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Numerical analysis of geosynthetic encased stone column

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ABSTRACT: Stone columns (or granular piles) are increasingly being used as ground improvement system particularly for settlement insensitive structures like road embankments, oil storage tanks etc. In the case of extremely soft soils the passive resistance developed in the surrounding soil may not be adequate to hold the stones intact. Moreover the stones charged to form the stone column may squeeze in to the surrounding soil. In such soils the required passive pressure can be induced by confining the stones by encasing the stone column with suitable geosynthetic. Apart from increasing the strength and stiffness of the stone column, the encasement prevents the loss of stones when it is installed even in extremely soft soils thus enabling quicker installation. This complex mechanism of load transfer and the interaction with surrounding soil is to be investigated experimentally as well as numerically to understand their behaviour. This paper investigates the improvement of load capacity of stone column by encasement through a comprehensive parametric study using Finite Element analysis. It is found from the analysis that due to encasement the settlement and bulging in stone column is controlled depending on the stiffness of the geosynthetic, and the encasement is more effective for stone columns of lesser diameter. Beyond 1m diameter the encasement effect is very minimal for the stiffness of geosynthetics considered in the analysis. The encasement is more essential in the top 40% height of stone column, where more bulging is expected.

1 INTRODUCTION

Ever since Greenwood (1970) introduced the load bearing mechanisms in stone columns with dilation of stones and induction of near passive pressure conditions in the soil surrounding the stone columns, many investigations are carried out in predicting the behaviour of stone column. Many researchers had pointed out the improved performance of the stone column based on experimental and numerical studies. As a further development, enhancing the load carrying capacity of stone columns is tried by suitably reinforcing the stone columns. Sharma (1998) and Sharma *et al.* (2004) explored numerically and experimentally the behaviour of stone columns reinforced with horizontal layers of geogrid at the top end of the stone columns where greater bulging is expected. Katti *et al.* (1993) proposed the theory for the improvement of soft ground using stone columns with geosynthetic encasement based on the particulate concept. Dimiter *et al.* (2005) have given the characteristics of geosynthetic encased stone column (GEC) by using high modulus low-creep geosynthetics as an end bearing element transferring the loads to a firm stratum and as high-capacity vertical drains. They have also reported the system as not completely settlement-free and recommended to install horizontal geosynthetic reinforcement on top of GECs (at the base of embankment) in order to equalize settlements and to increase global stability. Malarvizhi and Ilamparuthi (2004) reported the improved performance of the geosynthetic encased stone column based on small scale laboratory tests on end bearing as well as floating columns. The published literature on the performance of encased stone column is limited, thus further investigation is necessary for better understanding of the mechanism.

2 FINITE ELEMENT ANALYSIS

A detailed parametric study was carried out on the geosynthetic encased stone column using the Finite Element Program GEOFEM (Rajagopal, 1998). The stone columns were assumed to be arranged in square or triangular pattern in plan. The unit cell area around each stone column was analysed using axisymmetric idealization to understand the basic mechanism. In order to quantify the improvement achieved due to encasement, ordinary stone columns (OSC) installed in clay soil and geosynthetic encased stone columns (ESC) installed in clay soil were considered. The schematic of finite element mesh discretisation (all continuum elements) is shown in Fig. 1.

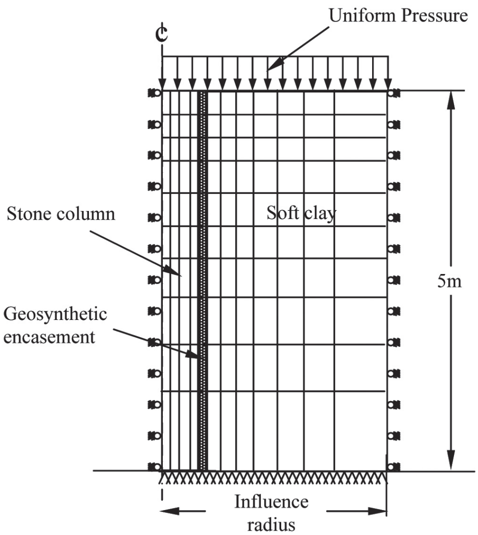

Figure 1. Schematic of finite element mesh showing the discretisation of 2-D elements (Axisymmetric).

Hyperbolic non-linear elastic model has been adopted for the stone column and the surrounding soft soil as given in Equation-1 (Duncan and Chang, 1970).

$$E_t = \left[1 - \frac{R_f\,(1 - \sin\phi)(\sigma_1 - \sigma_3)}{2\,c\cos\phi + 2\sigma_3\sin\phi}\right]^2 Kp_a\left(\frac{\sigma_3}{p_a}\right)^m \quad (1)$$

Where E_t is tangent elastic modulus; c is cohesion of foundation soil or stone column; ϕ is angle of internal friction for foundation soil or stone column; K is Young's modulus number; m is Young's modulus exponent; R_f is failure ratio; σ_1 and σ_3 are major and minor principal stresses and p_a is the atmospheric pressure. The geosynthetic encasement was modeled as linear elastic material. Different material properties were obtained from previous publications (Han and Gabr, 2002) and are listed in Table 1. The superimposed loads were modelled by applying uniform pressure of maximum expected intensity of up to 200 kPa on the top surface (ground surface). The geosynthetic encasement was simulated by placing elastic continuum element around the stone column (considering axisymmetric idealisation) with a Young's modulus, E calculated as per the equation $E = J \times t$. Where 'J' and 't' are respectively the secant stiffness and thickness of the geosynthetic encasement element.

Table 1. Material properties.

Materials	Hyperbolic model parameters						Unit weight kN/m^3
	K	m	μ	R_f	c kPa	ϕ	
Stone column	1200	0.7	0.45	0.7	0	42°	20
Foundation soil	50	0.5	0.45	0.7	20	0°	17
Geosynthetic encasement	Linear Elastic with Poisson's ratio, μ = 0.3						

In order to simplify the problem, it is assumed that the geosynthetic encasement is perfectly bonded to both the stones and the foundation soil. Thus the failure at the interfaces will happen in the weaker material surrounding the interfaces. Typical finite element mesh consisted of 1750 number of nodes and 550 number of 8-node quadrilateral elements. The external loading was applied in small increments. The solution at each step was iterated to reduce the norm of out of balance force to less than 0.1% or maximum 25 iterations. The stiffness matrix of the system was updated at every iteration in view of the dependence of the modulus on the stress state. The foundation soil in all the cases is assumed to be 5 m thick soft clay layer underlain by firm strata.

3 RESULTS AND DISCUSSIONS

Detailed parametric analyses were performed by varying the diameter of the stone column, spacing of stone column (in terms of the influence radius of the unit cell considered), depth of encasement from ground surface and stiffness of geosynthetic. The improved performance was quantified based on the reduction in settlement in the stone column. For the controlling case 1 m diameter stone column with 3 m influence radius was considered.

3.1 *Effect of encasement of stone column*

Series of analyses were performed with 1 m diameter stone column and various unit cell radii of 1 m to 5 m. The geosynthetic stiffness was 2500 kN/m for these analyses. Figure 2 shows the variation of settlement ratio (ratio of settlement of stone column to that of clay soil alone) with radius of the unit cell. Due to the encasement there is a reduction in the settlement ratio up to 20% for all the unit cell radius values.

3.2 *Influence of diameter of stone column on encasement effect*

Analyses were performed for stone column diameters of 0.6, 0.8, 1.0, 1.2, 1.4 and 1.6 m while the diameter of the unit cell was kept constant at 3 m. A quantity, *area ratio*, has been defined as the ratio between the stone column area and the total area of the unit cell

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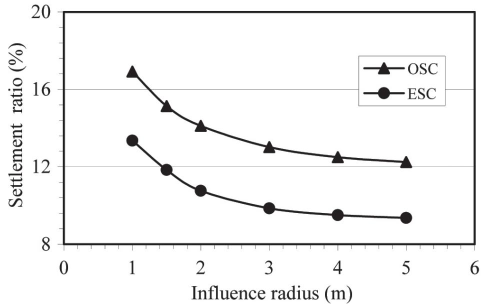

Figure 2. Settlement of stone column at different unit cell radius values.

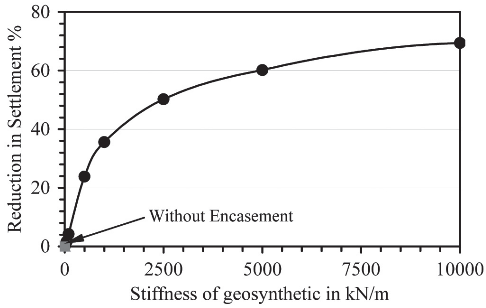

Figure 4. Influence of stiffness of geosynthetic encasement on the reduction in settlement of stone column.

in order to represent the area of soil replaced by stones. The area ratios for different diameters ranged between 4% and 30%. The geosynthetic stiffness was 2500 kN/m for these analyses. Figure 3 shows the variation of the settlement ratio with area ratio of the stone columns.

It could be noticed that geosynthetic encasement is more effective for stone columns of lesser diameter. Beyond an area ratio of 11% (1 m diameter) the encasement effect is very minimal for the stiffness of the geosynthetic considered. Moreover, from Fig. 3 it can be inferred that ordinary stone column of area ratio 11% undergoes approximately the same settlement as that of the encased stone column of 4% area ratio for equal applied pressure. This result shows that the encased stone columns can be of smaller diameter or provided at larger spacing in order to obtain the same performance as obtained from an ordinary stone column of certain diameter and spacing.

3.3 *Influence of stiffness of geosynthetic*

In order to investigate the influence of stiffness of geosynthetic, finite element analyses were performed by applying pressure only over the column area. Figure 4 shows the variation of percent reduction in settlement of encased stone column over that of uncased column for different stiffness values of geosynthetics while all other parameters remain constant. It could be observed that the settlement decreases appreciably up to a stiffness of 2500 kN/m beyond which the influence remained more or less constant. Hence it could be concluded that geosynthetic with stiffness of 2500 kN/m is sufficient for the required confinement of stones.

3.4 *Influence of depth of encasement*

The bulging of stone column upon loading will be confined to a height equal to 2 to 3 times the diameter of the stone column. So only the top portion of stone column needs more confinement for its stability. Analyses were performed by varying the height of encasement from top to investigate the influence of depth of encasement from ground level.

From Fig. 5 it is observed that the encasement for a height of more than twice the diameter of the column below the ground surface does not lead to further improvement. The pressure settlement curves for stone columns with varying heights of encasements are shown in Fig. 6, which clearly shows that it is adequate to confine only the top portion of the stone column.

This fact is reflected in the variation of hoop tension force developed in the geosynthetic (with stiffness of 2500 kN/m) used for encasement along the height of the stone column as shown in Fig. 7. The hoop tension is greater in the portion where maximum bulging is expected. There after it decreases almost

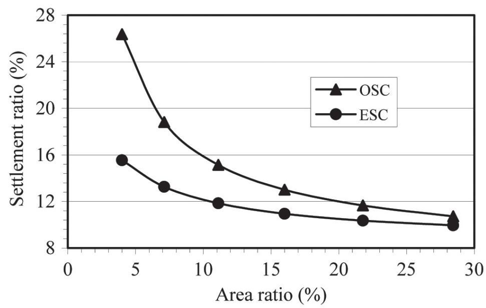

Figure 3. Variation of settlement in stone column with diameter.

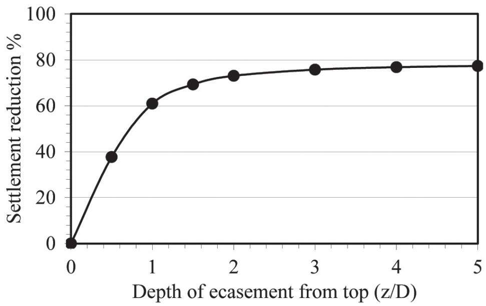

Figure 5. Influence of depth of encasement of stone column.

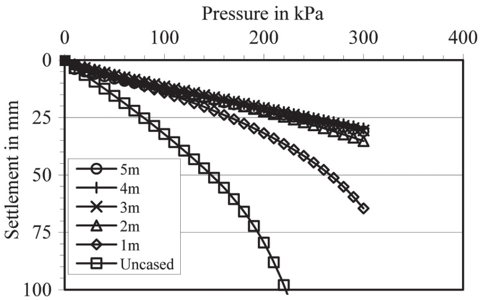

Figure 6. Pressure-settlement response with different depths of encasement.

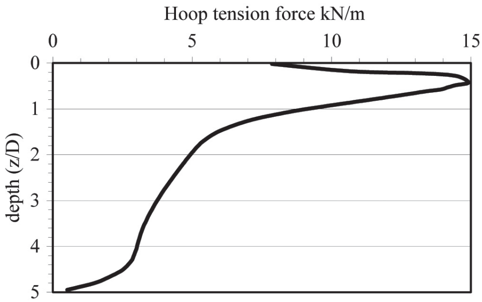

Figure 7. Hoop tension in geosynthetic at 200 kPa pressure.

linearly with the distance from the top of the stone column. These tensile forces are much below the ultimate long term tensile strength of most commercially available geosynthetics. Hence, the assumption of linear-elastic behaviour for the encasement elements is justified.

4 CONCLUSIONS

Encasing the stone column by suitable geosynthetics improves the load carrying capacity of the stone column as it induces the required passive resistance by confinement effect. From the numerical analyses performed on the geosynthetic encased stone column by considering one unit cell around the stone column the following conclusions can be drawn.

1. Geosynthetic encasement reduces the settlement of stone column by up to 20%. The effect of encasement decreases as the diameter of stone column increases. Beyond 1 m diameter the encasement effect is insignificant for the geosynthetic considered.
2. The maximum settlement in the encased stone column decreases steeply with increase in the modulus of the geosynthetic up to a value of 2500 kN/m for the present case. Thereafter the effect of encasement remained constant.
3. It is adequate to provide geosynthetic encasement in the top length equal to 2 to 3 times the diameter from the ground level.
4. The hoop tension force developed in the encasement is higher near the ground surface where mximum bulging occurs. The magnitude of the tensile force is very small even at large applied pressures corresponding to 10 m high embankments.

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