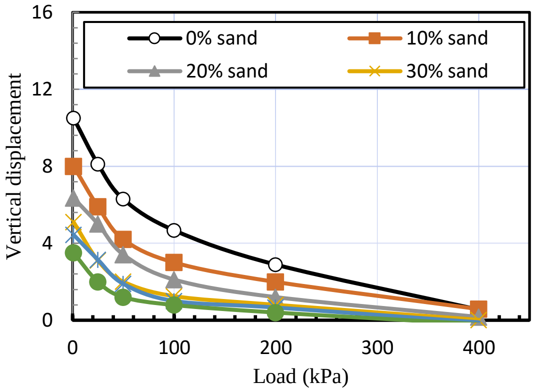

Figure 3. Relationship between vertical displacement and loads on the oedometer cell for the case of sand as a layer over bentonite.

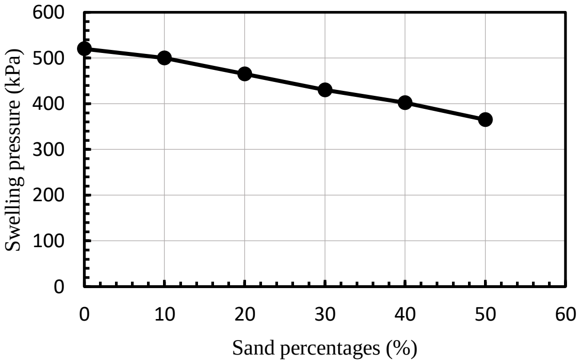

Figure 4. Percentage of Sand versus swelling pressure for bentonite–sand mixture.

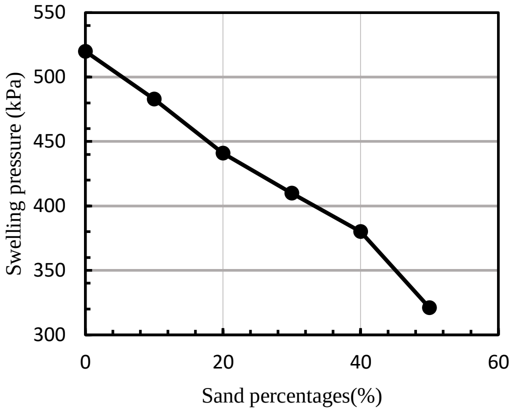

Figure 5. Percentage of Sand versus swelling pressure for sand as a layer over bentonite.

Table 5 and the two figures (6 and 7) show the oedometer test results for different sand percentages with bentonite (mixing or as a layer). The obtained results show that the addition of sand reduces the swelling pressure with the increase of sand for both cases of mixing or as a layer. Mixing allows sand particles to be distributed within the clay structure and consequently plays a good role in reducing the rate of swelling (absorbing the swelling in existing voids, and consequently reducing bonds between clay particles by interposition of the sand grains). Whereas in the case of sand added as a layer, the sand plays only one role that is to prevent the soil from swelling by inertia. Figure 6 shows a comparison between the results of variation of swelling pressure with sand percentages layer and mixing. While figure 7 presents the obtained results for the reduction in the swelling pressure for the two cases of sand-bentonite mixture and as a layer.

Table 5: Swelling pressure and percentage of reduction for different percentages of sand used for the two cases of bentonite-sand mixture and sand as a layer above bentonite

Sample description	**Swelling pressure, SP (kPa)**	**Reduction in swelling pressure, SP_r (%)**
100% B	520	-
Sand added as a layer		
90% B+10%S	483	7.1
80% B+20% S	441	15.2
70%B+30%S	410	21.2
60%B+40%S	380	26.9
50%B+50%S	321	38.3
Sand used as a bentonite–sand mixture		
90% B+10%S	500	3.8
80% B+20% S	465	10.6
70%B+30%S	430	17.3
60%B+40%S	402	22.7
50%B+50%S	365	29.8

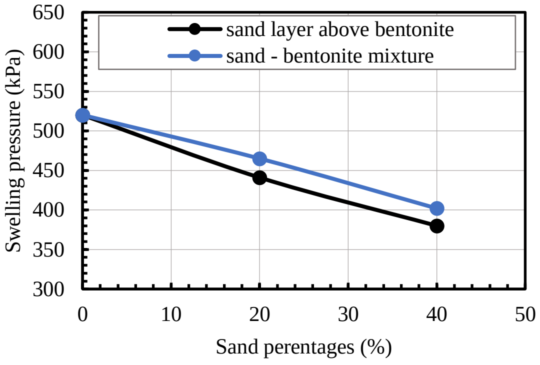

Figure 6. Variation of swelling pressure with sand percentages.

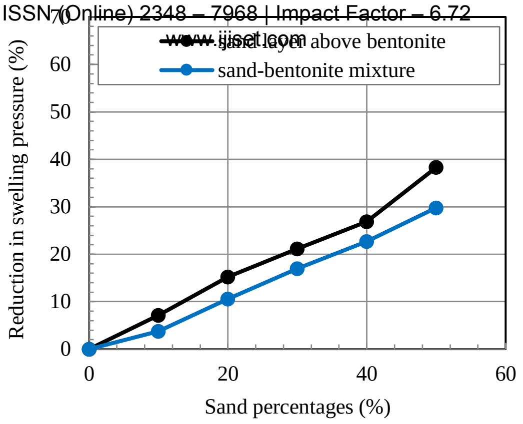

Figure 7. Percentages of sand versus reduction in swelling pressure of bentonite.

Table 6 and the two figures (8 and 9) show the impact of the two cases of adding EPS geofoam with two densities equal 10 and 20 kg/m^3 (EPS10 and EPS20) on the swelling pressure of the bentonite. The obtained results revealed that the thickness of geofoam plays an important role in the reduction of swelling pressures. Figure 8 shows that the addition of geofoam reduces the swelling pressure with the increase of thickness of the Geofoam from 2 to 14mm placed as a layer on bentonite and with the two densities of 10 and 20 Kg/m^{3}of the EPS geofoam. While, figure 9 shows the influence of adding EPS geofoam with different densities (10 and 20 kg/m^3) on the reduction of the swelling pressure of the bentonite.

Influence of the percentages of sand or EPS geofoam on the swelling pressure and reduction in the swelling pressure are shown in Figures (10 and 11). Improved soil Compressive modulus of Geofoam also influences the measured swelling pressure. EPS geofoam of lower modulus is more effective in minimizing the swelling pressures of swelling soils. Swelling pressure tests were performed according to [14].

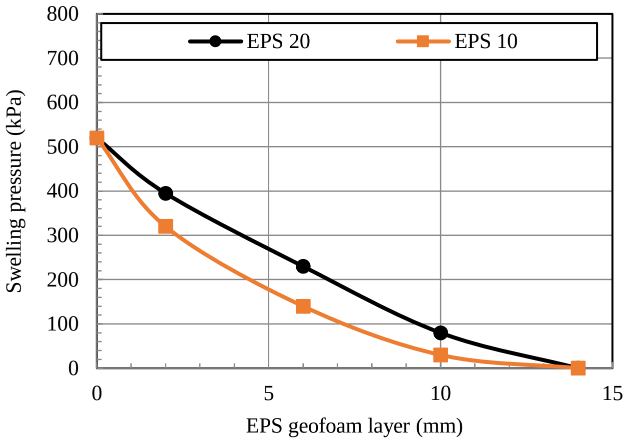

Figure 8. Swelling pressure versus EPS geofoam layer above bentonite.

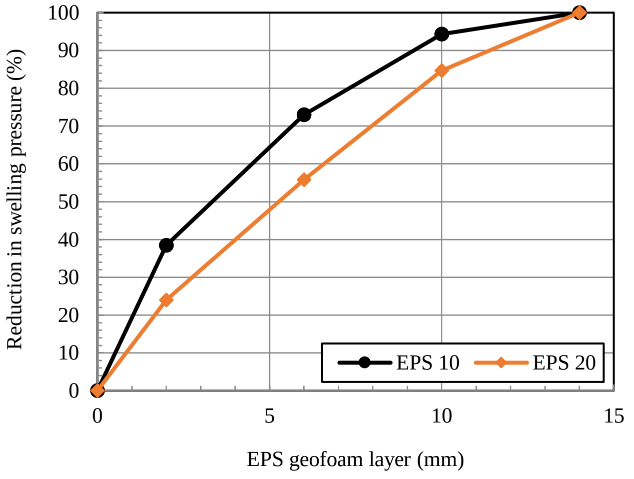

Figure 9. EPS geofoam layer versus reduction in the swelling pressure of bentonite.

Table 6: Reduction of swelling pressures for different densities and thicknesses of EPS geofoam

Test series	**Swelling pressure, SP (kPa)**	**Reduction in swelling pressure, SP_r (%)**
Bentonite without additives	520	-
Bentonite + EPS geofoam with density 10 kg/m^3		
B+2mm EPS	320	38.5%
B+6mm EPS	140	73.1%
B+10mm EPS	30	94.2%
B+14mm EPS	0	100%
Bentonite + EPS geofoam with density 20 kg/m^3		
B+2mm EPS	395	24.0%
B+6mm EPS	230	55.8%
B+10mm EPS	80	84.6%
B+14mm EPS	0	100%

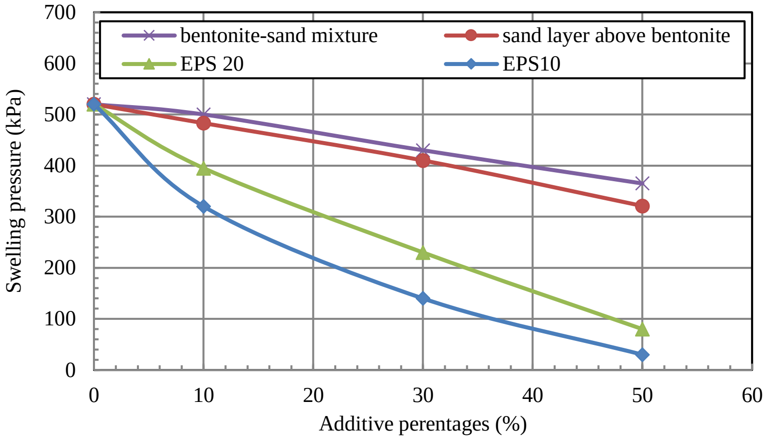

Figure 10. Influence of sand and EPS geofoam on the swelling pressure of bentonite

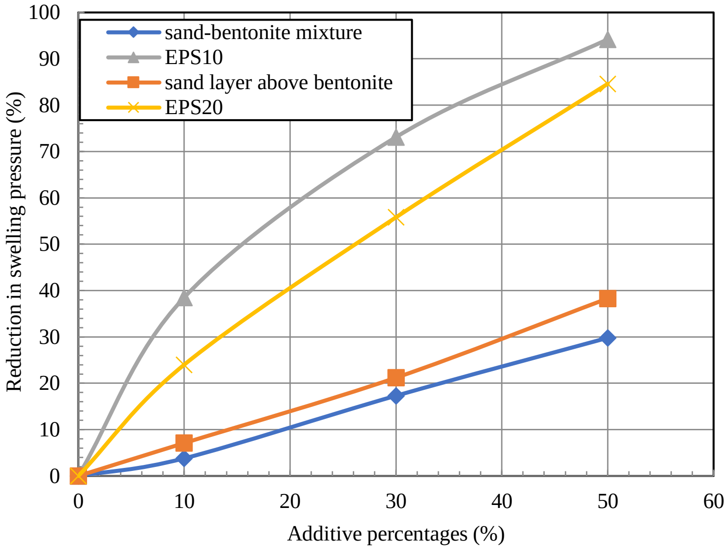

Figure 11. Influence of sand and EPS geofoam on the reduction in swelling pressure of bentonite (%)

3.2 Impact of sand additive on the compaction parameters.

This test provides optimum moisture content and maximum dry density of soil. Test was performed on soil sample in the laboratory. Dry density versus moisture content for different percentages of bentonite and sand mixture are given in Figure 12. Figures (13 and 14) and Table 7 show dry density and water content versus sand content for different percentages of bentonite and sand mixture. The obtained results show that increasing the percent of added sand has increased the maximum dry unit weight of the bentonite from (14.3 to 17 kN/m^3) and decrease the optimum moisture content of the swelling soil from (29.3 to 14.9%). According to ASTM- D 1557 [15], the compaction parameters of the swelling soil improved with sand were determined.

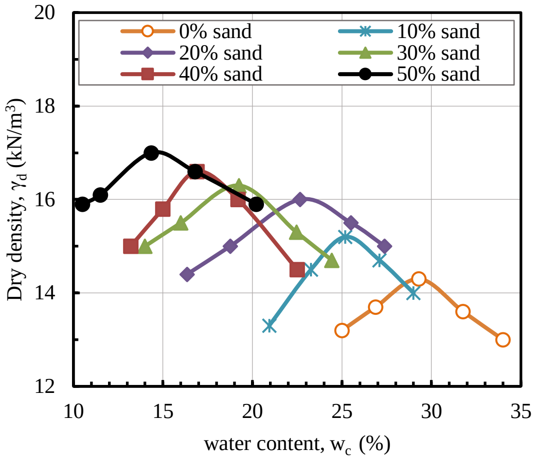

Figure 12. Dry density versus water content for different percentages of sand in the case of bentonite-sand mixture

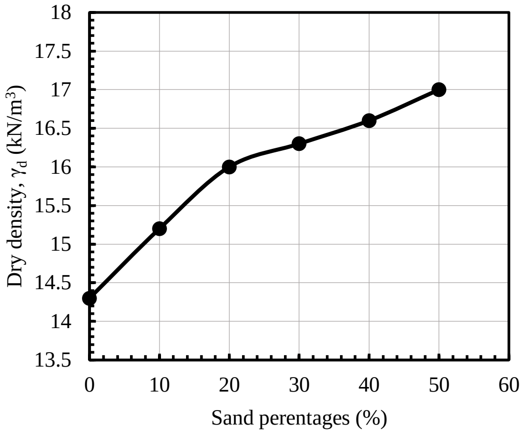

Figure 13. Dry density versus sand percentages in the case of bentonite-sand mixture.

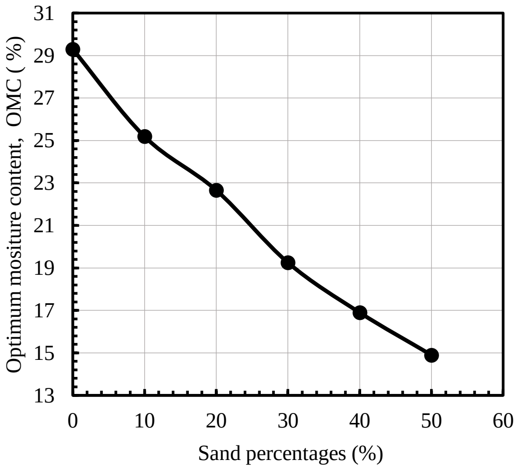

Figure 14. Optimum moisture content versus sand percentages in the case of bentonite-sand mixture.

Table 7: Maximum dry density (MDD) and optimum moisture content (OMC) in the case of bentonite- sand mixture

Test series	**OMC%**	**MDD (kN/M^3)**
Bentonite without additives	29.3	14.3
90%B+10%S	25.2	15.2
80%B+20%S	22.7	16
70%B+30%S	19.3	16.3
60%B+40%S	16.9	16.6
50%B+50%S	14.9	17

3.3 Effect of sand additive on the Free Swell

As shown in Figure 15 and Table 8, the free swell was found to be decreased with the increase of sand percentages. The free swell index was calculated as per [16]. From this figure it can be seen that, at low sand percentages the reduction rate exceeds the percentage of sand added. This reduction appears to be larger for a given percentage of sand particles when forming the sand fraction is coarse. This difference expresses the effect of the granularity of the sand on the swelling activity.

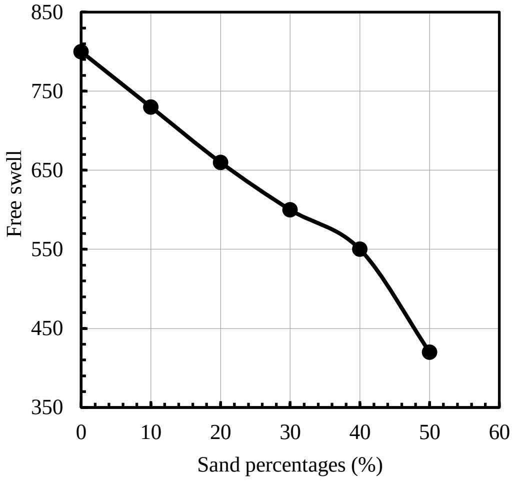

Figure 15. Relation between free swell and sand percentages

the obtained results can be interpreted by the fact that the clay content decreases by adding different percentages of sand, which is normally inert material. Indeed, a greater sand content mixture reduces the amplitude and the swelling pressure; this is on one hand. On the other hand, much of this swelling is absorbed by the voids between sand grains. When the fraction of sand is coarser, these voids become larger resulting in a decrease of swelling amplitude. Accordingly, there is a reduction of the potential and swelling pressure developed by the swelling soil. It could also be that with the particle size, the larger effects of gravity contribute to the reduction of swelling of the bentonite-sand mixtures**.**

Table 8: Free swell for different percentages of sand in the case of the bentonite-sand mixture

Sand (%)	**Free Swell (%)**
0.0	800
10	730
20	660
30	600
40	550
50	420

3.4 Effect of sand additive on Atterberg limits

In order to study the effect of sand percentages on Atterberg limits, series of tests were performed as per ASTM-D4318 [17], on bentonite without additives then on bentonite mixed with different percentages (10, 20, 30, 40 and 50%) of sand. The obtained results show that there is a reduction in the liquid limit with increasing the percent of sand as shown in Figure 16. The plastic limit value is decreased reaching 34 % as shown in Figure 17. Table 9 shows the reduction in liquid limit, plastic limit, and plasticity index.

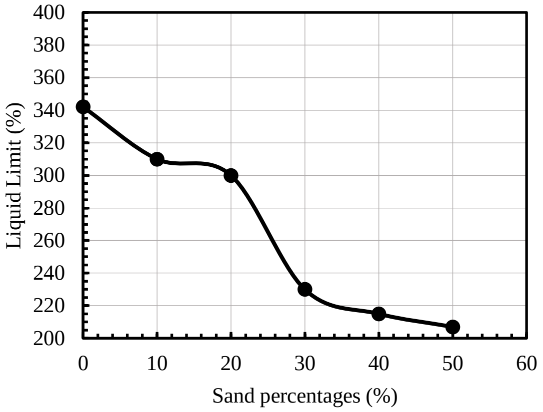

Figure 16. Liquid limit of bentonite-sand mixture for different percentages of sand

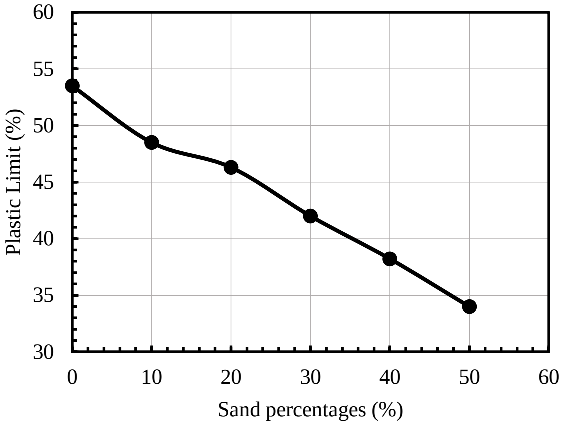

Figure 17. Plastic limit of the bentonite-sand mixture for different percentages of sand.

Table 9: Atterberg limits for different bentonite-sand mixtures

Bentonite-sand mixture	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index (%)**
Bentonite without additives	342	53.6	288.4
90%B+10%S	310	48.5	261.5
80%B+20%S	300	46.3	253.7
70%B+30%S	230	42	188
60%B+40%S	215	38.2	176.8
50%B+50%S	207	34	173

4. Conclusion

The present paper presents an investigation on the impact of adding sand and EPS geofoam to the expansive soil for different cases of bentonite-sand mixture, sand as a layer above bentonite and EPS geofoam with two different densities (EPS10 and EPS20). From this study, some conclusions can be drawn:

- From the oedometer test, it is found that the swelling pressure in all the cases has been reduced when sand was added to bentonite (mixing or as a layer). The swelling pressure is found to be reduced in the range of nearly about 7.1 to 38.3% for the case of sand layer above bentonite and to be reduced in the range of nearly about 3.8 to 29.8% for the case of sand-bentonite mixture. From the other hand, the expanded polystyrene (EPS) geofoam was found to be reducing the swelling pressure from 520 kPa for the case of bentonite without additives to nearly non swelling for the case of 14 mm EPS geofoam layer above bentonite.

- The liquid and plastic limits for the bentonite soil were found to be 342% and 53.6% respectively. Adding sand to bentonite soil has led to a significant reduction in the liquid limit from 310% to 207% for the two cases of 10 and 50 percentages of sand. The plastic limit was also found to be reduced from 48.5% to 34% for the two cases of 10 and 50 percentages of sand. Sand is a non-expansive soil which is having no plasticity, so the addition of sand to the expansive soil has resulted in a reduction in the liquid and plastic limits of the expansive soil.

- This study demonstrated that the replacement of bentonite soil by sand has decreased the free swell up to a great extent. Adding 50% of sand to the bentonite soil is found to be reducing the free swell from 80% to 42%, which makes a huge difference in the swelling soil properties.

- Regarding the compaction parameters; the bentonite soil was found to be having a dry density equals 14.3 kN/m^3 and a water content equals 29.3%. While sand was found to be having a higher dry density equals 18.4 kN/m^3 and a lower water content equals 9%. From the test results, the addition of sand to the bentonite was found to be increasing the dry density and decreasing the optimum moisture content of the sand-bentonite mixture.

Finally, this study revealed that adding sand in the form of sand-bentonite mixture or as a layer above bentonite; and expanded polystyrene (EPS) geofoam as a layer above bentonite is found to be a good technique in improving the swelling soil properties. However, adding EPS geofoam with 10 kg/m^3 density gives a better result in reducing the swelling pressure of the bentonite.

References

[1] A.I. Al-Mhaidib, "Swelling behavior of expansive shale": A case study from Saudi Arabia. In: Al-Rawas AA, Goosen MFA (Eds) Expansive soils: advances in characterization and treatment. Taylor and Francis, London. 2006.
[2] W. G. Holtz and H. J. Gibbs, "Engineering properties of expansive Clays". Trans Am Soc Civ Eng, 1956 121(1): Pp641–663.
[3] A. Sridharan and Y. Gurtug, "Swelling behavior of compacted fine-grained Soil''. 2004. Pp. 9-18.
[4] Hudyma and B. B. Avar, "Changes in swell behavior of expansive clay soils from dilution with sand". Environmental & Engineering Geoscience, 12, No.2, 2006. Pp. 137-145.
[5] M. K. Rao, G. Giri Babu, and Rani Suda, " Ch. Influence of coarse fraction on swelling characteristics. Electrical Journalof Geotechnical Engineering", 11, No.5, 2006, Pp. 216-220.
[6] A. K. Mishra, S. Dhawan, and M. S. Rao, "Analysis of swelling and shrinkage behavior of compacted clays". Geotechnical and Geological Engineering, 26(3), 2008, Pp. 289-298.
[7] F.H. Chen, "Foundations on expansive soils". Elsevier Scientific Publishing Co. Amsterdam. 1988.
[8] G. E. Abdelrahman and M.M. Shahien, " Swelling treatmentby using sand for Tamia swelling soil". In the proceeding of the 4thinternational engineering conference (4th IEC), Sharm El Sheikh, Egypt. 2004.
[9] A. AlKarni and S.M ElKholy, "Improving geotechnical properties of dune sands through cement stabilization". J Eng Sci 5(1) 2012, Pp.1-19.
[10] B. Louafi and R. Bahar, "Sand: an additive for stabilization of swelling clay soils". Int J Geosci 3 (4) 2012, Pp. 719-725.
[11] J.S. Horvath "expanded polystyrene (EPS) geofoam: an introduction to material behavior". Geotext Geomembr (4)1994, Pp. 263-28
[12] H.L. Liu, A. Deng, J. Chu " Effect of different ratios of polystyrene pre-puff beads and cement on the mechanical behavior of lightweight fill". Geotext Geomembr 24, 2006 Pp.331–338.

[13] M. A. Sakr, M. A. Sawaf, A. K. Nazir, and A. K. Rabah, "Behavior of collapsible soils stabilized with fibers", Proceedings of the AICSGE 8, Alexandria, Egypt, 2014, Pp. 119-129.
[14] Designation: D 4829, "Standard test method for expansion index of soils", American society for testing and materials (ASTM) 2008.
[15] Designation: D 1557, "Standard test methods for laboratory compaction characteristics of soil using modified effort", American society for testing and materials (ASTM) 2008.
[16] Designation: D 4546, " Standard test method for one-dimensional swell or settlement potential of cohesive soils", American society for testing and materials (ASTM) 2008.
[17] Designation 4318, "Standard test method for liquid limit, plastic limit and plasticity index of soils", American society for testing and materials (ASTM) 2008.