Effect of Geofoam under Strip Footing Rested on Swelling Soil

Adel Fouad Diab[1*], Nagwa Ragab El Sakhawy[2], Mohamed Elazab Elkilany[2], and Rehab Ahmed Al-Badwy[2]

[1] *Civil Engineering, Bilbis High Institute, Zagazig, Egypt*
[2] *Geotechnical Engineering Department, Zagazig University, Zagazig, Egypt*
[*] *Corresponding author. E-mail: a_fd2561@yahoo.com*

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Swelling soils are considered a highly problematic soil due to the volume change actions. The cyclic heave and settlement of expansive soils could be the main reason for considerable damages to the structures, roads, and highways. Many available methodologies are followed to combat these problems of the swelling soils. This paper presents the results of experimental research which performed to show the efficiency of the (EPS) geofoam layers system as a new technique for controlling the upward movement of structures over swelling soils. The performance of the geofoam layer under the footing at different positions is studied. Geofoam layer has two configurations; flat and ribbed cross-section. Different densities and thicknesses of geofoam are considered in the study. Sand with different thicknesses is placed above swelling soil as a partial replacement under the footing. Their effectiveness of the performance is analyzed and discussed. Test results show a noticeable reduction in heave as a result of using the ribbed geofoam layer and partial replacement by sand above the swelling soil.

Keywords: EPS, Geofoam, Compensated foundation, Swelling soil

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1. Introduction

Expansive soils cause great damage to foundations and structures. Damage due to expansive soils costs billions of dollars around the world [1]. When the water content changes, soil reaches the wet condition easily. These soils have swelling properties, because of the high volumetric changes. When the swell pressure exceeds the overburden pressure of the soil, distress may occur at any place of the structure [2]. Swelling is mainly occurred due to active clay minerals such as Montmorillonite which is responsible for the volumetric changes of this soil. Montmorillonite is often called swelling or expansive clay. Montmorillonite can expand by several times its original volume when it comes in contact with water [3, 4].

Swelling soils are found at different depths in many arid or semi-arid regions in Egypt where huge development is under construction such as El-Sherouq City, 6 October City, New Administrative Capital City, New El Alamein City, New Cairo City, and some urban regions in Cairo like Heliopolis. Hence, swelling behavior investigation for the swelling soils existed in these regions has become extremely important nowadays [5, 6].

To overcome these problems of swelling soils, geosynthetic materials have been introduced for geotechnical applications to improve the engineering behavior and control swell of expansive soil [7, 8].

Recently, Expanded polystyrene (EPS geofoam) blocks have been used as a lightweight fill material in many applications such as in landscaping over underground parking garages, around and above underground basements, as subgrade and fill material under flexible pavements, as lightweight embankments fills under roads and even bridge approaches [9, 10]. The swelling pressure can be reduced considerably by placing EPS geofoam above the soil [11, 12].

There are many methods of treatment for swelling soil like modification of footing shape or additives for soil, but geofoam is very lightweight, low price, and widely available. Previous studies of geofoam focused on thickness so this study suggests discussing and analyzing cross-section, densities, thickness, and partial replacement by sand. This study gives alternative solutions to control heave of swelling soil. These solutions are applications of flat geofoam, ribbed geofoam, and partial replacement of sand.

The objective of the study is to investigate the heave of swelling soil, due to the application of geofoam layer with a different configuration, and partial replacement of sand at various depths.

2. Experimental setup

2.1. Experimental setup

The experimental setup is shown in Fig. 1A. The assembly for the model test setup consists of: Large tank with dimensions 60 x 60 x 60 cm, smaller tank has holes in its sides with dimensions 40 x 40 x 40 cm placed in the large tank, and fixed to the large tank by four 10 cm steel angles, Paper filter sheet lines the sides of the small tank to prevent leakage of soil, Dial gauge to estimate heave, and Manometer on the side of the bigger tank to inundate the core of soil by water.

The 30 cm soil is placed in the inner tank. The clarence distance between the inner and the outer tank is filled with water. Footing is a steel plate of dimensions 15 x 15 x 0.1 cm. The steel plate is placed on the surface of swelling soil. EPS geofoam layer of dimensions 15 x 15cm with different thicknesses, densities, and cross-section is placed under footing on the soil surface. The two types of thickness are 1 and 2 cm. The two types of density are 10 and 20 kg/m^3. The two types of cross-section are flat and ribbed as shown in Fig. 1C. In the case of sand, geofoam is placed at depth 10 and 20 cm of the surface under a layer of sand. The geofoam is obtained from the Egyptian Foam Company in the 10th of Ramadan City. Ribbed geofoam is formed inside the company workshop using geofoam cutting machine according to the proposed model.

2.2. Soil properties

The swelling soil is collected from Upper Egypt Road, Giza, Egypt {29.98o N, 31.21o E}. A 1.5 m^3 of the swelling soil is brought to the laboratory, stored and covered with plastic to preserve its natural water content for different testing batches. The various experimental tests for swelling soils are shown in Table 1. These tests are carried out according to the Egyptian Code 2001 [4]. Experimental work has been performed in the laboratory at Bilbis High Institute for Engineering. Based on its liquid limit and plasticity index, the soil is classified as CH according to the Unified Soil Classification System [13]. Based on its free swelling percentage, the soil is classified as Very High swelling soil, and must be controlled. Sand, which used as a partial replacement, is tested according to Egyptian Code 2001 [4]. The results of sand are shown in Table 2, based on its relative density; the sand can be classified as Loose, and based on its grain size distribution, the sand can be classified as Medium to Fine Sand according to Unified Soil Classification System as shown in Fig. 2 [14].

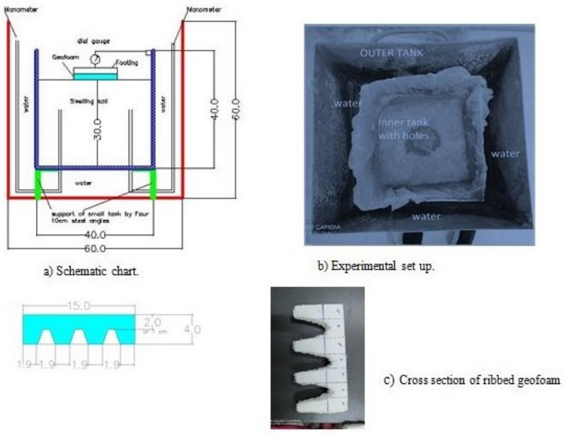

Fig. 1. Experimental set up. All dimensions in centimeter.

Table 1. Properties of the swelling soil.

Property	Value
Free swelling, %	160
Liquid limit, %	51
Plastic limit, %	27.33
Plasticity index	23.67
Natural water content, 29.1	
Clay activity, A	0.97
Bulk unit weight, KN/m^3	18.2

Table 2. Properties of the sand replacement.

Property	Value
Bulk density, KN/m^3	17.3
Void ratio, e	0.721
Max. Void ratio, e_{max}	0.82
Min. Void ratio, e_{min}	0.247
Relative density, DR %	0.173 (0.15-0.30)

2.3. Testing variables

The investigation considers different variables on the swelling soil behaviors as shown in Table 3.

Table 3. Properties of the sand replacement.

NO.	Test Configuration	Description	Test Code
1	Swelling soil only	-	SG-0
2	Swelling Soil + flat geofoam under footing	#Flat geofoam layer 10 mm thickness with density 10 kg/m^3, and 20 kg/m^3 #Flat geofoam layer 20 mm thickness with density 10 kg/m^3, and 20 kg/m^3	SFG1-10 SFG1-20 SFG2-10 SFG2-20
3	Swelling Soil + ribbed geofoam under footing	# Ribbed geofoam layer 10 mm thickness with density 10 kg/m^3, and 20 kg/m^3 # Ribbed geofoam layer 20 mm thickness with density 10 kg/m^3, and 20 kg/m^3	SRG1-10 SRG1-20 SRG2-10 SRG2-20
4	Swelling Soil + ribbed geofoam + Replaced sand	# Ribbed geofoam layer 10 mm thickness placed at depth = 10 and 20 cm of soil surface under a layer of sand	SSRG1-0.33(∗) SSRG1-0.67(∗)

(∗)Notes: SSRG1-0.33: one-third of swelling soil height is replaced with the sand layer.
SSRG1-0.67: two-third of swelling soil height is replaced with the sand layer.

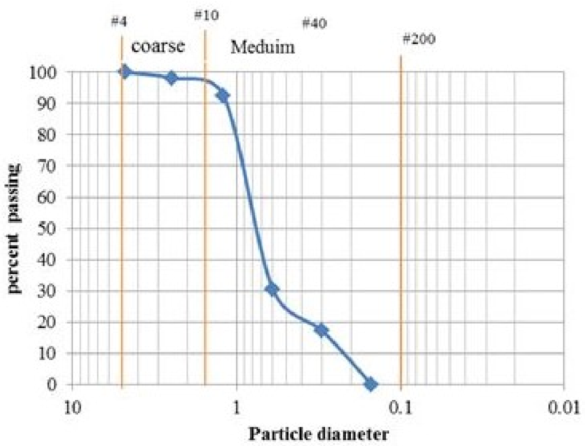

Fig. 2. Classification of sand replacement by its grading curve.

2.4. Test Procedure

A 30 cm of swelling soil is placed in the smaller tank in three equal layers at natural water content without any control arrangement for swelling soil, then The footing is placed at the center of the tank on the surface, then The dial gauge is placed over footing to record the swelling, then Water is allowed to inundate the soil by filling the clearance between large and smaller tank. Water enters through the holes in the tank sides and the manometer, then Readings are recorded at an interval of 5 minutes for the first hour. Then readings are recorded every 30 minutes up to 6 hours and then every 24 hours, until reading is constant, then the swelling soil is removed, and then another 30 cm of stored swelling soil batches with the same water content is placed for the test SFG1-10, then The flat geofoam layer with a density of 10 kg/m^3 and a thickness of 1 cm is placed on the surface under the footing, and then Repeat the steps for tests; SFG1-20, SFG2-10, and SFG2-20 as shown in the testing variables. The swelling soil is removed and then another 30 cm of stored swelling soil batches with the same water content is placed for the test SRG1-10. The ribbed geofoam layer with a density of 10 kg/m^3 and a thickness of 1 cm is placed on the surface under the footing. Repeat the steps for tests; SRG1-20, SRG2-10, and SRG2-20 as shown in the testing variables. The swelling soil is removed, and then another 20 cm of stored swelling soil batches with the same water content is placed, and then ribbed geofoam is placed above swelling soil, and then 10 cm of dry sand in one layer is placed above the ribbed geofoam as shown in Fig. 3A. Repeat the steps for test SSRG1-0.33.The swelling soil is removed, and then another 10 cm of stored swelling soil batches with the same water content is placed, and then ribbed geofoam is placed above swelling soil, and then 20 cm of dry sand in one layer is placed above the ribbed geofoam as shown in Fig. 3B. Repeat the steps for test SSRG1-0.67.

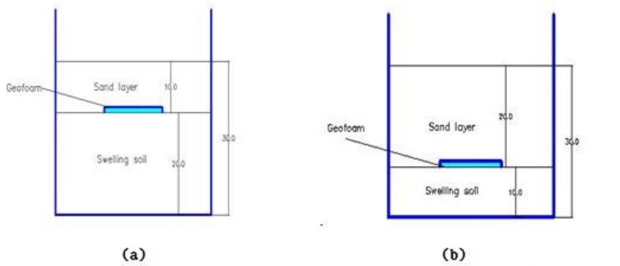

Fig. 3. Placement of geofoam layer under soil surface, a) at depth 10 cm, and b) at depth 20 cm.

3. Results

Results for swelling soil without any control arrangement are illustrated in Fig. 4. Swelling steadily increased with time. The maximum swelling is recorded 35 mm.

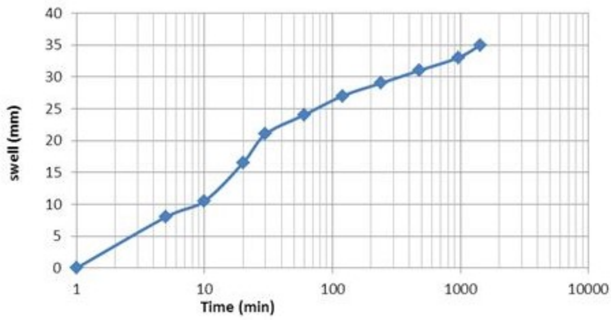

Fig. 4. Swelling behavior for the case of no geofoam.

3.1. Flat Geofoam Layer Effect

The heave of soil for the tests SFG1-10, SFG2-10, SFG1-20, and SFG2-20 is illustrated in Fig. 5. The maximum heave is 29 mm for the test (SFG1-10). The maximum swelling is 24 mm for the test (SFG2-10). The maximum swelling is 26 mm for the test (SFG1-20). The maximum swelling is 22.5 mm for the test (SFG2-20).Can be seen from Fig. 5 that, the more thickness and density of the flat geofoam layer, the less the swelling value of soil.

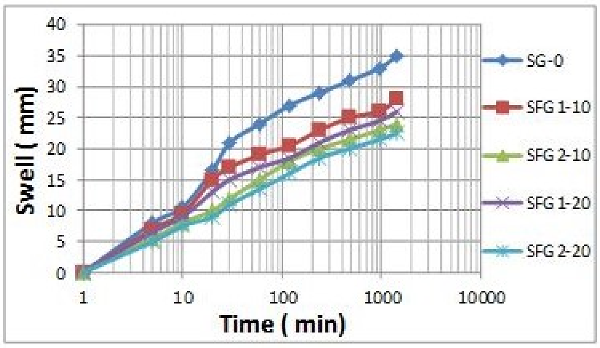

Fig. 5. Swelling Behaviors for the Case of without and with Flat Geofoam with Different Thickness, and Densities.

3.2. Ribbed Geofoam Layer Effect

The heave of soil for the tests SRG1-10, SRG2-10, SRG1-20, and SRG2-20 is illustrated in Fig. 6. The maximum swelling is 25 mm for the test (SRG1-10). The maximum swelling is 23 mm for the test (SRG2-10). The maximum swelling is 24.5 mm for the test (SRG1-20). The maximum swelling is 21 mm for the test (SRG2-20).Can be seen from Fig. 6 that, the more thickness and density of the ribbed geofoam layer, the less the swelling value of soil.

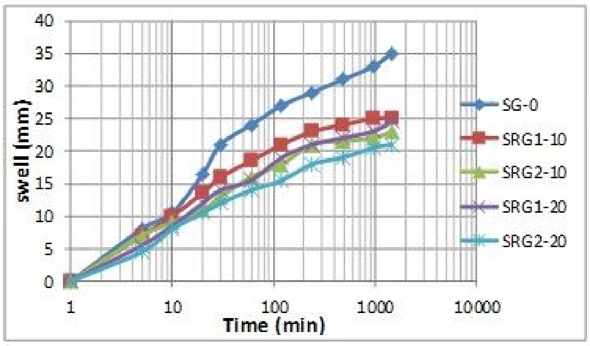

Fig. 6. Swelling behavior for the case of without and with ribbed geofoam with different thickness, and densities.

3.3. Effect of Geofoam Layer and Sand

The heave of soil for the tests SSFG1-0.33 and SSFG1-0.67 is illustrated in Fig. 7. The maximum swelling is 20 mm for the test (SSFG1-0.33). The maximum swelling is 18 mm for the test (SSFG1-0.67).Can be seen from Fig. 7 that, the more thickness of replaced sand, the less swelling heaves of soil.

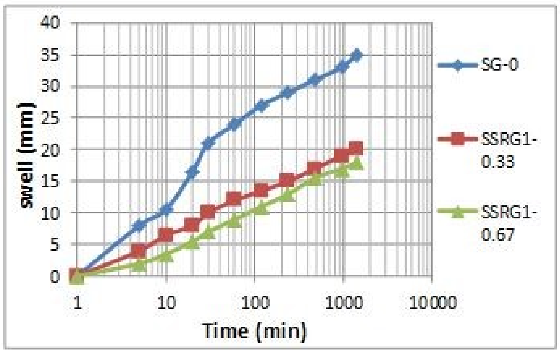

Fig. 7. Swelling behavior for the case of placing geofoam layer at depth 10, and 20 cm under soil surface.

From Fig.5, Fig.6, and Fig.7, there is more reduction of heave for swelling soil in case of ribbed geofoam and sand replacement more than the case of flat geofoam and only ribbed geofoam. The maximum percent of reduction reaches up to 50% in the case of ribbed geofoam and sand replacement, while the percent of reduction reaches up to 40% and 35% in the case of ribbed geofoam and flat geofoam respectively, so it is effective in control of swelling soil by mixing between ribbed geofoam and sand replacement as shown in Fig. 8.

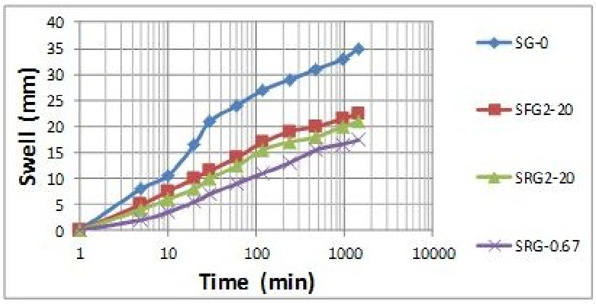

Fig. 8. Comparison between the heave for tests SFG2-20, SRG2-20, and SRG-0.67.

4. Conclusions

The following conclusions are obtained from the experimental tests:

1. Provision of the ribbed geofoam layer and sand under footing would be more effective for reducing the heave of swelling soil.
2. When the ribbed geofoam is placed at height two third of the soil surface and two-third of swelling soil height is replaced with the sand layer, the reduction of heave is increased up to 50% approximately.
3. The amount of reduction reaches up to 40% in the case of the ribbed geofoam layer with density 20kg/m^3 and thickness 2 cm.
4. The amount of reduction reaches up to 35% in the case of flat geofoam layer with density 20kg/m^3 and thickness 2cm.
5. The more density, and thickness of the flat and ribbed geofoam layer, the less swelling value of soil.

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