Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 48 No. 4 December 2017 ISSN 0046-5828

Numerical Modeling of Retaining Wall Resting on Expansive Soil

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ABSTRACT: To model the behaviour of expansive soil, it seems necessary to move towards elastoplastic models that have been used for different types of clays. Hardening soil model is chosen in this study. Retaining walls rested on expansive soils are subjected to uplift and lateral forces due to soil swelling. More importantly, the swelling in expansive soil tends to cause additional lateral pressure on wall that caused deformations and bending. Various pattern types of helical piles are used to reduce the vertical and lateral movement of retaining wall constructed on expansive soil. The backfill soil beyond retaining wall is affected by swelling of expansive soil that caused additional lateral earth pressure on the wall of retaining wall. This study showed that the use of inclined helical piles beside vertical helical piles under the base of retaining wall decreased vertical movement 94% and lateral movement 70% for ratio of length of helical pile to depth of expansive soil (L/H) equal to 3.2. In general, the presence of helical piles below retaining wall resisted and controlled the vertical movement but do not control lateral movement except the case of using inclined helical piles.

KEYWORDS: Helical pile, Expansive soil, Retaining wall, Uplifts movement.

1. INTRODUCTION

Retaining wall systems are affected by lateral pressure due to annual suction change. Seasonal moisture change creates a lateral earth pressure at or near the ground surface. Both the hot summer moisture evaporation and seasonal rainfall ratio changes in the active zone of soil at the top near the ground surface. Even the ground water level may vary depending upon the seasonal weather. The soil expansion in the active zone causes stress and deformation to the soil-retaining wall system. High lateral pressure causes not only stress and pressure but also causes bending moments and shear forces in the retaining wall (Sahin 2011). Helical piles derived their origin as anchors for structures such as power poles or transmission lines. They began to be used fairly frequently for foundation systems in the early 1990s. The original helical pile system had little resistance to lateral loads (Nelson et.al. 2015). More recently, helical pile systems have been developed that have a large diameter for the upper portion of the helical pile, such that they have the ability to provide some resistance to lateral force (Perko 2009). The lateral earth pressure experienced by a retaining structure is made up of several components. Under a typical non-expansive soil-loading scenario, the lateral earth pressure would consist of the lateral earth pressure as calculated by conventional lateral earth pressure equations (e.g., Rankine or Coulomb theory). Additional pressure caused by surcharge and hydrostatic loads would also be added to the lateral pressure that must be resisted by the structure. If the backfill is expansive, additional pressure is exerted due to the tendency for the soil to swell as it becomes wetted. If the structure was infinitely rigid and the soil was totally confined, the additional lateral stress due to the tendency to swell would be equal to the constant volume (CV) swelling pressure, σ''_{cv}. This would rarely be the case. Most structures will exhibit some deflection, the amount of which would depend on the rigidity of the structure (Nelson et.al 2015).

Furthermore, the soil is normally orthotropic in nature such that for a flat-lying deposit the swelling pressure in the lateral (i.e., horizontal) direction is usually less than that in the vertical direction. The lateral pressure exerted on the wall by the swelling of the expansive soil cannot exceed the passive pressure of the soil. If the swelling pressure is greater than the passive pressure of the soil, Pp, the soil will fail along a passive wedge, resulting in a limiting value of the lateral swelling pressure for that portion of the wall. Various methods of reducing the lateral swelling pressure have been proposed and implemented. The simplest method of reducing lateral swelling pressure is simply to backfill entirely with non-expansive soil. However, depending on the nature, stiffness, and thickness of the backfill material, lateral swelling pressures can still be exerted on the walls (Nelson et.al. 2015). The prediction of the swell pressures and taking them into consideration in the design of retaining structures is needed. In other words, if these pressures are not included in the design, the stability of the structure will be reduced, potentially to the point of failure. Retaining walls in expansive soils are subjected to uplift forces and friction forces due to the swelling of surrounding soil. More importantly, the walls are also subjected to swell pressures tending to cause additional deformations and bending (Eman, 2011). Figure 1 shows the collapse of a retaining wall that has a clay backfill (Day 1999; Day 2000). A numerical model for prediction behaviour of cantilever retaining wall constructed on expansive soil using helical piles is presented in this study.

Figure 1 The Collapse of a Retaining Wall that has a Clay Backfill (Dave, 2010)

2. PROBLEM DESCRIPTION

The problem consists of cantilever retaining wall with a height of 3.5m and base of 0.50m which varies to 0.30m at the top of wall. The length of retaining wall is 10m. The footing of retaining wall is rectangular footing with dimension (10x4) m and thickness of 0.60m. The layers beneath this footing are: sandy gravel layer (2m), expansive layer (5m) and dense sand layer (10m). The purpose of the problem is to find the maximum uplift movement under foundation with and without using different patterns of helical piles. The expansive soil layer is located above a layer of saturated dense sand with (10m) depth. At 7m depth, the water level rises caused a considerable swelling in expansive soil. The type of helical pile used in this problem is of three helix plates with diameter (0.30)m, the double helix plates located at lower part of pile and single helix located at the top of pile. The distance between helix plates is five times helix diameter. The cross section of helical pile shaft is square of (0.10x0.10) m. The effective length of helical piles used in this problem under footing of retaining wall is (10m and 16m). Figure 2 shows the description of the problem.

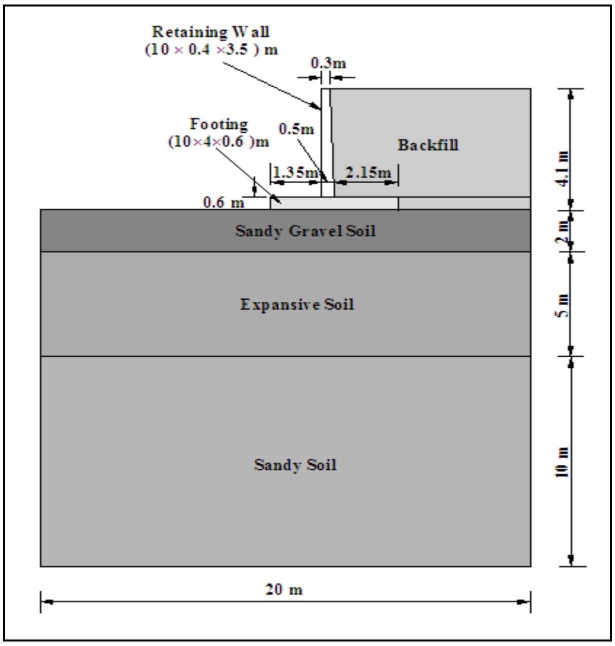

Figure 2 Cantilever Retaining Wall Problem

3. MATERIAL MODELING AND BEHAVIOR TYPE

The finite element model is composed of five types of materials, sandy gravel layer, and clay as an expansive layer, dense sand, backfill and concrete. The rigid steel is used as a material for both helical piles and helix plates and assumed as linear elastic model. All materials and models with set of parameters are listed in Tables 1 and 2. Table 2 shows the properties of soils obtained from consolidation and direct shear tests.

4. SWELLING MODELING OF EXPANSIVE SOIL LAYER

The swelling of expansive soil layer is modeled by applying a swelling potential (positive volumetric strain) of (6.5%) to the expansive soil cluster. This value of volumetric strain was obtained previously from the free swell test of expansive soil used. In reality, the rate at which expansive soil would normally swell depends on the position from the source of moisture and magnitude of overburden effective pressure. However, for simplification, in the analyses presented herein, the volumetric strain is applied uniformly across the full depth of the expansive soil layer.

Table 1 Steel Properties Considered in Finite Element Analysis (John, 2009)

Model Type	Model Parameters	Helix Plate	Pile Shaft
Linear Elastic	E (kN/m^2)	130,000,000	200,000,000
	Unit Weight (kN/m^3)	78	78
	Poisson's ratio	0.30	0.30
	Thickness (m)	0.01	-
	Dimension(m)	-	(0.10x0.10)

Table 2 Soil Properties Considered in Finite Element Analysis

Model Parameters	**Expansive Soil (undrained behavior)**	**Sandy Soil (drained behavior)**	**Sandy Gravel Soil Drained Behavior**	**Backfill Drained Behavior**	**Concrete (Non Porous)**
Model Type	**Hardening**	**Hardening**	**Hardening**	**Hardening**	**Linear Elastic**
γunsat(kN/m^3)	16	16	19	17	24
γsat (kN/m^3)	18	19	21	20	-
E50 (kPa)	5000	48000	65000	20000	30,000,000
Eoed(kPa)	5000	48000	65000	20000	-
Eur(kPa)	20000	144000	194000	60000	-
M	1	0.50	0.50	0.5	-
K^{NC}	0.60	0.40	0.43	0.5	-
Pref	100	100	100	100	-
c'*ref* (kPa)	2	0.10	0	1	-
Ø°	24	37	35	30	-
v'un	0.30	0.25	0.20	0.20	0.30
Ψ	0	7	5	0	-
Rinter	0.50	0.65	0.60	0.65	Rigid
Ko	Manual	Manual	Manual	Manual	Automatic

5. MESH GENERATION

The average element size and the number of the 15-node triangular elements depend on the global coarsenesses setting. The simple global finite element mesh of model is generated to present a more accurate stress distribution. The medium setting of mesh was selected by conducting patching test and multiple trials between other coarseness settings introduced in PLAXIS-3D, were found to be most suitable, and provide a sufficient accuracy.

6. CALCULATION STAGE

After completing the finite element modeling of described problems, the actual finite element calculations can be executed. For this type of problem, four phases are selected for finite element calculations. The first phase is construction of helical piles and base of retaining wall. The second phase is constructed of retaining wall. The third phase is backfilled retaining wall. At the fourth phase, the positive volumetric strain are activated in the cluster of expansive clay and the reference points at which the uplift and lateral movement should be calculated are selected, the points are selected at the left and right top of footing and top left side of retaining wall as shown in Figure 3. Plastic calculation and staged construction are selected to calculate the final uplift and lateral movement in the selected points. In all cases, the configurations of helical piles are arranged.

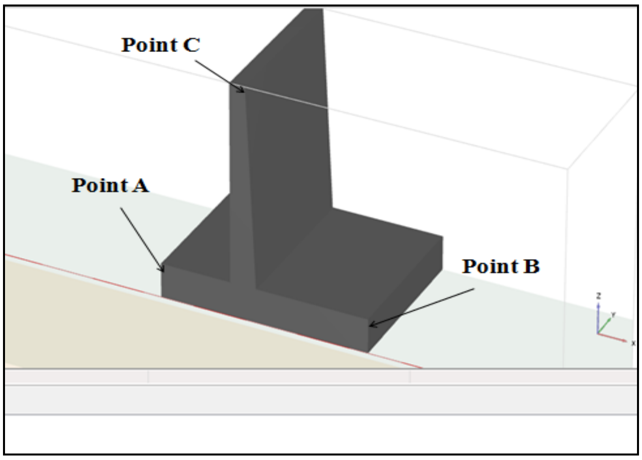

Figure 3 Important Points on Retaining Wall Surface

7. RESULTS AND DISCUSION

The original problem of cantilever retaining wall is analyzed without using helical piles. To know the movement of retaining wall, it chooses three points on surface of retaining wall, two point lie on the top side of base (point A and B) and the third point lies on top right of wall (Point C) as shown in Figure 3. It is clear from Figures 4 to 6 that the point A, at the top of left side of base, has large values of uplift movement and horizontal movement to the left reaches 26cm and 11.5cm respectively that caused cracks and tilting to the retaining wall. This behavior is attributed to swelling happened in expansive layer that gives additional earth pressure on retaining wall Also points B and C have uplift and horizontal movement lower than point A. The left side of base has high values of uplift movement due to non-backfill above it. Therefore; it is necessary and convenient to use helical piles to limit or reduce the uplift and horizontal movement. There are different patterns of using helical piles are adopted and discussed briefly as follows:

7.1 Case 1: Using two vertical helical piles below base of retaining wall

In this case, two lengths of helical piles are analyzed, the first length is 10m and the second length is 16m that gives length to thickness of expansive layer (L/H) equal to 2 and 3.2 respectively. The reduction

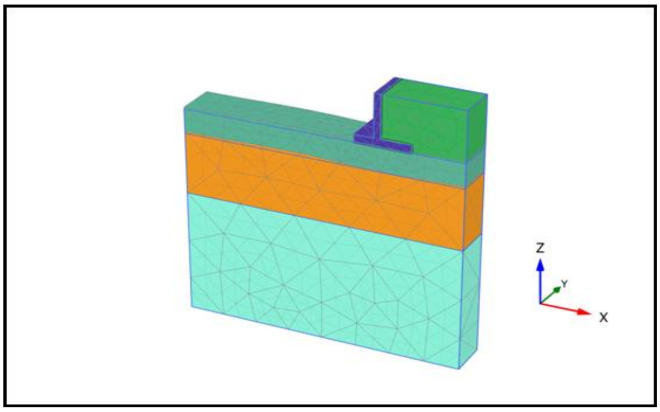

Figure 4 Deformed Shape of Cantilever Retaining Wall after Swelling of Expansive Soil for Unpiled Case

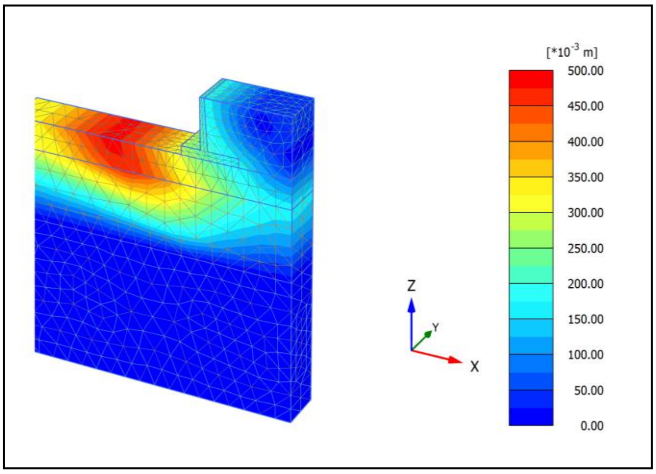

Figure 5 Total Displacement Distribution in (m) Resulting from Swelling of Expansive Soil for Unpiled Case

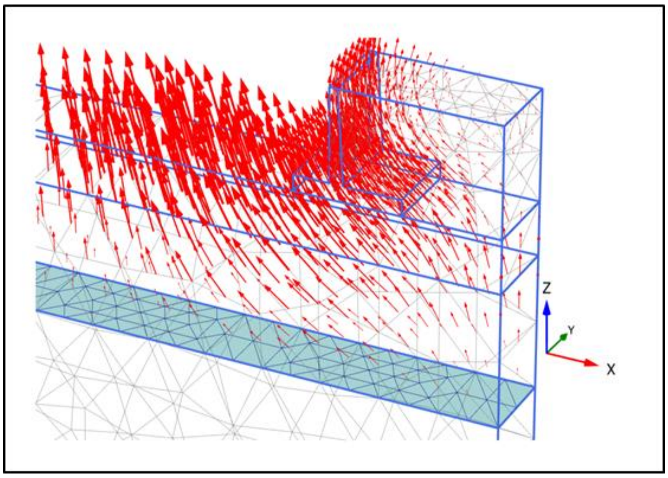

Figure 6 Vectors of Total Displacement Resulting from Swelling of Expansive Soil for Unpiled Case**.**

in uplift movement is approximately 20% and 90% for (L/H) ratio 2 and 3.2. The lateral movement of retaining wall to the left is reduced by 85% for ratio (L/H) equal to 2 but the increased to 30% for ratio (L/H) equal to 3.2. The reduction in uplift movement of retaining wall may be attributed to increase in anchorage resistance between helical piles and sandy soil. The increase in lateral or horizontal movement of retaining wall is due to increase in lateral earth pressure resulting from swelling of expansive layer as shown in Figures 7 to 9.

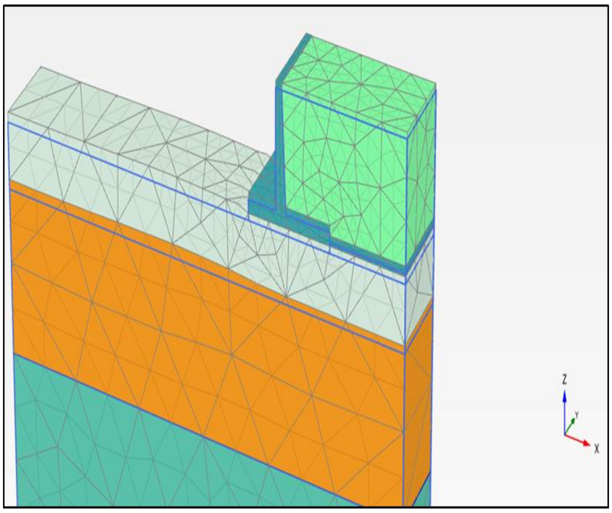

Figure 7 Deformed Shape of Cantilever Retaining Wall after Swelling of Expansive Soil for Two Vertical Helical Piles under the Base of Retaining Wall (L/H=2)

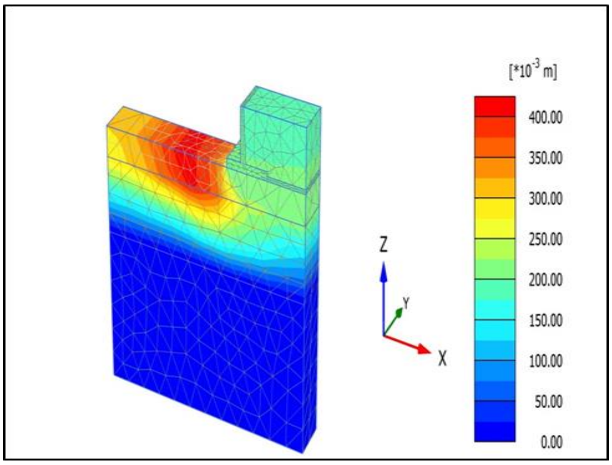

Figure 8 Total Displacement Distribution in (m) of Cantilever Retaining Wall Resulting from Swelling in Expansive Soil for Two Vertical Helical Piles under the Base of Retaining Wall (L/H=2)

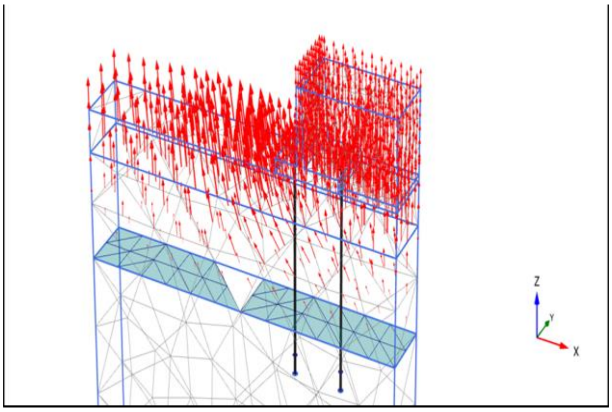

Figure 9 Vectors Total Displacement of Cantilever Retaining Wall Resulting from Swelling of Expansive Soil for Two Vertical Helical Piles under the Base of Retaining Wall (L/H=2)

7.2 Case 2: Using three vertical helical piles below base of retaining wall

In this case another helical pile is used between the two helical piles. The uplift movement of retaining wall is decreased by 35% and 95% for ratio of (L/H) equal to 2 and 3.2 respectively. On the contrary, the lateral movement is increased by 5% and 70% for ratio of (L/H) equal to 2 and 3.2 respectively. The addition of third helical pile increased the reduction of uplift movement of retaining wall but do not mitigate the lateral movement. This may be to increase in lateral earth pressure from backfill as a result from swelling of expansive layer as shown in Figures 10 to 12.

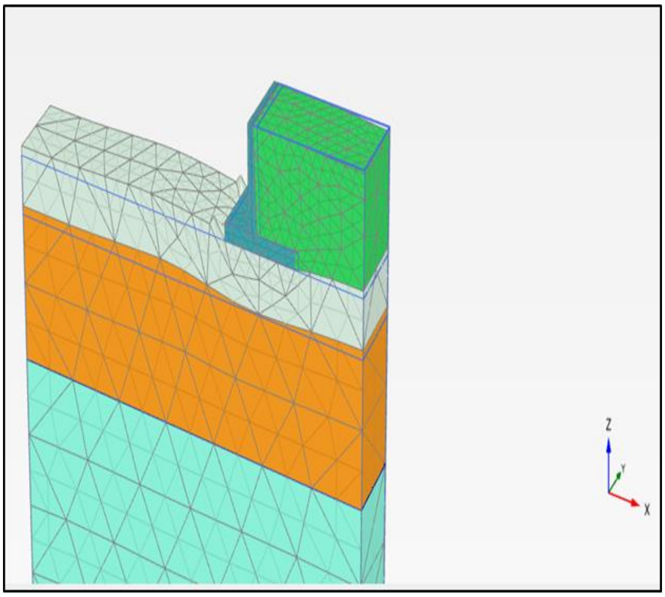

Figure 10 Deformed Shape of Cantilever Retaining Wall after Swelling of Expansive Soil for Three Vertical Helical Piles under the Base of Retaining Wall (L/H=3.2)

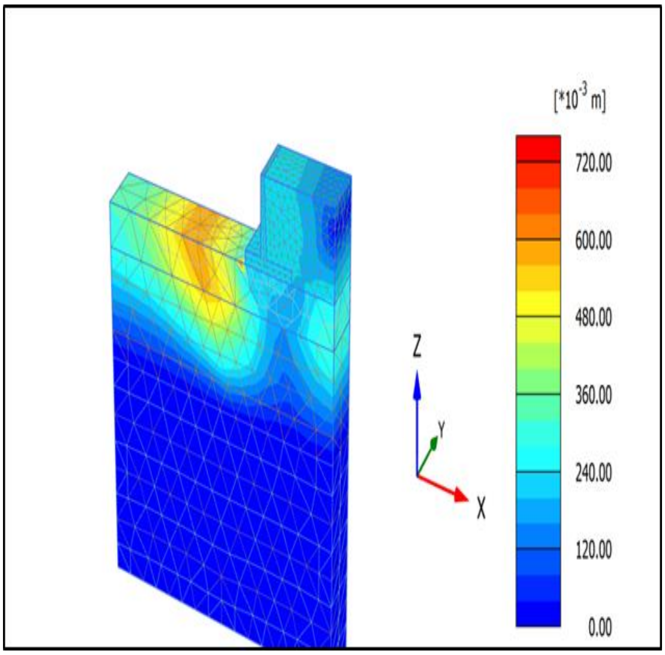

Figure 11 Total Displacement Distribution in (m) Resulting from Swelling in Expansive Soil of Cantilever Retaining Wall for Three Vertical Helical Piles under the Base of Retaining Wall (L/H=3.2)

7.3 Case 3: Using two vertical helical piles plus inclined helical pile below base of retaining wall

Inclined helical pile is used with inclination 30^0 from vertical, beside the vertical helical pile at the toe of base of retaining wall. The purpose of using inclined helical piles is to reduce the lateral movement of retaining wall. The reduction in lateral movement reaches 70% for ratio (L/H) equal to 3.2. Therefore; the addition of inclined helical pile resisted vertical and lateral movement of retaining wall more than the two cases mentioned above as shown in Figures 13 to 15.

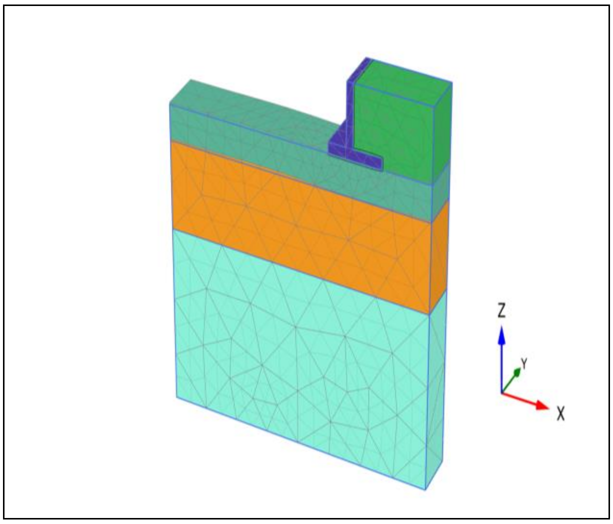

Figure 13 Deformed Shape of Cantilever Retaining Wall after Swelling of Expansive Soil for Two Vertical and One Inclined Helical Piles under the Base of Retaining Wall (L/H=3.2)

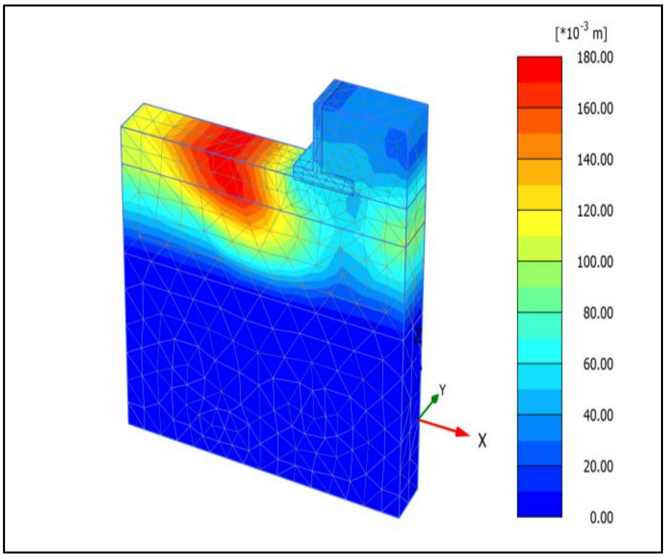

Figure 14 Total Displacement Distribution in (m) Resulting from Swelling of Expansive Soil of Cantilever Retaining Wall for Two Vertical and One Inclined Helical Piles under the Base of Retaining Wall (L/H=3.2)

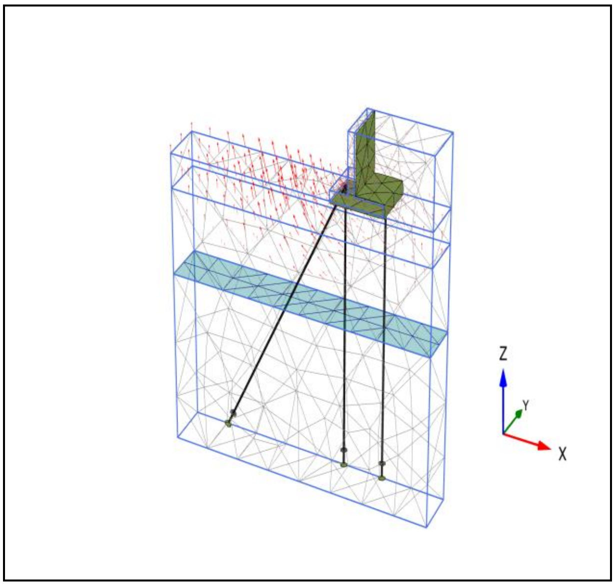

Figure 15 Vectors of Total Displacement of Cantilever Retaining Wall Resulting from Swelling of Expansive Soil for Two Vertical and One Inclined Helical Piles under the Base of Retaining Wall (L/H=3.2)

7.4 Case 4: Using three vertical helical piles below base of retaining wall plus three horizontal helical piles

Three horizontal helical piles with length 5m are carried out in the backfill region. In this case, the reduction in uplift movement of retaining wall is 95% for ratio (L/H) equal to 3.2 but the lateral movement is stilled large. The addition of three horizontal helical piles is not solved the problem of the lateral movement of retaining wall. This is may be attributed to the same reason mentioned previously in case 2. The presence of helical piles in unstable zone reduced the efficiency of helical piles as shown in Figures 16, 17, and 18.

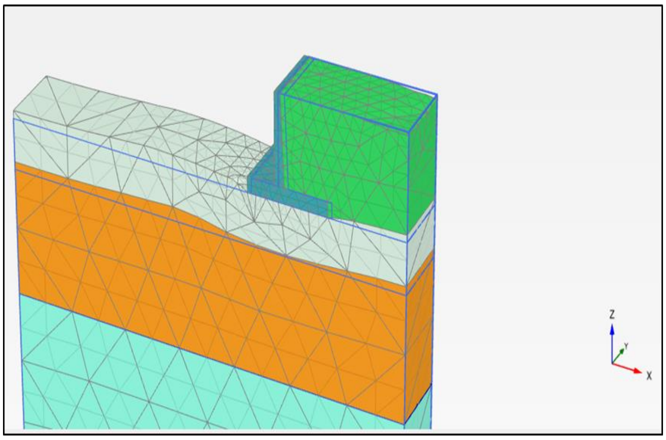

Figure 16 Deformed Shape of Cantilever Retaining Wall after Swelling of Expansive Soil for Three Vertical and Three Horizontal Helical Piles under the Base and Beside Wall of Retaining Wall (L/H=3.2)

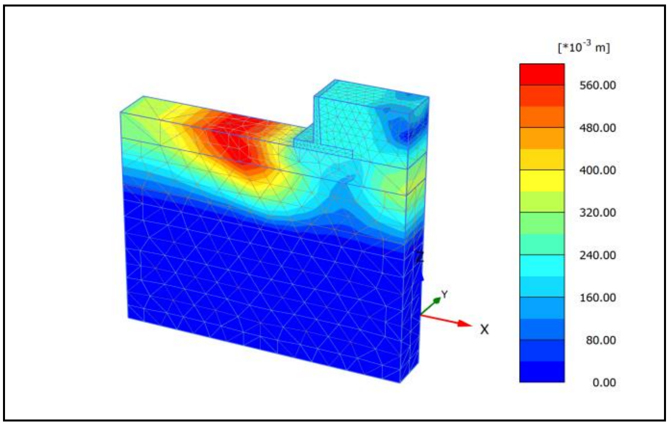

Figure 17 Total Displacement Distribution in (m) of Cantilever Wall Retaining Resulting from Swelling in Expansive Soil for Three Vertical and Three Horizontal Helical Piles under the Base and Beside Wall of Retaining Wall (L/H=3.2)

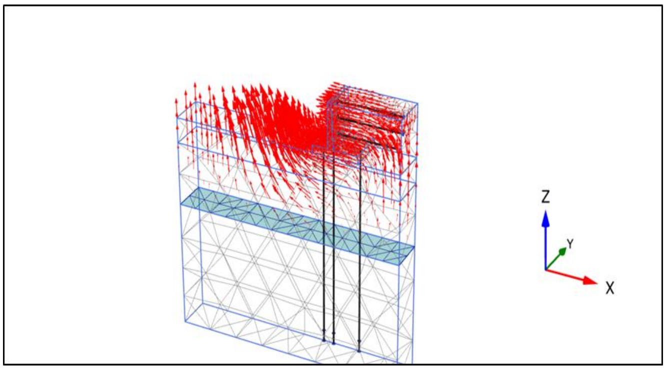

Figure 18 Vectors of Total Displacement Distribution of Cantilever Retaining Wall Resulting from Swelling in Expansive Soil for Three Vertical and Three Horizontal Helical Piles below Base and Beside Wall of Retaining Wall (L/H=3.2)

8. CONCLUSIONS

1. Helical piles must be driven to stable zone that does not change with changes in moisture content.
2. The increase in length of vertical helical piles in stable zone reduces vertical movement but increases lateral movement of retaining wall resting on piles in expansive soil.
3. The backfill soil beyond retaining wall is affected by swelling of expansive soil that causes additional lateral earth pressure on the stem of the retaining wall.
4. The use of inclined helical piles beside vertical helical piles under the base of retaining wall decreases vertical movement (94%) and lateral movement (70%) for ratio (L/H) equal to 3.2.
5. In general, the use of helical piles under the retaining wall resists and controls the vertical movement but does not control lateral movement except in the case where inclined helical piles are used.
6. The use of helical piles in earth retaining wall restraint is valuable and offers many advantages including construction immediately after pile installation.

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