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3D Numerical Stability Investigation of Sand Slope Reinforced Using Geogrid Encased Stone Column

M. Hajiazizi*, M. Nasiri

Engineering Faculty, Razi University, Kermanshah, Iran.

ABSTRACT: One of the efficient ways for reinforcing the earth's slope is Geogrid Encased Stone Column (GESC). This technique can increase bearing capacity and decrease the settlement rate of the slope. The goal of this study is to perform a three-dimensional finite-difference numerical study on the behavior of GESC in the stabilization of sand slope. According to the results of the three-dimensional finite-difference analysis, the existence of GESC in the middle of the sand slope, as the optimal location for stone column placement, increased stability to an ideal level compared with the ordinary stone column (OSC). Different parameters including stone column diameter, coupling spring cohesion, coupling spring friction, center to center distance of columns (S/D ratio), and the layout of encasements were evaluated and discussed in this paper. The results indicated that the efficient parameter in geogrid is coupling spring cohesion; in which by increasing this parameter, slope bearing capacity increased linearly (i.e. the bearing capacity of slope reinforced using GESC could enhance up to 1.8 times of slope reinforced using OSC). In the case of row stone implementation, the maximum bearing capacity was that of S/D=2. However, a decrease in the S/D ratio did not necessarily increase the bearing capacity of slopes.

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1. INTRODUCTION

Slope Stabilization is one of the important issues in human lives. Generally, stabilization methods categorized into three sections; experimental, numerical, and analytical approaches. Stabilization methods included special techniques, which should be practically applicable. Providing stable conditions for slopes can be reached using various methods such as; changing slope geometry, using reinforcement elements or installing structural elements like stone columns. Stone columns are among well-known methods, which can increase slope stability safety factors. They also are simple and economical methods. Stone columns increase bearing capacity, decrease settlement rate, and liquefaction potential, enhance slope stability and bearing more shear stresses [1, 2]. Stone columns under compression loads, failed in three categories; bulging [3, 4], general shear failure [5], and sliding [6].

Bearing capacity of stone columns depends on lateral stresses, so it necessary to provide additional confining pressures in some soils. Various techniques have been proposed in this regard. Among different methods, use of the geogrid layer, as encasement, in order to improve the performance of stone columns proposed and discussed before [7, 8].

Despite the performed researches up to now, as far as authors concern, there is no paper conducted a full study on the behavior of sandy slopes reinforced using Geogrid Encased Stone Column (GESC). This technique was introduced as a novel method in the present paper. The objective of this article is to compare the mechanism of the ordinary stone column and geogrid encased stone column in order to reinforce the sand slopes.

2. 3D NUMERICAL MODELING

In this paper, 3D finite-difference modeling was performed using silty sand [9], stone column [10], and geogrid layer as encasement. In order to investigate the effects of geogrid encasement in sandy slopes, coupling spring cohesion, coupling spring friction, and coupling spring stiffness used as changing parameters. Modeling was performed in two cases, a single stone column and a row of stone columns. Model dimensions are presented here: model length 10m, slope crest 2 m, slope depth 2 m, slope length 3 m, slope height 2.35 m and slope angle was 38 degrees. Slope width was selected 2.4 and 4.8 m according to the type of analysis (single stone or a row of stones). The slope model dimensions illustrated in Figure 1.

The analysis was carried out in static conditions in which, side and bottom boundaries fixed along x- and y-axes, and the model can only move in the z-direction. Stone columns had a distance of at least 5 times of stone diameter from sidewalls.

*Corresponding author's email: mhazizi@razi.ac.ir

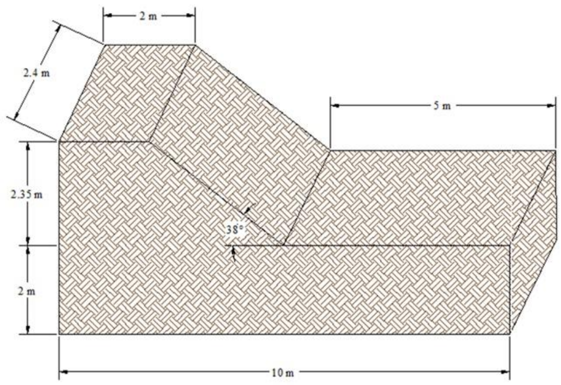

Figure 1. Slope Geometry.

Table 1. Sensitive Analysis Results.

Element No.	FOS	Run Time
Single stone		
27840	1.06	8 hours
3000	1.07	30 minutes
A row of Stones		
11800	0.97	4 hours
9500	0.98	38 minutes

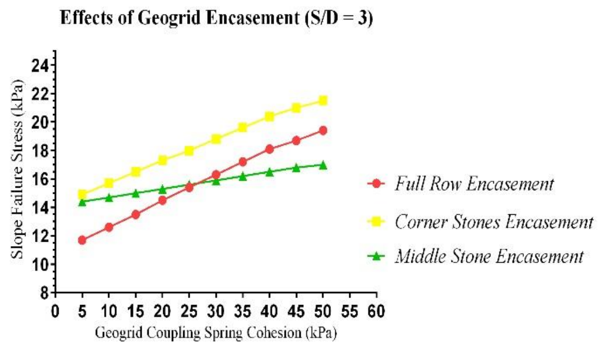

Figure 2. Effects of Encasement Layout in Slope.

The criterion for slope failure was that if displacements along the z-axis reach 10 cm and along x-axis reach 9 cm in the single stone. While in the case of a row of stones, if this amount reaches 12 cm and 10 cm along the z- and x-axes respectively. In Table 1, the results of the sensitive analysis are illustrated.

3. RESULTS AND DISCUSSION

3.1. Effects of Stone Column Diameter

In this research, five different geogrid encased stone columns by diameters of 20 to 60 cm installed in optimal location [11-13] and tested. Stone with a diameter of 20 cm had the least bearing capacity. By increasing the coupling spring cohesion of geogrid, the rate of bearing capacity enhancement is linear. The performance of stone with a diameter of 40 cm was better than a stone with a 60 cm diameter from the specified amount. In addition, these results indicated that increasing the diameter of the stone does not necessarily enhance the bearing capacity of reinforced slopes.

3.2. Effects of Geogrid Coupling Spring Stiffness

This parameter had no significant effect on the bearing capacity of the GESC reinforced slopes.

3.3. Effects of Geogrid Coupling Spring Cohesion and Friction Angle

Geogrid coupling spring friction had no significant effect on the bearing capacity of the slopes, while increasing geogrid coupling spring cohesion, the bearing capacity enhanced linearly.

3.4. Effects of *S/D* Ratio

In this research, different ratios of S/D (from 2 to 3.5) were analyzed and it was indicated that in the case of S/D=3 and S/D=3.5 the differences are not significant.

3.5. Effects of Encasement Layout

Encasing only the middle stone cannot be efficient enough, and increasing coupling spring cohesion in this regard cannot result in higher bearing capacity. However, encasing side stones will cause a considerable change in bearing capacity. As indicated in Figure 2 reinforcing only middle stone was not a good option, but in the case of limitation for encasing a full row of stone columns, reinforcing side stones will result in better bearing capacity enhancement.

4. CONCLUSION

The results of this paper showed that the geogrid encased stone column can efficiently enhance the bearing capacity of the saturated sand slope. The use of GESC depended on the type and characteristics of the geogrid layer, which could increase bearing capacity up to 1.8 times of OSC. 3D numerical results suggested that since S/D=3 and S/D=3.5 have good similarity, from an economics point of view it is better to use S/D=3.5 for practical purposes. Another important finding of this research indicated that reinforcing only middle stone could not be sufficient to overcome large overburden pressures. In this regard, encasing side stones can be chosen as an appropriate option in the condition that encasing a full row of stones is not applicable.

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