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EXTENDED ABSTRACT

Investigation of Loose Sandy Soil Improvement with Granular Blanket and Stone Column in a Unit Cell

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1. Introduction

In this study, the effect of the unreinforced and geogrid-reinforced granular blankets, end-bearing stone columns and the combination of these techniques on the behaviour of loose sand soil models have been investigated through laboratory and numerical simulations. In the models, a stone column from a large group of them with a triangular pattern was simulated in a unit cell. Since the rupture of the geosynthetic reinforcement within the reinforced granular blanket has never been experimentally investigated, a novel method of installing the geogrid reinforcement was used, allowing it to mobilize and ultimately fail under loading. The optimal thickness of the unreinforced and geogrid-reinforced blanket, the optimum layout of the reinforcement within the blanket and the changes in the stress concentration ratio of the stone column in different modelling conditions have been determined. Another objective of the present study is to discover the relationship between the failure of the geogrid layers and the characteristics of load-carrying capacity and settlement of the model tests.

2. Methodology

2.1. Experimental study

In the experiments of the present study, a stone column from a large group of them with a triangular pattern was constructed in a cylindrical steel tank with 208mm inside diameter as a unit cell. A total of 10 test types have been conducted to compare the load-settlement characteristics of different modes of improving the loose sand bed. An identical procedure was utilized in all tests to prepare the sand bed and construct the stone column and the granular blanket. Based on the Buckingham similitude theory (1914), the ratio of the length scale of the model test to the prototype model is $1/\lambda$, which has been taken as 1/10 in this study. A 75mm diameter end-bearing stone column with a length-to-diameter ratio equal to 7 was physically constructed in the centre of the unit cell. According to the laws of similarity, geogrid reinforcement with a tensile strength of 8kN/m has been used for laboratory model tests. The Blankets, with thicknesses of 35mm and 65mm, were reinforced with one and two layers of geogrid. The intended load was applied as displacement control with a 1mm/min strain rate in all tests. The loading on several model tests until reaching 20mm settlement, as reported in the literature (Deb et al., 2011; Debnath and Dey, 2017), have been performed.

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2.2. FE modeling

The FEM-based software package, PLAXIS 2D V8.6, was used for the numerical modelling and complementary analysis. Since the unit cell simulation is considered axisymmetric, modelling with the 2D finite element software has been done. The input parameters for numerical modelling are taken from the laboratory results. The hardening behaviour mode has been used for sandy soil and aggregate materials. Numerical models' geometry and boundary conditions were chosen according to the physical model conditions. The side boundaries of the models were assigned as vertical rollers, while the fixed nodes were considered at the bottom of the model. In addition, 15-node triangular elements were used, and elastoplastic behaviour was used for the reinforcement due to the potential geogrid rupture. The prescribed displacement method has been used to adapt the numerical model's loading conditions to the laboratory model tests with equal strain mode.

3. Results and discussion

3.1. Effect of geogrid-reinforced blanket and stone column

Reinforcing the blanket with geogrid significantly boosted the load-carrying capacity and reduced the settlement of the model tests. Under conditions with a stone column, the geogrid rupture at a higher intensity of load and less settlement due to the stiffer bed caused by the presence of a stone column. In these charts, first, the slope of the load-settlement graphs increases until reaching a certain value; then, it becomes nearly constant within a range of the chart, after which the gradient rises again. Compared to the unreinforced model, the inclusion of geogrid in the blanket alters the charts' shape and slope. In addition, a noticeable prominence in load-settlement features and a change of direction of chart concavity at the threshold of geogrid rupture in the settlement ranging from 1-5 mm is observed. The shift in concavity direction and varying the slope from ascending to constant trend are related to the yielding of geogrid. During the load enhancement process, two stages of slope variation and concavity direction change are observed when two geogrid layers are used in the blanket. The first prominence is related to the failure of the first layer of geogrid reinforcement, followed by the failure of the second layer, which forms another prominence. There have been no reports of changes in the slope and direction of the concavity of the load-settlement characteristics in investigations of reinforced blankets with sheet geosynthetic reinforcement. All models with a layer of geogrid near the top of the blanket have load-settlement characteristics with steeper slopes and less settlement at the same load extent compared to the model with geogrid at the bottom. Similar findings have been observed while using two geogrid layers in the middle and near the top of the blanket, compared to placing the geogrid in the bottom and middle of the blanket.

The load ratio parameter (Ghazavi and Nazari Afshar, 2013) is derived by dividing the improved sand bed load-carrying capacity by the sand bed load-carrying capacity without improvement. This parameter, known as "LR", is related to the improved and unimproved models' load-carrying capacity in an equal settlement. In addition, the settlement ratio parameter, which is by dividing the model settlement by the diameter of the footing, can be defined. The load ratio-settlement ratio characteristics for the models with reinforced blankets reveal a prominent peak. These noticeable peaks are caused by the geogrid's tensile strength mobilization, followed by a sudden drop yielded by the geogrid's rupture. After the failure of the reinforcement layers, the resistance was only generated by sand and aggregate materials, which explains the sudden drop in LR variations. In the model tests with a reinforced blanket including two layers of geogrid, the LR increases with the settlement ratio, then drops suddenly after the prominent peak point. It indicates that all reinforcement layers ruptured within a relatively short period. Upon adding the stone column to the model with layer(s) of geogrid reinforcement, the growth of the load ratio increased further. Similar to using a single layer of geogrid, when two layers of the geogrid move away from the base of the footing while getting closer to the top of the stone column, the effect of the column in enhancing the load-bearing and reducing the settlement is intensified. Although, placing geogrid reinforcement layer(s) closer to the base of the footing is an optimum arrangement in the laboratory and numerical investigations. Generally, it can be said the maximum LR in all finite element models has been obtained at the optimal blanket thickness equal to 0.16 times the diameter of the footing.

3.2. Stress concentration ratio (SCR)

So far, fewer studies have been conducted about the effect of the blanket positioned over the stone column-improved bed on the stress concentration ratio. The SCR variations are due to changes in the axial stiffness of the stone column materials subjected to compressive loading (Debnath and Dey, 2017). The stiffness of aggregate materials in the range of low axial strain is the main reason for the high values of the stress concentration ratio. In conditions of thin unreinforced blanket thickness, after applying further pressure on the model and the possibility of displacement of the column's aggregates, its stiffness and load-carrying capacity are reduced, resulting, in the SCR reduction. By increasing the thickness of the blanket from 0.2 to 0.5 times the footing diameter, the stress concentration ratio has increased maximum of about 16%. But after that, by further increasing the thickness ratio to about 0.8, an almost constant slope has obtained at the end of the SCR chart, as mentioned in other research (Murugesan and Rajagopal, 2006; Ghazavi and Afshar, 2013). It seems that the cause for the increase of SCR until it reaches the thickness ratio of 0.5 is related to the fact that in thinner blankets, the stress transfer to the stone column and the circumferential soil is almost the same as when there is no blanket. In this condition, because of the significant densifying potential of the sandy bed and, as a result, increasing the confining stress around the stone column relative increase in the load-carrying capacity happened. Increasing the thickness of the unreinforced blanket exceeding a specific limit leads to a decreasing the amount of stress transferred to the soil and the confining stress on the stone column. Finally, it causes the reduction of changes in the stress concentration ratio. In the high thickness ratio, i.e. more than 0.8, the stress is applied less and more uniformly on the soil and the top of the stone column. So, changes in the stress concentration ratio become to be almost constant.

It can be said that the value of SCR for the stone column-improved sand bed models, including different layouts of a single geogrid within the blanket, is not constant while the footing is settled. The minimum value of SCR corresponds to a model with a 20 mm thick blanket reinforced with a geogrid layer near the top of it. In the models with reinforced blankets, due to the considerable increases in the load-carrying capacity, the values of the stress concentration ratio have also increased. It is noted in the case of an optimum thickness ratio of 0.16 while the geogrid is placed near the top of the blanket, compared with other layouts of the geogrid, the amount of SCR was less.

4. Conclusions

It should be noted that the geogrid reinforcement rupture mechanism has not been investigated earlier in reinforced blanket studies; thus, the findings of this research can be applied in practice. The following are the most prominent conclusions from the current laboratory study:

- The results indicate that including geogrid reinforcement in the blanket significantly improves the load-carrying capacity and reduces the settlement of all model tests .The comparison of reinforcement layouts of the reinforced blanket with the geogrid indicates that when the geogrid is closer to the base of the footing, it will play a more effective role in enhancing the load-carrying capacity and decreasing the settlement. In models with stone columns causing stiffer beds, the geogrid reinforcement ruptured under more loading intensity and at less extent of settlement.
- According to the maximum percentage increase in the load ratio in all the models, including the model tests with an unreinforced blanket and the geogrid-reinforced blanket with single or two layers of geogrid, the optimal thickness of the blanket is estimated to be 0.16 times the diameter of the footing.

5. References

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