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Numerical modeling of geogrid reinforced stone column groups with Plaxis 3D

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Abstract

Unlike reinforced concrete bored piles, unreinforced stone columns may not be able to safely withstand high structural loads. In this study, stress-strain behavior of stone column groups under vertical loads and the effect of geosynthetic reinforcement will be examined. The physical and mechanical properties of the soil, columns and geogrids to be used in this study will be determined by considering the material parameters available in previous studies. Within the scope of the study, the bearing capacity and settlement of stone column groups placed under the raft foundation in different configurations will be discussed. In this context, loading tests will be carried out on standard and geogrid reinforced stone column groups to investigate the effect of geosynthetic coating reinforcement on settlement amounts and bearing capacities in the improved soil cell. As a result of the study, findings regarding the effect of geosynthetic reinforcement on the mechanical properties of group stone columns were reported. Based on the numerical analyses results, it is observed that the wrapped stone columns having 3×D center to center spacing can be taken as the optimum pattern for the site applications while decreasing the foundation deformations effectively. It is believed that the results of the study may pave the way to the development of a novel stone column manufacturing technique that can be more efficient in terms of both strength and economy.

Introduction

In a recent study, the important functions of the stone columns are stated as the increase in the bearing capacity and shear resistance of soils, decrease in the amount of settlement, acceleration of the consolidation in cohesive soils and decrease in the liquefaction sensitivity in the cohesionless soils [1]. In a recent thesis study, it is stated that the interaction of the foundation and a single stone column in the group is important, that each stone column under the foundation has a different load-settlement behavior and that the stone column in the middle of the foundation will receive the most load. In this study, the test outputs for the stone columns under the group effect were compared with the numerical analysis results [2]. Gniel and Bouazza presented the results of small-scale model experiments to investigate the behavior of geogrid-wrapped stone columns in their study. In their study, a uniform clayey soil representing the natural ground is preferred as bedding material. In their study, length-column-diameter ratio, cell diameter-column diameter ratio, aggregate particle diameter-column diameter and aggregate diameter-geogrid cell void ratio were under concern. The behavior of stone columns under the group effect is simulated with the unit cell model [3]. Castro and Karstunen, in their study, utilized finite element technique for modeling stone column behavior [4]. According to Isaac and Girish, stone columns reduce the settlement of the soil on which it is applied and increases the bearing capacity. In addition, it helps to increase the consolidation speed of the clayey soils and prevents large settlements that will occur later [5].

Within this study, numerical analyses were performed to investigate the efficiency of stone column groups using three-dimensional finite element modeling technique. Actual geometries for site applications were considered in the numerical simulations. Based on the results of the analyses performed for the standard and reinforced stone column groups using Plaxis 3D program, the effect of geogrid wraps on the settlement amounts and bearing capacities of the improved soil are investigated within this concept.

Material and Method

In Plaxis3D modeling software, the cross-sectional diameter (D) of the stone columns was taken as 1 meter, which is commonly used in conventional site applications. The center to center spacing of the columns were considered as the variable parameter and taken as 2×D, 3×D, 4×D. Within the analyses unwrapped and wrapped stone column models were modeled. For the bedding material, and stone columns, analyses were performed according to the Mohr-Coulomb hypothesis, based on the data obtained from previous studies. The foundation that will transfer the loads coming from the superstructure to the ground is defined as a very rigid. The model is divided into finite elements by mesh method as shown in Figure 1. Since there is no groundwater level for the considered problem, pore water pressure and groundwater level are not defined in the model. Soil mesh points just below the foundation were chosen for the comparison of the nodal points. The surcharge load is defined to represent the loads that may come from the superstructure. Since the modeled raft foundation is very rigid and does not deform, a uniformly distributed load has been defined according to represent the loads that come from the superstructure. The vertical stress coming from the superstructure were taken as 297 kN/m^2 corresponding to the stress value measured in the laboratory tests. The finite element model used in this study is shown in Figure 2.

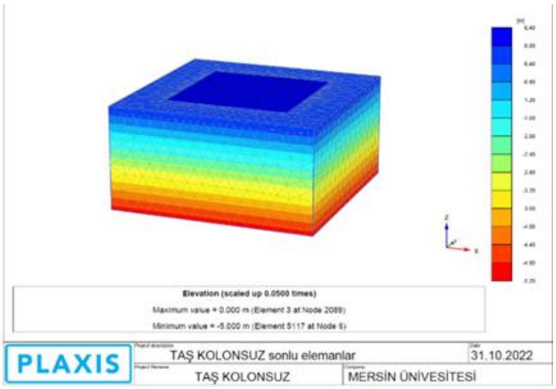

Figure 1. Plaxis3D finite element mesh for the bedding material

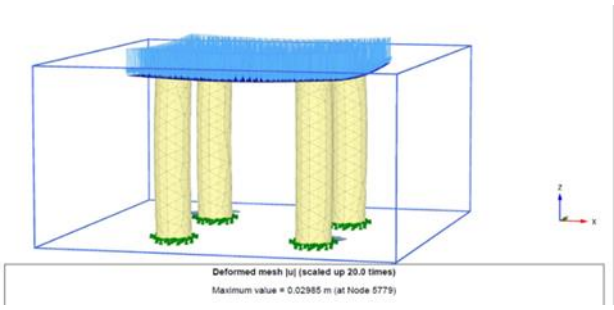

Figure 2. Plaxis3D finite element model for the stone columns and the raft foundation (loading were also depicted)

Results

Three-dimensional finite element model and the stress conditions are shown in Figure 3. The maximum displacement value for the model without stone columns was found as 33.25 mm. A displacement value of 28.71 mm occurred in the loading of the unwrapped stone column model at 2×D center to center spacing. The maximum displacement value of the unwrapped stone column model for 2×D center to center spacing under loading was 29.84 mm. The maximum displacement value of the wrapped 2D stone column model is found as 24.06 mm.

The horizontal displacement values in two different axes were found 1.567×10^{-3} mm and 1.585×10^{-3} mm. The horizontal displacement contours for the investigated model are shown in Figure 4. The maximum displacement value of the wrapped stone column model under loading was 24.56 mm, whereas the horizontal displacement values were around 1.8×10^{-3} mm. Maximum displacement value for the unwrapped column groups with 4×D center to center spacing under loading is obtained as 29.85 mm. The maximum displacement value of the column groups with 4×D center to center spacing under loading is 24.9 mm, the horizontal maximum displacement values were around 1.95×10^{-3} mm.

Conclusion

In three-dimensional finite element analyses, it was observed that an improvement of approximately 13.5 percent occurred between unwrapped stone column groups at 2×D center to center spacing and the no stone column case. For the analyses performed on unwrapped stone column groups at 3×D center to center spacing, an improvement of approximately 10.01 percent occurred when compared to no stone column case. An improvement of approximately 27.5 percent was noted between the wrapped stone column groups at 2×D center to center spacing and the no stone column case. The improvement ratio was approximately 26 percent for the wrapped stone column groups at 3×D center to center spacing. The improvement ratio was approximately 10 percent for the unwrapped stone column groups at 4×D center to center spacing whereas it is 25% for the wrapped stone column groups at 4×D center to center spacing

Based on the numerical analyses results, it is observed that the wrapped stone columns having 3×D center to center spacing can be taken as the optimum range for the applications. Although additional improvement can be achieved for wrapped stone column groups at 2×D center to center spacing, the group interaction effects and the construction problems may be more pronounced. Hence it can be considered that wrapped stone columns at 3×D center to center spacing can provide optimal load bearing capacity. Results indicate that no significant improvement in deformation reduction capacity between unwrapped columns at 3×D and 4×D center to center spacing.

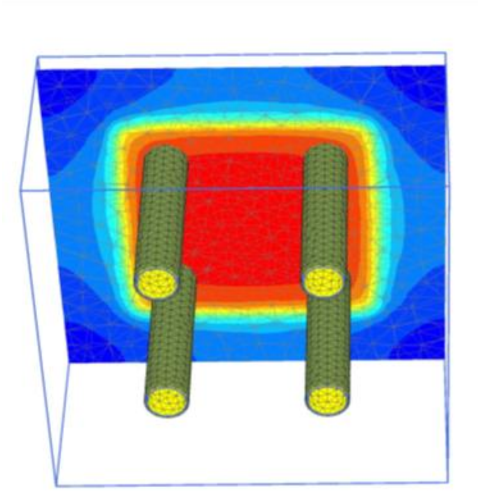

Figure 3. Finite Element Analysis Model and stress conditions

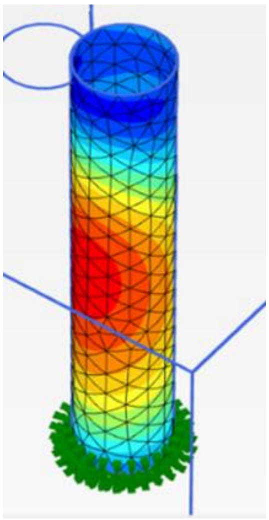

Figure 4. Horizontal displacement model

Table 1. Comparison of the deformation values for different stone column configurations

	Cohesionless bedding material	Non wrapped model 2×D spacing	Non wrapped model 2×D spacing	Wrapped model 2×D spacing	Wrapped model 3×D spacing	Non wrapped model 4×D spacing	Wrapped model 4×D spacing
Displacement (mm)	33.2	28.35	29.84	24.06	24.56	29.85	24.9
Bearing Capacity Increase Rate		0.14	0.101	0.275	0.26	0.1009	0.25

Acknowledgement

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