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Numerical Analysis of Heave Reduction Using EPS Geofoam Inclusions

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Abstract:
***Background**: Expansive soils have a destructive influence on civil engineering structures; mainly the light loaded structures over the world. This damage takes place because the swelling soils undergo significant changes in volume and strength as a result of changes in moisture content. Expansive soils can swell or shrink when their water content increase or decrease depending mainly on the kind of clay minerals present in the soil formation. The variation of soil moisture content may be developed from many sources such as gardening wetting, lawn, pipe leaky, and climate changes. Therefore, the design of the structural foundation on this problematic soil needs to the knowledge of the behavior and stress-related deformability of the soil, also the geologic conditions. The prediction of the behavior of expansive, unsaturated soils should deal with many issues, that included soil properties characterization and a computing tool that can model the non-linear nature of expansive soils. Many methods can be used for the prediction of the swell/shrink behavior of expansive soil with different degrees of precision. Due to the difficulties of predicting the swell/shrink behavior of unsaturated soil, the numerical model considered the most common method for solving the equation of water seepage and soil deformation. Several treatment methods can be used for controlling the swell/shrink behavior of expansive soil such as soil replacement, moisture control, thermal methods, and surcharge loading. However, these methods have their limitations concerning costs and their effectiveness. Among the diverse treatment techniques, EPS geofoam can be used to mitigate the swelling of expansive soils and to reduce the structural straining actions that result from the ground heave.*
***Materials and Methods**: The EPS, as a soft soil inclusion, allows the expansive soil to swell. As such, structures on expansive soil may be designed with the aid of EPS to withstand only a small value of the swelling forces that may be induced by ground heaving under a constrained condition or a small part of the ground heave as the volume change is diverted away from the foundations. The essential aim of this paper is to present a tool for estimating, predicting, and mitigating the ground heave that associated with expansive soils. Moreover, study the impact of using EPS geofoam piles to minimize and reduce the effect of the heave potential associated with unsaturated, expansive soils on the structure foundations.*
***Results**: Numerical modeling of the behavior of expansive soil considered a powerful computing tool for estimating the volume change problems of structures rested on expansive soils. EPS geofoam as a compressible inclusion material has a significant effect on the matric suction distribution of unsaturated, expansive soils, and the decreasing of the soil heave.*
***Conclusion:** Numerical analysis shows 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 a significant reduction in the soil heave.*
***Key Word**: Volume change behavior; Expansive soil; EPS Geofoam; Soil water characteristic Curve; Swelling potential; Unsaturated soil.*

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I. Introduction

With any variation in the soil moisture content due to an environmental change, expansive soils may undergo significant movements in its volume (heave/shrink). However, the soil in the field near to the surface zone, the lateral expansion might be prevented by the surrounding soil. As a result of that, the soil expansion or swell predominantly occurs in the vertical direction. The soil shrinkage may occur by the particle's movements due to a reduction in the pore water pressure. The soil decreases its volume in the lateral and vertical directions. If the soil volume decreases vertically, it causes the ground surface to go down (shrink), but the lateral decrease causes the soil to crack if it is enough[1]. Swelling soils movements (heave/shrink) can cause extensive damage to building foundations, roads, airports, pipelines, irrigation canals, and infrastructure near 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[2]. 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[3]. In Egypt, there is no official survey for damage from expansive soils. However, it is clear, for all geotechnical specialists that the costs of damage or over-design are incredibly high. Volume change prediction of expansive soils can be estimated using many diverse analytical methods. The finite element analysis method is considered a popular and immensely powerful tool that could be used to simulate the most geotechnical engineering problems. The finite element method is used in the present paper for modeling the mechanical behavior of expansive soils by solving both water-flow and equilibrium equations simultaneously (Coupled approach).

Expanded polystyrene (EPS) geofoam over the last four decades used efficiently as geotechnical material. EPS was regarded as a polymeric/plastic foam, rigid, and closed-cell with the chemical structure of C_8H_8[4]. It is considered a super lightweight fill material, where its weight is about 1% and 10% of that of soil and other lightweight fill materials respectively. As a result of the low EPS density compared with conventional backfill soils, geofoam can significantly decrease both lateral and vertical stresses on the system. The use of EPS geofoam in construction projects can reduce the overall cost and construction time[5]. Because of the variety of its compressive resistances, EPS geofoam can be used with expansive soils to reduce stresses that result from the ground movements. The EPS compresses and allowing the soil to swell, so that when designing a structure on expansive soil; a small value of the forces that results from the ground heaving should be taken into consideration[6].

The recent study focused on the modeling of expansive soil using two dependent processes; namely, seepage analysis (water flow) and stress deformation analysis that is performed by the finite element program 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 rewritten program results; namely, a slab on the ground placed on Regina clay subjected infiltration rate[7]. Moreover, study the effectiveness of using EPS Geofoam piles and calculate heave reduction percentage for the case study. 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.

II. Case Study: Slab on Ground Placed on Regina Clay Subjected Infiltration Rate[7]

This case considered a 5.0 m thick deposit of Regina swelling clay that partially covered with a light loaded structure. A constant infiltration rate of 2.0 x 10^{-8} m/s assigned to the ground surface around the structure over 175.0 days (Figure no 1). The soil-water characteristic curve (SWCC) for the Regina clay[8] and the soil permeability function (k function) represented in Figure no 2. The mechanical properties of Regina clay presented in Table no 1.

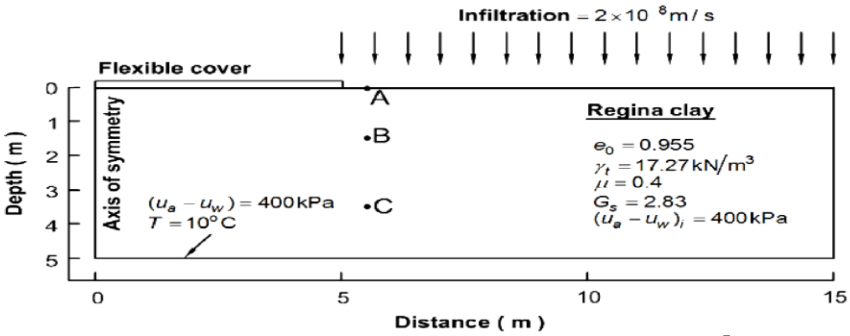

Figure no 1: Geometry and boundary conditions of case study[7]

For the wetting conditions when cracks in the soil substantially close, the coefficient of the earth pressure at rest (K_0) suggested being 0.67. Thus, the Poisson's ratio μ = 0.4. The modulus of elasticity of unsaturated soil is a function of the matric suction $(u_a - u_w)$ and the net normal stress $(\quad_{av} - u_a)$. It is suggested that the saturated modulus of elasticity calculated by the volume change index (Cs) subject to changes in net normal stress for the 2-D plane [9] as the following equations. For swelling soil having e_0 = 0.955, C_S = 0.088, □ = 0.4, the average value of saturated modulus of elasticity of soil from equation no 1 to be 1100 kPa. A pressure head value of -40.787 m was applied along the bottom boundary (i.e., -400 kPa / 9.807 kN/m^3). The infiltration case study was re-analyzed with the coupled approach using Geo-studio programs. The same soil properties and the boundary conditions given by Vu & Fredlund, (2006) were adopted. The finite element geometry and mesh are presented in Figure no 3.

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

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

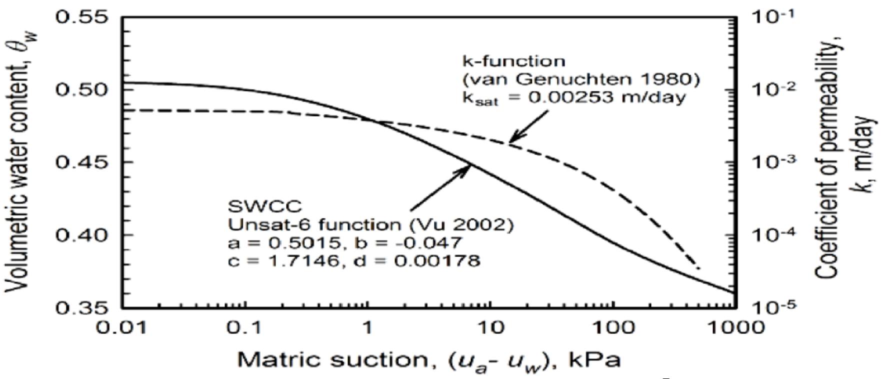

Figure no 2: Hydraulic properties of Regina clay[7]

Table no 1: Mechanical properties of Regina clay[7]

Soil properties	Values
Atterberg limits	w_l = 69.9%, w_p = 31.9%, I_p = 38%,
Unified soil classification system	CH, Inorganic clay of high plasticity
Specific gravity	G_s = 2.83
Maximum dry unit weight	□$_{dmax}$ = 14.01 kN/m^3
Optimum water content	w_{optm} = 28.5%
Swelling index	C_s = 0.088
Corrected swelling pressure	P_s = 300 kPa
Total unit weight	□$_t$ = 17.27 kN/m^3
Initial void ratio	e_o = 0.955
Swelling index	C_s = 0.088
Poisson's ratio	□ =0.40
Saturated modulus of elasticity	E_{sat} =1100 KPa
Saturated coefficient of permeability	K_{sat} = 0.00523 m/day
Saturated volumetric water content	□$_s$ = 0.5015
Initial matric suction	$(u_a - u_w)_i$ = 400 KPa

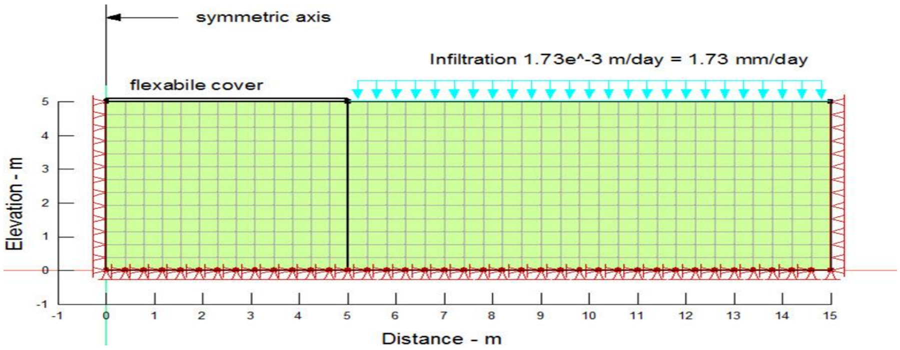

Figure no 3: The finite element mesh and distribution element

III. Verification Result

Vu & Fredlund, (2006) modeled the soil heave at 3 points A, B, and C at different depths, located at the right of the slab edge as shown in Figure no 1. The heave at the same points was also simulated using SIGMA/W program. Figure no 4 illustrates a comparison between soil heave with time using Geo-Studio program with the numerical modeling results published at three locations A, B, and C. The distribution of matric suction variation under the cover after 53 days of water infiltration simulated by Vu & Fredlund, (2006) and the finite element program were presented in Figure no 5, and Figure no 6, respectively.

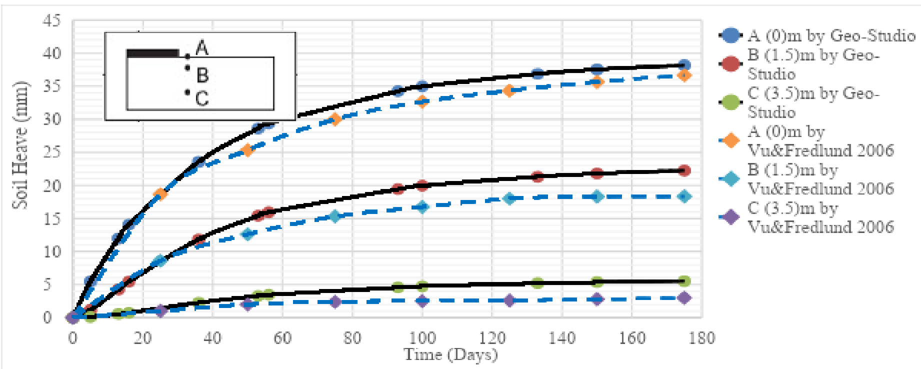

Figure no 4: Comparison between the soil heaves using Geo-Studio and Vu & Fredlund, (2006) method.

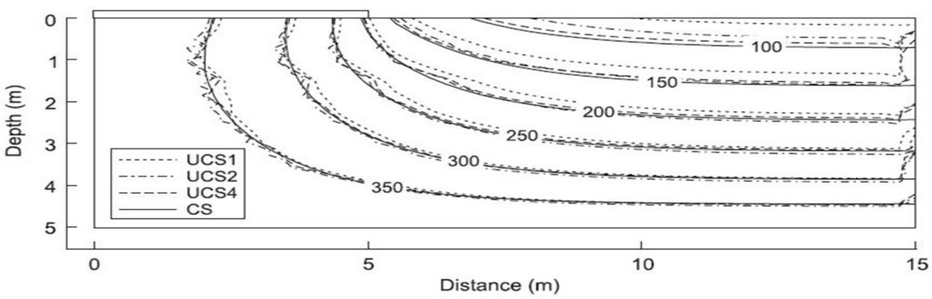

Figure no 5: Matric suction distribution after 53 days of infiltration using Vu & Fredlund, (2006).

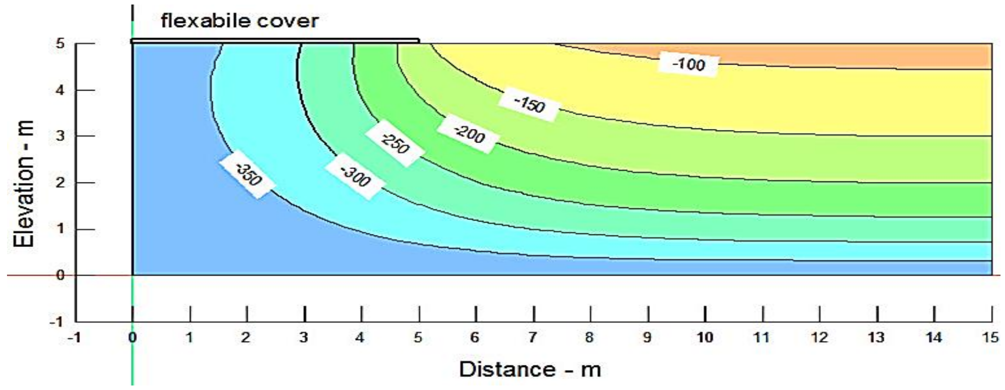

Figure no 6: Matric suction distribution after 53 days of infiltration using the SIGMA/W program.

The results of the analysis appear to be consistent with the values reported by Vu & Fredlund (2006). It can be noted that the heave after 175 days at point (A) is about 3.67 cm from the analysis by Vu & Fredlund (2006) and 3.82 cm from analysis using Geo-studio. The minor differences between the results and the reported values (that about 5 %) may be attributed to the difference between the assumed relation between *E* and *H* by SIGMA/W (H= E/ (1-2 μ)), and the corresponding values reported in the case study. It may be concluded that carrying out the seepage analysis and the stress distribution using the SIGMA/W program can be adapted to study the effect of the infiltration of water and unsaturated swelling soil heave with time.

IV. Heave Reduction by Using EPS Geofoam

Expanded polystyrene (EPS) Geofoam is used as a compressible inclusion material in this study to examine its impact in heave reduction of expansive soils. The case study re-analyzed by applying EPS Geofoam piles with the same Regina clay properties and the same boundary conditions mentioned above. The EPS Geofoam piles arranged uniformly with 2m spacing in both directions, with different diameter 10 cm (D/H =0.05), 30 cm (D/H =0.15), and 50cm (D/H =0.25) (where D and H are the geofoam pile diameter and height, respectively). The mechanical properties of the used EPS geofoam in the finite element model is illustrated in Table no 4. The model geometry and EPS inclusions arrangement presented in Figure no 7.

Table no 2: The mechanical properties of EPS geofoam used in the finite element model[11].

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, ? (°)	1.5	2	2.5
Modulus of elasticity (kPa)	2400	5500	7800
Poisson's ratio	0.10	0.125	0.17

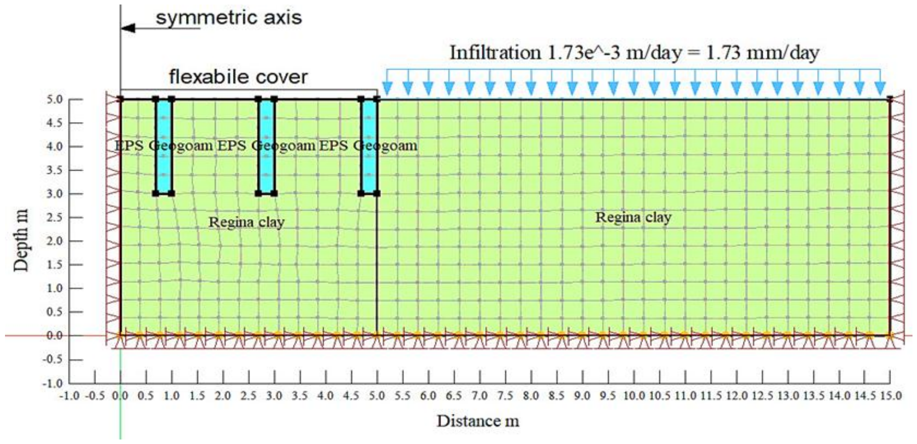

Figure no 7: Geometry and boundary-conditions and EPS inclusions arrangement.

After applying EPS geofoam on the case study with different geofoam densities and various inclusions diameter, the soil heave was compared for different values under the flexible cover after 175 days of infiltration. The reduced proportion at the center of the building reached 62.76% and at the edge of the slab achieved 19.95% by using EPS15 geofoam inclusions with 50cm diameter after 175 days as presented in Table no 3. Figure no 8 presented the matric suction after 53 days of infiltration by using 2m depth geofoam inclusions. Also, the vertical displacement after 175 days with using EPS15 geofoam inclusions with diameter 10cm, 30cm are shown in Figure no 9, and Figure no 10, respectively. The heave reduction due to using 30cm EPS30 geofoam piles at point (A) at 0.4 m from the edge of the flexible cover represent in

Figure no 11. A comparison between the surface heave of the flexible cover after 175 days by using 2m depth EPS22 geofoam piles with a different diameter represented in Figure no 12.

Table no 3: Surface heave after 175 days with and without using 2m depth EPS geofoam piles.

inclusions diameter (cm) / EPS Density		Dia. 10 cm (D/H = 0.05)		Dia. 30cm (D/H = 0.15)		Dia. 50cm (D/H = 0.25)	
		Value (cm)	Reduction (%)	Value (cm)	Reduction (%)	Value (cm)	Reduction (%)
Without geofoam	Center	2.366	-----	2.366	-----	2.366	-----
	Edge	3.66	-----	3.66	-----	3.66	-----
With EPS 15	Center	2.016	14.79%	1.495	36.81%	0.881	62.76%
	Edge	3.46	5.46%	3.18	13.11%	2.93	19.95%
With EPS 22	Center	2.169	8.33%	1.819	23.11%	1.333	43.66%
	Edge	3.50	4.37%	3.27	10.44%	305	16.67%
With EPS 30	Center	2.210	6.59%	1.929	18.47%	1.523	35.36%
	Edge	3.50	4.37%	3.28	10.38%	3.07	16.12%

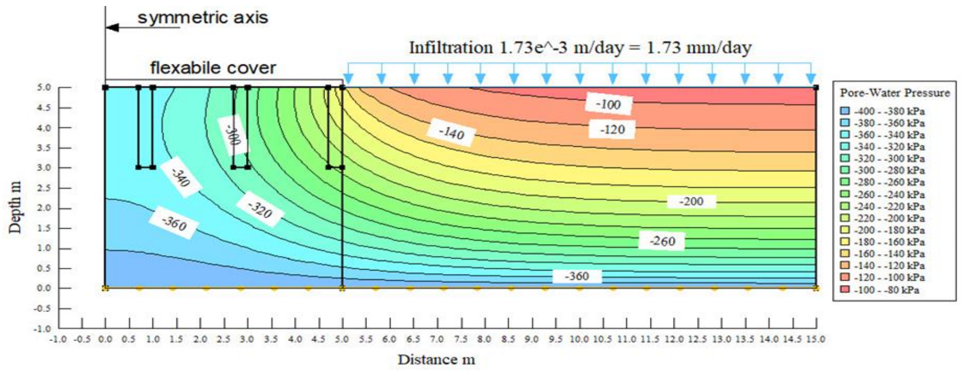

Figure no 8: The matric suction after 53 days by using 2m depth geofoam inclusions.

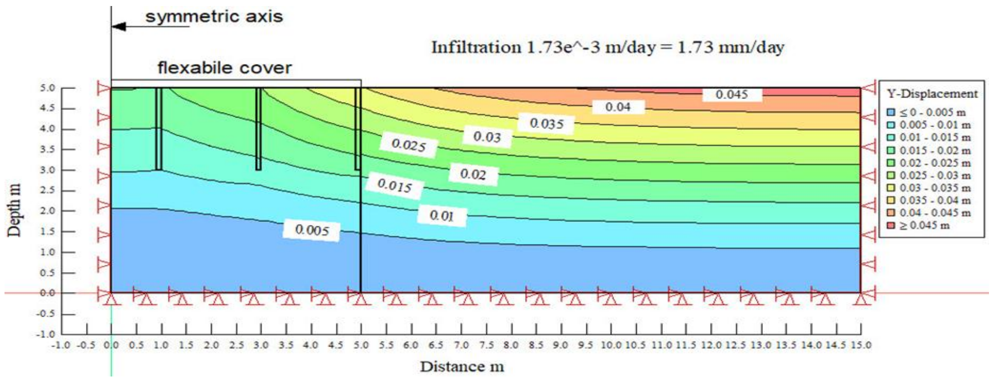

Figure no 9: Vertical displacements after 175 days with using 10 cm dia. EPS15 geofoam inclusions.

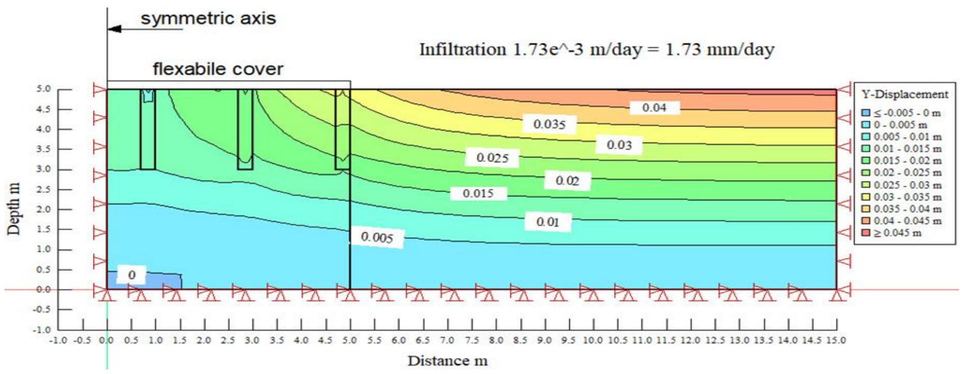

Figure no 10: Vertical displacements after 175 days with using 30 cm dia. EPS15 geofoam inclusions.

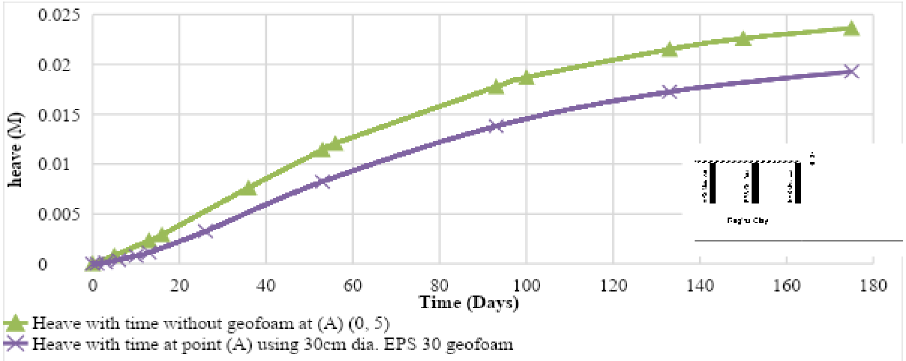

Figure no 11: Heave with time at points (A) at 0.4m from the edge of cover with/out using 30 cm dia. EPS (30) geofoam inclusions.

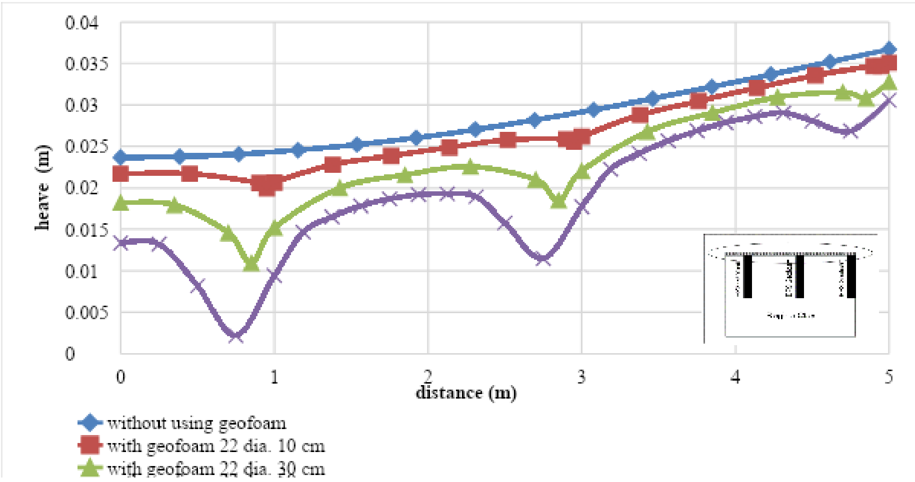

Figure no 12: Surface heave after 175 days with/out using EPS22 geofoam inclusions with different diameters.

The soil swelling reduced by increasing the diameter of EPS geofoam piles. The impact of increasing density of EPS geofoam piles using a constant diameter (30 cm) was slight after 175 days of infiltration as it can be observed from Figure no 13. The lower value of EPS geofoam density is selected to yield greater compressibility.

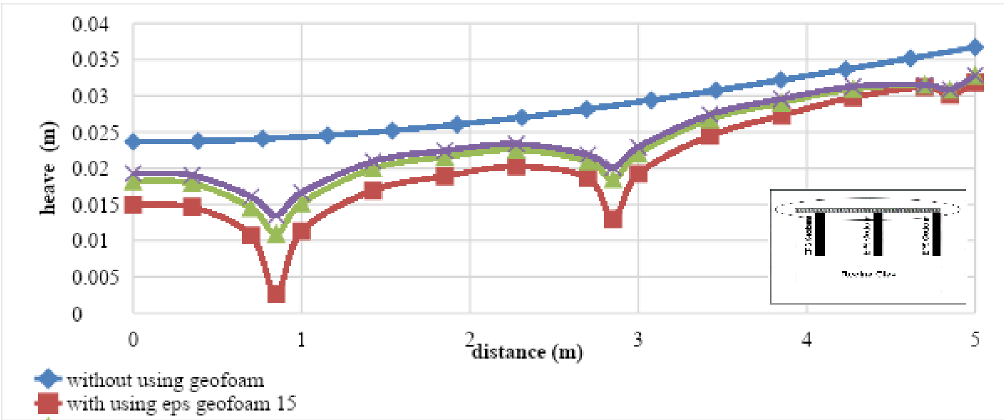

Figure no 13: Surface heave with/out using 30 cm EPS Geofoam inclusions with different density after 175 days.

The EPS geofoam inclusions depth considered the most influential parameter in reducing the soil heaving by using geofoam with 30cm diameter as demonstrated in Figure no 14. The minimized percentage of ground heaving by using EPS30 geofoam with 4m depth reached 20.49% where its value by 2m depth was 10.38% under the flexible cover. Increasing the used EPS piles diameter (D/ts) % (ts swelling soil layer) leads to a decrease in soil heave with time. With applying a rigid concrete slab instead of the flexible cover, the soil heave is linear as shown in Figure no 15, and Figure no 16, respectively.

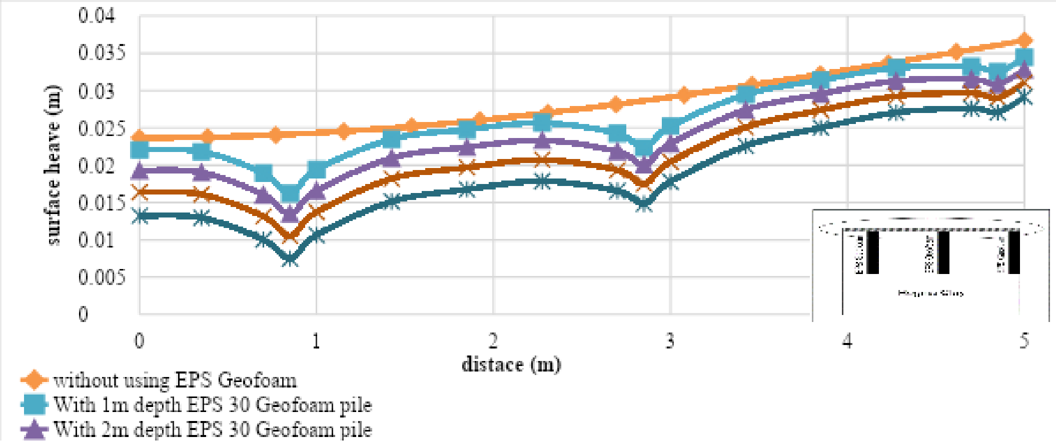

Figure no 14: Surface heave after 175 days with/out using 50cm EPS30 geofoam inclusions with different depths (1m, 2m, 3m, 4m).

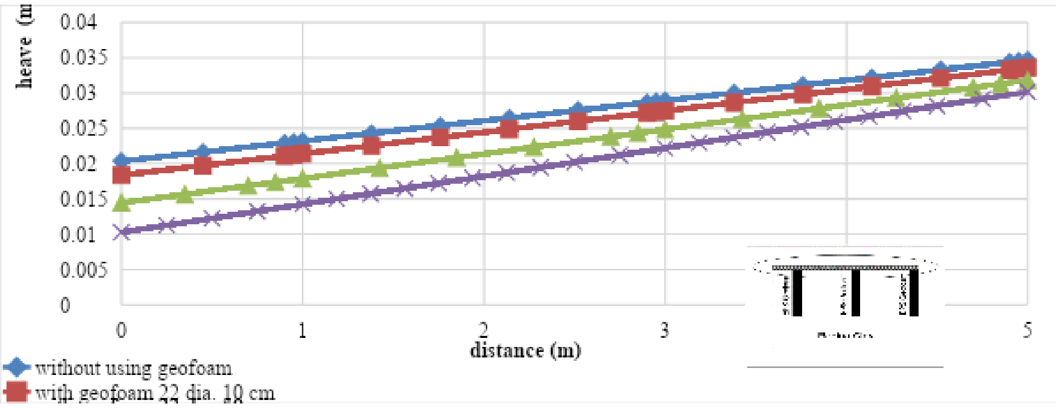

Figure no 15: Surface heave with/out using EPS (22) geofoam inclusions with a different diameter after 175 days under the rigid slab.

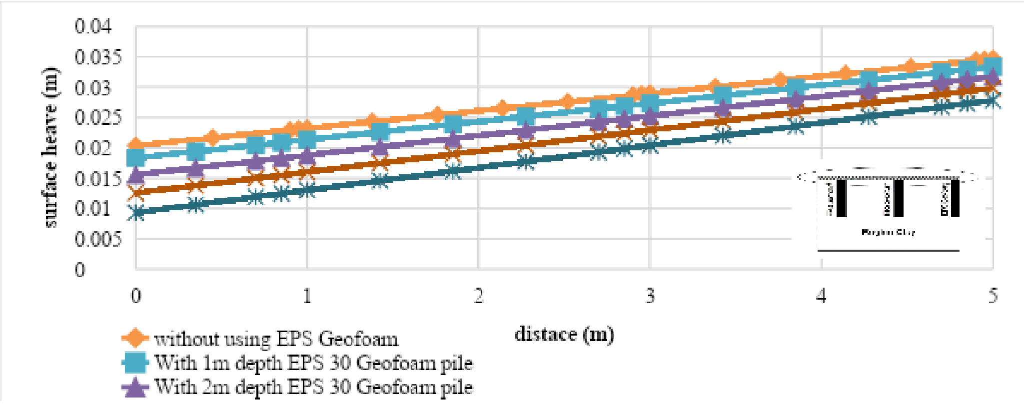

Figure no 16: Surface heave with/out using EPS (30) geofoam inclusions with a different depth after 175 days under the rigid slab.

The horizontal displacement of soil after 175days of water infiltration at the ground surface with using 50cm diameter EPS30 geofoam inclusions with depths 2m, 3m, and 4m were presented in Figure no 17, Figure no 18, and Figure no 19, respectively. It is noted that the effect of horizontal displacement of EPS geofoam increases with the increase of its depth.

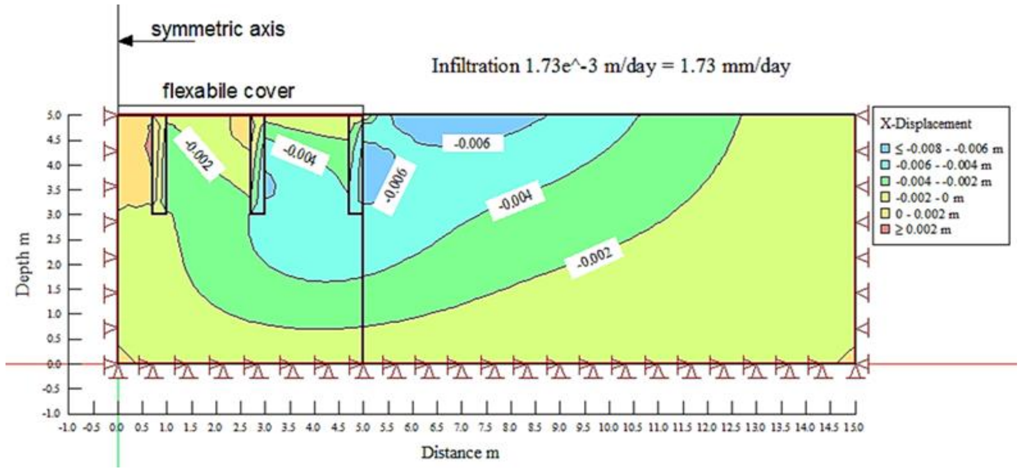

Figure no 17: The horizontal displacement of soil after 175days with using 50cm diameter EPS30 geofoam piles with 2m depth.

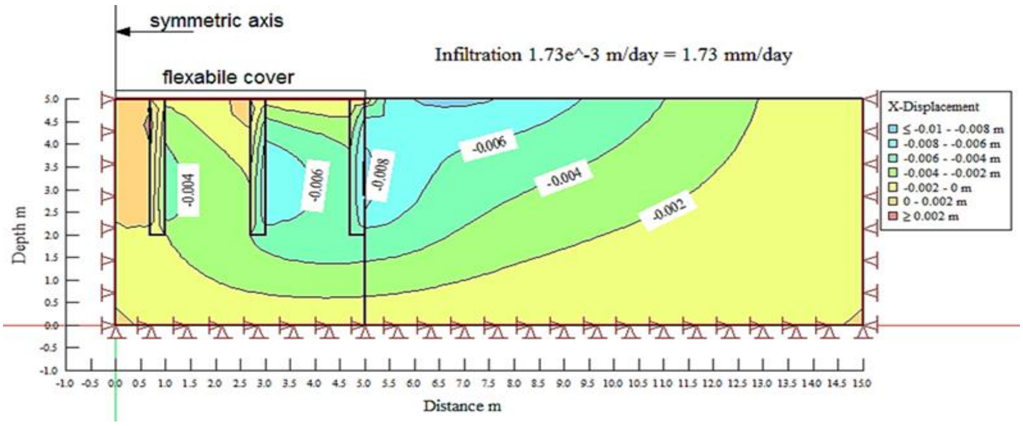

Figure no 18: The horizontal displacement of soil after 175days with using 50cm diameter EPS30 geofoam inclusions with 3m depth.

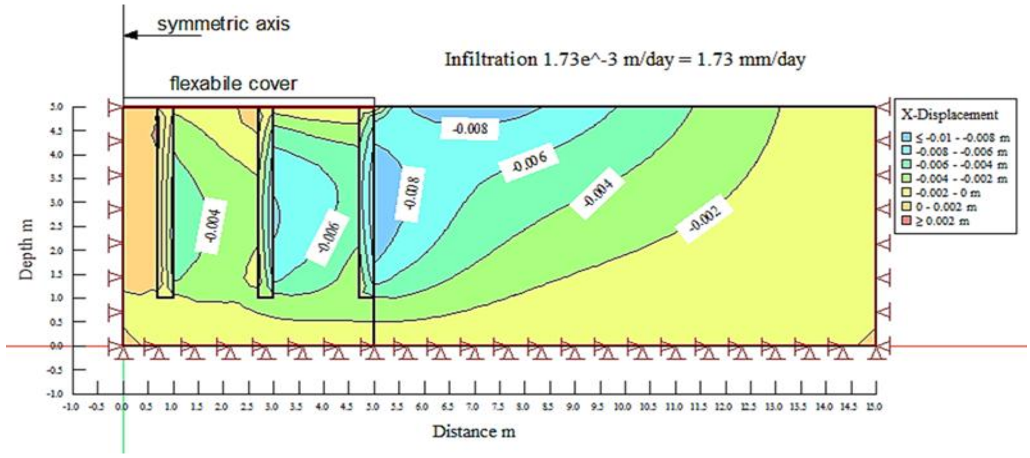

Figure no 19: The horizontal displacement of soil after 175days with using 50cm diameter EPS30 geofoam inclusions with 4m depth.

V. Conclusion

In this study, the numerical analysis results of using EPS geofoam inclusions with different depths to control the soil movements on structures constructed on swelling soils have been presented. Moreover, the use of SIGMA/W program to simulate 2-D analysis associated with a heave of expansive soils has been verified with the published results of a case study. The following are some of the major conclusions of the present study:

1- Coupled approach for the analysis of the behavior of unsaturated, expansive soils is regarded as a suitable method for expecting the swell/shrink behavior of unsaturated, expansive soils.
2- The elasticity parameters of unsaturated clays should be expressed as formulations of soil suction and stress variables.

3- The final soil suction distributions should be used as input for the stress-deformation analysis to model the swell/shrink behavior of unsaturated, expansive soils.
4- It is possible to simulate seepage and stress distribution analysis for unsaturated soil using SIGMA/W program to study the effect of infiltration and soil heave with time.
5- Using EPS geofoam as a compressible inclusion material has a significant effect on the matric suction distribution of unsaturated, expansive soils, and the decreasing of the soil heave.
6- Increasing the used EPS inclusions diameter (D/ts)% (ts swelling soil layer) leads to a decrease in soil heave with time.
7- The decrease in EPS geofoam density leads to an increase in the percentage of footing heave reduction. This means that the lower density of EPS geofoam is selected to yield higher compressibility and more heave reduction.
8- Increasing the EPS geofoam inclusions depth is the most significant factor in the soil heave reduction.
9- The soil heave reduction by using EPS geofoam inclusion under the flexible cover is non-linear. The heave decrease with higher values at the centers of geofoam inclusions compared with its value between the geofoam inclusions. Conversely, the heave reduction with EPS geofoam is linear under the rigid footing.
10- The effect of horizontal displacement of EPS geofoam increases with the increase of EPS geofoam depth.
11- Decreasing the diameter of the EPS pile near the center of footing and increasing its density can be significant in reducing the footing differential heave/settlement.

References

[1]. Adem, H. H, Modulus of elasticity-based method for estimating the vertical movement of natural unsaturated expansive soils, Ph.D. thesis, Citeseer, 2015.
[2]. Jones D. E. and Holtz, W. G., “Expansive soils-the hidden disaster,” Civil Engineering, 1973; vol. 43, no. 8, pp. 49-51.
[3]. Puppala A. J. and Cerato A., “Heave distress problems in chemically-treated sulphate-laden materials,” Geo-Strata—Geo-Institute of ASCE, 2009; vol. 10, no. 2, p. 28
[4]. Ravve A., Principles of polymer chemistry, Springer Science & Business Media, 2013.
[5]. Elragi A. F., Selected engineering properties and applications of EPS geofoam, State University of New York. College of Environmental Science and Forestry, Syracuse, NY, 2000.
[6]. Stark T. D., Bartlett S. F., and Arellano D., “Expanded polystyrene (EPS) geofoam applications and technical data,” The EPS Industry Alliance, 2012; vol. 1298, p. 36.
[7]. Vu H. Q. and Fredlund D. G., “Challenges to modeling heave in expansive soils,” Canadian Geotechnical Journal, NRC Research Press, 2006; vol. 43, no. 12, pp. 1249-1272.
[8]. Hung V. Q. Uncoupled and coupled solutions of volume change problems in expansive soils, Saskatoon, SK, Canada, 329 p: Ph.D. Thesis, University of Saskatchewan, 2003.
[9]. Vu H. Q. and Fredlund D. G., “The prediction of one-, two-, and three-dimensional heave in expansive soils,” Canadian Geotechnical Journal, 2004; vol. 41, pp. 713--737.
[10]. Fredlund D. G. and Xing A., “Equations for the soil-water characteristic curve,” Canadian geotechnical journal, 1994; vol. 31, no. 4, pp. 521-532.
[11]. Padade A. and. Mandal J., “Feasibility studies on expanded polystyrene (EPS) geofoam,” in Proc., Int. Conf. Ground Improvement and Ground Technique, ICGI2012, India, Research Publishing Chennai, 2012, pp. 903-906.
[12]. Vu H. Q. and Fredlund D. G., “Challenges to modeling heave in expansive soils.,” Canadian Geotechnical Journal, 2006; vol. 43, pp. 1249-1272.