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Effect of Granular Bed on Behaviour of Stone Column Improved Ground

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Abstract-Stone columns are known as an economically and efficient method to improve a wide range of soils. For drainage purposes, as well as distribution of the applied stress coming from superstructure, usually a granular bed, performs on top of the stone columns improved ground. In this paper effects of the granular bed on the stone column were studied numerically. Mohr-Coulomb failure criterion was considered for all the materials. Accuracy of the model verified by other laboratory test data and was found to be in good agreement. The results showed that construction of a granular bed causes more stress to transfer to depth of the column and thus stress concentration reduced in the upper part of the column and lateral bulging reduced subsequently. Also, influence of the granular bed on the settlement and bearing capacity was evaluated and it was found that placing a granular bed on the stone column improved ground significantly increase bearing capacity and decrease settlement of the ground.

Keywords- *Stone column, Granular bed, Settlement, Bearing capacity, Bulging*

I. INTRODUCTION

Today, due to the urban sprawl and construction on unsuitable lands, the need for improvement methods of soil can be felt more than ever. In ground improvement techniques, issues such as economic justification, efficiency and the required equipment have been always introduced. Stone columns (or granular piles), are one of the ground improvement techniques that have been recognized as economically and environmentally friendly method [1, 2]. They are called to dense columnar elements made of granular material in weak soil that can be constructed by different methods. The advantages of this technique are increasing of the bearing capacity, reduction of the settlement, acceleration of the consolidation due to the vertical drainage, improvement of slope stability and mitigation of liquefaction potential. They can be constructed for supporting foundations of the buildings, embankments and storage tanks. So far, several studies have been carried out on the behavior of improved ground with stone columns by various researchers [3-7]. In practice, usually a granular layer with the thickness of 30 cm or more is performed on top of the ground improved by stone columns for drainage purposes, as well as distribution of the stresses coming from superstructures [8]. Due to high stress concentration near top of the granular pile, bulging and subsequent failure of granular pile occurs in this region. This stress concentration is significantly influenced by the presence of granular mat [9]. Shahu et al. [9] presented a simple theory to predict the behavior of soft ground reinforced by granular piles with granular mat on top, under a rigid foundation. The granular mat is asummed to be rigid and smooth; therefore it was a shortcoming for their study. However, they concluded that placement of the granular bed on the granular pile improved ground, reduce the stress concentration factor on top of the granular pile and reduce the settlement subsequently.

Ambily and Gandhi [10], investigated effect of sand pad thickness on stress concentration ratio (SCR) in stone column through finite element method. They concluded that in the case of rigid load, SCR decreases slightly with increasing thickness of granular pad, but in the case of flexible loading SCR increases with increase in pad thickness. Deb [11] developed a plane strain theoretical model to evaluation of the behavior of granular bed-stone column-improved soft soil, which incorporates the nonlinear behavior of the granular fill soil and soft soil and a linear elastic behavior of the stone columns. They concluded that higher shear modulus or thickness of the granular fill helps to transfer of more stress from surrounding soft soil onto stone column which causes more settlement reduction. Deb et al. [12] investigated the behavior of unreinforced and geogrid-reinforced sand bed over single stone column-improved soft clay, through model tests. They have been observed decrease in bulge diameter and increase in depth of the bulge due to placement of sand bed over stone column-improved soft clay. Also, further decrease in maximum bulge diameter and increase in depth of bulge have been observed due to reinforcing sand bed by geogrid.

In this paper a numerical simulation carried out on granular bed-stone column improved ground and effects of granular bed on bearing capacity, settlement and bulging were investigated.

II. NUMERICAL ANALYSIS

Numerical analyses were carried out using the finite difference program FLAC3D [13] Due to the symmetry planes, only one quarter of the model was simulated. In all the performed models, it was assumed that a rough rigid circular footing with a diameter of 2 m rested on single stone column improved ground and influence of the granular bed were evaluated. It was assumed that the stone column located on a rigid substrate (end bearing stone column) and the groundwater level is in the same level of the clay bed. Due to the significant deformation that occurs at the edge of the footing, mesh density was more refined in this region. Typical adopted mesh is shown in Fig. 1. Interface between the soil and the column is a mixing zone that columns materials are tightly interlocked with the surrounding soil [7], also the shear strength properties in this region can vary depending on the method of installation that is not precisely known [14], therefore, any interface element between the surrounding soil and the column was used. This approach was also adopted by other researchers [15, 14, 2, 7]. Vertical boundaries restricted in the horizontal direction (x and y) and horizontal boundary in the bottom of the model restricted in all directions (x, y and z). Analyses were performed under controlled displacement due to the rigidity of the footing. Hence, a uniform settlement applied in the vertical direction to all nodes at the soil-footing interface. Also, lateral displacement constrained in these nodes due to the roughness of the footing. Apply the equal displacement is performed through "Velocity" command in Flac3d that it represents the applied displacement in each step. Frydman and Burd [16] and Ghazavi and Lavasan [17] showed that a change in the velocity applied on footing nodes has a great effect on the bearing capacity. In this study by performed sensitivity analysis it was found that a velocity of 5×10^{-6} (m/step) will suffice for adopted model, since by further reduction, change in bearing capacity and settlement was negligible.

Mohr–Coulomb failure criterion and drained behaviour was considered for all the materials. Material properties that have been adopted in this study are presented in table 1.

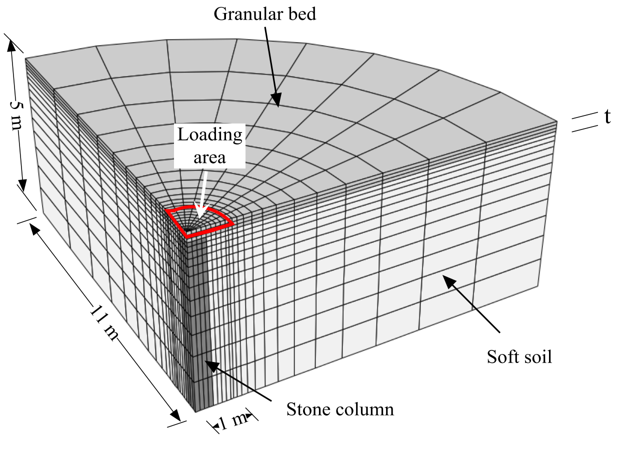

Figure 1. Typical mesh shape for numerical analyses

TABLE I. MATERIAL PROPERTIES

Properties	Materials		
	Soft soil	Granular bed	Stone column
$E\ (kPa)$	3000	30000	60000
υ	0.35	0.3	0.3
φ'	20	35	42
ψ	-	5	12
$C'(kPa)$	5	-	-
$\gamma_{sat}\ (kN/m^3)$	18	18	20

Accuracy of the developed model was verified using laboratory test data published by [18]. They performed laboratory tests on stone columns with diameters of 60, 80, and 100 mm and a length to diameter of 5 using large test box with plan dimensions of 1.2 m ×1.2 m and 0.9 m height. Loading was applied through a rigid steel plate with diameter of 200 mm. Mesh discretization for verification is shown in Fig. 2. Fig. 3 shows that results of numerical simulation carried out in the present study match well with experimental results of [18].

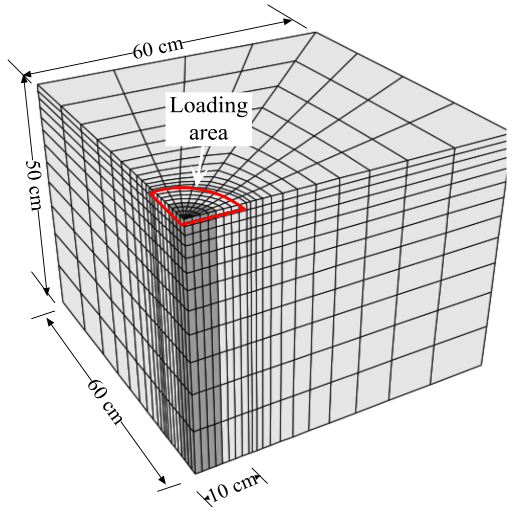

Figure 2. Mesh discretization of model tests by [18]

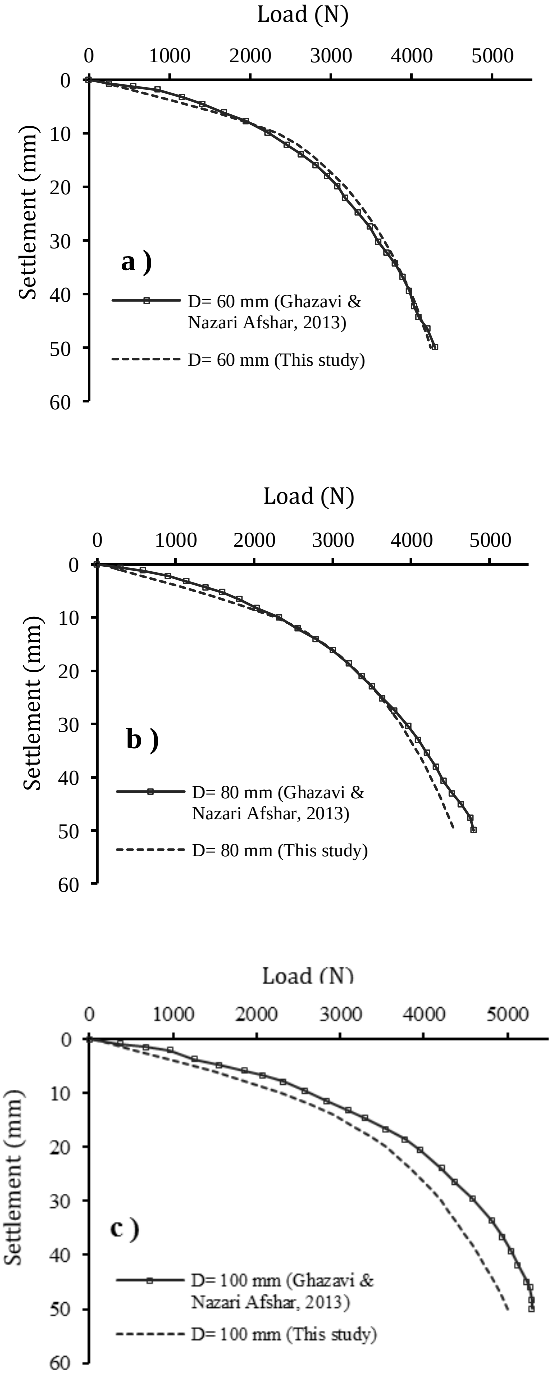

Figure 3. Validation of numerical model by results of [18]: a) D_c = 60 mm, b) D_c = 80 mm, c) D_c = 100 mm

III. Results

A. Pressure-settlement characteristics

Pressure-settlement characteristics of the unimproved soft soil, stone column improved soft soil and granular bed-stone column improved soft soil for different diameters of stone columns are shown in Fig. 4, that D_f, D_c, H and t are footing diameter, stone column diameter, height of soft soil, and thickness of granular bed, respectively. It is clearly observed that the behavior of soft soil has been improved due to the presence of stone column which this improvement increases by increase in column diameter.

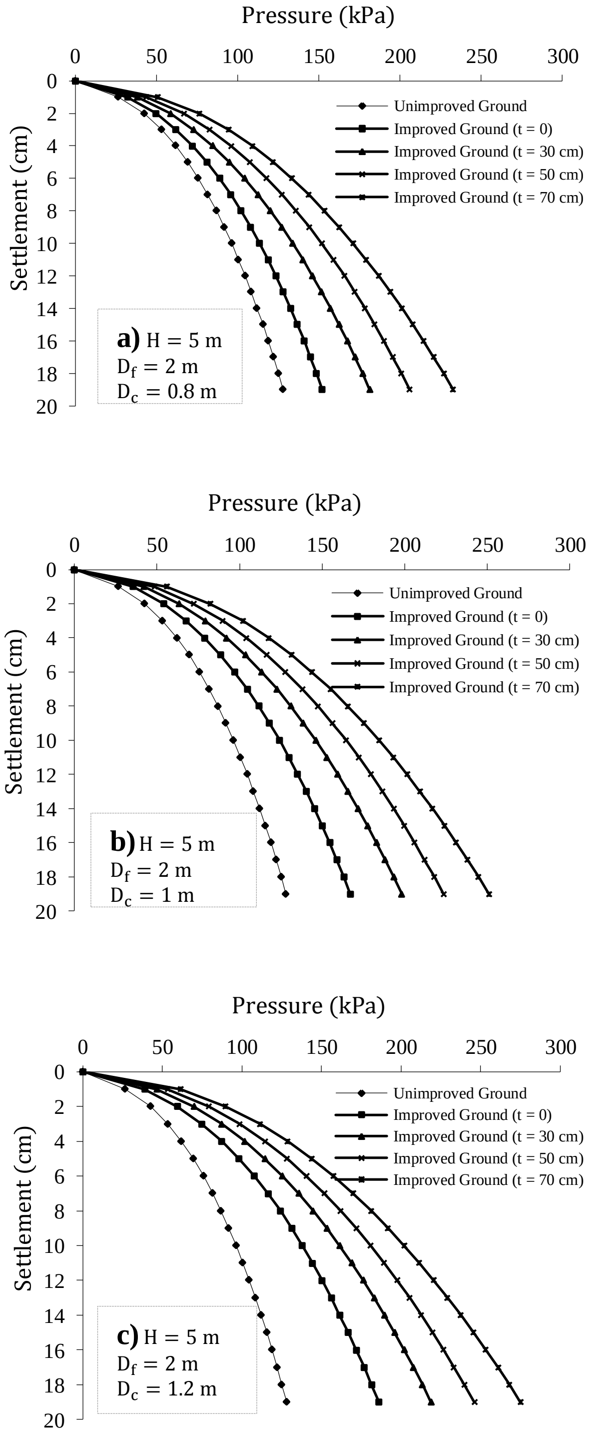

Figure 4. Pressure versus settlement curves for different diameters of stone columns: a) D_c = 0.8 m, b) D_c = 1 m, c) D_c = 1.2

B. *Bearing capacity ratio (BCR)*

The bearing capacities for all the models were determined from the load–settlement curves at 10% of the footing diameter. Increase in bearing capacity due to the presence of stone column and subsequently placement of a granular-bed on the column was determined through a dimensionless parameter, the bearing capacity ratio (BCR), which is defined as follows:

$$BCR = q_{improved} / q_{unimproved} \quad (1)$$

The results were presented in the form of BCR versus the D_c/D_f for different conditions (Fig. 5). It is observed that with increasing thickness of granular bed, a significant increase is occurred in the amount of BCR.

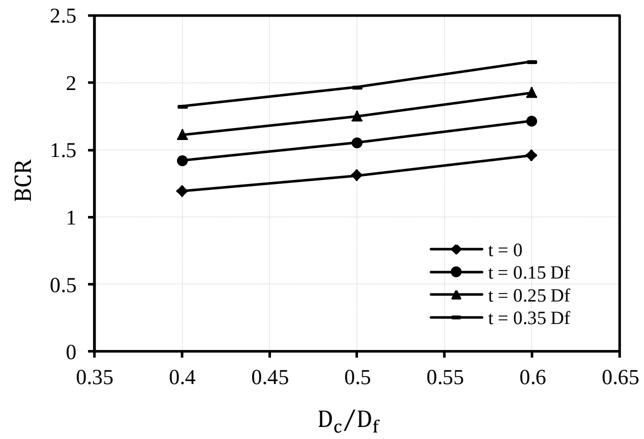

Figure 5. BCR versus the D_c/D_f for different thickness of granular bed at settlement of 0.1 D_f

C. *Settlement improvement factor (SIF)*

Further investigations were carried out on settlement improvement factor (SIF), which is a dimensionless parameter and is defined as follows:

$$SIF = S_{unimproved} / S_{improved} \quad (2)$$

Amount of the SIF obtained from settlement that occurs in pressure of 100 kPa. Value of 100 kPa is about ultimate bearing capacity of the unimproved soft soil. Fig. 6 shows SIF amount versus D_c/D_f for different values of the t/D_f. It can be seen from Fig. 6 that the SIF increases with the implementation of stone column. Further increase is achieved by placing granular bed on the ground which this increase is greater for higher values of the t/D_f. Also, it is clearly observed that the value of the SIF increases with increasing stone column diameter.

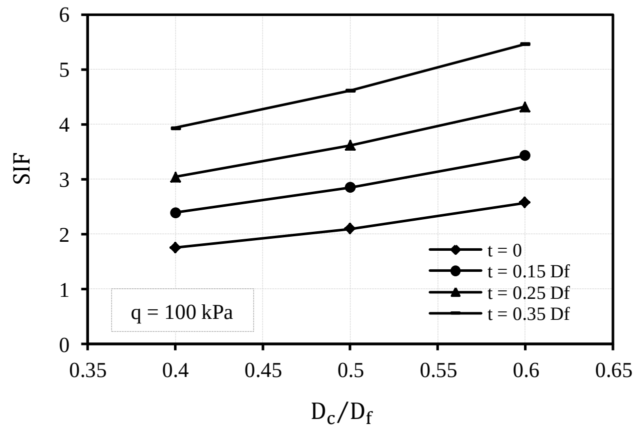

Figure 6. SIF versus the D_c/D_f for different thickness of granular bed at pressure of 100 kPa

D. *Bulging of the stone column*

Bulging is a mode of deformation of stone column that usually occurs up to a depth of 1.5 to 2 times the diameters of column [18]. The lateral bulging observed in the stone column with and without placement of granular bed at a pressure load of 100 kPA is compared in Fig. 7. Lateral bulging presented in terms of $\Delta D_c/D_c$, that Dc and ΔD_c are initial diameter of the column and variations of the column diameter due to loading, respectively. It is observed that placement of the granular bed with thickness of $0.15D_f$, reduce the bulging of the column about 24 %. Further reductions in bulging are observed by increasing thickness of the granular bed. So that with granular bed thickness of $0.35D_f$, 55 % decrease is observed in the bulging.

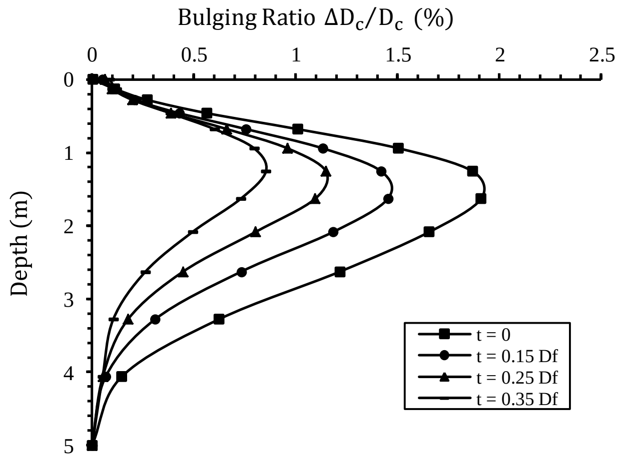

Figure 7. Bulging ratio versus the Depth for different thickness of granular bed at pressure of 100 kPa

Fig. 8 shows effective stress contours at an applied pressure of 100 kPa. It is observed that by placing a granular layer, the vertical stresses decrease in upper of the stone column and instead increase in lower part of the column. In fact, a granular layer plays the role of a stress distributor, so that transfer the applied stresses to depth of the column, where more support takes place from the surrounding soil. This phenomenon causes lower bulging occurs in the column, and thus a significant improvement in behavior of the stone column is achieved.

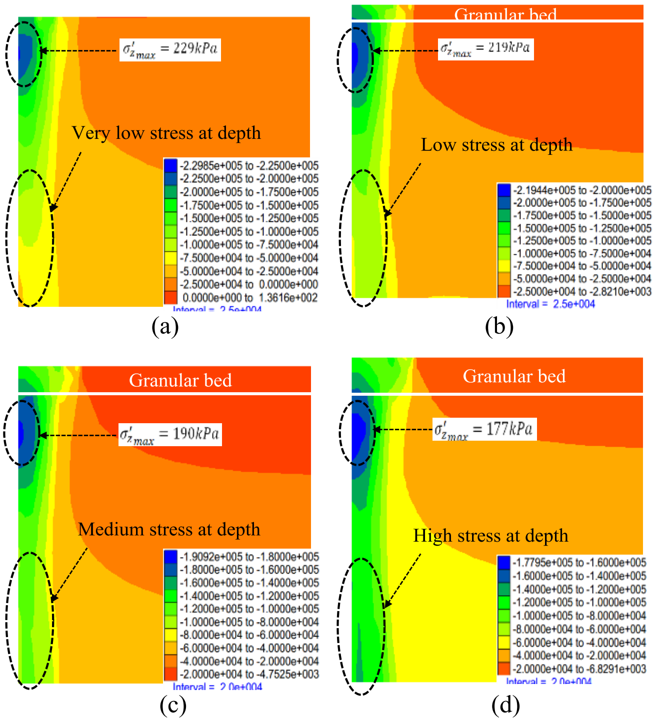

Figure 8. Effective stress contours for different thickness of granular bed at pressure of 100 kPa: a) t = 0, b) t = 0.15 D_f, c) t = 0.25 D_f, d) t = 0.35 D_f

IV. CONCLUSIONS

Numerical investigations were performed to study the influence of granular bed on stone column improved ground. Mohr–Coulomb failure criterion and drained behavior considered for all the materials. Based on performed analyses, the following conclusions are drawn:

- Placement of the granular bed on the stone column improved ground significantly increases the bearing capacity and decreases the settlement of the ground that this effects increases with increasing thickness of the granular layer.
- A granular layer plays the role of a stress distributor, so that transfer the applied stresses to depth of the column, where more support takes place from the surrounding soil. This causes that lower bulging occurs in the column. So that in this study 24 % and 55 % reduction in bulging was observed due to the construction of a granular layer with thickness of $0.15D_f$ and $0.35D_f$, respectively.

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