Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (41) No. (3) July, 2019

Reduction of Swelling Pressure of Expansive Soil Using Geofoam

Ahmed M. Fathy[1], Sayed M. Elsayed[2], Tamer M. Sorour[2]
1- Demonstrator, Construction and Building Dept., October 6 University, Giza, Egypt.
2- Associate Professor, Faculty of Engineering, Ain Shams University, Egypt.

ملخص البحث
يحتوى هذا البحث على دراسة نظرية لتحديد مدي فاعلية إستخدام جيوفوم البولستيرين في تقليل قيمة الانتفاش للتربة الانتفاشية. وللتحقق من نمذجة العناصر المحددة تم مقارنة نتائج النموذج باستخدام النتائج لدراسة سابقة قد تم نشرها في هذا المجال من قبل. وإعداد دراسة تهدف لتقيم مدي تأثير العوامل المختلفة التى تتحكم في سلوك الجيوفوم في تقليل ضغوط الانتفاش والتى تتضمن كثافة/صلابة الجيوفوم، وايضاً قطر وعمق خوازيق الجيوفوم المستخدمة في تقليل قيمة الانتفاش للدراسة السابقة.

ABSTRACT

Expansive soils are widespread geotechnical problem causing substantial threats to civil engineering structures located in arid regions or semi-arid areas of the equatorial climate. It shows a susceptible volume change (shrinkage or heave) when it's moisture content decreases or increases. In the absence of sufficient experience to deal with volume change behavior of swelling soils, many defects may appear to any structure rested on expansive soils. Among the diverse treatment techniques, the using of expanded polystyrene (EPS) geofoam as a compressible inclusion is considered a simple, innovative solution for reducing the swelling pressures on the foundation that result from the expansive soil movements (heave/shrink) In the present study, the effectiveness of using EPS geofoam will numerically be examined for heave reduction of expansive soils. The results of published case study are used to verify the finite element simulation. Also, a parametric analysis is conducted to assess the factors controlling the use of geofoam including the geofoam density/stiffness, the diameter of the geofoam piles and the depth of the piles. Numerical analysis show that there is a reduction in the vertical swelling of soil with the inclusion of EPS geofoam. Also with the increase in EPS dimensions, there is significant reduction in the soil heave.

KEYWORDS

Expansive soil, EPS Geofoam, Swelling potential, Soil water characteristic Curve, Unsaturated soil.

Introduction

The volume change of swelling soils causes extensive damage to building foundations, roads, airports, pipelines, irrigation canals, and infrastructure near to the surface zone. The damage to the light loaded structures constructed on expansive soils exceeds those the cumulative deleterious effects of floods, hurricanes, tornadoes, and earthquakes combined (Jones & Holtz, 1973). It is reported that the cost of damage due to expansive soils in the United States had risen dramatically to over $13 billion per year (Puppala & Cerato, 2009). In Egypt, there is no official record for damage from expansive soils. However, it is clear, for the geotechnical specialists that the costs of damage or over-design are incredibly high.

Over the last four decades, expanded polystyrene (EPS) geofoam used efficiently as geotechnical material. It is considered a super lightweight fill material, where its unit weight is about 1% to 10% of soil and other lightweight fill materials (Elragi, 2000). Because of the variety of its compressive resistances, EPS geofoam can be used with expansive soils to reduce stresses result from the ground movements. The compressibility of EPS allows the soil to swell, so that, when designed a structure on expansive soil, only a small amount of the stresses will be taken into consideration (Horvath, 2005).

The recent study focused on modeling of expansive soil using two dependent processes; namely, seepage analysis (water flow) that is performed by the commercial flow program SEEP/W and stress deformation analysis that is estimated by the commercial software SIGMA/W (Geo-slope 2016). Seepage analysis provides the change in pore-water pressure (or hydraulic head) to the stress deformation analysis that determines the vertical and horizontal displacement.

A case study was used to verify the programs results; namely, edge lift for a flexible impervious cover & a slab with a uniform thickness. Moreover, study the effectiveness of using EPS Geofoam piles with swelling soil, and estimate heave reduction percentage for the case study.

Case Study: Edge Lift for a Flexible Cover & Concrete Slab with Uniform Thickness

The case under study considered a 3-m layer of swelling Regina clay exposed to various infiltration rates below a flexible cover or concrete slab. The model geometry and the boundary conditions for seepage and stress-deformation analysis are shown in Fig. (1) (Fredlund & Vu, 2003). The soil-water characteristic curve (SWCC) and the permeability function (K) for the soil were described using the Fredlund & Xing, (1994) chart as represented in Fig. (2). The elasticity parameter function for the soil is calculated from the void ratio constitutive surface using Poisson's ratio.

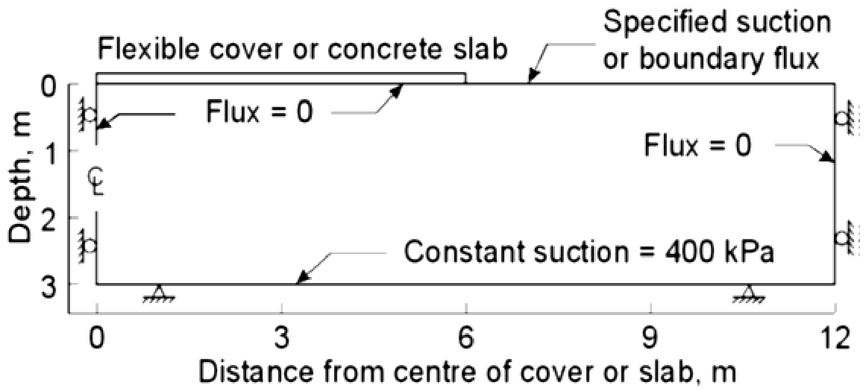

Fig.1 Case Geometry and the Boundary Conditions for Seepage and Stress-deformation Analysis (Fredlund & Vu, 2003).

For the wetting conditions when cracks in the soil substantially closed, the coefficient of the earth pressure at rest (K_0) suggested being 0.67, and Poisson's ratio μ = 0.4. For edge lift slab, the concrete slab was represented by a uniform load of 0.5 KPa, and 10 KN/m assign around the slab perimeter. The soil properties for stress/deformation analysis and seepage analysis were listed in Table.1. This case was re-analysed by using Geo-studio program with the same soil properties and boundary conditions that mentioned above. The modulus of elasticity of unsaturated soil is function of the matric suction $(u_a - u_w)$, H, and the net normal stress $(\sigma_{av} - u_a)$, E. It is suggested that the modulus of elasticity calculated for the 2-D plane (Fredlund & Rahardjo, 1993) as the following equations:

$$E = \frac{4.605\ (1 + \nu)(1 - 2\nu)(1 + e_0)}{C_s}(\sigma_{av} - u_a) \quad (1)$$

$$H = \frac{4.605\ (1 + \nu)(1 + e_0)}{C_m}(u_a - u_w) \quad (2)$$

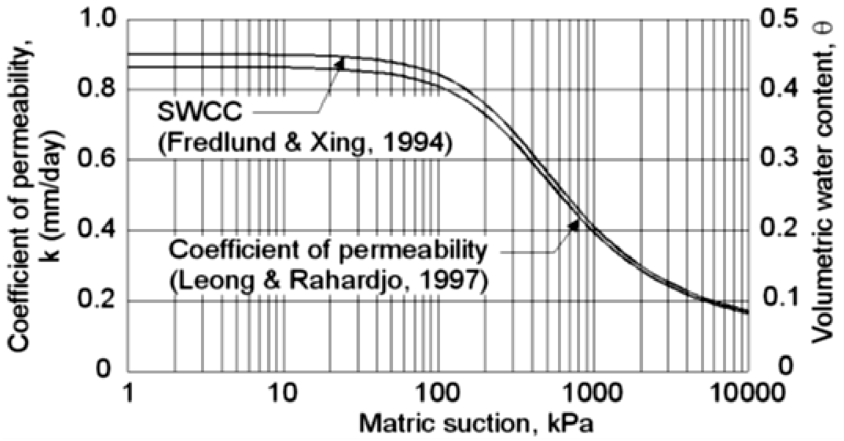

Fig.2 The Permeability Function and Soil Water Characteristic Curve (SWCC) (Fredlund & Vu, 2003).

Table 1 Assumed Soil Properties for Stress and Seepage Analysis (Fredlund & Vu, 2003).

Soil properties	Values
Total unit weight	$\gamma t = 17.2\ kN/m^3$
Initial void ratio	$e_o = 1.00$
Swelling index related to change in net normal stress	$C_s = 0.15$
Swelling index related to change in matric suction	$C_m = 0.13$
Poisson's ratio for the soil	$\mu = 0.40$
Specific gravity	Gs =2.80
The saturated coefficient of permeability	Ksat = 1310^{-8} m/day
Saturated volumetric water content	υs = 0.45
Initial matric suction	$(u_a - u_w)i = 400$ KPa
Parameters for SWCC and the permeability function (Fredlund & Xing, 1994)	a = 300 kPa
	n = 1.5
	m, p = 1

The seepage analysis for the infiltration was modeled using SEEP/W program. Then, the final soil suction profiles were used to model the stress deformation analysis by using SIGMA/W program. Vertical displacement at the ground surface after one day of infiltration (with flexible cover) and the vertical movements of the slab after loading with time were included in the published results of finite element modeling.

Analysis Results

Fredlund & Vu, (2003) analyzed this case by using the general partial equation solver (FlexPDE). The vertical displacement with time at the edge of the flexible cover is indicated in Fig. (3). For edge lift of the slab, the vertical movement of the building after loading and wetting with time is shown in Fig. (4).

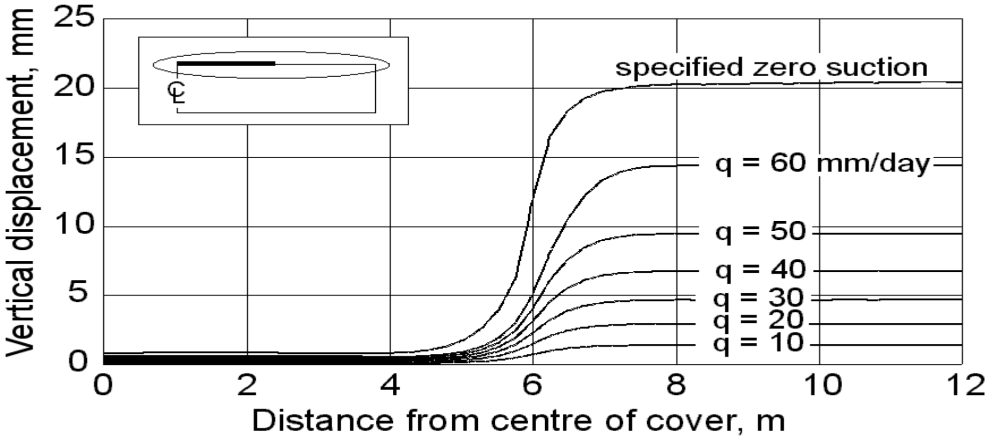

Fig.3 Vertical displacements of the ground surface after one day of different infiltration rates (Fredlund & Vu, 2003).

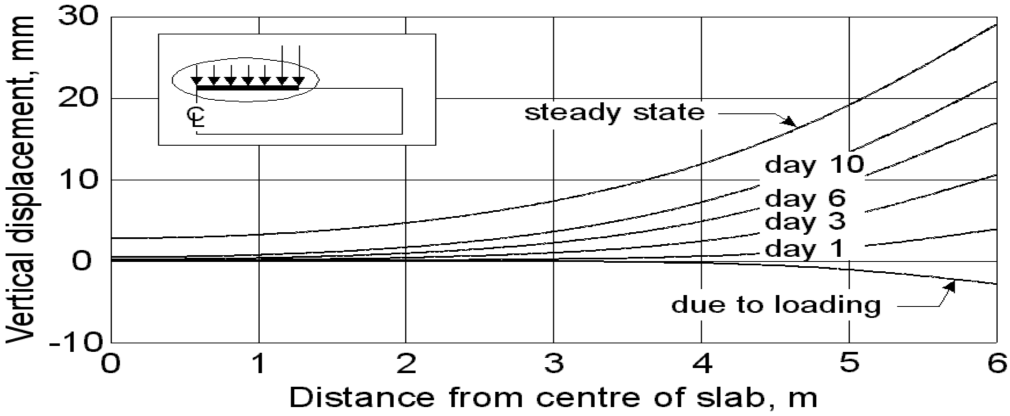

Fig.4 Vertical displacement of the slab due to infiltration with time(Fredlund & Vu, 2003).

This case was re-analyzed using Geo-studio programs with the same soil properties and boundary conditions. The vertical displacement with time at the edge of the flexible cover is indicated in Fig. (5). For edge lift of the slab, the vertical movement of the building after loading and wetting with time are shown in Fig. (6). The result of the analysis by Geo-Studio program for the case study appears to be reasonable and consistent with predicted values reported by hung and Fredlund. The variation in the results in heave prediction because SIGMA/W assume that the relationship between *E* and *H* for saturated soils $H= (E/ (1-2v))$ is valid for the unsaturated soils

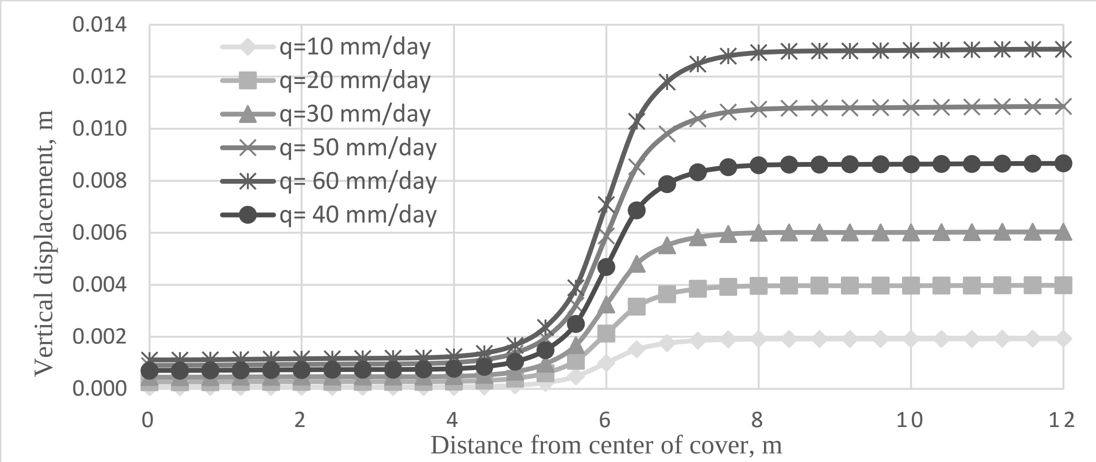

Fig.5 The Vertical Displacements at the ground surface after one day of infiltration for various infiltration rates using SIGM/W program

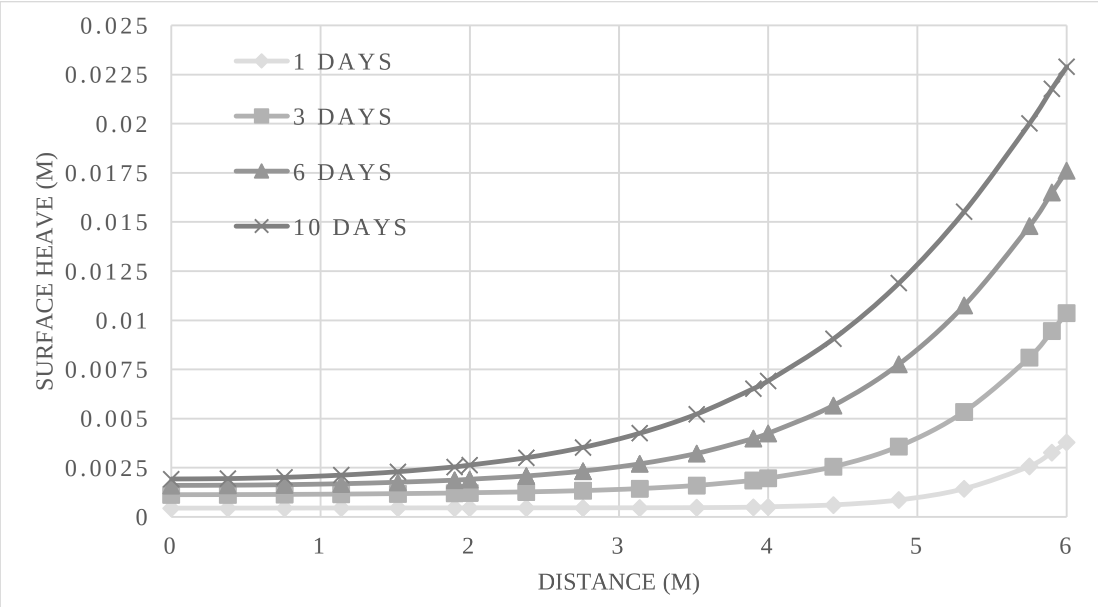

Fig.6 Vertical movement of the slab due to infiltration with time using SIGMA/W program.

From the analysis results, it is possible to simulate seepage and stress distribution analysis for unsaturated soil using GEO-Studio programs to study the effect of infiltration and soil heave with time.

Heave Reduction Using EPS Geofoam

In this study expanded polystyrene (EPS) Geofoam is used as a compressible inclusion material to examine its impact on heave reduction of expansive soils. The case is re-analyzed with the same soil properties and boundary conditions as mentioned before. The mechanical properties of EPS geofoam used in the finite element model followed the limits stated in ASTM D-6817 and Padade & Mandal, (2012); they are summarized in Table. (2). The EPS Geofoam applied in this case were uniformly arranged with two meters spacing in both directions, with different diameter 10 cm (D/H = 0.05), 30 cm

(D/H = 0.15), and 50 cm (D/H = 0.25), and with 1, and 2 meters in height as shown in Fig. (7)(where D and H are the geofoam pile diameter and height).

Table 2 The mechanical properties of EPS Geofoam used in finite element model (Padade & Mandal, 2012).

Property	**EPS15**	**EPS22**	**EPS30**
EPS Geofoam Density (kN/m^3)	0.15	0.22	0.30
Cohesion (kPa)	33.75	41.88	62.00
The angle of internal friction, ϕ (°)	1.5	2	2.5
Modulus of elasticity (kPa)	2400	5500	7800
Poisson's ratio	0.10	0.125	0.17

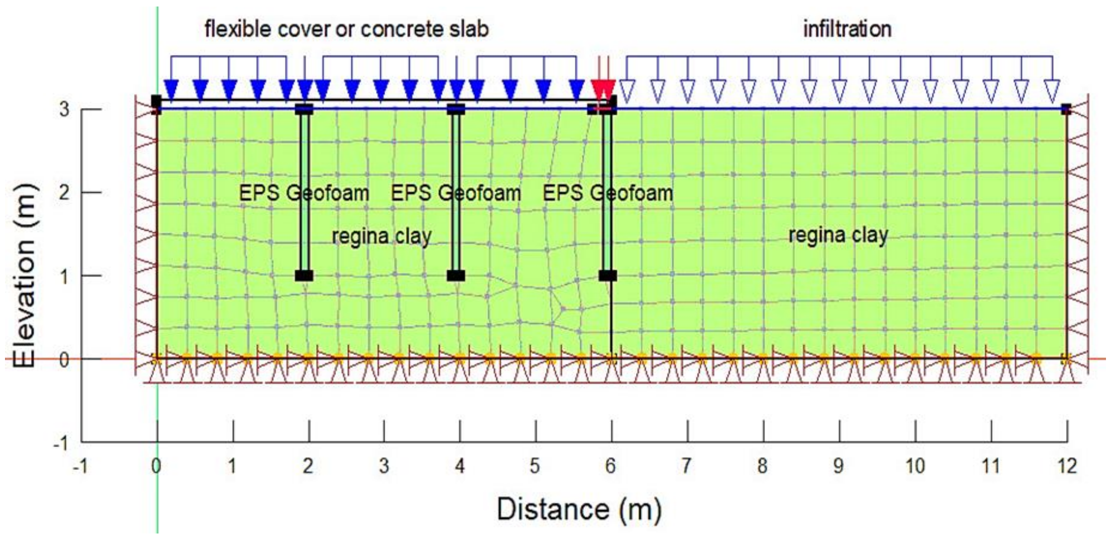

Fig.7 Simulated Finite element model with EPS geofoam Piles arrangement

Analysis Results

The vertical displacement and the horizontal displacement after 10 days of water infiltration at the ground surface with using 50 cm diameter EPS15 geofoam piles are shown in Fig. (8) and Fig. (9). It noted that, the using of EPS geofoam piles has a significant effect on reduction the vertical displacement of swelling soil. The reduced proportion of the ground heave after 10 days of water infiltration by using EPS 30 geofoam piles with 50 cm diameter shown in Fig. (10). The soil swelling is reduced by using EPS geofoam piles.

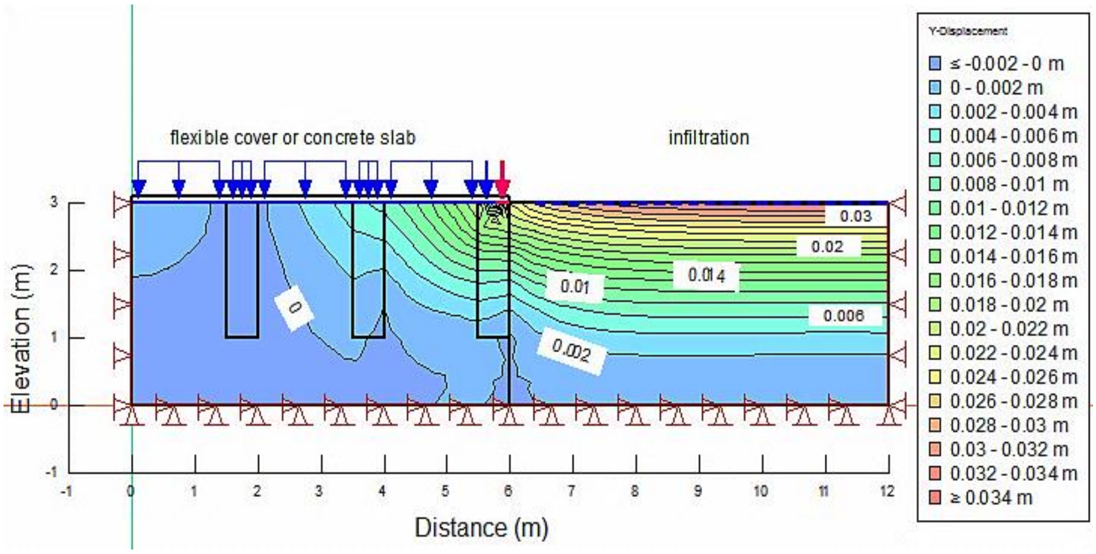

Fig.8 The Vertical displacement after ten days with using 50 cm EPS15 geofoam piles.

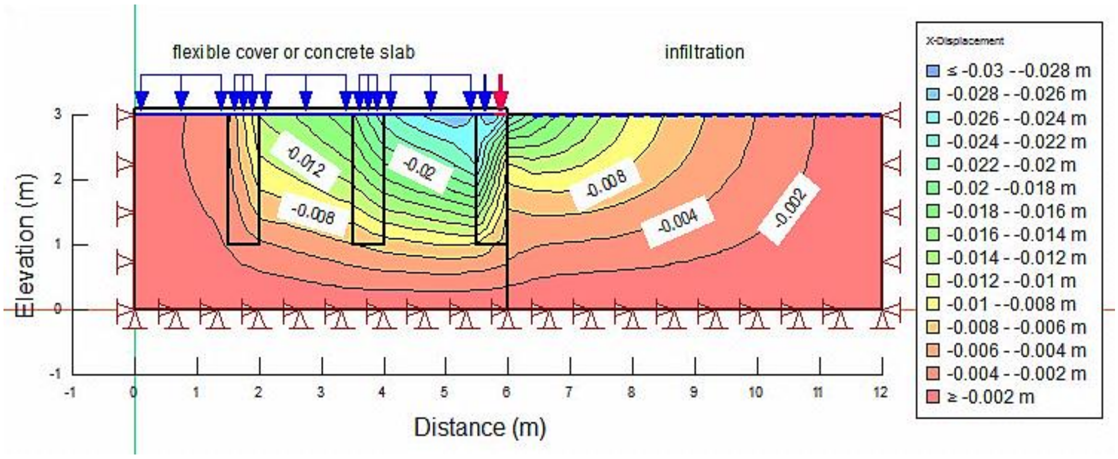

Fig.9 The Horizontal displacement after ten days using 50 cm EPS15 geofoam piles.

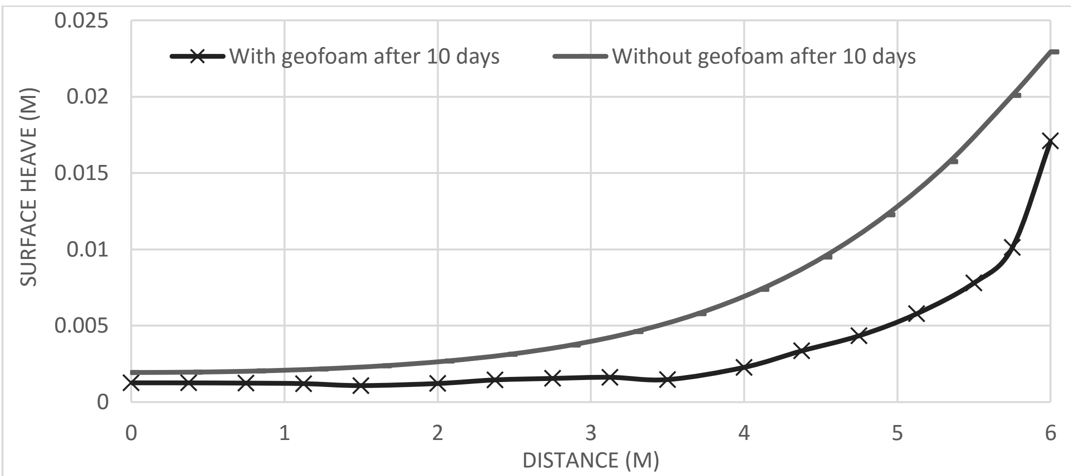

Fig.10 Surface Heave after ten days with/out using 50 cm diameter EPS 30 geofoam piles.

Effect of the density of geofoam piles

The impact of using 50 cm diameter EPS geofoam piles with different densities after ten days of water infiltration represented in Fig. (11). It noted that the decreased of EPS geofoam density has a slight effect on the heave reduction. The lower density of EPS geofoam is selected to yield greater compressibility and more heave reduction.

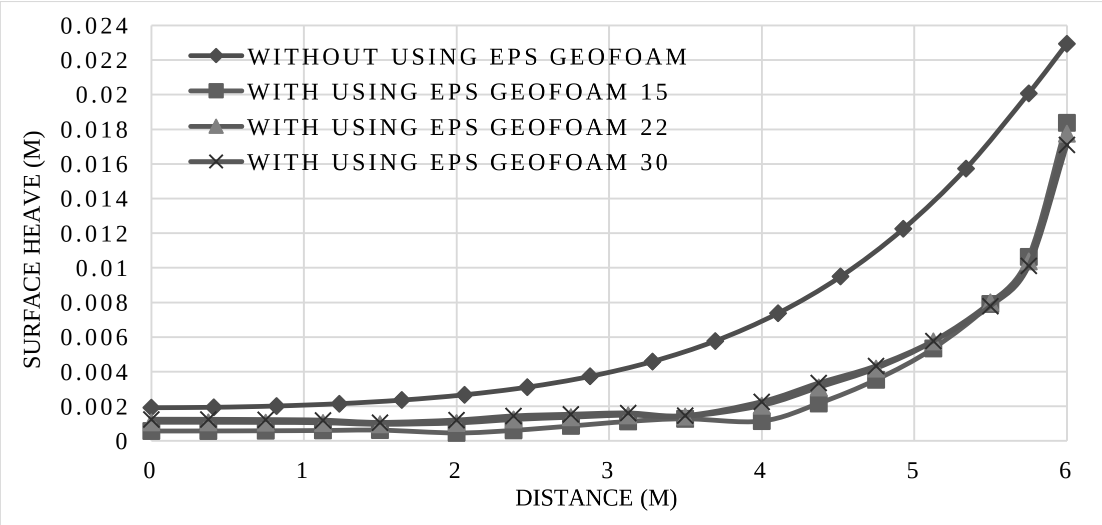

Fig.11 Surface heave with/out using EPS geofoam piles with dia.50cm with different densities after ten days.

Effect of the diameter of the geofoam piles

The swelling of soil minimized, Whenever EPS geofoam diameter increased as illustrative in Fig. (12). The heave reduction increases with the increase of EPS geofoam diameter.

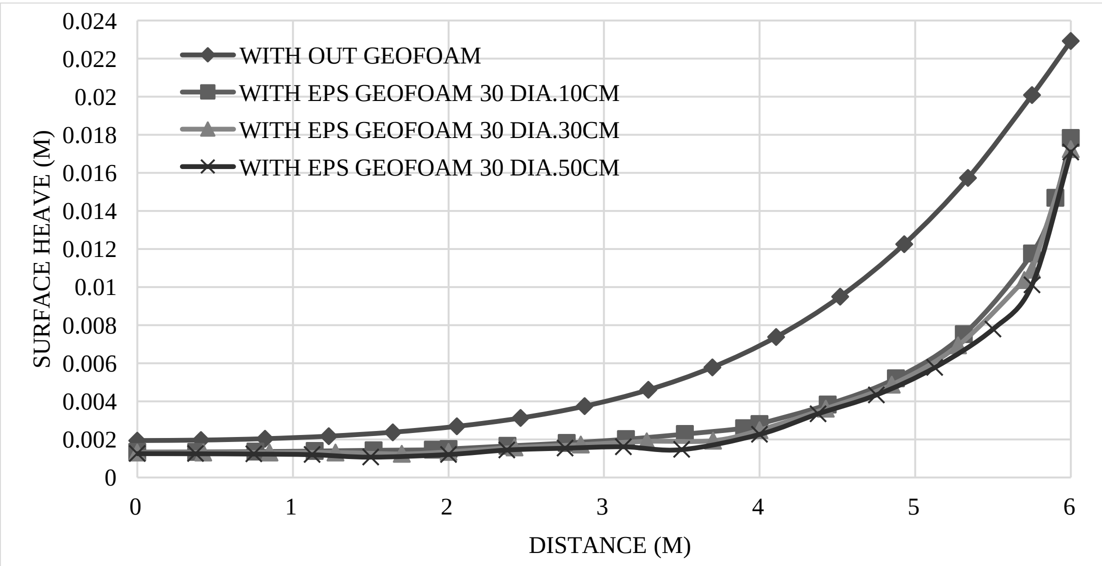

Fig.12 Surface heave with/out using EPS30 geofoam piles with different diameter after ten days.

Effect of the depth of geofoam piles

Fig. (13) shows the effect of increasing the length of EPS geofoam piles after ten days of rainfall of infiltration using EPS 30 geofoam piles. The reduction percentage was about 21.04 % and 24.79% by using 1m and 2 m depth of EPS piles so that EPS geofoam pile depth is more efficient than its density.

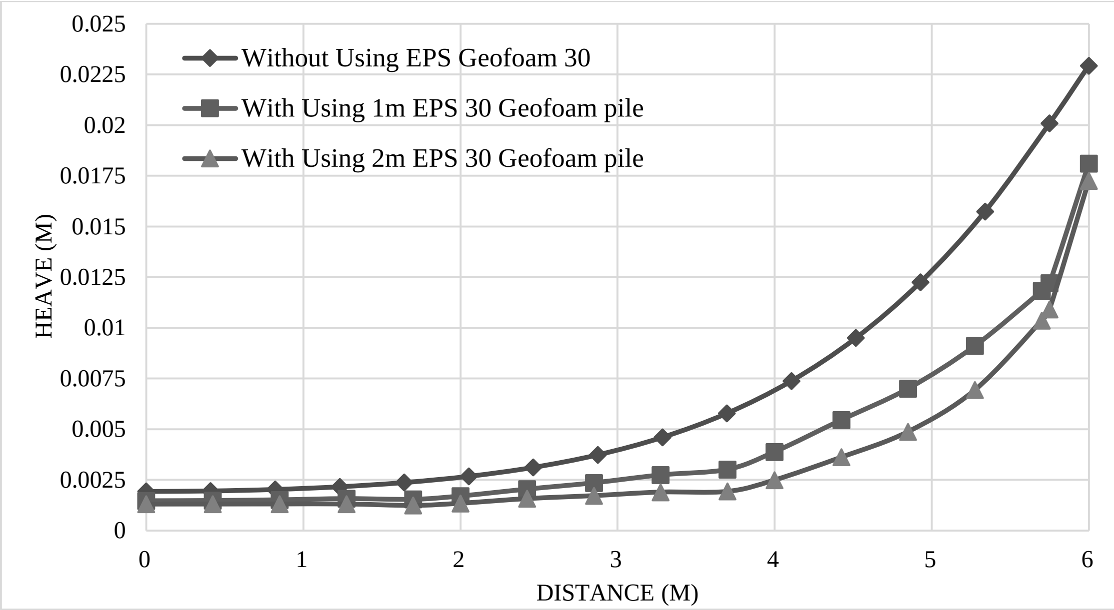

Fig.12 Surface heave with/out using EPS30 geofoam piles with different length after ten days.

CONCLUSIONS

In this study, the numerical analysis results of using EPS geofoam piles with different depths to control the soil movements on structures constructed on swelling soils has been investigated. Moreover, the using of SIGMA/W and SEEP/W programs to simulate 2-D analysis associated with heave of expansive soils has been verified with the results of a published case study. The following are the major conclusions deduced from the present study:

1) It is possible to simulate seepage and stress distribution analysis for unsaturated soil using Geo-Slope programs (SIMA/W & SEEP/W) to study the effect of infiltration and soil heave with time.
2) EPS geofoam as a compressible inclusion material has a significant effect on reduce the heave of unsaturated, expansive soils.
3) The decrease in EPS geofoam density leads to an increase in the percentage of footing heave reduction.
4) Increasing the used EPS piles diameter (D/H) % leads to decrease of soil heave with time.
5) Increasing the EPS geofoam piles depth is the most significant factor in the soil heave reduction depends on the depth of expansive soil.

REFERENCES

1. ASTM, D., D6817. Standard specification for rigid cellular polystyrene geofoam, ASTM, West Conshohocken, Pennsylvania, USA, pp. 1-4.
2. Elragi, A. F., 2000. Selected engineering properties and applications of EPS geofoam. State University of New York. College of Environmental Science and Forestry, Syracuse, NY.
3. Fredlund, D. G. & Vu, H. Q., 2003. Numerical modelling of swelling and shrinking soils around slabs-on-ground. In: Proceeding, Post-Tensioning Institute Annual Technical Conference. Huntington Beach, CA, USA: s.n.
4. Fredlund, D. G. & Xing, A., 1994. Equations for the soil-water characteristic curve. Canadian geotechnical journal, 31(4), pp. 521-532.
5. Fredlund, D. G. & Rahardjo, H., 1993. Soil Mechanics for Unsaturated Soil. New York: John Wiley & Son, Inc.
6. GEO-SLOPE, 2016. Stress-Strain modeling with GEO-Studio: An engineering methodology. Calgary, AB, Canada: GEO-SLOPE International Ltd.
7. Horvath, J. S., 2005. Expanding the use of expanded polystyrene (EPS) geofoam in practice. In: proc. bsces asce geo-institute fall 2005 geotech. engrg. sem., boston soc. civ. engrs. sec. asce. s.l.:Citeseer.
8. Jones, J. D. E. & Holtz, W. G., 1973. Expansive soils-the hidden disaster. Civil Engineering, Volume 43, pp. 87-89.
9. Padade, A. & Mandal, J., 2012. Feasibility studies on expanded polystyrene (EPS) geofoam. In: Proc., Int. Conf. Ground Improvement and Ground Technique, ICGI2012. India: Research Publishing Chennai, pp. 903-906.
10. Puppala, A. J. & Cerato, A., 2009. Heave distress problems in chemically-treated sulfate-laden materials. Geo-Strata—Geo Institute of ASCE, 10(2), p. 28.