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(Article)

Reduction Heave of Swelling Soil under Isolated Footing with Flat and Ribbed Geofoam

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ABSTRACT

Swelling soils are considered 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 study presents the results of experimental and numerical research for effect of geofoam under footing rested on the swelling soil as a new technique for controlling the upward movement of structures over the swelling soils. Geofoam blocks are made of Expanded Polystyrene (EPS). It has lightweight, low price, and widely found in Egypt. It can be produced in many shapes and densities. The geofoam layer has two cross-sections; flat and ribbed. Different densities and thicknesses of geofoam are considered in the study. There is a marked reduction in the case of the flat and ribbed geofoam layer with density 20kg/m3 and thickness 2 cm. The swelling soil was modeled by the finite element method ADINA software. Modeling of two cases; flat and ribbed cross-sections is performed by the critical state model with different densities and thicknesses of geofoam.

Keywords: Swelling Soil, EPS, Geofoam

1-Introduction

Foundations and structures are severely harmed by expansive soils [1]. Expansive soils cause billions of dollars in damage all around the world. When the water content of the swelling soil changes, it quickly becomes wet. Because of the large volumetric changes, these soils have swelling properties [2]. Distress can occur anywhere in the structure when the surge pressure surpasses the soil's overburden pressure. Swelling is mostly caused by active clay minerals like Montmorillonite, which are responsible for volumetric changes in this soil[3],[4]. The structure of Montmorillonite is similar to that of illite (see Figure. 1), but the layers are held together by weak van der Waals forces[5]. The smectite clay family includes Montmorillonite[6]. It's aluminum smectite with Mg2+ replacing a little quantity of AL3+. This results in a charge imbalance, which is balanced by the exchangeable cations Na+ and Ca2+, as well as orientated water[4], [7], [8]. Water can easily enter the bond and split the layers in Montmorillonite, resulting in swelling[9]. There are two water layers if the major exchangeable cation is Ca2+ (calcium smectite), but only one water layer if the major exchangeable cation is Na+ (sodium smectite). Sodium smectite absorbs enough water to separate the particles[4], [10]. Because of its divalent cations, calcium smectite does not absorb enough water to promote particle separation. Montmorillonite is also known as "swelling clay" or "expansive clay." When water comes into touch with Montmorillonite, it expands by several times its original volume.

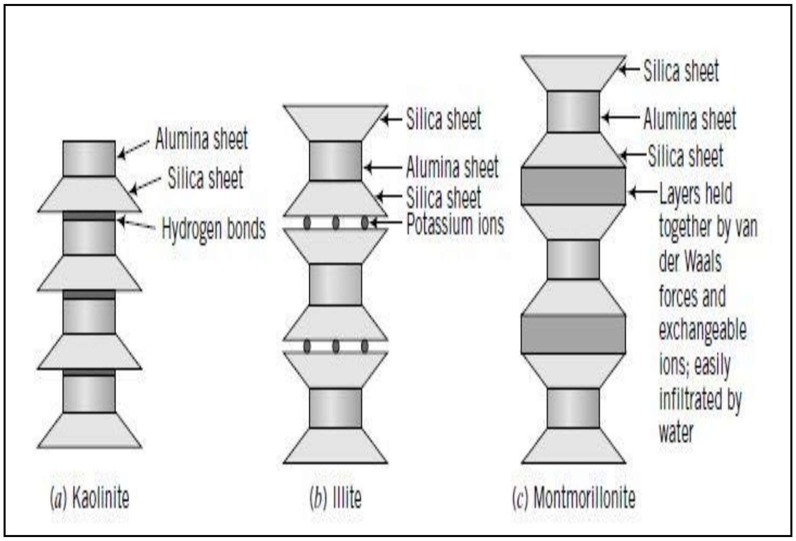

Figure1. Structure of Kaolinite, Illite, and Montmorillonite [11]

Many arid or semi-arid located in Egypt, such as El-Sherouq City, 6 October City, New Administrative Capital City, New El Alamein City, New Cairo City, and several urban neighborhoods in Cairo, such as Heliopolis, have swelling soils at various depths. As a result, investigating the swelling behavior of the swelling soils found in these areas is became increasingly important [12].

Geosynthetic materials are introduced for geotechnical applications to improve the engineering behavior and regulate the swell of expansive soils to address these challenges of swelling soils [13]. Expanded polystyrene (EPS geofoam) blocks have recently been used as lightweight fill material in a variety of applications, including landscaping over underground parking garages, around and above underground basements, as subgrade and fill material under flexible pavements, as lightweight embankment fills beneath roads, and even bridge approaches. Placing EPS geofoam at surface of the swelling soil reduces the swelling pressure significantly [14].

There are a variety of ways to control swelling soil, such as changing the footing design or adding soil additives, but geofoam is extremely lightweight, inexpensive, and readily available[2], [15]. Previous geofoam research has primarily focused on thickness; however, this research proposes discussing and analyzing cross-section, densities, and thickness. These are flat geofoam and ribbed geofoam uses. The goal of study is to estimate the heave of swelling soil caused by the use of a geofoam layer with a distinct configuration.

2- Experimental

2.1Experimental set up

The experimental setup is shown in Fig. 2.a. The assembly for the model test setup consists of:

- Large tank with dimensions 60 x 60 x 60 cm,
- The 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.
- 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.

A 30 cm of the swelling soil is placed in the inner tank. The clearance 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 over the surface of swelling soil. EPS geofoam layer of dimensions 15 x

15 cm with different thicknesses, densities, and cross-section is placed under footing over 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 the cross-section are flat and ribbed, as shown in Fig. 2.c. The geofoam is obtained from the Egyptian Foam Company on the 10^{th} of Ramadan City. Ribbed geofoam is formed inside the company workshop using a geofoam cutting machine according to the proposed model.

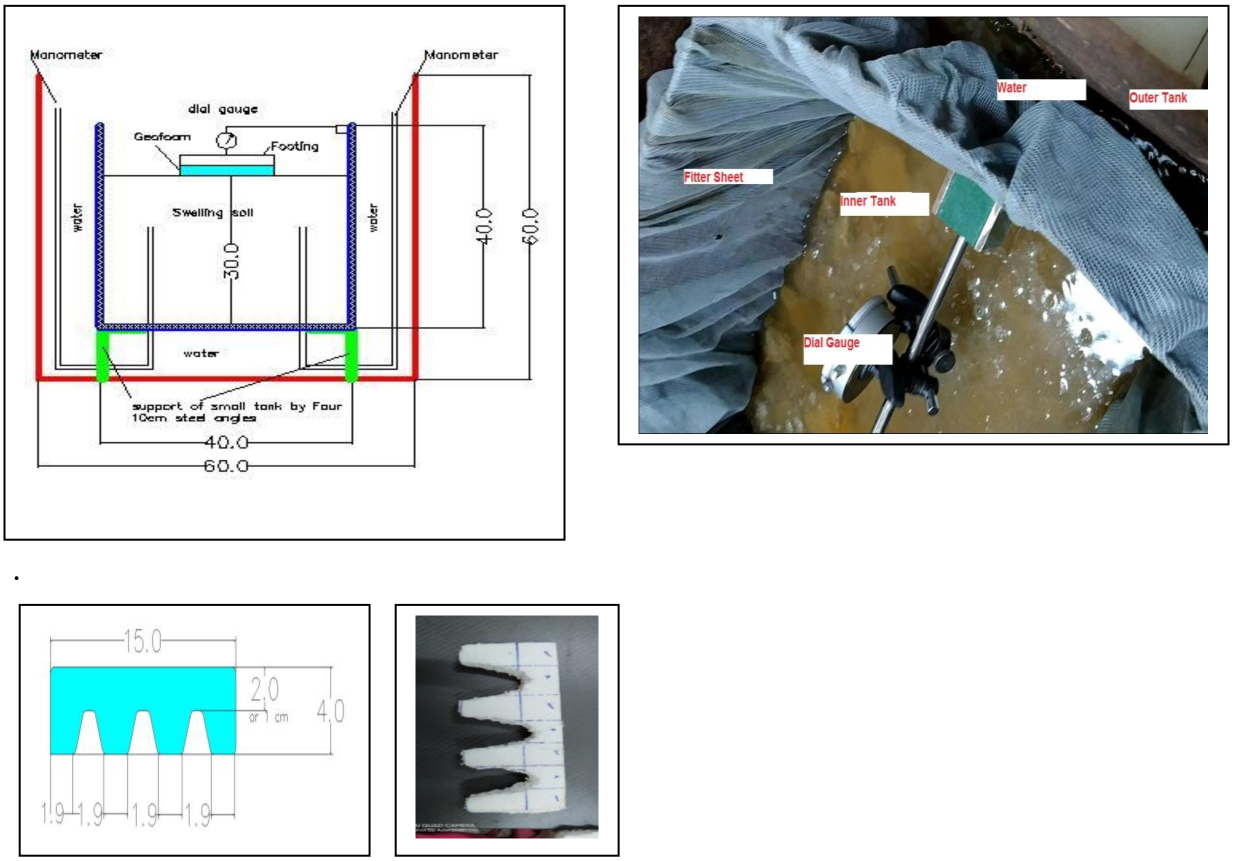

Figure2. Experimental setup
All dimensions in centimeter

2.2 Soil properties

The swelling soil is collected from Upper Egypt Road, Giza, Egypt {29.98^{o} N, 31.21^{o} 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. Experimental work has been performed in the soil 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. Based on its free swelling percentage, the soil is classified as Very High swelling soil and must be controlled [11].

Table1. Properties of the swelling soil

Property	value
Free swelling%	120
Liquid limit %	61
Plastic limit %	27.33
Plasticity index	33.67
Natural water content	21.9
Clay activity (A)	0.97
Bulk unit weight (KN/m^3)	18

2.3 Test Variables

The investigation considers different variables on the swelling soil behaviors as shown in Table 2.

Table2. Testing variables

NO.	Test Configuration	Description	Test code
1	Swelling soil only	______________	SG-0
2	Swelling Soil + flat geofoam under footing	1cm thickness with density 10 kg/m^3	SFG1-10
		1cm thickness with density 20 kg/m^3	SFG1-20
		2cm thickness with density 10 kg/m^3	SFG2-10
		2cm thickness with density 20 kg/m^3	SFG2-20
3	Swelling Soil + ribbed	1cm thickness with density 10 kg/m^3	SRG1-10

	geofoam under footing	1cm thickness with density 20 kg/m^3	SRG1-20
		2cm thickness with density 10 kg/m^3	SRG2-10
		2cm thickness with density 20 kg/m^3	SRG2-20
4	Numerical study by ADINA	Flat geofoam layer	NSFG
		Ribbed geofoam layer	NSRG

Where:
[F] dotes to Flat, [G] donates to Geofoam, [N] donates to Numerical, R donates to Ribbed, and [S] donates to Swelling Soil. [0] donates to no geofoam, [1, and 2] donate to geofoam thickness, and [10, 20] donate to geofoam density.

2.4 Test Procedure:

a) 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.

b) The steel plate footing is placed at the center of the tank over the swelling soil surface.

c) The dial gauge is placed over footing to record the swelling. It is fixed on the wall of the inner tank by its magnetic base, as shown in Fig. 1.b.

d) Water is allowed to inundate the soil by filling the clearance between large and smaller tanks. Water enters through the holes in the tank sides and the manometer.

e) 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 the reading is constant.

f) 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

g) 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.

h) Repeat the steps from b to e for tests; SFG1-20, SFG2-10, and SFG2-20 as shown in the testing variables.

i) 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

j) The ribbed geofoam layer with a density of 10 kg/m^3 and a thickness of 1 cm is placed over the surface under the footing.

k) Repeat the steps from b to e for tests; SRG1-20, SRG2-10, and SRG2-20 as shown in the testing variables.

3- Numerical Study

One of the most applied numerical analyses in the geotechnical analysis is the finite element method; FEM. Numerical analysis in this paper is performed by the finite element software ADINA 8.7.3. The name ADINA stands for Automatic Dynamic Incremental Nonlinear Analysis [16].

3.1 ADINA Models in This Study

Cam-Clay was developed in 1960s. There are two versions of this model. The first is the Original Cam-Clay model while the other is the Modified Cam-Clay model, [17]. The original Cam-Clay, CC, and Modified Cam Clay models, MCC were formed by studying the deformation of soils in laboratory reconstituted states, [18]. In this study, modelling is limited to the Modified Cam Clay models, MCC.

Cam-Clay model requires six parameters to define the model. These parameters are:

a- The initial void ratio $\mathbf{e_o}$;

b- The Poisson's ratio $\boldsymbol{\upsilon}$;

c- The unloading-reloading index $\boldsymbol{\kappa}$;

d- Slope of the virgin consolidation line $\boldsymbol{\lambda}$;

e- The isotropic pre-consolidation pressure $\mathbf{p_o^t}$;

f- And the friction angle $\mathbf{\Phi}$.

The first five parameters express the soil stiffness. The sixth parameter is used to predict the shear strength.

Generally, two models are listed under this group; they are **isotropic linear elastic** and orthotropic linear elastic. In this study, modeling is limited to the isotropic linear elastic model [16], [19].

In this paper the modeling of the experimental investigation, the following cases are considered:

1- Modelling of the footing over the swelling soil by reinforced concrete.

2- Modeling of the footing with flat geofoam over the swelling soil; the geofoam thickness is 1& 2 cm, and v is 10 & 20 kg/m^3.

3- Modelling of the footing with ribbed geofoam over the swelling soil; the geofoam thickness is 1& 2 cm, and v is 10 & 20 kg/m^3.

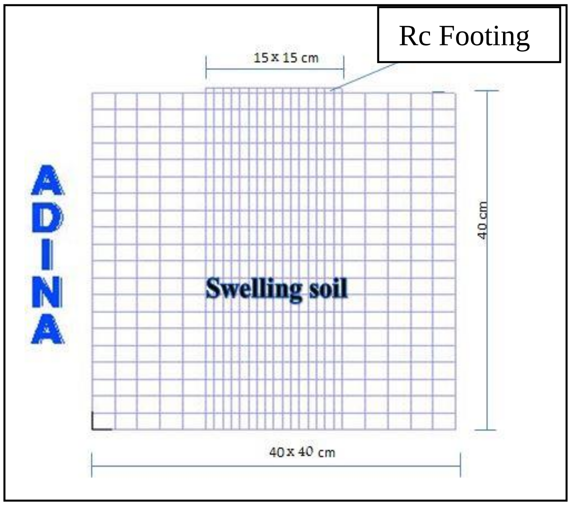

Figure3. Modelling of the footing over the swelling soil

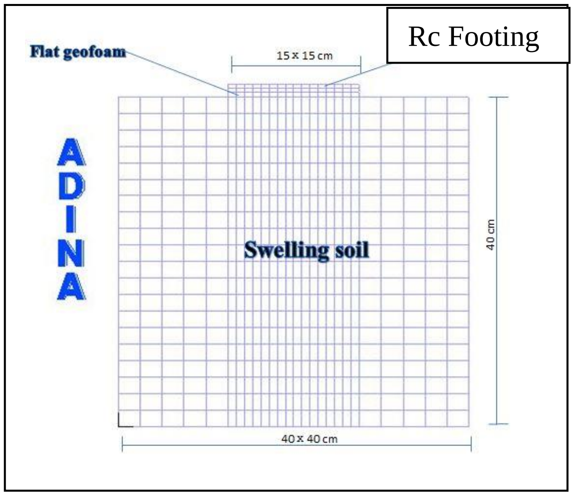

Figure4. Modeling of the steel plate footing with flat geofoam over the swelling soil

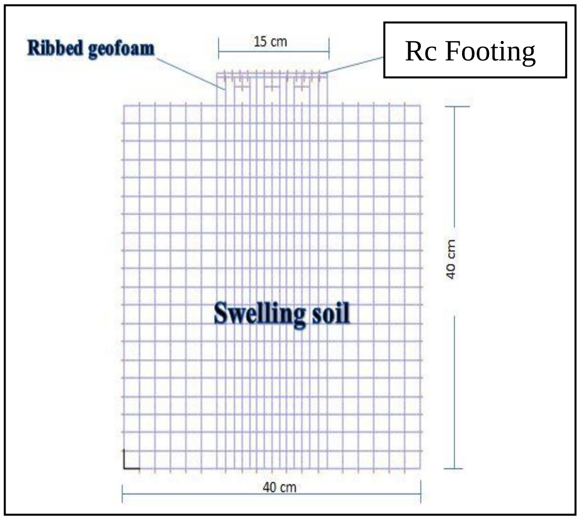

Figure5. Modeling of the steel plate footing with ribbed geofoam over the swelling soil

The parameters of the modelled materials in this study are listed below. The swelling soil was presented in ADINA software by the Cam-Clay model. The isolated footing and the geofoam layer was presented in ADINA software by Elastic-isotropic model.

Table3. parameters of swelling soil in ADINA software, SI units[19]

Modulus of elasticity (E)	$20*10^6$
Poisson ratio (n)	0.45
Unit weight (v)	1800
OCR	3.5
K_o	0.93
Γ	1.88
λ	0.093
K	0.035
M	0.95

Table4. Parameters of a RC footing, SI units [19]

Modulus of elasticity (E)	$22*10^8$
Poisson ratio (n)	0.2
Unit weight (v)	2500

Table5. Parameters of geofoam in ADINA software, SI units

Unit weight (v)	v=10	v= 20
Modulus of elasticity (E)	$16.11x10^3$	$50.86x10^3$
Poisson ratio (n)	0.1	0.12

There are two boundary conditions. Both sides of the swelling soil were defined as roller. The end of swelling soil was defined as hinged.

One of the loading phases of the model is the exposure to inundation. As a result of inundation, hydrostatic pore pressure is induced. In this study, the soil is modelled as fully saturated. This assumption seemed to be conservative and would overestimate the computed heave. The water pressure is represented as triangle load.

4- Results

4.1 Laboratory Results

Laboratory tests are to investigate the heave of swelling soil, due to the application of a geofoam layer with a different configuration.

Figure 6 shows the behavior of the swelling soil- upon inundation- with time. Swelling steadily increased with time. The maximum swelling is recorded at 21 mm.

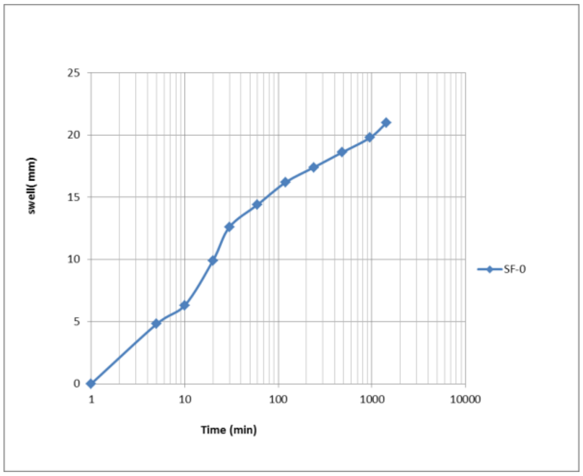

Figure 6. Behavior of the swelling soil with time

Fig. 7 shows soil heave under different flat geofoam. The maximum heave is 17.4 mm for the test (SFG1-10). The maximum swelling is 14.4 mm for the test (SFG2-10). The maximum swelling is 15.6 mm for the test (SFG1-20). The maximum swelling is 13.5 mm for the test (SFG2-20). As can be seen from Fig. 7, the more thickness and density of the flat geofoam layer, the less the swelling value of soil.

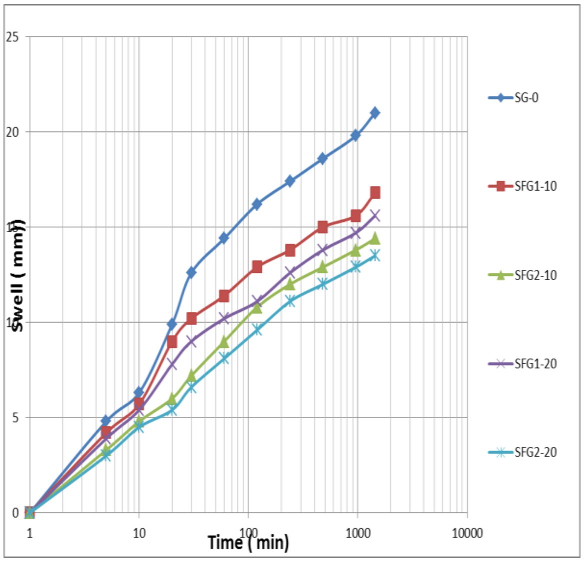

Figure 7. Soil heaves under different flat Geofoam

Fig. 8 shows soil heave under different ribbed Geofoam. The maximum swelling is 15 mm for the test (SRG1-10). The maximum swelling is 13.8 mm for the test (SRG2-10). The maximum swelling is 14.7 mm for the test (SRG1-20). The maximum swelling is 12.6 mm for the test

(SRG2-20). As can be seen from Fig. 8, the more thickness and density of the ribbed geofoam layer, the less the swelling value of soil.

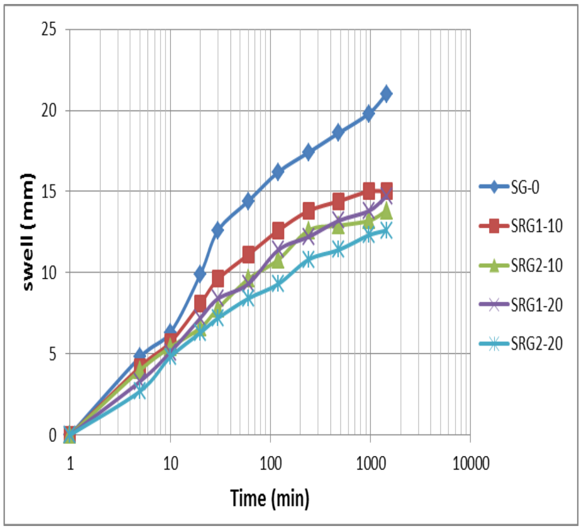

Figure 8. Soil heaves under different ribbed Geofoam

4.2 Numerical Results

Swelling soil heave is numerically computed at the last stage, i.e. after exposure to inundation. The total swelling soil heave is calculated at end of the third phase. It is computed at many points of soil, where maximum swelling soil heave is expected to occur. The maximum heave is 18.6 mm in the case of swelling soil without geofoam.

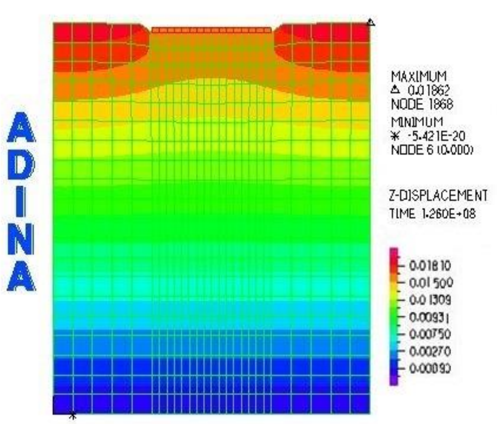

Figure 9. Numerical results for swelling soil only

Swelling soil heave with flat geofoam various density and thickness is numerically computed at the last stage, i.e. after exposure to inundation. The total swelling soil heave is calculated at end of the third phase. It is computed at many points of soil, where maximum swelling soil heave is expected to occur.

Table 6. Numerical results of swelling soil with flat geofoam

Case	Max swelling value (mm)
Thickness=1cm, and density=10kg/m^3	15
Thickness=1cm, and density=20kg/m^3	12.9
Thickness=2cm, and density=10kg/m^3	13.5
Thickness=2cm, and density=20kg/m^3	11.8

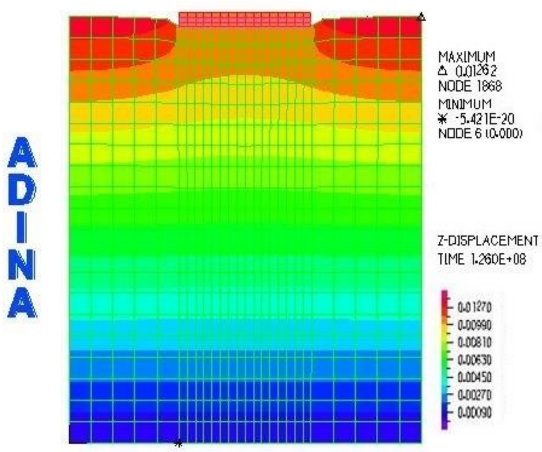

Figure 10. Numerical results for swelling soil and flat Geofoam with thickness=1cm

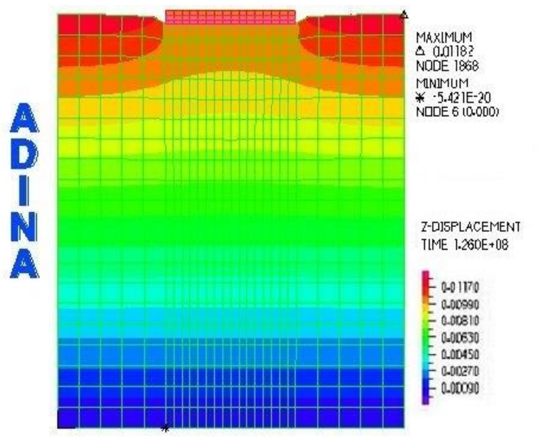

Figure 11. Numerical results for swelling soil and flat Geofoam with thickness=2 cm

Swelling soil heave with ribbed geofoam various density and thickness is numerically computed at the last stage, i.e. after exposure to inundation. The total swelling soil heave is calculated at end of the third phase. It is computed at many points of soil, where maximum swelling soil heave is expected to occur.

Table7. Numerical results of swelling soil with ribbed geofoam

Case	Max swelling value (mm)
Thickness=1cm, and density=10kg/m^3	13
Thickness=1cm, and density=20kg/m^3	11.5
Thickness=2cm, and density=10kg/m^3	12
Thickness=2cm, and density=20kg/m^3	10.4

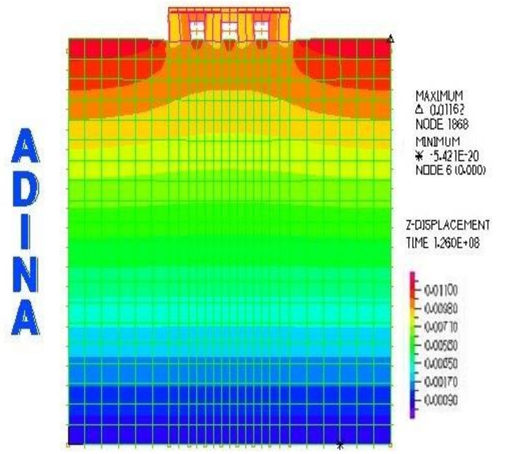

Figure 12. Numerical results for swelling soil and ribbed Geofoam with thickness=1 cm

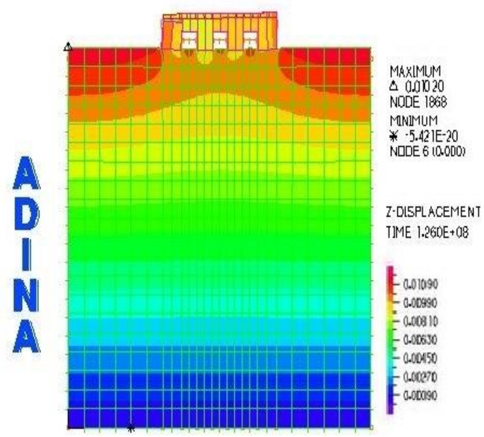

Figure 13. Numerical results for swelling soil and ribbed Geofoam with thickness=2 cm

Fig. 14 represents a comparison between experimental and numerical results for flat geofoam. The difference is small between experimental and numerical results. In such a case the numerical model is confirmed to be capable of accurately reproducing the experimental model.

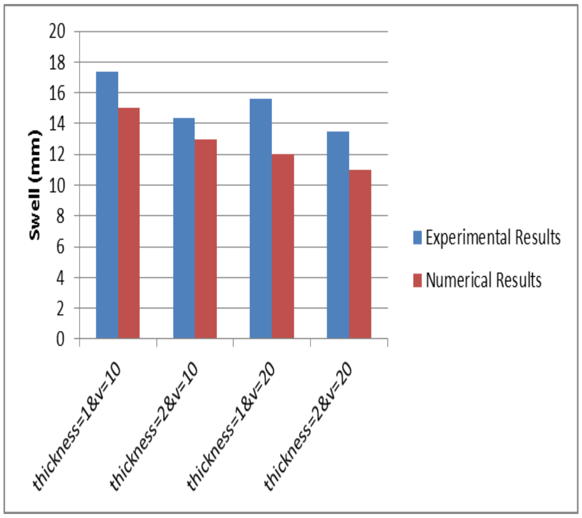

Figure 14. Comparison between Experimental and Numerical Results for Flat Geofoam

Fig. 15 represents a comparison between experimental and numerical results for ribbed geofoam. The difference is small between experimental and numerical results. In such a case the numerical model is confirmed to be capable of accurately reproducing the experimental model.

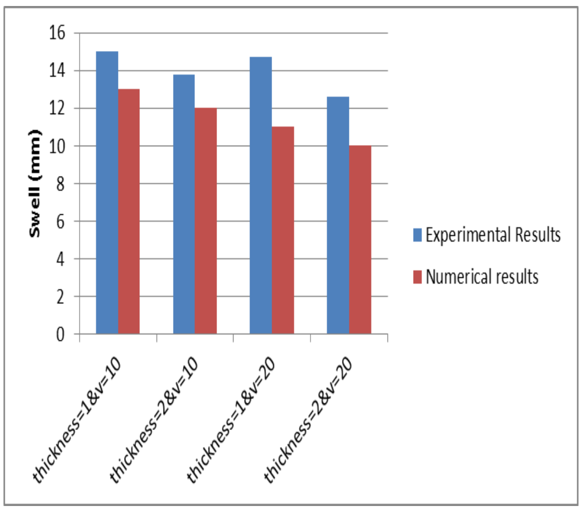

Figure 15. Comparison between Experimental and Numerical Results for Ribbed Geofoam

5- Conclusion

Based on the results of the current study, the following conclusions are presented:

a. Provision of the ribbed geofoam layer under footing would be more effective for reducing the heave of swelling soil.
b. There is a marked reduction in the case of the ribbed geofoam layer with density 20kg/m^3 and thickness 2 cm.
c. There is a marked reduction in the case of flat geofoam layer with density 20kg/m^3 and thickness 2cm.
d. The more density, and thickness of the flat and ribbed geofoam layer, the less swelling value of soil.
e. By comparing the flat cross-section with the ribbed cross-section, there is a reduction in the heave in the case of the ribbed cross-section. This reduction resulting from bulges and voids that absorbed swelling energy.
f. By comparing the experimental results with the numerical results, the difference between them is within the permissible limits. In such a case the numerical model is confirmed to be capable of accurately reproducing the experimental model.

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