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Performance Enhancement of Stone Columns with Geocell Overlay: Numerical Insights

Razib Hussain[1] and Amarnath Hegde[2]

[1] Research Scholar, Department of Civil and Environmental Engineering, Indian Institute of Technology Patna, Patna-801103
[2] Assistant Professor, Department of Civil and Environmental Engineering, Indian Institute of Technology Patna, Patna-801103
ahegde@iitp.ac.in, razib_2121ce22@iitp.ac.in

Abstract. Granular blankets are usually provided above the stone columns to ensure proper drainage and also to enhance the performance of the stone columns. The present study investigates the overall performance of the stone columns with geocell reinforced granular blanket. The effect of geocell overlay has been studied using the finite element analysis software package ABAQUS. Geocell with three different infill materials, namely, aggregate, sand and silty clay, were considered in the study. The equivalent composite approach was adopted to simulate the geocell in a 2-dimensional framework. It was observed that the use of geocell in the granular blanket resulted in a 60% increase in the peak stress concentration ratio value as compared to the ordinary stone column. Similarly, a 13% reduction in ground settlement and a 42% increase in the load-carrying capacity of the stone column was observed in the presence of geocells. Maximum improvement in the load-carrying capacity was observed when the geocell was infilled with aggregates. Further, geocells were found to reduce the stress intensity on the stone columns by distributing the load to wider areas. As a result, the lateral bulging of the stone column was found to be reduced by 16% in the presence of geocell.

Keywords: Stone Column; Geocell; Infill Materials; Clay Bed; ABAQUS

1 Introduction

Construction of infrastructure on weak soils such as soft clay is a challenging task in the field of geotechnical engineering. Over the years, various ground improvement techniques have been developed to enhance the performance of weak soils and prevent unacceptable settlements [1–3]. One of the most widely used ground improvement techniques is the installation of stone columns in weak soil. The use of stone columns has been found to be effective in increasing the bearing capacity, reducing the settlement, accelerating the consolidation process and reducing the liquefaction potential of the soil [4–8].

Stone columns are usually constructed with a granular blanket placed above, which serves as a drainage layer as well as allows the distribution of stresses from the superstructure [5, 9]. Various researchers have used geosynthetic reinforcement within the granular blanket, which reduces the settlement and increases the load-carrying capacity of the soft soil [10–12].

However, the use of a cellular system of reinforcements is found to be more attractive and effective than planar geosynthetic reinforcements due to their three-dimensional structure [13–16]. Geocells are made of three-dimensional pockets filled with soil, thus providing all-round confinement. The use of the geocell helps to improve the bearing capacity of the soil, reduce the settlement and increase the stiffness. It enhances the stability of a structure and is cost-effective compared to other products [13], [17–20].

It was observed from the literature that a very limited studies are available on the use of geocell in the granular blanket. Therefore, in this study, a numerical approach was adopted to evaluate the effect of the geocell reinforced granular blanket on the performance of stone columns. Both drained and undrained analyses have been performed using the finite element software package ABAQUS, and the results are compared for different infill materials.

2 Numerical Modelling

The finite element analysis was carried out using the software package ABAQUS due to its capability to model various types of geotechnical problems. An axisymmetric model of the stone column of diameter 100 mm and height of 700 mm was modelled. Half of the soil bed was modelled due to symmetry, which has original dimensions of 1000 mm × 1000 mm × 700 mm with a 150 mm granular blanket overlying the clayey soil. The schematic representation of the test setup of ordinary stone column (OSC) and stone column system with geocell is presented in Fig. 1(a) and Fig1(b), respectively. As compared to practical cases, the smaller dimensions of stone columns are chosen in the simulation to reduce the computational efforts. However, results are presented in a normalised form to generalise the findings to practical cases as well.

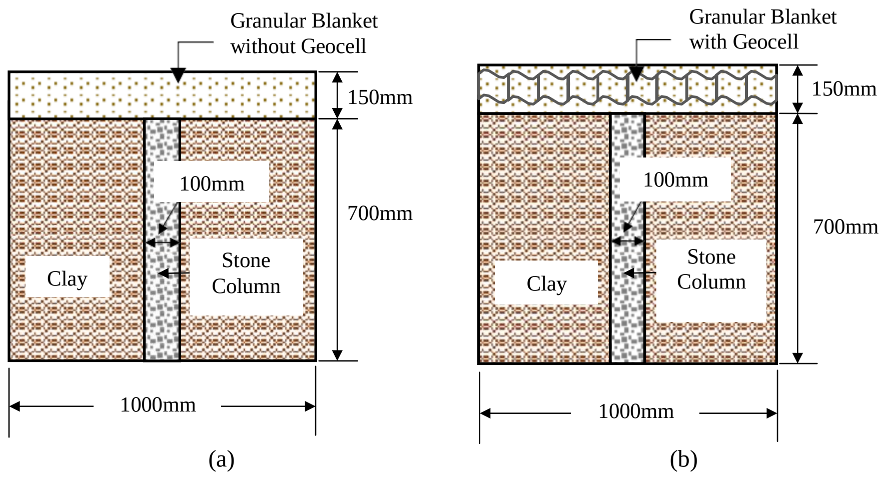


Fig. 1. Schematic representation of test setup of (a) ordinary stone column and (b) stone column system with geocell

Uniformly graded aggregate, silty clay and sand are the three different infill materials used in the study. The properties of the infill materials and the geocell were chosen based on the study done by [18], as listed in Table 1. The equivalent composite approach was used in the study to model the geocell in a 2-dimensional framework. In the equivalent composite approach, the geocell is modelled as a soil layer with enhanced shear strength properties [21–23]. As observed by [24], geocell mobilises the apparent cohesion in the soil without affecting the friction angle of the original soil. The properties of the other materials, including soft clay, stone column, and granular blanket, are listed in Table 2.

The elasto-plastic behaviour of the stone column and granular blanket was simulated using the Mohr-Coulomb plasticity model, whereas the plasticity behaviour of clayey soil was simulated using the Modified Cam Clay model. The interaction between the stone column and the surrounding soil was defined using tie constraints, which assumed close interlocking between the stone column and the soil [26]. The stone column, granular blanket and clayey soil were discretised using an 8-node axisymmetric quadrilateral, biquadratic displacement, and bilinear pore pressure elements with reduced integration (CAX8RP).

Table 1. Properties of infill materials and geocell in the geocell soil composite layer (Borrowed from [18, 21])

Properties	Geocell	Unreinforced sand	Geocell soil composite		
			Sand	Aggregate	Silty Clay
Friction angle, ϕ (^{o})		35	35	40	26
Cohesion, c (kPa)		0	34	38	28
Shear modulus, G (MPa)		5.77	25	30	20
Bulk modulus, K (MPa)		12.5	50	60	40
Poisson's ratio, v		0.3	0.3	0.3	0.3
Young's modulus, E (MPa)		15	65	78	52
Cell size (mm)	250 × 210				
Cell depth (mm)	150				
Density (g/cm^3)	0.95(±1.5%)				

Table 2. Material properties used in the numerical modelling for validation (Borrowed from [25])

Properties	Clay	Stone column	Granular blanket
Unit weight, γ (kN/m^3)	16	19	19
Permeability, k (m/sec)	4.0×10^{-9}	1.0×10^{-6}	1.0×10^{-6}
Cohesion, c (kPa)	30	0	0
Friction angle, ϕ (^{o})	0	47	42
Dilatancy angle, ψ		17	12
Pre overburden pressure (kPa)	10		
Slope of the swelling line, κ	0.026		
Slope of the virgin consolidation line, λ	0.101		
Poisson's ratio, ν	0.15	0.2	
Young's modulus, E (MPa)		35.25	12

The bottom of the model was restricted in vertical as well as horizontal directions, whereas the vertical boundary at the right side of the model was restricted in the horizontal direction only. XSYMM boundary condition was applied at the left vertical boundary to create symmetry about the plane normal to X-axis. The pore pressure value was kept as zero at the top of the model to simulate the free drainage behaviour. The details of loading and boundary conditions applied in the model are presented in Fig. 2.

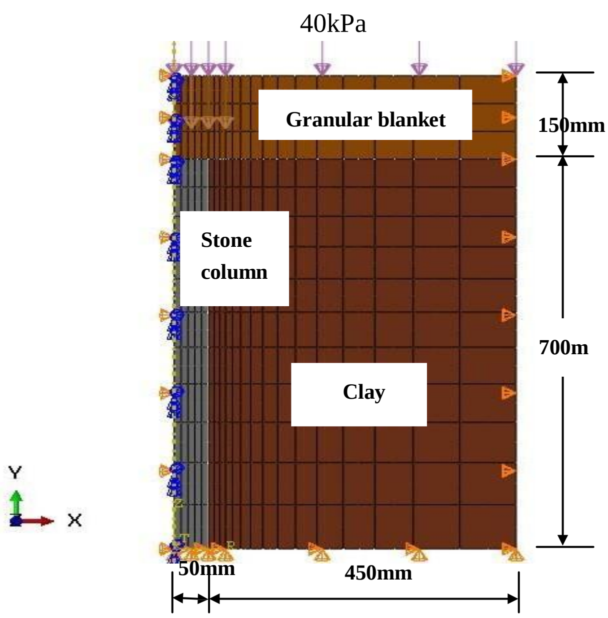


Fig. 2. Detailed loading and boundary conditions in the axisymmetric model

Initially, the geostatic step was carried out to create the equilibrium in the model. In the second step, a vertical pressure of 40kPa was applied at the top, and the consolidation analysis was carried out for a time period of 100 days to investigate the time-dependent behaviour of the stone column. In the final step, an undrained load test was carried out to evaluate the load settlement behaviour of the stone column. The experimental and numerical procedures are described in detail in [25].

2.1 Model Validation

The numerical modelling approach was validated by comparing the results of the present study with the experimental results reported by [25]. The pressure-settlement response obtained from the experimental study and the numerical analysis is shown in Fig. 3. It was observed that the numerical modelling results were in good agreement with the results obtained from the experimental study. In the further part of the study, the validated numerical model was used to predict the behaviour of stone columns in the presence of a geocell-reinforced granular blanket.

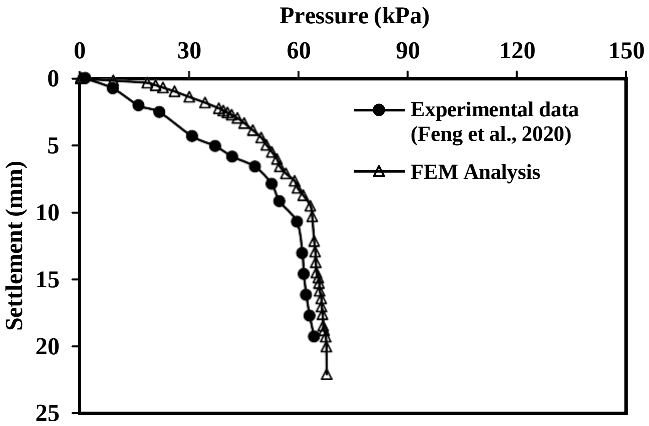


Fig. 3. Pressure-settlement curve to compare the experimental and numerical result

3 Results and Discussions

3.1 Stress Concentration Ratio (SCR)

Stress Concentration Ratio (SCR) is defined as the ratio of the vertical stress on the stone column to the vertical stress on the soil. SCR is an important parameter as it indicates the degree of stress transfer from the surrounding soil to the column. The variation of SCR with time is shown in Fig. 4 for different cases. The stress concentration ratio was found to increase rapidly with time until the consolidation was almost complete and then gradually became constant.

The stress concentration ratio of the stone column system in the presence of geocell was found to be higher than the ordinary stone column without geocell, which is due to the increased stiffness and rigidity provided by the geocell. The use of a geocell-reinforced sand blanket placed over the stone column resulted in a 60% increase in the peak SCR value as compared to the ordinary stone column (OSC). Further findings revealed that the use of aggregate and silty clay as an infill material in the geocell increased the maximum peak SCR by 74% and 53%, respectively.

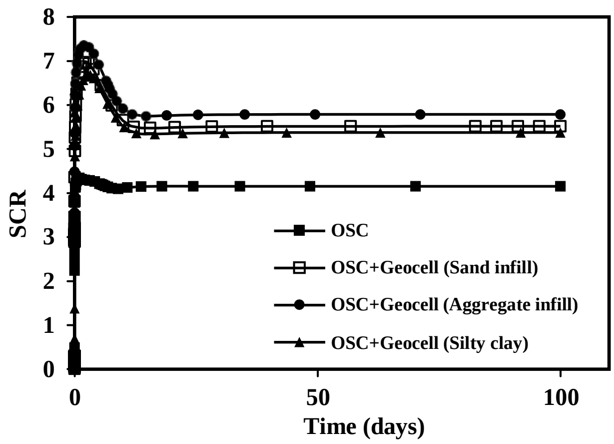
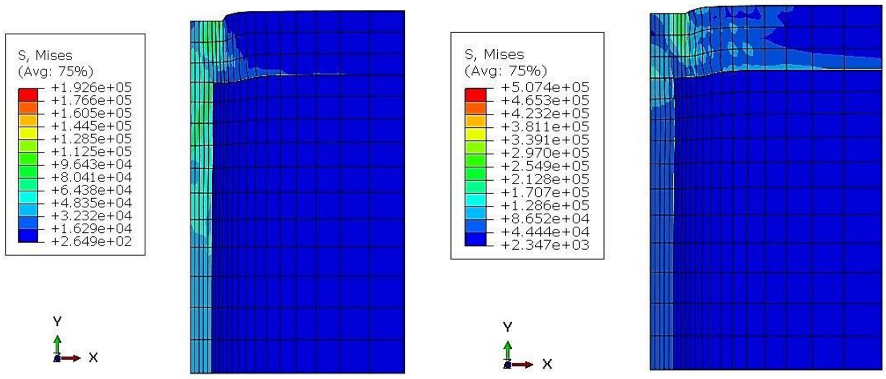


Fig. 4. Variation of SCR with time



(a) (b)

Fig. 5. Stress contours of (a) OSC, (b) OSC + Geocell (Sand infill)

The stress contours of the ordinary stone column (OSC) and stone column with a geocell-reinforced sand blanket is presented in Fig. 5. From the figure, it can be observed that the load was distributed to wider areas in the presence of geocell. Due to which, the stone column was subjected to a lesser magnitude of stress intensities, causing a reduction in the settlement as well as lateral bulging.

3.2 Settlement

The variation of normalised settlement (*S/D*) with respect to time for the stone column system with and without geocell overlay is shown in Fig. 6. It was observed that the settlement increased rapidly during the loading stage and then gradually became constant till the end of the consolidation stage. Test results revealed that the settlement of 61% of column diameter was observed at the end of the consolidation stage in the case of the ordinary stone column (OSC). Whereas the settlement was reduced by 13% when a geocell-reinforced sand blanket was placed above the stone column. The normalised settlement of *S/D* = 48% and *S/D* = 57% was reported at the end of the consolidation stage when geocell pockets were filled with aggregates and silty clay, respectively.

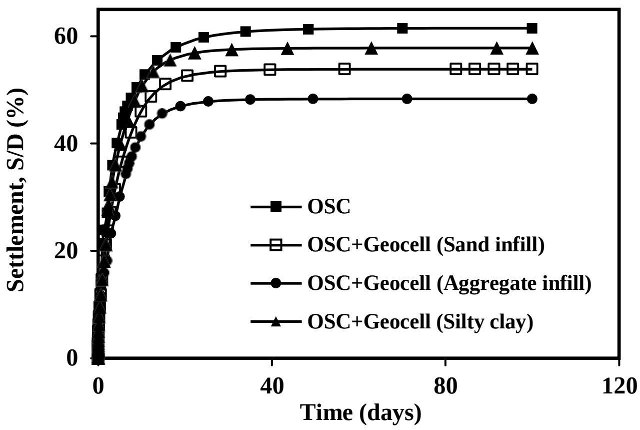


Fig. 6. Variation in settlement with time

3.3 Lateral Bulging

The variation of normalised lateral bulging with respect to the normalised depth of the stone column is shown in Fig. 7. The stone column diameter (*D*) was used to normalise both lateral bulging and the depth of the stone column. The bulging was found to be the highest at the top surface, and then it gradually decreases with depth, which is similar to the findings of [27]. The maximum bulging was observed at a depth of nearly 0.5D in the ordinary stone column (OSC) with an unreinforced sand blanket, as shown in Fig. 8(a). However, bulging depth was increased to 1D, and bulging diameter was reduced by 16% when a geocell-reinforced sand blanket was introduced over the stone column, as shown in Fig. 8(b). This is due to the fact that the load gets redistributed to wider strata when geocell is used in the sand fill layer. As a result, the bulging gets reduced due to lesser stress intensity on the stone column and increased lateral pressure from the surrounding soil. However, in the case of the geocells, the increase in the overburden pressure at a normalised depth of 1D (as compared to 0.5D in OSC) caused some bulging in the stone columns. The use of aggregate and silty clay as infill material resulted in a 22% and 7% reduction in bulging diameter as compared to the ordinary stone column (OSC).

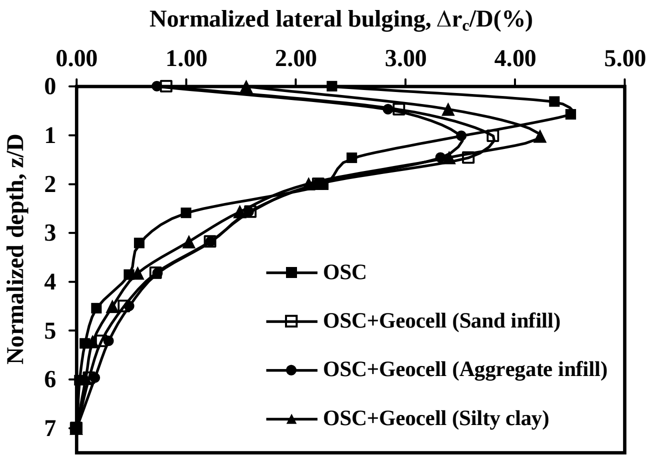


Fig. 7. Effect of geocell on lateral bulging

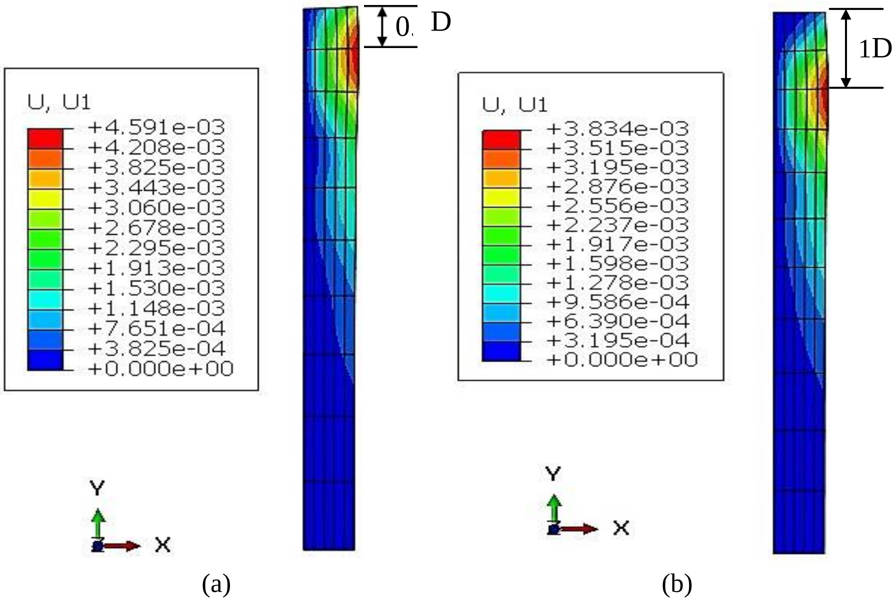


Fig. 8. Lateral bulging profile of (a) OSC, (b) OSC + Geocell (Sand infill)

3.4 Pressure-Settlement Behaviour

An undrained load test was simulated in ABAQUS on the stone column system with and without geocell overlay. The analysis was carried out till the settlement of 25mm was reached. The pressure settlement response obtained from the numerical analysis is shown in Fig. 9. As compared to OSC, an improvement of 42% in load carrying capacity was observed when a geocell-reinforced sand blanket was placed over the stone column. Using silty clay as an infill material in geocell pockets resulted in a 34% improvement in load carrying capacity compared to OSC. However, a maximum improvement of 47% in load carrying capacity was observed when aggregate was used as infill material.

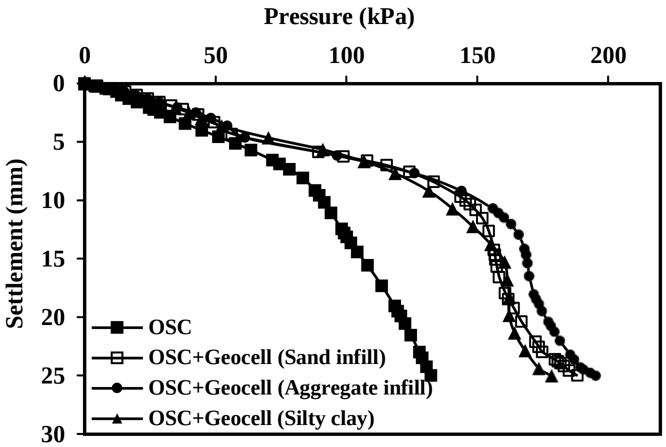


Fig. 9. Pressure-settlement curve

4 Conclusions

The effect of the geocell reinforced granular blanket on the performance of stone columns was studied with the help of axisymmetric finite element analysis. Sand, aggregate and silty clay were three different infill materials used in the study to fill the geocell pocket. The following conclusions can be drawn from the results of the numerical analysis:

1. The stress concentration ratio was found to increase rapidly with time till the consolidation was almost complete and then gradually became constant. As compared to the ordinary stone column, the peak SCR value increased by 60% due to the presence of a geocell reinforced sand blanket placed over the stone column. In addition, it was found that using aggregate and silty clay as infill materials in the geocell increased the maximum peak SCR by 74% and 53%, respectively.
2. The settlement of the stone column was significantly reduced in the presence of geocells. The settlement of 61% of column diameter was observed at the end of the consolidation stage in the case of the ordinary stone column (OSC). In contrast, the settlement was reduced by 13% when a geocell-reinforced sand blanket was placed above the stone column. The use of aggregate and silty clay as infill resulted in a normalised settlement of S/D = 48% and S/D = 57%, respectively.
3. An increase in the depth of bulging and a decrease in bulging diameter was observed due to the placement of a geocell-reinforced granular blanket over the stone column. As compared to the ordinary stone column, the maximum reduction of 16%, 22% and 7% in bulging diameter was observed when sand, aggregate and silty clay were used as infill.

4. In the presence of geocell, the load carrying capacity of the stone column was found to improve by 42%, 47% and 34% when sand, aggregate and silty clay were used as infill. Maximum improvement in the performance of the stone column was observed when geocell pockets were filled with aggregates.

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