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Numerical Analysis of Concrete Pile on expansive soil slope

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Abstract— This paper presents a numerical model that can be used to analyze the effect of lateral pressure due to swelling deformation action through simulations. An example problems were analyzed involving the behavior of a swelling soil for slope without pile. An equation proposed by Zhang (2010) is introduced in ABAQUS considering the swelling as surface force. The tendency for increase water content in homogenous expansive slope stabilized with pile has been proved by the result obtained from the analysis. The comparison between different pressures acting on the pile under different water content shows that the maximum pressure of 450 kPa is achieved when the water content was 20% at the pile active zone. Furthermore, the result shows that the pressure acting on the pile in the passive zone is a bit greater than that acting on the pile active zone. The pile horizontal displacement is affected by water content change by about 39.13%. The developed FE models can serve as a numerical platform for performance predictions of concrete pile on expansive soil with different slope and water content.

Keywords— Expansive soil; Slope stability; Concrete pile, Pile-soil interaction; Finite element method, ABAQUS.

1 Introduction

EXPANSIVE soils or swelling soils that exist in many parts of the world, show excessive volume change with increasing water content. As a result of this volume change, expansive soils apply vertical and lateral pressures to the structures located or buried in these regions. Many research have been carried out on vertical swelling pressures to help engineers to design structures (e.g. slope, retaining wall etc.) that are capable of withstanding theses stresses (J. P. Krohn and J. E. Slosson (1980) M. Carter and S. P. Bentley (1991), F. D. Hasan and H. Filson, (1980), L. t. Johnson and D. Snethen, (1978) [3], [13-15] etc. Wherever people want to build any kind of civil construction, "soil" crosses their path. Nowadays, building constructions need to be durable and need to live a long time. Therefore, a good knowledge about the soil is necessary before the start of each building project. Soil is a complicated material, it doesn't behave like most other building materials.

In the past, there was no theoretical basic knowledge for soils design. People had to rely on trial and error. Coulomb (1773) was the first who saw the importance of using mechanics to solve problems of soil.

When the construction is built under soils like expansive soil, it will face a big problem for civil engineering because this soil can swell and shrink when wetted and dried, respectively [7,8]. The existence of expansive soil often causes catastrophic failure of geotechnical engineering, especially in slope engineering. Expansive soil, also called shrink-swell soil, is a very common cause of foundation problems. Depending upon the supply of moisture in the ground, shrink-swell soils will experience changes in volume of up to thirty percent or more. Foundation soils which are expansive will "heave" and can cause lifting of a building or other structure during periods of high moisture. Conversely during periods of falling soil moisture, expansive soil will "collapse" and can result in building settlement. Either way, damage can be extensive.

Expansive soil will also exert pressure on the vertical face of a foundation, basement or retaining wall resulting in lateral movement. Shrink-swell soils which have expanded due to high ground moisture experience a loss of soil strength or "capacity" and the resulting instability can result in various forms of foundation problems and slope failure. Expansive soil should always be suspected when there is evidence of active foundation movement. In order for expansive soil to cause foundation problems, there must be fluctuations in the amount of moisture contained in the foundation soils. If the moisture content of the foundation soils can be stabilized, foundation problems can often be avoided. Figure 1 shows the cracks in expansive soil caused by drying, shrinking and swelling of soils.

The deformation of structures above the expansive soils is caused by apparent swelling-shrinkage behavior of the soils with changes of water content, which is different from the common foundation systems whose settlements are controlled by soil compressibility and strength. To the engineering constructions in the area of expansive soils, piles are commonly used to be digged into deep soil layer with no apparent change of water content, which may greatly decreases the upward movements of the structures.

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Fig. 1. Swelling soil situation (a) cracks in expansive soil caused by drying (b) shrinking and swelling of soils

The deformation of structures above the expansive soils is caused by apparent swelling-shrinkage behavior of the soils with changes of water content, which is different from the common foundation systems whose settlements are controlled by soil compressibility and strength. To the engineering constructions in the area of expansive soils, piles are commonly used to be digged into deep soil layer with no apparent change of water content, which may greatly decreases the upward movements of the structures.

Since pile is inserted into expansive soils, it must be pulled by upward shear force transmitted from the soil to the pile. If the upward shear force is greater enough, the pile may even be broken by such great tension. Collins (1981) suggested an expression to calculate tensile stress of the pile based on the assumption that slippage occurs between pile and expansive soils at the interface. The pile also use to stabilize slope and slope can be reinforced with pile using different methods and techniques. Tomio Ito and Tomotsu Matsui (1975) [11] proposed a limit equilibrium method to deal the problem of stability of slopes containing piles. The slope stability problems with pile is very complex because of presence of interaction between soil and pile.

Numerical analysis plays an important role in the investigation of the behavior of soils by highlighting aspects which are important in engineering practice and illustrating the effect on the behavior of geotechnical structures. The finite element method is the powerful methods employed in decencies to solve same complex engineering problems G.R. Martin et al. (2005) [16], J.-R. Peng (2006) [17], W. Wei and Y. Cheng (2009) [18], Gaia Capasso and Stefano Mantica (2006) [19] etc. This paper presents a numerical solution for the prediction of lateral pressure due to swelling deformation into an expansive soil slope stabilized with concrete pile. The solution results are illustrated through simulations analysis. A finite element program called ABAQUS (Chao, 2011) was used for the analysis of the example problem.

In this paper, the influence of water content is analyzed on lateral pressure, and horizontal pile displacement. The main idea is to find out the affect of water content change on expansive soil slope stabilized with pile.

2 Method of Using Finite Element Analysis

Expansive soil is one kind of clay soil. Expansive soil produce at lot of damages around the world. It can swell and shrink when the water on presence and drain out. However, the simulation of swelling behavior using finite element or computational program is a gain of time. The construction of retaining wall, slope, and foundation have to be design carefully. To simulate swelling behavior, an introduction of an equation using on ABAQUS is required. ABAQUS is one of the most used software in geotechnical engineering. Zhang Wei-Ming (2010) investigated large number of trials test and proposes a model of expansive soil. In his study, expansive soil swelling model was summarized a reference formula. Furthermore, the expansive soil of Henan province are providing the expansive soil model parameter values. The method used to simulate swelling behavior through ABAQUS software is simple method. The equation is introduced on ABAQUS. The parameters in equation 1 were obtained experimentally by Zhang wei-ming (2010). This equation was modeled in ABAQUS software so as to conduct real behaviors of swelling deformation. The equation is as in the following form:

$$\delta = A + K_w w + K_\gamma r + K_p \log P \quad (1)$$

Where: δ is swelling deformation, Kw and, r is dry density, W is water content, p is overburden pressure, A, Kw, Kγ and Kp are constant parameters.

- When the swelling deformation is zero, case (1) value is chosen to compute the load magnitude or overburden pressure. However, the load magnitude value is 19.355 kPa with water content, W, 23 %, and dry density, γ_d, 1.49 g/m3,
- When the swelling deformation is different to zero, case (2) is assumed with water content W, 23 %, dry density, 1.49 g/m3.

TABLE 1: CONSTANT OF SWELLING VALUE (ZHAO, 2010)

Case	A	Kw	Kr
(1)	-1.603	-0.32	10.767
(2)	4.197	-0.439	10.265

The calculation of load magnitude can be given by hands easily using the equation (1), then, introduces in ABAQUS using the surface traction option. If we assume the situation of case (1) with water content, w, 23%, dry density, γd, 1.49 g/m3, the value of load magnitude is 19.355 kPa. However, following this procedure is made the swelling behavior deformation through finite element method software.

3 Constitutive Laws of Materials and Models Geometry in Abaqus Software

This part is devoted to present swelling deformation and slope reinforced with pile simulation using finite element method. Firstly, the swelling deformation simulation is based on the test result given from previous experimental tests. Therefore, test results obtained by Zhao-chao (2010) proposed an equation defining the relation between water content, dry density, overburden pressure and others constants parameters related to them respectively. Secondly, the equation of swelling deformation is introduced through ABAQUS software, the swelling behavior is assumed like expansion force existing in underlying soil when the water is added to slope. Thirdly, pile slope model is modeled to prove a good interaction between pile and soil. Finally, all the results is compared to the reference model from Fei-kong (2009) and Zhao (2010) and showed good correlations.

3.1 Model geometry

Geometry of the slope is modeled and described as in Figure 2. The height of slope is 10 m and the angle of slope is 20°. The slope is assumed to be homogenous.
A two dimensional analysis was considered in this analysis. The slope material is expansive soil and the material assumed for our model is from the paper published by Chao-Zhao (2011).

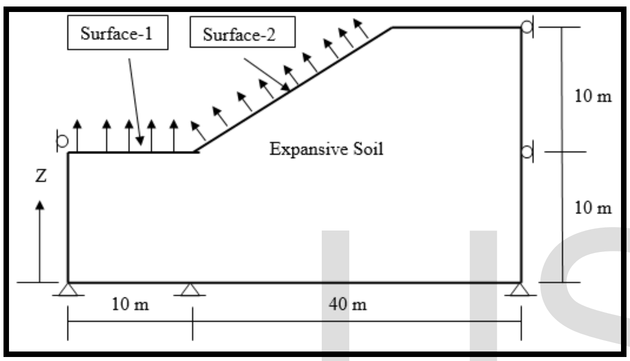


Fig. 2. Geometry of slope

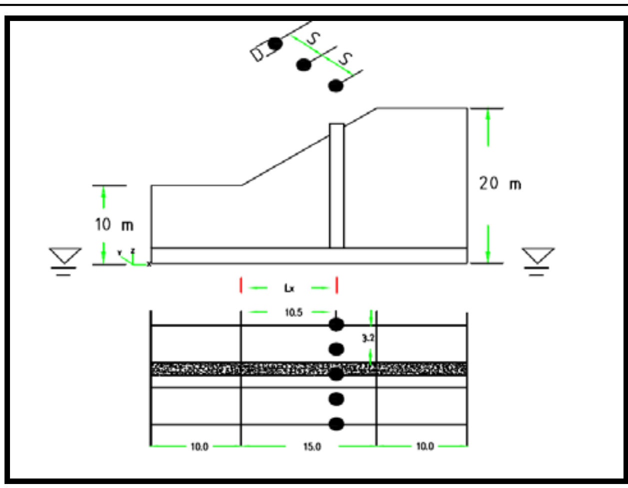


Fig. 3. Model geometry

3.2 Materials properties

The soil properties used for modeling in ABAQUS are tabulated in Table 2. Dry unit weight of the soil, γd, is 19.05 kN/m^3 ; elastic modulus of the soil, E, is 100MPa ; Poisson's ratio, υ, is 0.35; coefficient of permeability, kw, is 1.27 *10E-10 m/sec, initial void ratio, e0 , is 1.04, soil cohesion, c, is 40 kPa; and, the angle of internal friction, φ, is 14.5°.

The slope is assumed homogenous with height of 10 m, the ratio is 1:1.5, the distance between toe of slope and pile, Lx, is 10.5 m, the length of pile L, is15.5 m, the diameter of pile is 0.80 m, the distance or space between piles is 4D 3.2 m, the distance between the base of the slope and end point of pile is 2.0 m. Figure 2 and figure 3 shows the geometry of the model.

3.3 Finite element model calibration

TABLE 2
MATERIALS PROPERTIES

Soil parameters	Designation	Values
Dry unit weight of the soil,	γ_d	19.05 kN/m^3
elastic modulus of the soil,	E	100MPa
Poisson's ratio,	Υ	0.35
coefficient of permeability,	k_w	1.27e-10 m/s
Initial void ratio	e_0	1.04
Cohesion,	C	40 kPa
Angle of friction,	Ø	14.5°

TABLE 3
SLOPE WITH PILE METERIALS PROPERTIES

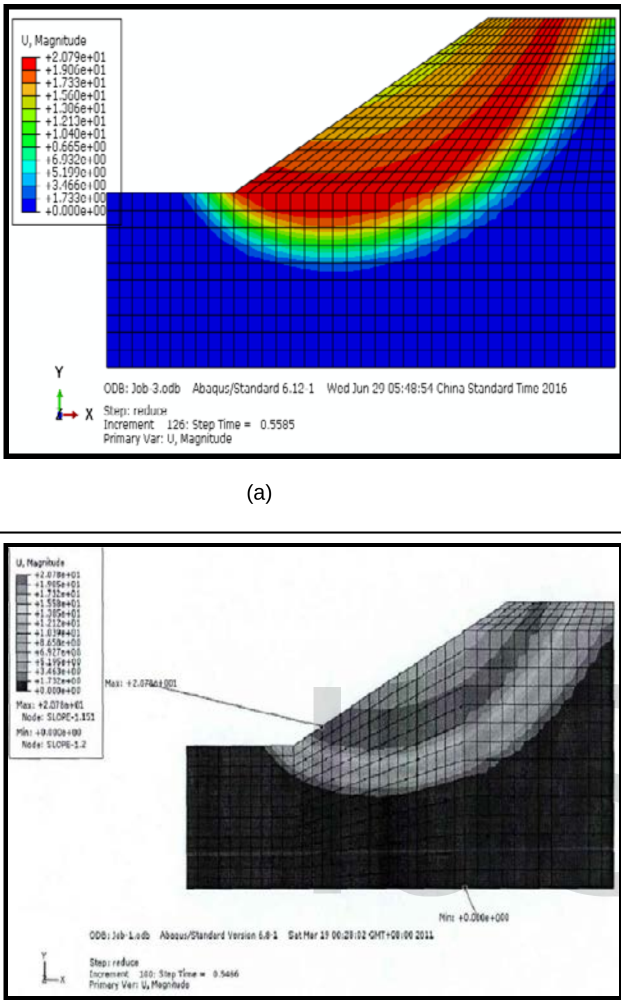
Parameters	Density (kPa/m^3)	Cohesion (kPa)	Angle friction (°)	Ψ (°)	Elastic modulus E (MPa)	Poison ratio v
Soil	20	20	36	0	100	0.25
Mohr coulomb	-	40	55.46	-	-	-
Pile	24	-	-	-	30000	0.20

TABLE 4
PILE AND SLOPE DIMENSIONS PROPERTIES

Item	Pile depth (m)	Diameter of the pile (m)	Pile length (m)	High of slope (m)	Thickness (m)
Value	20	0.8	15.5	10.0	1.6

The second part of this study was concentrated on validation of the FE model (ABAQUS) software by using available examples to study swelling deformation and slope stability using the models studied by Chao-zhao (2011) and Fei-kong (2009), respectively, while the parametric study was considered after confirmed that our model is correct.
The goal of this calibration (comparison between the FE model by using ABAQUS and the previous published results) was to ensure that the material properties, elements, and boundary condition are adequate to model the response of the slope pile and make sure that the simulation process is correct.
According to model which studied by Chao-zhao (2011), different cases has been carried out in order to apply is method on engineering field. However, our model is compared with their model (Chao, 2011). The results showed good agreement with displacement magnitude of 20.79 mm 20.78 mm for our model and Chao-zhao model, respectively. This confirm that our model through ABAQUS finite element software is correct as shown in Figures 4~ 7. Factor of safety showed a typical

values with that obtained from Fei-kong model as illustrated in Figure 7.



(a)

(b)

Fig. 4. (a) our model (b) Ref. paper Chao-Zhao (2011)

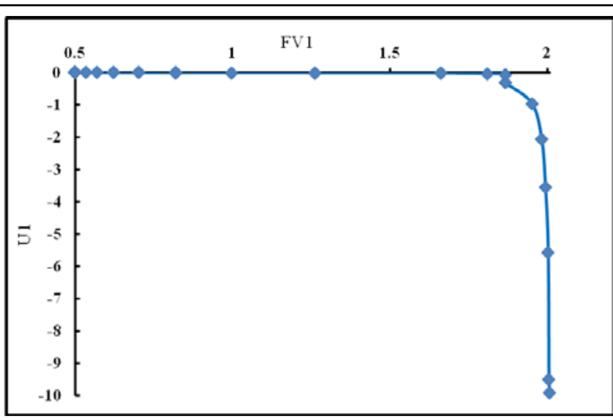


Fig. 5. FOS versus U1 (our model)

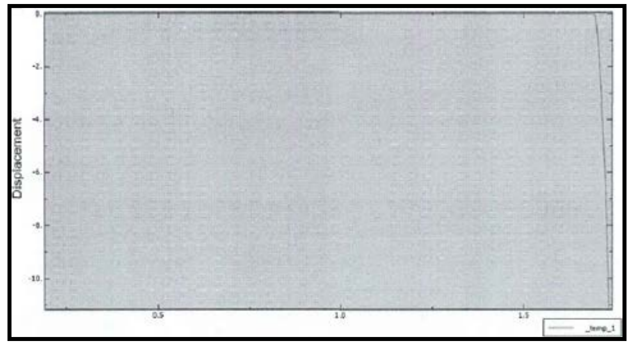


Fig. 6. FOS versus U1 (reference model))

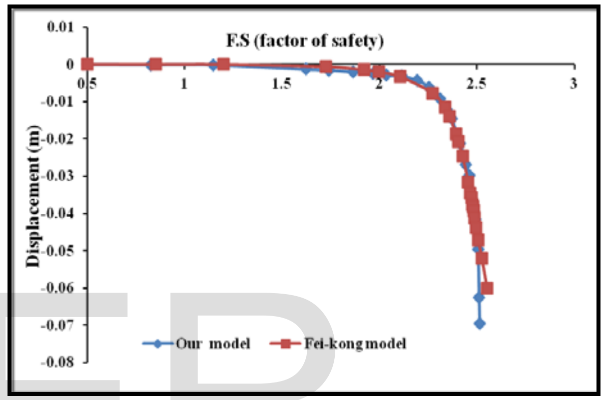


Fig. 7. F.S and displacement relationship

4 Results and Discussions

4.1 Discussion with respect to water content

In this part, the key points are to find how the changes and the effect of water content on pressure acting on the pile. Accordingly, this modeling was conducted through these points: (1) For different water content, load magnitude is computed and entered to ABAQUS software using surface traction option. (2) Based in the Figure 2, the load was applied at the pile surface using surface option traction which available in ABAQUS (two load is created and applied for each surface in order to find the correctness). Finally, different analysis is obtained and it will presented in this section.

4.2 Horizontal displacement of the pile

Figure 8 shows the horizontal displacement on pile. As can be seen from figure 8, pile displacement decreases when the water content increase. The maximum pile displacement of 23×10^(-3) m is conducted when the water content was 20 %, while 100×10^(-3) m was achieved when the water content is 23%. The pile displacement is almost the same when the water content was 15~30 % which approximately around 14×10^(-3) m and 13.5×10^(-3) m, respectively.

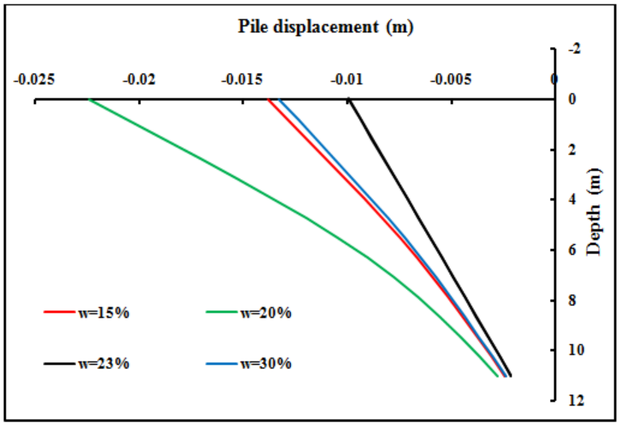


Fig. 8. Horizontal pile displacement (m)

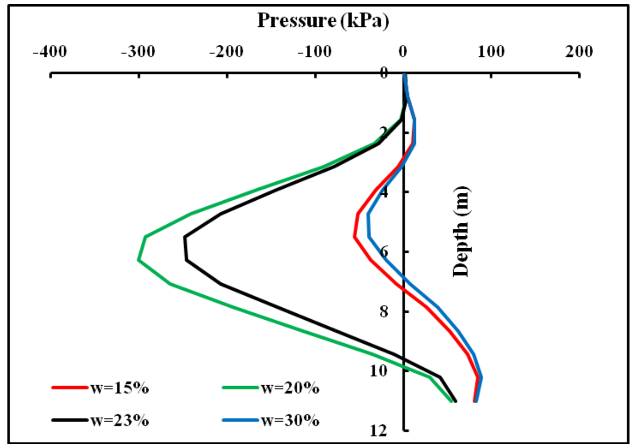


Fig. 9. Pressure acting on pile at passive zone.

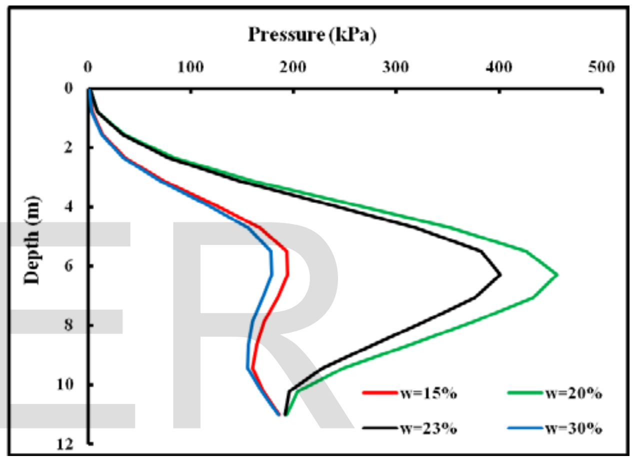


Fig. 10. Pressure acting on pile at active zone.

4.3 Pressure acting on the pile

TABLE 5
LOAD MAGNITUDE AND WATER CONTENT VALUES

	$w = 10\%$	$w = 15\%$	$w = 23\%$	$w = 30\%$
Load magnitude	19.3914	19.4519	19.355	19.2711

The important point in this section is to analyses the pressure acting on the pile due to swelling deformation. The swelling deformation generated after the water content change. Figure 9 and Figure 10 show the pressure acting on the pile at the passive and active zones, respectively.

The difference of values in these figures is due to difference of the pressure acting on both sides of the pile. From the Figure 9, the pressure acting on passive zone is 50 kPa when the water content is 15%.

However, when the water content increased to 5%, the pressure in this side also increased until reaches 320 kPa, then, it was increased again to 240 kPa when the water content increased to 3%. In the same way, when the water content increased to 7%, the pressure acting on passive zone decrease to 40 kPa. The depth 0 m means, the bottom of the pile, it can be seen from the figures, the pressure increase from 0 to 5 m then decrease from negative to positive value. The pressure acting on pile is look like the retaining wall design pressure. The maximum pressure, -320kPa with negative value is reach at the medium or at 5 m of the depth, then decrease to 50 kPa below the 10 m.

Figure 10 shows the pressure acting on active zone. The maximum pressure, 450 kPa is reach when the water content is 20% while minimum pressure, 150 kPa when the water content was 30%. When the water content increase 5%, the pressure reach the maximum pressure 450 kPa then decrease to 150 kPa. It can be seen, from the Figure 10, the pressure acting on pile increase then decrease.

5 CONCLUSIONS

From the results obtained by using ABAQUS FE analysis, the following conclusions are drawn.

The tendency for increase water content in homogenous expansive slope stabilized with pile has been proved by the result obtained from the analysis. The comparison between different pressures acting on the pile under different water content shows that the maximum pressure of 450 kPa is given when the water content was 20% at active zone. The result also shows that the pressure acting on the pile in the passive zone is a bit greater than the pressure acting on the pile in the active zone. The pile horizontal displacement is affected by water content change about 39.13%.

Finally, the developed FE models verified in this study could be used as an alternative to experimental test which is typically costly and time-consuming. The FE modeling using ABAQUS can serve as a numerical platform for performance prediction of RC beams with circular openings.

6 RECOMMENDATIONS

It is recommended that more analysis respect to swelling behavior should be continually conducted. Specially, for unsaturated soil, the swelling process under different water content seems too different with that under different expansion force.

Due to the relationship between swelling deformation, water content, dry density, overburden pressure, it is recommended that the investigation on the relationship should be carried out by theoretical and experimental work.

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