Numerical analysis on load-settlement response of reinforced granular blanket over ordinary stone column

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ABSTRACT

Stone columns are a more economical and efficient method to enhance the strength of expansive soils. Using a granular blanket over the top of the ordinary stone columns (OSC) improves the drainage and distribution of the applied stress impending from the superstructure. The present study studied the effect of geogrid layers in a granular blanket (GB) over the top of the OSC numerically using 'PLAXIS 2D'. 'Mohr-Coulomb failure criterion was deliberated for the stone column, granular blanket, expansive soil, and elastoplastic behavior is considered for geogrid layers as reinforcement. Present review results are validated with the experimental results and agree greatly. Numerical results show that the construction of a GB with a geogrid layer over the stone column increases stress transformation to the depth of OSC. Thus 'stress concentration' is decreased in the higher zone of the OSC. Likewise, assessing the impact of geogrid layers in a granular blanket on the 'bearing capacity and settlement of OSC, it was observed that it reduces the lateral bulging, settlement and increases the ground's bearing capacity.

Keywords: Geogrid layers, Granular blanket, Stone column, Settlement, Bulging.

1. INTRODUCTION

Soft soil deposits cover a lot of regions all over the world, often located in important cities along rivers and seas. The lower shear strength and higher compressibility properties of deposits pose a significant problem to geotechnical engineers. Due to the construction of structures on soft soil, many challenges are expected to occur related to the soft clay layer, such as excessive settlement, significantly if this layer extends to a deep level below the foundation level. A few strategies are accessible to further develop ground conditions, like lime stabilization, granular piles, grouting, compaction, preloading and so on prior to utilizing any of these techniques; it is needed to realize the nearby ground conditions exhaustively. Despite the fact that processes are expensive, tedious, and should be done to choose the most appropriate and applicable ground improvement technique. Improving the ground by stone columns technique overcomes these difficulties by improving soil strength parameters as bearing capacity and decreasing vertical and lateral displacement.

Today, because of the development on unsatisfactory grounds and never-ending suburbia, feel the requirement for further developed strategies for soil like never before. Today, due to the construction on unsuitable lands and urban sprawl, feel the need for improved methods of soil more than ever. In-ground improvement methods, economic justification, effectiveness, and the necessary equipment have been presented all the time. Stone columns are appropriate ground improvement techniques that have been perceived as economical and harmless to the ecosystem techniques. They are called thick columnar components made of granular material in soft soil that various

techniques can develop. The advantages of this technique are increasing the bearing capacity, mitigation of liquefaction potential, and reduction of the settlement. They can be built to reinforce the structures, banks, and capacity tanks. So far, several studies have been carried out on the behavior of improved ground with stone columns by various researchers using various methods such as analytical (Bostjan et al., 2011; Deb and Mohapatra, 2013; Nazariafshar and Ghazavi, 2014). experimental (Ghazavi and Nazariafshar, 2013; Murtaza and Samadhiya, 2016) and numerical (Han and Gabr, 2002; Hanna et al., 2013; Chakraborty and Kumar, 2014). The ultimate bearing capacity of soft soil rises significantly due to GB and reducing the bulging of the stone column because of geotextile and geogrids as reinforcement in stone column and granular blankets, respectively (Mehrannia et al., 2018; Nazariafshar et al., 2019). The use of OSC enhances the tension and bearing capacity of the soft soil, (Niroumand et al., 2011).

The strength of reinforcement increases in both 'VESC and HRSC', increasing the bearing capacity of reinforced stone columns. And due to the use of geotextiles decreases the lateral bulging. In addition, for both 'VESC and HRSC', the 'stress concentration ratio' of the columns also increases. Performed experimental work on both unreinforced and reinforced geosynthetic encased stone columns, (Nazariafshar and Ghazavi, 2014). Ambily and Gandhi (2007) studied the influence of GB thickness on the 'stress concentration ratio' in stone columns numerically. Murugesan and Rajagopal (2009) studied the performance of reinforced and unreinforced geosynthetic single and grouped stone columns 'load-bearing capacity, bulging, 'stress concentration ratio'. And found that the role of modulus of encasement and dia. of stone column depend on rising the axial load capacity of stone column. Madhav and Vitakar (1978) presented the failure mechanism of a granular trench or pile using plane strain and concluded that the bearing capacity of weak clay deposits rises due to the use of granular trench or pile. Vijayalakshmi and Satyam (2011) presented the analysis of tunnels in Siwalik Hills using FEM by PLAXIS 3D. Manne and Satyam (2013) studied the numerical modeling of granular soils under cyclic triaxial testing and identified that the uniformly graded sample has a greater resistance to failure during cyclic loading than non-uniform distribution.

Shahu et al. (2016) introduced a straightforward hypothesis to anticipate the behavior of soft ground supported by stone columns with a GB under and on top rigid foundation and, they recognized that position of the GB on the OSC further developed ground reduced the stress concentration factor on top of the stone column and decreased the settlement.

Many researchers have reported behavior of single and grouped floating stone columns in soft clay with and without vertical and horizontal reinforcement. In past studies, numerical analysis on load- settlement response of reinforced granular blanket over ordinary stone column are not found, but very limited experimental work has been carried out on granular blanket over an ordinary stone column. The present study investigated a numerical simulation on GB, OSC, and 'load-settlement response' with varying geogrid layers, their positions, and bulging.

2. MATERIAL PROPERTIES

The material properties of soft clay, stone column, and Granular blanket used in the present study are as mentioned below in Table 1.

Table 1. Properties of soft clay, stone column, and Granular blanket

Parameter	Soft Clay	Stone column	Granular blanket	Unit
γ_{unsat}	15.50	14.30	15.50	kN/m^3
γ_{sat}	19.10	16.90	15.50	kN/m^3
E	50	40500	20000	kN/m^2
N	0.45	0.30	0.30	---
C	6.5	0	0	kN/m^2
Φ	0	46	30	^{o}
Ψ	0	7	4	^{o}

3. METHODOLOGY

The single floating OSC is modeled using the FEM, 'PLAXIS 2D'. The axisymmetric model was taken on to modernize the stone column with a dia. of 100 and 80 mm. The length of OSC is considered 5 times the dia. of OSCs in all cases. However, the soil model is simulated by considering the half part of OSC from its center due to the symmetry, as shown in Fig. 1.
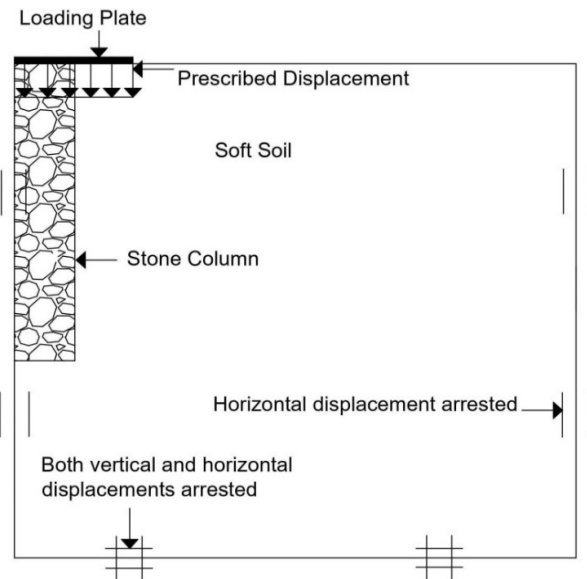

Fig. 1. Soil parameters

In the FEM model, triangular elements were used as of 15 nodded to achieve more data generation accuracy. Medium mesh has been used for the analysis. Based on (Tan et al., 2018) the boundary influence will be insignificant whenever the depth and width of the geometric model are kept 4 times higher than the footing dia. (4D). In this study, to prevent the influence of results due to the geometry model, horizontal and vertical boundaries were assigned higher than the 4 times dia. of OSC. Besides, the model's boundary conditions are entirely controlled at the model's base and restrained horizontally along the vertical boundaries. A Uniform downward prescribed displacement of 50 mm was applied on a rigid circular steel plate. The rigid plate is modeled as elastoplastic behavior, and its modulus of elasticity is considered 2×10^5 N/mm^2. The rigid plate dia. used 200 mm for each case deliberated in the current study and avoided the interface between soil and stone column. To measure the settlement and respective stress, selected nodal points at the center of the loading surface.
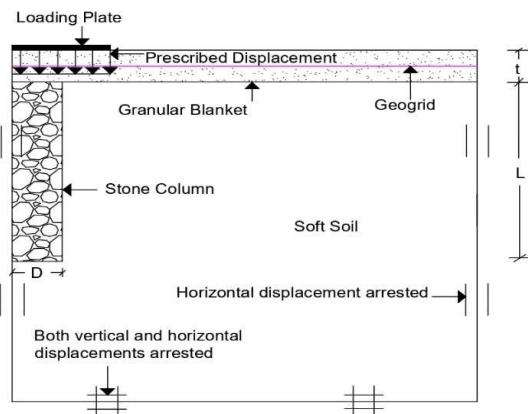

Fig. 2. Schematic diagram of a geogrid granular blanket over OSC

The soil, stone column, and granular blanket are modeled as the Mohr-Columb model and considered undrained for soil and drained behavior for OSC and GB. The Mohr-Coulomb model is a perfect linear elastic-plastic model. Among models, this model, because of the simplicity of formulation as well as the lesser data input determined by simple tests, has more applications than other models (Obrzud, 2010). The GB is laid over OSC as depicted in Fig. 2. The different arrangement with and without a geogrid granular blanket over soft soil and stone column is depicted in Fig. 3. The cross-section of the granular blanket is considered the same as soil, but its thickness is regarded as 30, 40, and 50 mm. Also, a geogrid layer is inserted at different positions over soft clay and OSC in a granular blanket to improve the load settlement response. The geogrid layer is placed at the mid and bottom of GB in case GB is placed over soft clay and at the bottom of GB when GB is placed over OSC. The

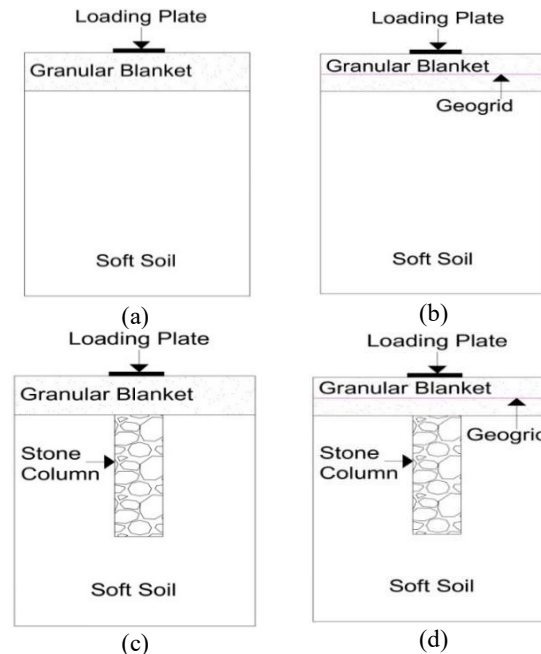'Mohr-Coulomb failure criterion and 'drained behavior' were deliberated for all the materials.

Fig 3. The different arrangements of with and without a geogrid granular blanket over soft soil and stone column (a) granular blanket over soft soil, (b) geogrid granular blanket over soft soil, (c) granular blanket over OSC, (d) geogrid granular blanket over OSC.

4. RESULTS AND DISCUSSION

The numerical analysis results were validated with Rezaei et al. (2019). It shows the good agreement as depicted in Fig. 4. Rezaei et al. (2019) presented the experimental results of a single granular pile reinforced with vertical bars and horizontal disc and, concluded that the bearing capacity of reinforced granular pile increases in both the cases due to the higher stiffness of granular pile and additional lateral confinement. The dia. of the OSC was used as 100 mm, and its length 5 times the dia. of the OSC.
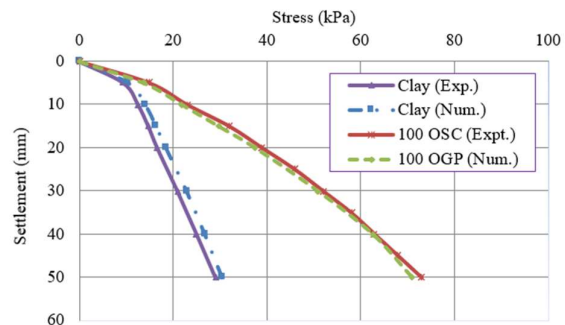

Fig. 4. Validation of results

4.1 Effect of the Granular Blanket over Soft Clay

The effect of a GB over soft clay is determined by laying the granular blanket of the same width as that of soft clay. Fig. 5 depicts the 'load-settlement response' of soft clay increase with the addition of GB over soft clay. The effect of a granular blanket of 'load-settlement response' over soft clay is determined. For the same, the thickness of the GB was kept as 30, 40, and 50 mm. It shows that due to the addition of a granular blanket of thickness 30, 40, and 50 mm over soft clay, the load settlement response increased by 11.74%, 12.84%, and 13.58%, respectively, as compared to the soft clay. It was concluded that the load settlement response increases by increasing the granular blanket's thickness over soft clay.
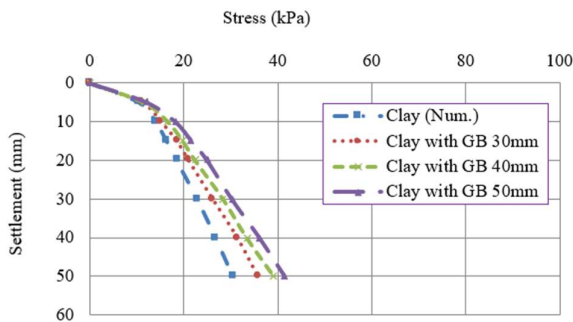

Fig. 5. Effect of a granular blanket over soft clay

The effect of a reinforced granular blanket on 'load-settlement response' over soft clay is determined. The thickness of granular blanket is considered as 30, 40, and 50 mm. In all the cases, the geogrid is placed at the bottom of the granular blanket and mid-position of granular blanket over the soft clay. Fig. 6(a, b, c) depicts the effect of the reinforced granular blanket over soft clay on load settlement response and, it shows that the load settlement response has been increased as compared to GB over the soft clay. For 30 mm GB, 'load-settlement response' increases by 20.66% when reinforcement is placed at the bottom of GB and 33.51% when it is placed at the mid position of GB, as shown in Fig. 6(a). For 40 mm GB, 'load-settlement response' increases by 18.04% when reinforcement is placed at the bottom of GB and 33.56% when it is placed at GB's mid position, as depicted in Fig. 6(b). Similarly, for 50 mm GB, 'load-settlement response' increases by 17.06% when reinforcement is placed at the bottom of GB and 39.63% when it is placed at GB's mid position, as depicted in Fig. 6(c).

It can be concluded that when the position of reinforcement is placed at the mid-position of the GB, it shows better results than the bottom of GB.
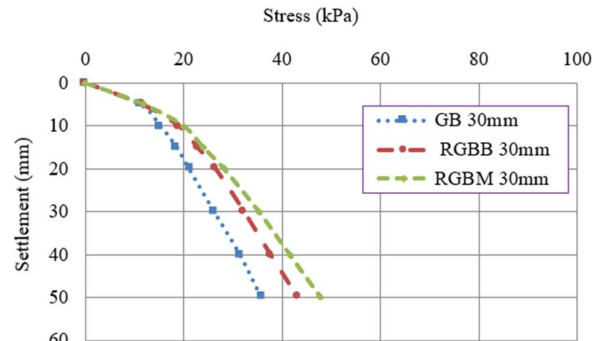
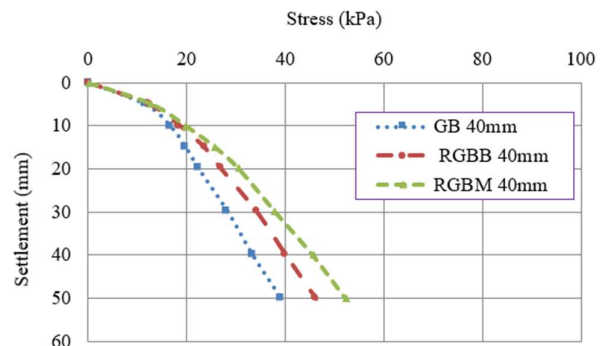## 4.3 Effect of a Granular Blanket Over Stone Column

D = 100 mm stone column
From Fig. 7(a), it's observed that the 'load-settlement

response' of OSC with an unreinforced granular blanket over it is more than the load settlement response of OSC by 12.02%, whereas it is more than the 'load-settlement response' of soft clay having granular blanket over it by 221.94% and, it is more than load settlement response of soft clay by 260.67%.
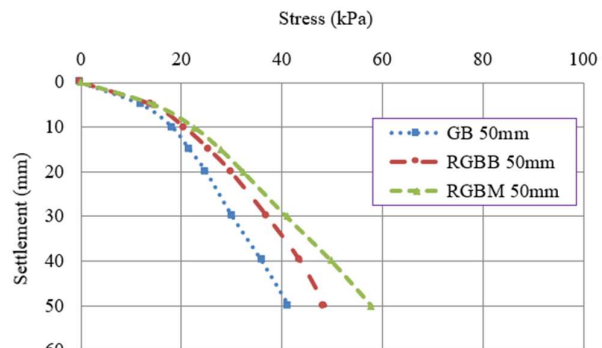
D = 80 mm stone column

(a)

(b)

(c)

Fig. 6. Effect of the reinforced granular blanket over soft clay (a), (b), and (c)

From Fig. 7(b), it's observed that the 'load-settlement response' of OSC with unreinforced GB over it is more than the 'load-settlement response' of OSC by 10.27%, whereas

it is more than the load settlement response of soft clay having granular blanket over it by 74.44% and, it is more than 'load-settlement response' of soft clay by 204%.

From Fig. 7(a and b), it can conclude that the granular blanket over the stone column gives better results of load settlement response; also, it increases its strength and reduces bulging of OSC because the load transformation is correctly done.
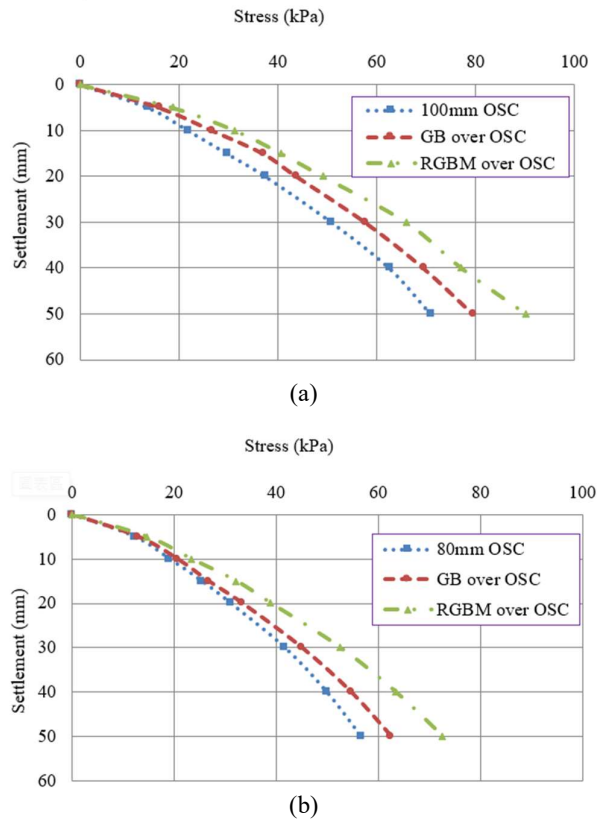

(a)

(b)

Fig. 7. Effect of GB and RGB over OSC

4.4 Effect of the Geogrid Granular Blanket over Stone Column

D = 100 mm stone column

Fig. 7(a) shows that the 'load-settlement response' of OSC increased when a GB was placed over on it with geogrid placed at the bottom of the granular blanket. By 13.43% than the unreinforced granular blanket over OSC, whereas it is more than the OSC by 27.07%, and it is more than the 'load-settlement response' of the granular blanket over soft clay by 251.77% and, it is more than the 'load-settlement response' of soft clay by 295%.

D = 80 mm stone column

Fig. 7(b) shows that the 'load-settlement response' of OSC increased when a granular blanket is placed over it, with geogrid placed at the bottom of the granular blanket. By 16.18% than the unreinforced granular blanket over OSC, whereas it is more than the OSC by 28.12%, and it is more than the 'load-settlement response' of the granular

blanket over soft clay by 202.68% and, it is more than the 'load-settlement response' of soft clay by 238%.

It indicates that the placement of reinforced geogrids in a granular blanket over a stone column gives a better effect than an unreinforced granular blanket over a stone column.

4.5 Improvement Factor

The improvement factor (IF) is the dimensional parameter, which is helpful to analyze the effectiveness of the OSC in improving the 'load-settlement response' of the soft clay. It is defined as the 'ultimate capacity of the reinforced soft clay bed' to the 'bearing capacity of the soft clay bed'.

$$IF = \frac{\text{ultimate capacity of the RGB over OSC soft clay bed}}{\text{bearing capacity of the soft clay bed}}$$
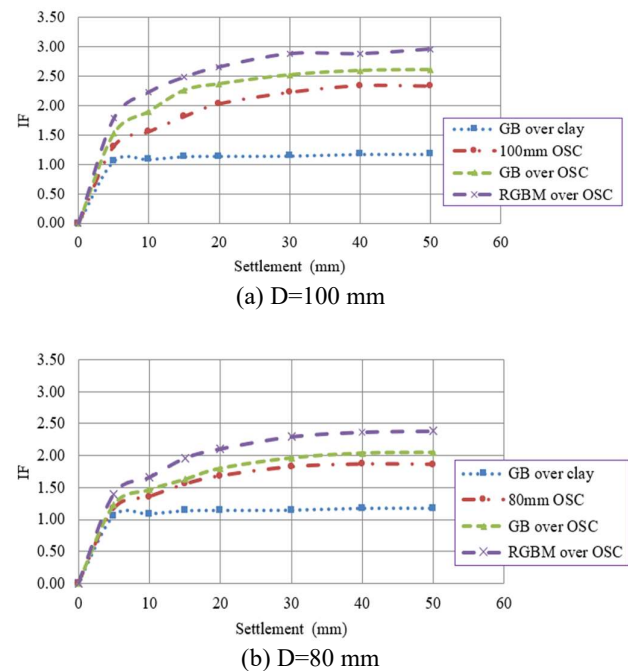

(a) D=100 mm

(b) D=80 mm

Fig. 8. Variation of improvement factor (IF)versus settlement for GB and RGB over OSC

As shown in Fig. 8, the lowest 'load-settlement response' was related to a GB over the OSC, and the highest 'load-settlement response' was accompanying a GGB over the OSC. The maximum load-displacement response varied from 1.17 to 2.96 for a granular blanket over soft clay, RGB over an OSC for 100 and 80 mm dia. stone columns vary from 1.17 to 2.38. 'Load-settlement response' was significantly increased for a geogrid-reinforced blanket over the ordinary stone column because geogrids with excellent tensile strength set up soil particles and raise the resistance between soil particles and the geogrids, which highly increases the 'load-settlement response'.

5. CONCLUSION

In the present study, numerical investigations were performed to determine the effect of GB on OSC-developed ground. The subsequent conclusions are drawn based on the performed analyses:

- Using a GB over soft clay raises the 'load-settlement response'.
- Soft ground improves significantly when a Gb is placed over the OSC. And, also enhances the bearing capacity and reductions the settlement of OSC.
- As it increases, the thickness of the GB over the soft clay and OSC up to a certain thickness increases the bearing capacity of soft clay and OSC and reduces the bulging of OSC.
- A granular layer plays a vital role in stress distribution and transformation of the applied pressures to a deepness of the OSC, where additional support takes place from the surrounding soil.

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Abbreviations
 OSC = Ordinary stone column
 GB = Granular blanket
 RGB = Reinforced granular blanket
 RGBB = Reinforcement at bottom in granular blanket
 RGBM = Reinforcement at mid in granular blanket
 IF = Improvement factor
 FEM = Finite element method
 dia. = Diameter
 Fig. = Figure
 D = Diameter of stone column
 L = length of stone column
 t = Thickness of granular blanket
 VESC = Vertical Encased Stone Columns
 HRSC = Horizontal Reinforced Stone Columns