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Finite element numerical modeling of geogrid-reinforced shallow foundation's behavior on loose soils

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ABSTRACT

Investigating of foundations actions on soil is one of the most important topics in geotechnical engineering. This behavior indicates the stability conditions of the foundation under structure loading on the foundation and soil responses. In this regard, the foundation's behavior is affected by soil behavior and failure is likely. In recent years, the use of soil reinforced stabilization is considered as the most successful procedure to increase bearing capacity and reduce foundation's settlements. In this paper by using finite element numerical modeling, attempted to evaluate the behavior of the geogrid-reinforced soil which conducted by Plaxis2D software. For this purpose, with the series of modeling, the soil- foundation behavior for both unarmed and reinforced conditions has been evaluated and the of geogrids performance was estimated. Based on the results of modeling, it has been determined that the geogrids has a good ability to improve and stabilize soil conditions.

1. Introduction

All structures are eventually placed on the ground, so the performance of the foundation is one of the most important issues in the field of soil mechanics and foundation engineering. Foundations can be affected by static, dynamic, or a combination of loads. If the soil under the foundation does not have sufficient resistance to withstand the loads, you can use the methods of replacing suitable soil and compaction instead of loose soils. In some cases, the thickness of the replaced soil does not meet the required bearing capacity, or in addition, geometric and economic constraints may make the implementation of soil improvement methods inappropriate. In these conditions, the use of reinforcements with tensile strength in order to reinforce and increase the bearing capacity of the soil will be a suitable solution (Sitharam and Sireesh, 2006).

The use of polymeric materials such as geogrids to increase soil bearing capacity has been considered by engineers and researchers in the field of geotechnics in recent decades (El-Soud and Belal, 2018). A geogrid is geosynthetic material used to reinforce soils. Geogrids are commonly used to reinforce retaining walls, as well as subbases or sub-soils below roads or structures. Soils pull apart under tension. Compared to soil, geogrids are strong in tension. Geogrids are commonly made of polymer materials, such as polyester, polyvinyl alcohol, polyethylene or polypropylene. They may be woven or knitted from yarns, heat-welded from strips of material or produced by punching a regular pattern of holes in sheets of material, then stretched into a grid (Basudhar et al., 2007).

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The development of methods of preparing relatively rigid polymeric materials by tensile drawing in a sense cold working, raised the possibility that such materials could be used in the reinforcement of soils for walls, steep slopes, roadway bases and foundation soils (Chakraborty and Kumar, 2014). The principal function of geogrids is for reinforcement. This area, as with many other geosynthetics, is very active, with a number of different products, materials, configurations, etc., making up today's geogrid market. The key feature of all geogrids is that the openings between the adjacent sets of longitudinal and transverse ribs, called apertures, are large enough to allow for soil strike-through from one side of the geogrid to the other. The ribs of some geogrids are often quite stiff compared to the fibers of geotextiles. As discussed later, not only is rib strength important, but junction strength is also important. The reason for this is that in anchorage situations the soil strike-through within the apertures bears against the transverse ribs, which transmits the load to the longitudinal ribs via the junctions. The junctions are, of course, where the longitudinal and transverse ribs meet and are connected. They are sometimes called nodes (DeMerchant et al., 2002).

Currently there are three categories of geogrids. The first, and original, geogrids were invented by Dr Frank Brian Mercer in the United Kingdom at Netlon, Ltd., and were brought in 1982 to North America by the Tensar Corporation. A conference in 1984 was helpful in bringing geogrids to the engineering design community. A similar type of drawn geogrid which originated in Italy by Tenax is also available, as are products by new manufacturers in Asia (Hou et al., 2017). The second category of geogrids are more flexible, textile-like geogrids using bundles of polyethylene-coated polyester fibers as the reinforcing component. They were first developed by ICI Linear Composites LTD in the United Kingdom around 1980. This led to the development of polyester yarn geogrids made on textile weaving machinery. In this process hundreds of continuous fibers are gathered together to form yarns which are woven into longitudinal and transverse ribs with large open spaces between. The cross-overs are joined by knitting or intertwining before the entire unit is protected by a subsequent coating. Bitumen, latex, or PVC are the usual coating materials. Geosynthetics within this group are manufactured by many companies having various trademarked products. There are possibly as many as 25 companies manufacturing coated yarn-type polyester geogrids on a worldwide basis (Huang and Tatsuoka, 1990). The third categories of geogrids are made by laser or ultrasonically bonding together polyester or polypropylene rods or straps in a gridlike pattern. Two manufacturers currently make such geogrids (Mosallanezhad et al., 2016).

Several researches have demonstrated that the ultimate bearing capacity and the settlement characteristics of the foundation can be improved by the inclusion of reinforcements in the ground (Kolay et al., 2013). The findings from several laboratory tests and numerical models indicated the ultimate bearing capacity of shallow foundations can be modified by application of geogrids under the foundation for stabilize the soils with multiple layers. Yin (1997) and Bowders et al. (1998) provide the compiled comprehensive literature in the handbook of geosynthetic in foundation reinforcement and erosion control systems. Kolay et al. (2013) mentioned in the design of shallow foundations in the field, the settlement becomes the controlling criteria rather than the bearing capacity. Thus, it is important to evaluate the improvement in the foundations' bearing capacity at different settlement levels. According to the several scientific reports, it can be concluded that the bearing capacity of soil also changed with various factors like type of reinforcing materials, number of reinforcement layers, ratios of different parameters of reinforcing materials, and foundations (Mosallanezhad et al., 2016). The ratio of improvement in the bearing capacity can be expressed in a non-dimensional form as bearing capacity ratio which is the ratio of bearing capacity of reinforced soil to bearing capacity of unreinforced soil. The presented study used the numerical models to estimate the bearing capacity ratio from reinforced soil vs unreinforced soil under shallow foundations.

2. Material and Methods

Numerical methods include various methods such as finite elements (FEM), discrete elements (DEM), boundary element (BEM) methods and etc. Among them, the FEM has a good efficiency in soil due to its algorithmic assumptions that are used for analysis in continuous environments (Das and Samadhiya, 2020). By definition, soil is a continuous and homogeneous environment (Chen et al., 2020). Considering the soil's linear elastic-plastic behavior and the Mohr–Coulomb failure criterion's validity, the geo-mechanical behavior of soils against the stress-strain of different structures can be determined by numerical methods such as finite elements. In this regards, the presented article use the FEM models by Plaxis software (PLAXIS, 2018) to provide the appropriate assessment of bearing capacity of shallow foundation and settlement conditions. Figure 1 is presented the studied foundation geometrical status where numerical procedures conducted.

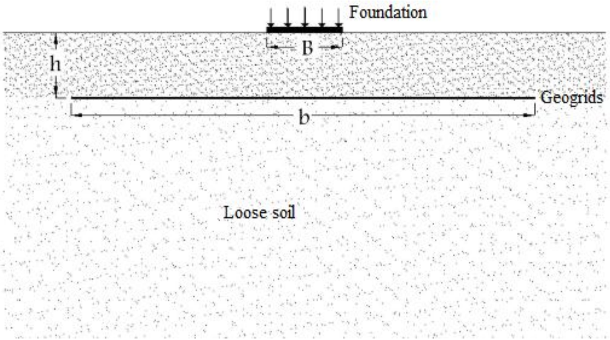

Figure 1. Geometrical status of shallow foundation and geogrids

In order to achieve accurate modeling of soil conditions, in this study, most of the coverage in the parameters considered in soil analysis is proposed and applied in the model. Therefore, the model is prepared in four stages: geometric modeling of the mass, boundary conditions, property allocation and definition of behavioral models, and mechanical modeling for the two states of being on the ground of the weapon with geogrid and for the state armed with geogrid. It becomes. The following is a brief description of the modeling process.

2.1. 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 is an inescapable possibility. According to the main topic of this dissertation, this is to investigate the bearing capacity of foundations in soil under reinforcing conditions and parameters in modeling for foundation as concrete in situ under static loading. This issue is considered for both armed and unarmed soils by Geogrid, which has shown the purpose of behavioral analysis to improve soil conditions in the control of the following wedge rupture. In this regard, two series of geometrical models have been prepared, which are given in Figs. 2 and 3. As can be seen in these figures, the environmental conditions in the foundation load are continuous and the same conditions are considered to emphasize the behavior of the foundation and materials and geogrid.

2.2. Model boundary conditions

In general, two types of boundaries are introduced for the analysis of deformation in the soil environment for Plaxis software in static conditions. In this study, two main types called free boundaries and closed boundaries are used in two axes:

A) *Closed boundaries (two-axis and single-axis)*: Closed boundaries can be referred to as a special type of boundary condition where the boundaries are in the x-axis or y-axis or both closed to prevent reflection at those points. This type of boundary limits the possibility of displacement and deformation along a specific axis or both axes.

B) *Free boundaries*: This type of boundary condition, as its name implies, allows the occurrence of movement and displacement for the mass in the lateral boundaries. It can be appropriate to use this boundary to determine the status of stimulus stresses and particle mobility in soils.

2.3. Assignment of properties and behavioral models

In order to determine the behavioral properties and to determine the behavioral model for the model, the choice of body materials based on the range in the soils under load is considered. Problematic soils that are subject to extensive subsidence are usually classified as sticky-non-sticky soils, which have the ability to paste, plasticize and continuously shrink, respectively. Therefore, considering the soil in such conditions can indicate extensive changes in soil masses. In the present modeling, a concrete surface foundation is placed on a subsidence-prone soil mass, which is based on the purpose of evaluating the wedge and soil rupture (soil load analysis). In this regard, three groups of materials are described as the first material related to the foundation material, which is concrete, and the geotechnical parameters of concrete. The second material is related to the parameters in the bed soil and the third material is related to the geotechnical properties of the geogrid / geogrid group to which the relevant materials are assigned. Table 1 lists the input parameters for the model and in Figs. 4 and 5 the model for assigning the given properties. The behavioral model used in this study is the Mohr–Coulomb elastoplastic model.

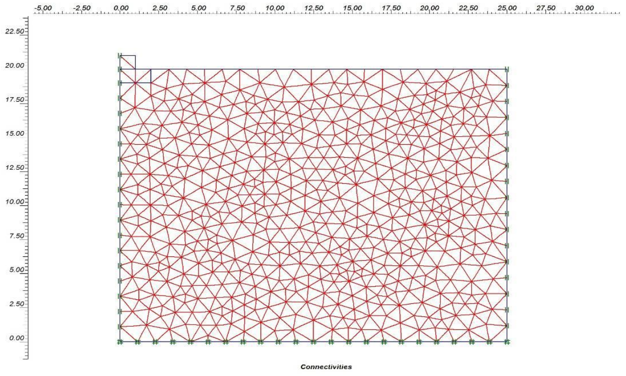

Figure 2. Geometrical modeling of shallow foundation without geogrids

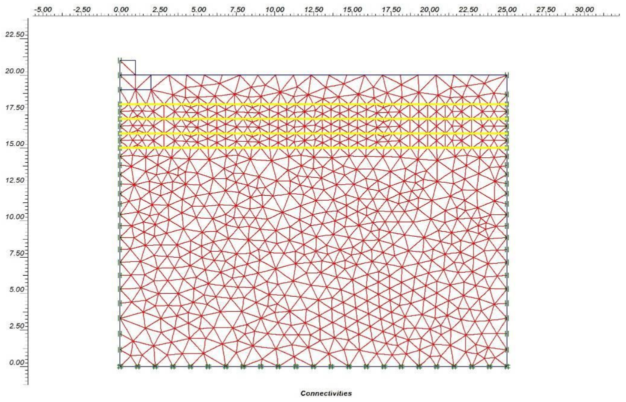

Figure 3. Geometrical modeling of shallow foundation with geogrids

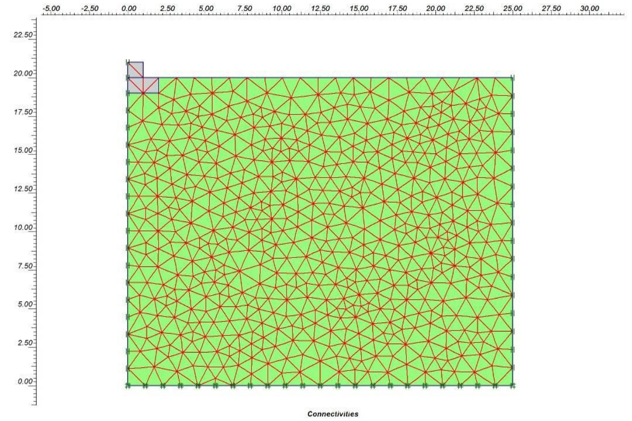

Figure 4. Geometrical modeling of shallow foundation without geogrids

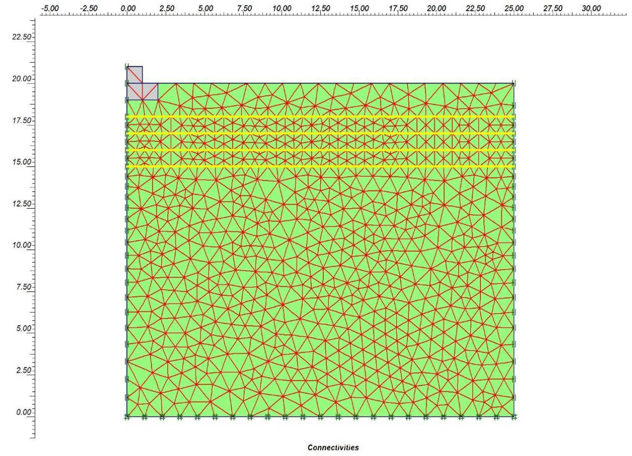

Figure 5. Geometrical modeling of shallow foundation with geogrids

Table 1. Input parameters for model

Section	Parameters	Unit	Value
Foundation	γ_{unsat}	kN/m^3	24
	γ_{sat}	kN/m^3	24
	E_{ref}	kN/m^2	500000
	υ	-	0.25
	C_{ref}	kN/m^2	500
	ϕ	Degree	35
	ψ	Degree	00
Soil mass	γ_{unsat}	kN/m^3	17.20
	γ_{sat}	kN/m^3	20
	E_{ref}	kN/m^2	13000
	υ	-	0.3
	C_{ref}	kN/m^2	120
	ϕ	Degree	31
	ψ	Degree	00
Geo-gried	E_{ref}	kN/m^2	10^{15}
	Model	-	Elastic

3. Results and Discussions

After geometric modeling, determination of boundary conditions and assignment of properties and behavioral model to the model, the model is considered and solved under the conditions. In this regard, two modeling groups related to surface foundation have been prepared that vertical changes (against subsidence) have been measured and the axial stress-strain field for the foundation has been measured. The results of this evaluation are presented as a mechanical model and the results are used to interpret the prevailing conditions. Mechanical modeling is performed on the modeled surface foundation and the results are as follows.

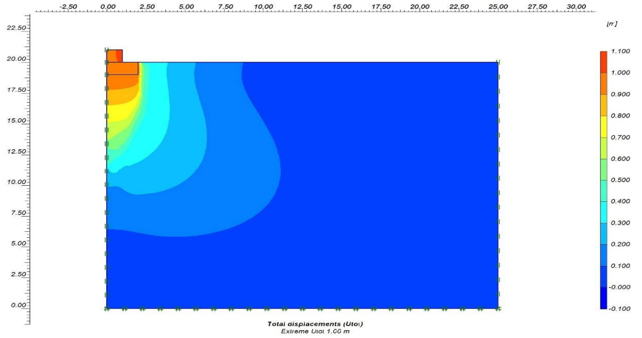

Figure 6. The state of total deformation and displacement in the soil-foundation system without geogrids

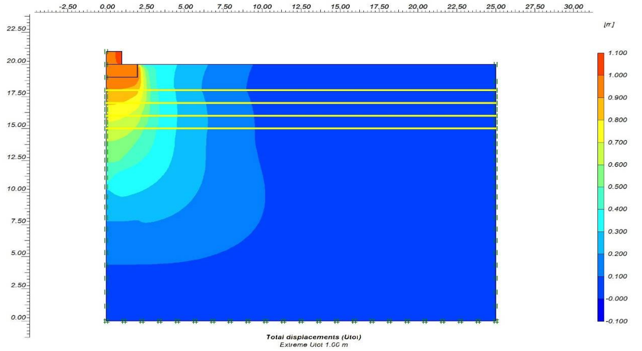

Figure 7. The state of total deformation and displacement in the soil-foundation system with geogrids

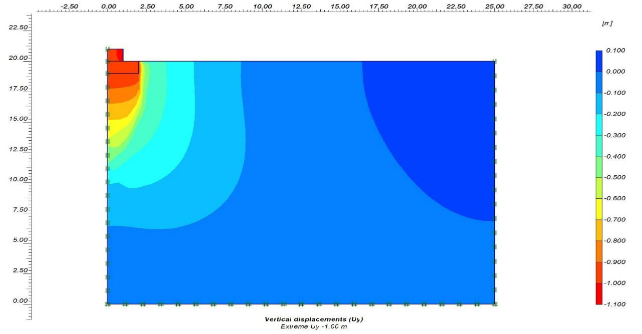

Figure 8. The state of vertical displacement in the soil-foundation system without geogrids

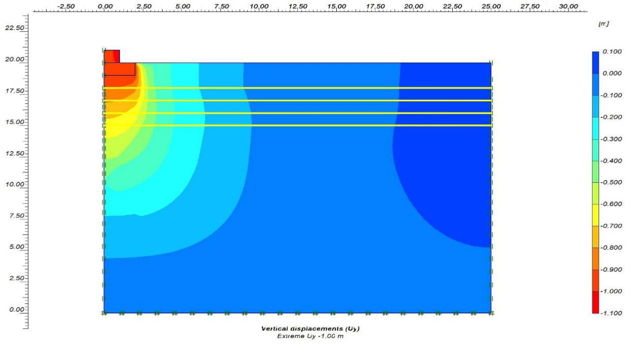

Figure 9. The state of vertical displacement in the soil-foundation system with geogrids

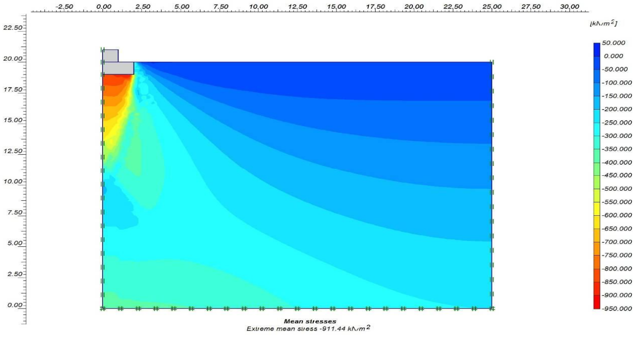

Figure 10. The state of in-situ stress in the soil-foundation system without geogrids

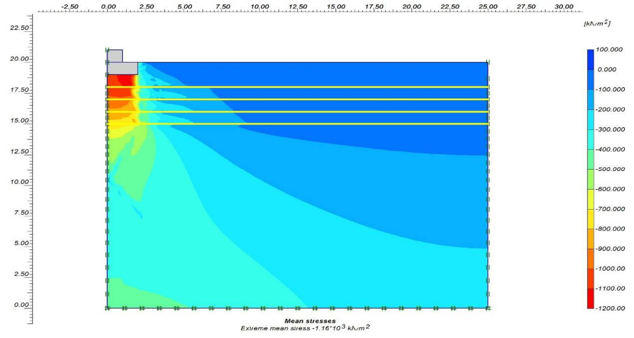

Figure 11. The state of in-situ stress in the soil-foundation system with geogrids

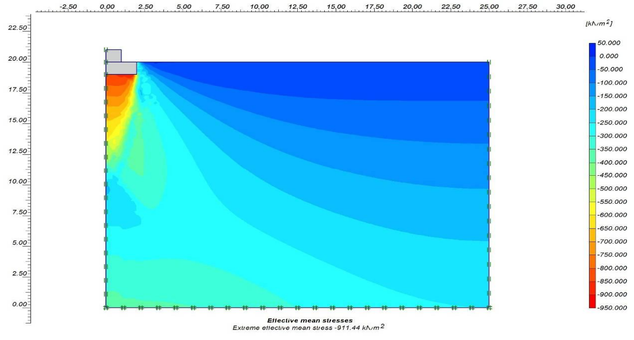

Figure 12. The state of effective stress in the soil-foundation system without geogrids

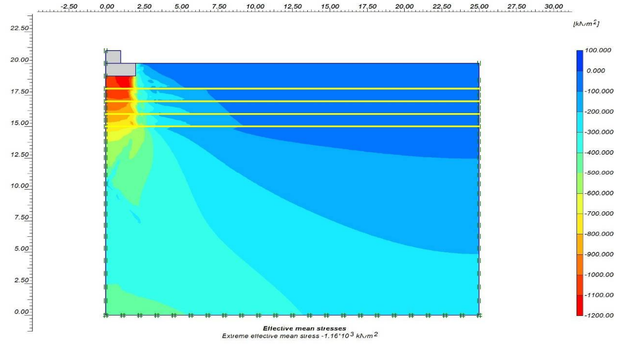

Figure 13. The state of effective stress in the soil-foundation system with geogrids

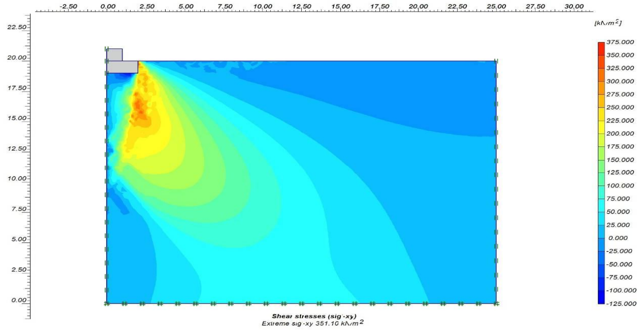

Figure 14. The state of shear stress in the soil-foundation system without geogrids

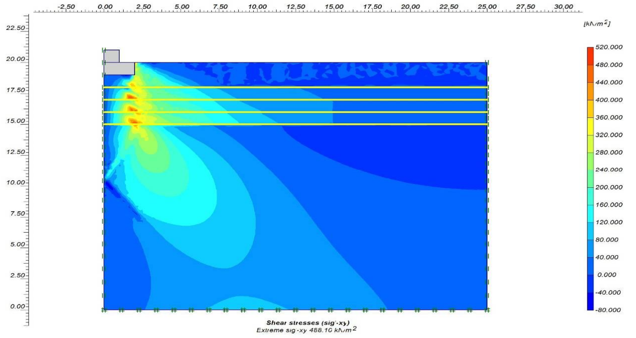

Figure 15. The state of shear stress in the soil-foundation system with geogrids

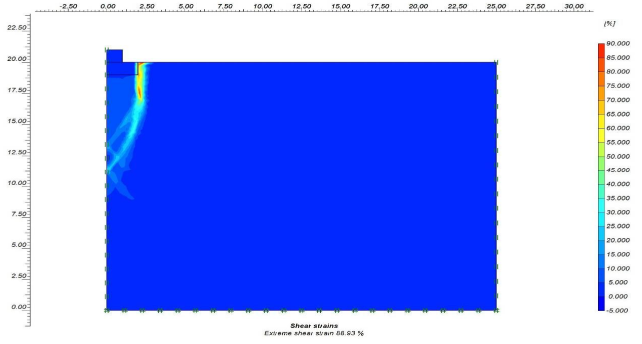

Figure 16. The state of total strain in the soil-foundation system without geogrids

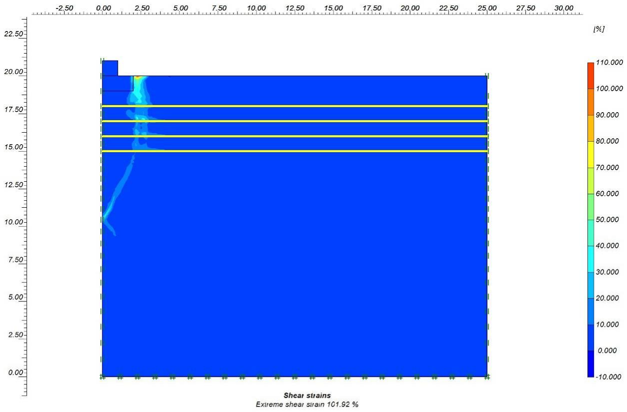

Figure 17. The state of total strain in the soil-foundation system with geogrids

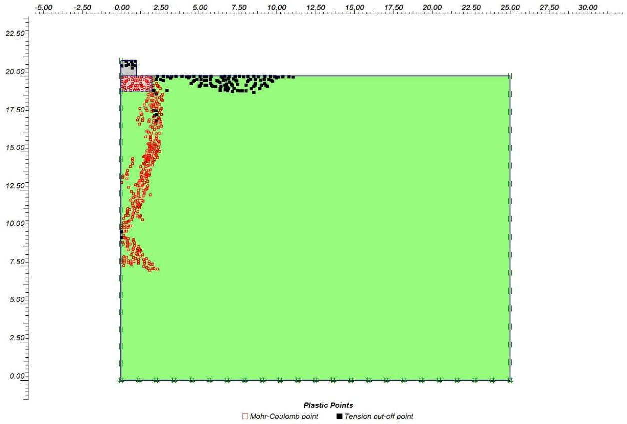

Figure 18. The state of plastic points in the soil-foundation system without geogrids

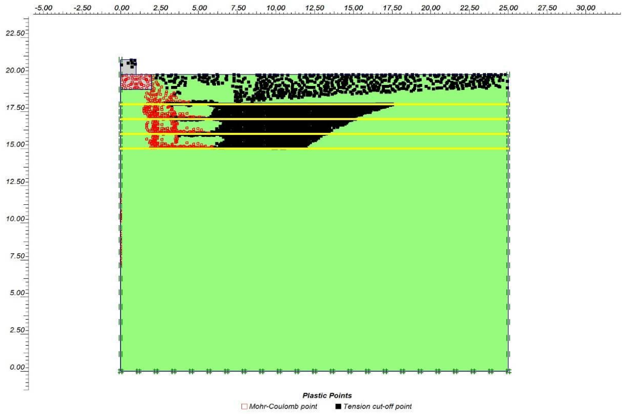

Figure 19. The state of plastic points in the soil-foundation system with geogrids

Numerical modeling allows data monitoring during analysis under different conditions to achieve an effective result. In experimental analyzes, monitoring is possible based on performing multiple tests to check the current situation. But it requires more money and time than numerical analysis. In this regard, the use of numerical approaches, especially FEM methods to analyze the work of soil mechanics is very priority. In this research and the results of mechanical modeling, surface analysis is presented to evaluate the performance of deformations related to the implementation of the soil reinforcement system by Geogrid. For this purpose, two simulation groups have been used, which can be divided into non-run geogrid and run geogrid. Figure 20 shows the wedge rupture condition. As can be seen in this figure, the highest stress concentration is absorbed in the foundation range after geogrid execution and has prevented its deep expansion. This indicates the ability of the geogrid group to control the wedge rupture under the foundation.

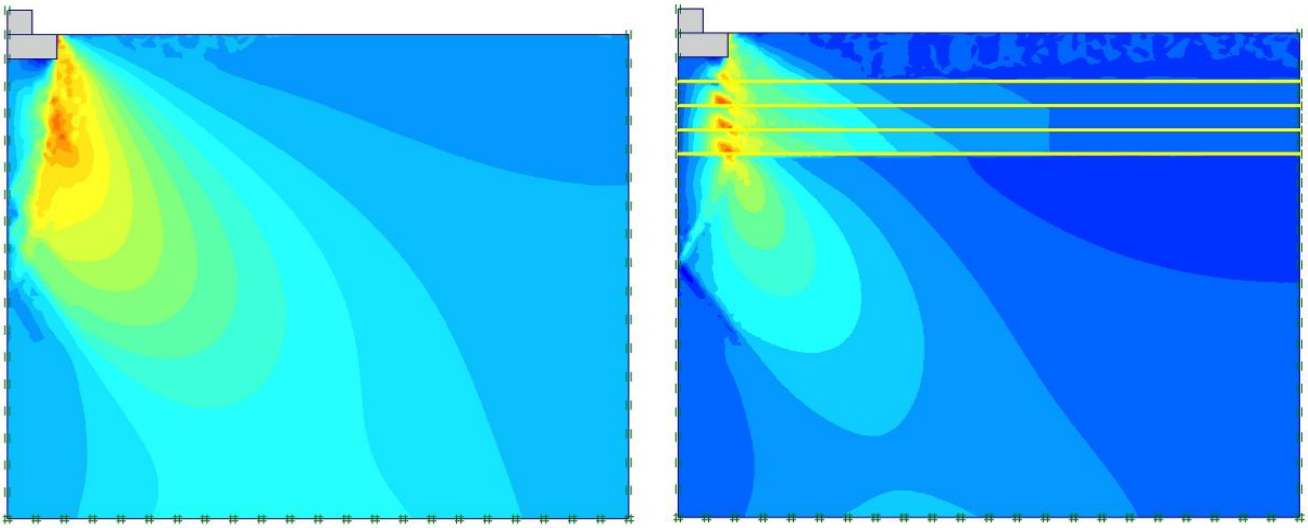

Figure 20. The performance of geogird application on settlement control by model

4. Conclusion

The present study investigates the effect of layered geogrids on loose soils to investigate the performance of soil stabilization in soil-foundation system by utilizing the finite element numerical method and Plaxis software. For this purpose, a set of modeling including geometrical models, behavioral model and boundary conditions, mechanical model and load analysis and foundation settlement assessment have been conducted. The aim of this implementation is to measure the performance and ability of the model in the optimal execution of geogrids. During the simulation operation, two parts of the soil-foundation system were evaluated before and after the implementation of geogrids. Based on the results of numerical modeling, it has been determined that the use of geogrids is very efficient for the improvement and stabilization of loose soils.

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