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Numerical Modeling for Behavioral Analysis of Expansive Soil under Shallow Foundations

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ABSTRACT

This study focuses on the potential for inflation and damage resulting from the construction of buildings and shallow foundations on expansive soils. As it is known, the geotechnical properties of expansive soils are controlled by the two main parameters of moisture absorption and soil's clay particles which is mainly occurred in fine-grained soils. When expansive soils absorb water and swells. This swelling causes extensive damage and rupture to surface/shallow foundations. Studying on soil swelling behavior of the expansive soils on shallow foundations can be considered as most important aspect of problematic soil's investigations. In this regard, the finite element numerical modeling by Plaxis software has been included in this article. The model is prepared based on shallow loading on expansive soil and evaluate the deformations. Numerical results indicate the failure status under foundation with respect to the behavioral displacement on soil.

1. Introduction

Expansive soils are covered in large parts of the world, especially in arid and semi-arid regions. These soils belong to the group of clay-based soils that are usually a mixture of clay and non-clay minerals. The geotechnical characteristics of these soils are controlled by their clay side (Tang et al., 2018). This soil contains a significant amount of clay minerals like montmorionite, smectite, which swells with dewatering and shrinks due to water loss. These soils are a serious problem for engineering structures due to their ability to swell and shrink in the face of fluctuations. In the United States, the annual damage from the destructive behavior of expansive soils to highways, passages, airports, tunnels, irrigation canals, and other structures is estimated over than 9,000 million dollars which has been greater than the damage caused by natural disasters such as floods, hurricanes, and/or earthquakes (Mahedi et al., 2020). An important parameter in the expansive soil's study is swelling-shrinkage phenomena and the effect of changing the moisture content of swollen soils which depending on environmental conditions, the soil is more exposed and successive drying (Khadka et al., 2020). Expansive soils are prone to swelling are usually classified as problematic cohesion soils. These soils are known as swellability like clay soils containing montmorionite, bentonite, kaolinite and illite (Selvakumar and Soundara, 2019). Non-cohesion soils are usually is not shows swelling potential (Das, 2008). Problematic soils in urban areas, construction sites, large and small development projects have always had their own problems (Das, 2005). Various researchers have conducted extensive studies on the classification of various problematic soils

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especially expansive soils and have tried to quantify the situation and conditions governing it by various experimental, workshop and laboratory methods to formulate this phenomenon (Kumar and Thyagaraj, 2021). Soil swelling along with soil liquefaction is one of the biggest causes of landslides and one of the major issues in geotechnics around the world, but this phenomenon occurs in soils containing fine clay particles that show high ability to absorb water (Tang et al., 2018). In Iran, due to the existence of different geological formations, facies, different climatic conditions, and being located in the arid and semi-arid zone of the tropics and the presence of arid deserts and large semi-arid regions in the country has created suitable conditions throughout the country in terms of problematic soils, especially expansive soils (Chen, 1988). Cities such as Yazd, Isfahan, Qom, Mashhad, Semnan, etc., are important evidence that the resulting damage of expansive soils has been recorded (Sajadian and Barkhordari, 2015).

Extensive or active soils are those soils that contain clay material that shrinks and decreases in volume when moisture is lost (at the dry-wet cycle) which expand and increase in volume by water (Briaud et al., 2003). As a result, the soil in a short period of time shows a very large behavior based on the decrease and increase of moisture-dependent volume (Chittoori et al., 2018). Increased humidity in these soils may be due to rainfall, climate change, leakage from water and sewage pipes, broken surface water transfer channels and so on. Moisture loss in these soils can also be attributed to climate change, evaporation, sunlight, sunny days and climate (Reddy et al., 2021). Swelling and shrinkage are not intrinsic properties for clay particles, but rather the result of the function between moisture uptake and suction and the inherent mineralogical and hydrophilic properties of clay particles in the soil (Charlie et al., 1984). The phenomenon of swelling or shrinkage and the extent of their effect is a function of the mineralogical conditions and type of clay minerals involved in the soil (for example, chlorite, illite, smectite or montmorionite). Quantity, shape, grain size, site topography, climatic and climatic conditions are the most important controlling factors in soil inflation potential (Eyo et al., 2017). A direct and observable result in the behavior of swollen soils is related to montmorionite mineralization (Al-Baidhani and Al-Taie, 2019).

Wetting and drying (inflation-shrinkage) are very well adapted to large-scale seasonal climate change (Bell, 1983). When shrinkage occurs, cracks form in the soil as it dries, which can be a good guide to identify them (Grimm, 1968). During the rainy season, swollen clay soils absorb large amounts of water, mainly through these mud cracks formed during shrinkage. The result is extensive changes in mass volume (Han, 2015). Inflation or contraction, or both, can cause enormous damage to structures that have been built on or within them, or have been used as building materials. . In general, cyclic swelling-shrinkage processes in swollen soils are very complex and practically inseparable. Figure 1 shows a view of water uptake and re-swelling in swelling soils. When a structure is built on swollen soils, the behavior that these soils normally perceive (when the soil is dry) is a normal behavior of other soils. As a result, the resistance parameters (such as stiffness, durability and strength) obtained from soil remediation studies provides high and acceptable values. On the other hand, they show a high carrying capacity.

2. Behavior of swollen soils

Wet and drying behavior of swollen soils can be studied based on changes in the parameters of void ratio (e) and soil moisture content (w). Changes in these two parameters in the wetting and drying process of the soil characterize its swelling-shrinkage paths. These pathways are important in understanding the processes of inflation and shrinkage and provide a tool for predicting volume change due to inflation and soil shrinkage. According to Han (2015), soil drying leads to different phases of deformation in its shrinkage curve. These contraction phases, as seen in Fig. 2, occur in three stages. In the first stage, which is called structural shrinkage, the moisture of a small number of large soil cavities is drained and the reduction of soil volume is less than the volume of lost water (Karunarathne et al., 2018).

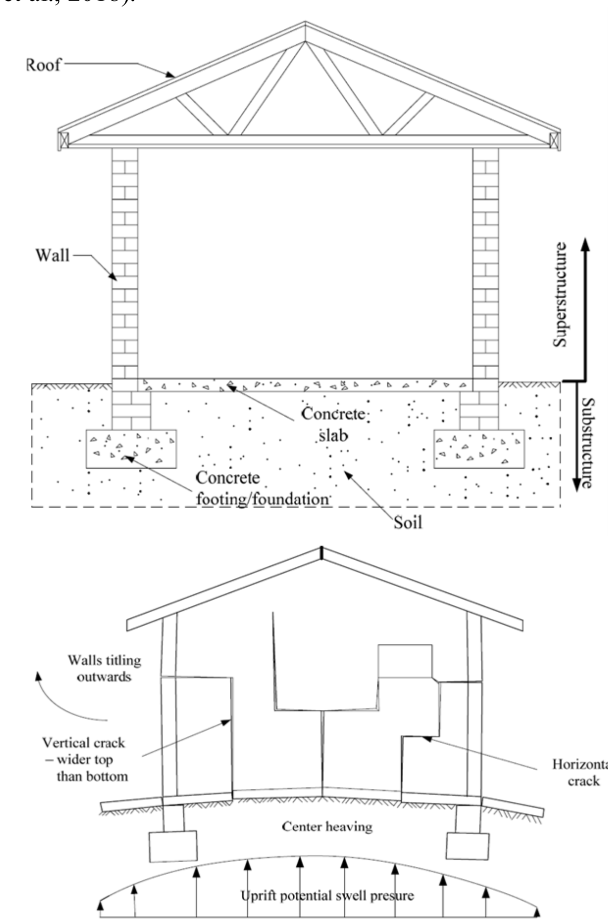

Figure 1. Scheme of inflation pattern under the foundation of a building (Goosen and Al-Rawas, 2007)

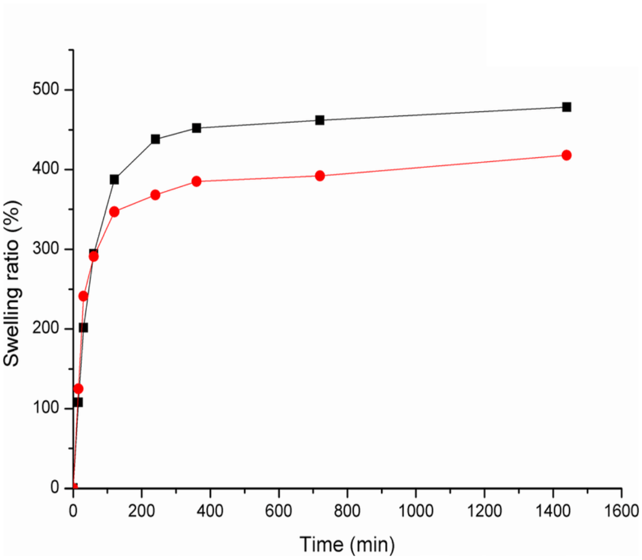

Figure 2. Swelling ratio vs time is expansive soils (Goosen and Al-Rawas, 2007)

In the second phase, called normal shrinkage, the reduction in soil volume is approximately equal to the volume of water lost, and the slope of the shrinkage curve at this stage is 45 degrees. With more drying of the soil and the beginning of the third phase of shrinkage, the slope of the shrinkage curve changes and at a moisture content equal to the shrinkage limit of the soil, air enters its empty spaces. In this phase, due to the proximity of soil particles to each other, the reduction in soil sample volume is less than the volume of moisture lost (Gao et al., 2018). Several factors such as moisture and initial porosity ratio, type of clay minerals, coarse units' structures as well as existing overheads play a very important role in the swelling potential of swollen soils. The change in volume of such soils is mainly affected by the amount and type of clay minerals. So that volume change in large scales is always accompanied by the presence of very large amounts of active masses. When these soils become dry due to the decrease of moisture, the phenomenon of shrinkage occurs and the subsequent increase of moisture causes them to swell, resulting in the absorption of pore water (Goosen and Al-Rawas, 2007).

Tripathy et al. (2002) on the study of the properties of expansive soils due to wet and dry cycles in the consolidation system so that wet and dry cycles with increasing water to the sample to achieve maximum swelling and drying of the sample to air flow device is made with the creation of a heating system. In the phenomenon of inflation, there are usually three phases, which are primary inflation, secondary inflation and non-inflationary phase. The cause of swelling of clay minerals is the absorption of water by the intercrystalline network of clay minerals. Among kaolinite clay minerals, illite and montmorionite are the most important minerals whose swelling properties are controlled by their lattice structure (Goosen and Al-Rawas, 2007).

As mentioned, the increase in humidity causes swelling and the depth of the soil section in which the change of moisture occurs intermittently is known as the "active zone". Dry and wet seasons cause changes in temperature and naturally cause the phenomenon of soil contraction and expansion, all of which cause physical and chemical erosion of the soil. Changes in seasons, precipitation, and evaporation are some of the factors that have caused soil erosion to be affected by contraction-expansion cycles. Soil foundations are built, subject to strong interaction forces due to inflation. These forces cause protrusions, cracks, and fractures to form and signify (Goosen and Al-Rawas, 2007). In order to determine the status and damage potential of expansive soils, laboratory experiments and numerical analytical methods are designed assuming construction conditions and are widely used in geotechnical soil operations studies. The presented study attempted to use numerical procedure to investigate the expansive soils behavior under the surface structures like shallow foundations.

3. Material and Methods

The presented article used finite element numerical model by Plaxis software. Plaxis software is two-dimensional analysis software for analysis of stability, deformation, subsidence, compaction, compaction and leakage under static and dynamic conditions in the field of geotechnics (Tsegaye, 2010). In order to achieve a correct modeling of the conditions governing the mass, in this dissertation, most of the parameters considered in soil swelling susceptibility analysis are proposed and applied in the model. So, the model is prepared and implemented in four stages: geometric mass modeling, boundary conditions, property allocation and definition of behavioral models, and mechanical modeling under clay saturation conditions. The following is a brief description of the modeling process:

Geometric modeling: Dealing with soils containing problematic materials is always natural and possible in geotechnical engineering. Soils are widely used as materials in design and construction. In other words, it can be said that geotechnical structures are made and executed from soil, with soil and in soil. Therefore, the existence of problematic soil (which in this study is expansive soil) is an inescapable possibility. In order to cover the problem and investigate in the most critical situations possible, we tried to collect information about the impact and importance of swollen soils and based on statistical analysis and the normal distribution function on the data and normalize them. The most important type of approach as the basis of geometric modeling should be considered in this study. In this modeling, a surface foundation of a concrete structure built on montmorionite clay soils' properties is analyzed.

Boundary conditions and free borders: Zienkiewicz et al. (1988) stated that boundary conditions based on the fixation of lateral boundaries of nodes and nodes for the ability to control the body of the mass. This action reduces the amount of computational error under the analysis time which is usually the maximum time range or operation applied in the consolidation analysis in the model.

Assignment of properties and behavioral models: In order to determine the behavioral properties and to determine the behavioral model for the model of mass body material selection based on the range determined for clayey soils and shallow foundation is considered. Table 1 shows the input parameters of Plaxis software for assigning properties to the expansive soil and foundation. The behavioral model used in this study is the Mohr–Coulomb criterion (MC). This behavioral model based on failure envelope under normal-shear stresses in the form of plane (2D) and spatial (3D), makes it possible to analyze the failure in both tensile and compressive loading condition (Tsegaye, 2010). Stress analysis as a 9-state tensor with 6 independent criteria is considered in spatial analysis.

Table 1. Geotechnical properties of the soil and foundation

Materials	Parameters	Unit	Value
Foundation	γ_{unsat}	kN/m^3	19.00
	γ_{sat}	kN/m^3	19.00
	E_{ref}	kN/m^3	1000000
	υ	-	0.3
	C_{ref}	kN/m^3	712
	ϕ	Degree	54.9
	ψ	Degree	0.00
Expansive soil	γ_{unsat}	kN/m^3	17.20
	γ_{sat}	kN/m^3	19.00
	E_{ref}	kN/m^3	200000
	υ	-	0.33
	C_{ref}	kN/m^3	255
	ϕ	Degree	0.00
	ψ	Degree	0.00

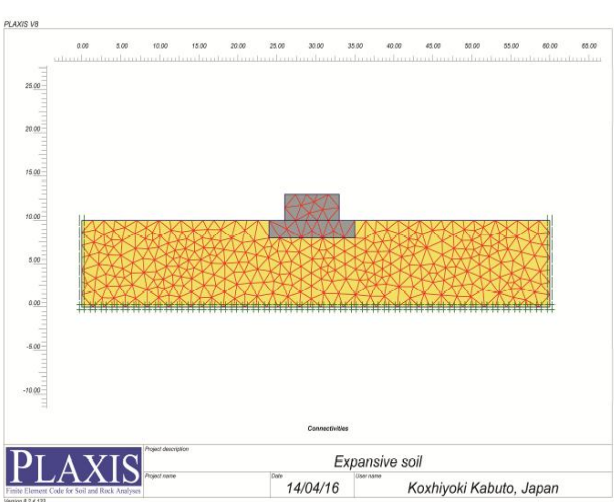

Figure 3. The model for studied foundation on expansive soil

Mechanical modeling: After geometric modeling, determining the boundary conditions, assigning properties and behavioral model to the model, the model is solved under the certain conditions. The results of this evaluation are presented as a mechanical model which is provided the deformation, stress-strain status, displacements of the model. The mechanical model of the shallow foundation is considered in this study which is illustrated in Fig. 3. The model solved and extracts the simulation results for behavioral study on shallow foundations under loading were located on expansive soils.

4. Results and Discussions

By considering the various stages of the modeling mentioned in the previous section, the model is implemented step-by-step to prepare mechanical stages. In the step model calculated and run to evaluate the deformations, displacements and stress-strain status regarding the expansive soil loading. Figs. 4 to 10 are illustrated the results of the mechanical modeling of the shallow foundation behavior on expansive soil. These model indicated that the

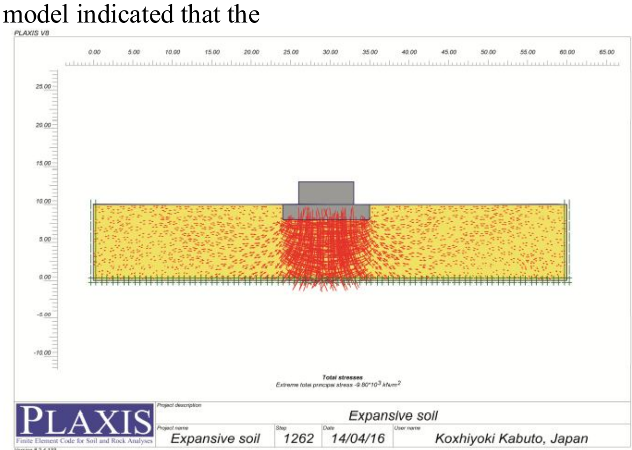

Figure 4. The main stress distribution on expansive soil

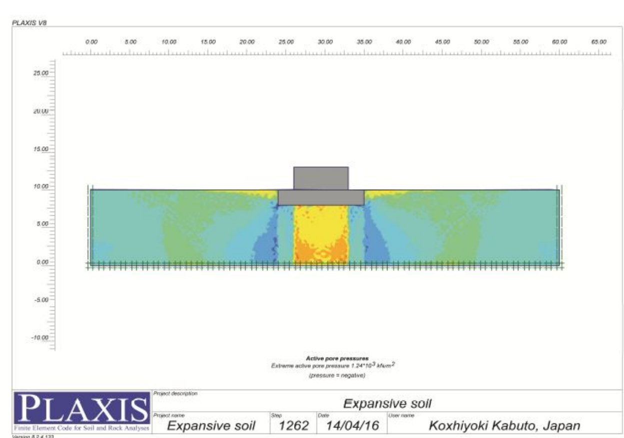

Figure 5. Active water pore-pressure condition for expansive soil

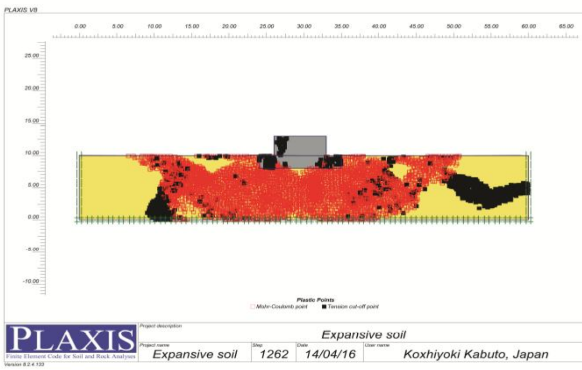

Figure 6. The plastic points distribution in expansive soil under loading

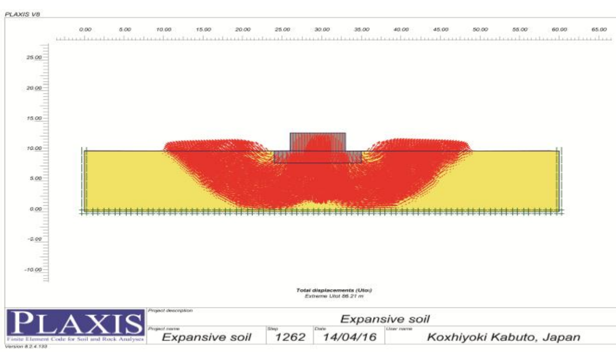

Figure 7. The displacement status in expansive soil under loading

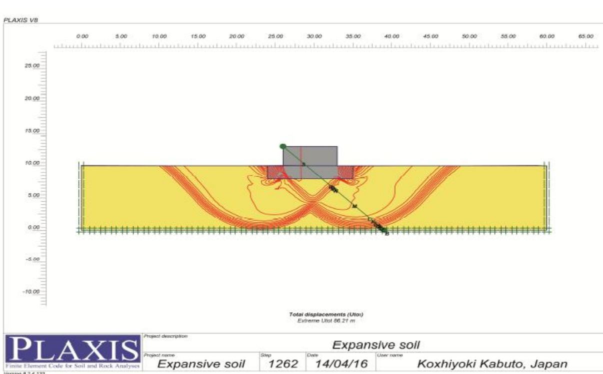

Figure 8. expansive soil failure status under the foundation

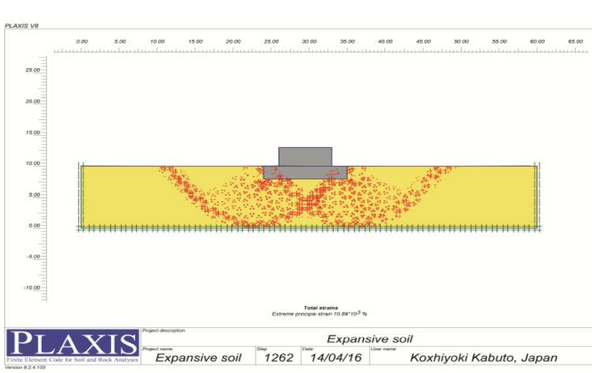

Figure 9. The strain status in expansive soil under loading

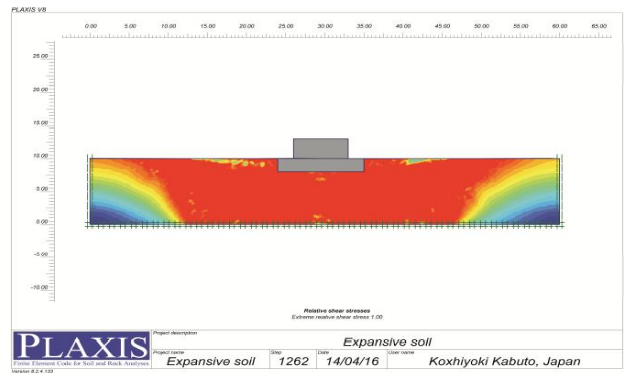

Figure 10. The shear stress condition in expansive soil under loading

5. Conclusion

In nature, there are many problematic soils, the most important of which can be found in the soils that are congested, etc. Combined soils are the most common problem-solving soils, which in geotechnical studies have the greatest losses in dry and semi-arid areas on structures, especially light and surface structures. Inflammation in the deposited soils is controlled by the presence of clay particles, especially the monteurionite group. It should be noted, of course, that the inflation potential and the inflation range depend to a large extent on the amount and type of clay minerals present in the soil samples. Due to the presence of a special surface and the ability to absorb high surface area, the monteurionite group has the greatest effect on soil inflation. Clay particles with high plasticity and sedimentary sediments are absorbed by the water in their structure, and if the structures are built on them, they cause damage to the structure and structure. The inflation phenomenon is a cyclical phenomenon that has distinguished this phenomenon from other problem-solving soils. The rapid return of its dependence to the changes in moisture content in the space between the particles of the existing surfaces in the soil (monteurionite) has become a one-time basic cleaning of the engineered soils. Inflammatory cycles - naturally occurring cystic fibrosis is a natural debate, and this phenomenon always occurs in a cyclical fashion. Therefore, the processes of control, control and improvement of these soils are different from those of other problematic soils, such as the Rawangra soils, if they are different. Appropriate dredging, non-use of cross and cement coverings, the implementation of proper replacement with low-grade soils, including the methods of soil inflation phenomena.

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