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Influence of positions of the geotextile on the load-settlement behaviour of circular footing resting on single stone column by 2D Plaxis software

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ABSTRACT

Purpose: This study aims to study the load – settlement behaviour of circular footing rested on encased single stone column.

Design/methodology/approach: The effect of vertical, horizontal and combined vertical-horizontal encasement of stone column on the load carrying capacity were examined numerically. The effect of stone column dimension (80 mm and 100 mm), length (400 mm and 500 mm), and spacing of reinforcement on the load carrying capacity and reinforcement ratio were assessed.

Findings: The obtained results revealed that the load carrying capacity of geotextile encased stone columns are more than ordinary stone columns. For vertically encased stone columns as the diameter increases, the advantage of encasement decreases. Whereas, for horizontally encased stone column and combined vertical- horizontal encased stone column, the performance of encasement intensifies as the diameter of stone column increases. The improvement in the load carrying capacity of clay bed reinforced with combined vertical-horizontal encased stone columns are higher than vertical encased stone columns or horizontal encased stone column. The maximum performance of encasement was observed for VHESC1 of D = 80 mm.

Research limitations/implications: For this study, the diameter of footing and stone column was kept same. The interface strength factor between stone column and clay bed was not considered.

Practical implications: The encased stone column could be use improve the laod bearing capacity of weak soils.

Originality/value: Many studies are available in literature regarding use of geosynthetic as vertical encasement and horizontal encasement of stone column. The study on combined effect of vertical and horizontal encasement of stone column on load carrying capacity of weak soil is very minimal. Keeping this in view, the present work was carried out.

Keywords: Clay bed, Circular footing, Stone column, Geotextile, Numerical analysis

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ANALYSIS AND MODELLING

1. Introduction

For unsuitable soils, stone columns are commonly used as ground improvement tool for improving bearing capacity and restrict excessive settlements. Apart from this, it can facilitate radial drainage and quickly dissipate additional pore water pressure which may faster consolidation process. If shear strength of the surrounding soil is insufficient, the stone column may fail due to bulging or punching or general shear, when subjected to compressive loads. The stone column having length greater than its critical length (that is about 4 times the column diameter) is called as long stone column and irrespective whether it is end bearing or floating, it fails by bulging as shown in Figure 1a. However, column shorter than the critical length (called as short stone column) are likely to fail in general shear if it is end bearing on a rigid base as shown in Figure 1b and in end bearing if it is a floating column as shown in Figure 1c.

The unnecessary bulging and squeezing of stones can be overcome with encasement of stone column with geosynthetic materials. The encasement will provide addition confinement to the stone column which may increase the load carrying capacity of the footing rested on weak soils.

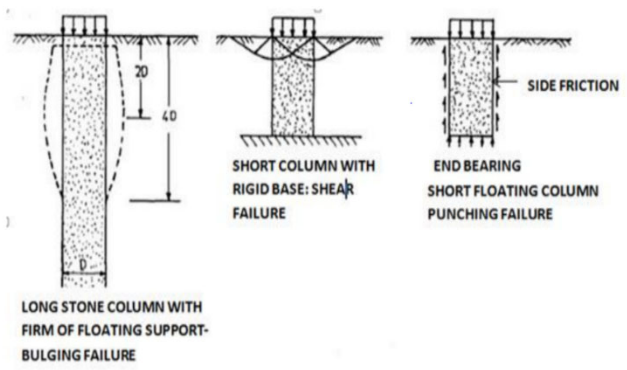

Fig. 1. Type of failure of stone column subjected to compressive load (IS: 15284-2003) [1]

The concept of lateral confinement of stone was first introduced by Van Impe [2]. In the three decades' serval analytical, theoretical, model and field tests have been carried out by many researchers' on the ordinary stone column and encased stone column. Ambily and Gandhi [3] numerically analyzed the influence of sand pad thickness on the load distribution between the stone column and the ground. Sivakumar et al. [4] reported improvement in the bearing capacity of clay bed reinforced with sand column. Deb et al. [5] documented the algorithm evolutionary genetic technique to study the reliability of geo-synthetic encased embankments placed on stone columns. Tandel et al. [6] reported that reinforced stone columns with smaller diameters performs better than reinforced stone columns with bigger diameters. Castro [7] depicted that if the area replacement ratio (area of the columns over area of the footing) and the ratio of encasement stiffness to column diameter were kept constant, the column structure would remain stable. Basack, S et al. [8] created an in-house computer formula based on the Lagrangian approach and associated functions to under standard the nature of a stone column including the lateral displacement. Samanta and Bhowmik [9] studied the effect of surface percentage replacement, aspect ratio, and material qualities of the stone column, and slenderness ratio of the pile on pile raft base. Alarifi Hamzh et.al [10] explored the compressive strength of regular and non-uniform stone columns in weak soil.

Majorities of the experimental studies have used geo-synthetic for vertical encasement of stone column [11-18]. Verma et al. [19] reported enhancement in the load carrying capacity and settlement performance of ring footing rested on geosynthetic encased stone column. Bhatia and Kumar [11] reported improvement in bearing capacity and reduction in settlement of fly bed treated with geosynthetic encased concrete debris column. Murugesan and rajagopal [12] documented that the stiffness of encasement material of stone column plays a vital role in strength improvement of bed. The impact of length and modulus of stiffness of geosynthetic encasement on the load carrying capacity of stone column were studied [13-15].

Very seldom researchers have used geosynthetic as horizontal reinforcement of stone column [20-25]. Sharma et al. [20] studied the influence of horizontal geogrid utilization on the compression response of granular piles. Ayadat et al. [21] reinforced the stone column horizontally with plastic, steel and aluminium sheets and reported improvement in the load carrying capacity of stone column by the use of horizontal reinforcement and increasing the number of layers of reinforcement. Similarly, Ghazavi et al. [22] and Prasad and Satyanarayanna [23] reported increase in bearing capacity of stone column and reduction in settlement of soil bed with the reduction in the spacing between the geogrid layers.

Most of the studies have reported increment in the bearing capacity of footing rested on weak soil with inclusion of stone column. The encased stone column has performed better than ordinary stone. Very seldom work has been carried out till yet on the effect of position of encasement of stone column on load carrying capacity of weak soil. Bonad et al. [26] conducted small-scale laboratory tests on circular footing rested on geotextile encased column of length/diameter ratio of 5 and assessed the impact of position of encasement. In this study, the impact of vertical, horizontal and vertical-horizontal combined encasement of stone column on the load carrying capacity of circular footing rested on weak soil were examined numerically. The effect of stone column dimension, length and space of reinforcement have been evaluated.

2. Problem definition and model parameters

In this study, Plaxis 2D software was used to assess the load-settlement behaviour of circular footing resting on unreinforced and reinforced clay bed subjected to a vertical concentric load. Low plasticity clay of specific gravity 2.6 was used in this study. It had Liquid limit = 48%, plastic limit = 25%, plasticity index = 23%, and undrained shear strength = 15 kPa. The maximum dry unit weight and optimum moisture content of the clay are 15.5 kN/m^3 and 19%, respectively [26]. According to the Wood et al. [27], the ratio of column diameter to fill material diameter should lie in range of 12-40. Considering this in view, the crushed stone aggregates of size between 2 to 10 mm were used to fill the stone column. Maximum dry unit weight, minimum dry unit weight, specific gravity, coefficient of uniformity (Cu), and coefficient of curvature (Cc) of stone aggregates were 16.9 5 kN/m^3, 14.3 5 kN/m^3, 2.7, 2.25, and 1.62, respectively [26]. It was classified as poorly graded gravel. For encasing the stone column, nonwoven polypropylene geotextile of thickness, secant stiffness at ultimate strain, and ultimate tensile strength equal to 1.4 mm, 15 kN/m, and 10 kN/m, respectively was used. The cast iron circular footing of 30 mm thickness and of two diameters 80 mm and 100 mm were used. For modelling, the poisson ratio of footing was taken as 0.2 [28]. The imput paramters of soil, foundation and stone column for FEM modleing are shown in Table 1.

Load – settlement behaviour of circular footing rested on single geotextile encased stone column clay bed were studied for three cases: (i) vertically encased stone column (VESC), (ii) horizontally encased stone column (HESC), and (iii) vertically-horizontally combined encased stone column (VHESC). The effect of stone column dimension, length and space of reinforcement were studied. The details of the varied parameters for which the analysis were carried out are shown in Table 2. Apart from that the analysis were also conducted for ordinary stone column (OSC).

3. Finite element meshing and boundary condition's

Typical numerical model of circular footing resting on unreinforced clay bed and reinforced clay bed are shown in Figure 2. The clay bed model of dimensions 5B from the edge of footing in both X and Y direction was created. Keeping the minimum stresses at the boundaries in view, the boundaries of the model were selected. At the boundaries of the model, general fixities condition was imposed.

Table 1.
Properties of soil, stone column, and footing used for modelling

Properties	Soil	Stone column	Footing
Bulk unit weight at 23% moisture content, kN/m^3 [26]	19.1	-	-
Bulk unit weight at 70% relative density, kN/m^3 [26]	-	16	-
Young modulus, E [30]	9 MPa	150 MPa	210 GPa
Assumed Poisson‘s ratio, μ [30]	0.35	0.15	0.2
Friction angle at 70% relative density [26]	-	46	-
Cohesion, c, kN/m^2 [26]	7.5	-	-
Dilation angle, Ψ [30]	0	0	-
Interface strength factor [28]	1	1	1

Table 2.
Details of the analysis carried out

Reinforcement type	L*/D*	Parameters varied		
VESC	5	Lr = L	Lr = 0.5L	Lr = D, S = D
HESC	5	S= 0.5D	S = D	
VHESC	5	Lr = L, S 0.5D	Lr = L, S = D	Lr = D, S = D

*Lengh of stone column, L = 400 mm and 500 mm
*Daimter of stone column, D = 80 mm and 100 mm
*Spacing of the layer, S.

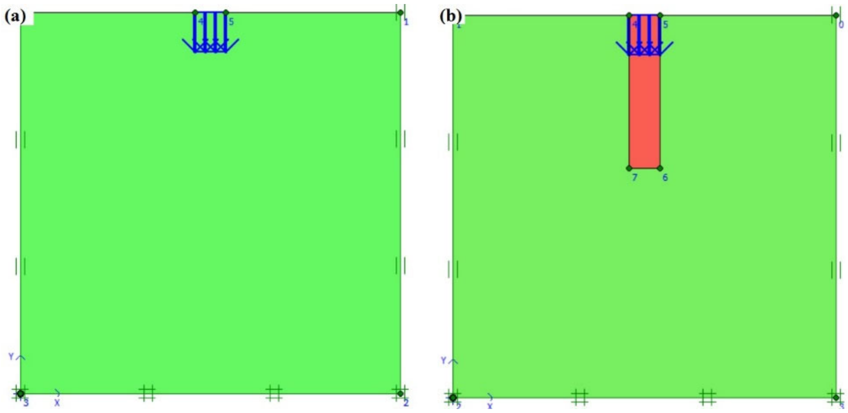

Fig. 2. Numerical model: (a) unreinforced clay bed (b) reinforced clay bed

The meshing in Plaxis software consists of different types of scheme such as coarse, medium, fine. For the analysis, medium meshing of 15 noded triangular element was used. The mohr-Coulomb model was used as it less computational time compared to other models [29]. As per guideline of IS 15284, the dimensions of footing should be twice that of column diameter [1]. For this study, the diameter of footing and stone column was kept same. The interface strength factor between stone column and clay bed was not consider because no significant friction occurs at the stone column-clay boundary.

4. Results and discussion

The different arrangement of vertical, horizontal and vertical-horizontal geosythetic encased stone columns for D = 80 mm are shown in Figure 3. The numerical analyses were carried for two diameter of encased stone columns (D = 80 and 100 mm).

4.1. Vertically encased stone column

The load-settlement curves of circular footing resting on single vertically encased stone column of diameter 80 mm and 100 mm are revealed in Figures 4a and 4b, respectively. Figures 4a,b reveal that the introduction of OSC and VESC improves the load taking ability of the clay bed. For OSC1 and OSC2, the improvement in the load carrying capacity was 22.86% and 55.17%, respectively compared to clay bed. Further, the load carrying capacity of the kaolin soil was improved by 76.49% and 149%, for D = 80 mm and 100 mm, respectively, when the kaolin soil was reinforced with VESC1 and VESC4. Whereas, the introduction of VESC2 and VESC3 improved the load carrying capacity by 47% and 60%, respectively. Similarly, For VESC5 and VESC6, the improvement of 141.19% and 145.46% were witnessed as displayed in Figure 4b. The introduction of OSCs increase the load carrying capacity of clay bed because it transfers the upcoming load to greater depth. But, the enhancement in load carrying capacity of clay bed reinforced with VESCs are more as compare OSCs because of lateral confinement provided by vertical reinforcement which reduces the bulging and squeezing of the column. Similar results were also reported by Bonad et al., [26].

On comparing the OSC1 of D = 80 mm to OSC2 of D = 100 mm, the improvement of 28.3% in the load carrying capacity was perceived. For all VESCs, with the increase in stone column diameter, an average increase of 18.4% in the load carrying capacity was witnessed. However, for VESCs

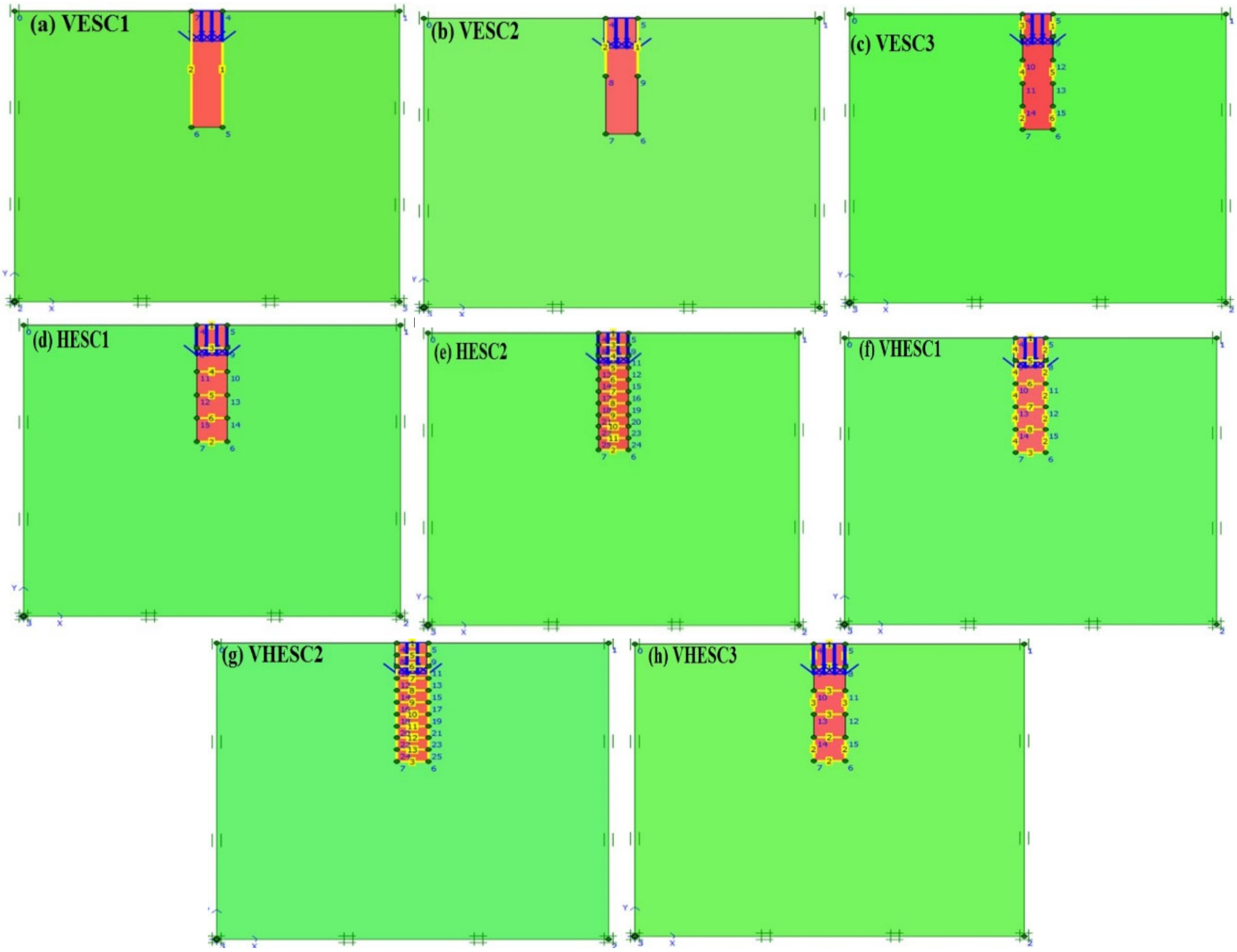

Fig. 3. Different arrangement of vertical, horizontal and vertical-horizontal geosythetic encased stone columns for D = 80 mm

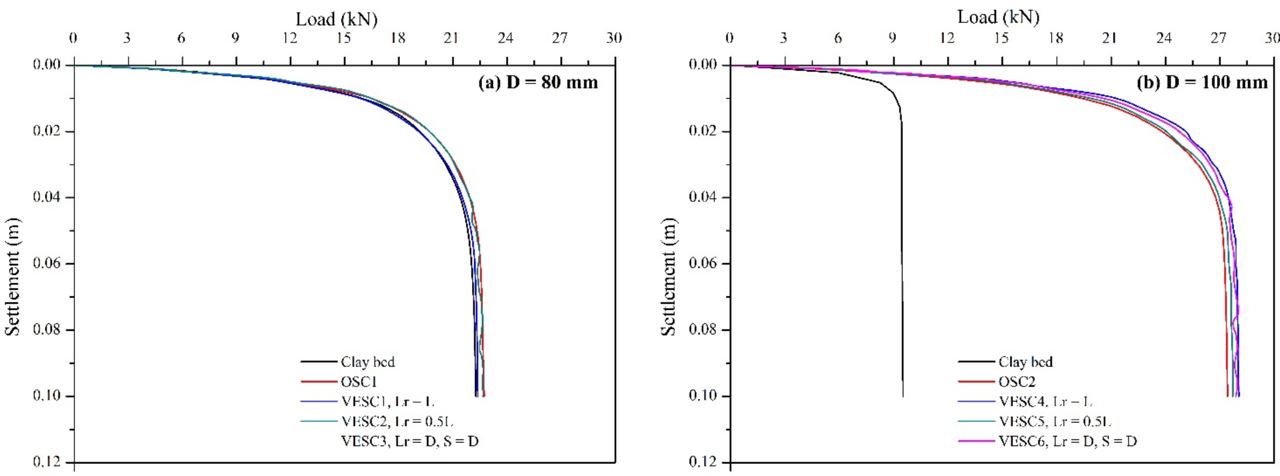

Fig. 4. Load-settlement behaviour of vertically encased stone column (a) D = 80 mm (b) D = 100 mm

increasing the stone column diameter reduces encasement performance because of mobilization of high confining stresses in smaller diameter stone column.

To check the effect of length of geotextile on the load carrying capacity of VESCs, three different length of geotextile were taken. An improvement of 20.06% and 3.46% was seen by increasing the geotextile length from half to full for D = 80 mm and 100 mm, respectively. It clearly reflects that ability of fully vertically encased stone column to carry the load is greater half-length vertically encased stone column because of its higher stiffness [26]. However, insignificant improvement in the load carrying capacity was observed, when stone column was vertically encased at depth D to 2D. An increase of 8.45% and 1.76% in the load carrying capacity of clay bed were witnessed on comparing VESC2 and VESC5 with VESC3 and VESC6, respectively. It clearly shows that the performance of VESC3 and VESC6 towards the upsurge in load carrying capacity is identical as that of VESC2 and VESC5. Stone columns reinforced with heights (0.6 L) have a similar efficiency to half reinforced stone columns (0.5 L). Keeping this observation in view, it could be concluded that the confinement should be provided up to a length where bulging occurs.

4.2. Horizontally encased stone column

Figures 5a,b exhibits the load-settlement behaviour of single horizontal encased stone column of 80 mm and 100 mm diameter, respectively. The load carrying ability of clay bed increases with the addition of HESCs. For D = 80 mm, HESC1 (S = 0.5 D) and HESC2 (S = D) increased load carrying capacity of clay bed by 91.83% and 75.31%, respectively. Also, For D = 100 m, HESC3 and HESC4 increased by 142.46% and 125.77%, respectively. It shows that for HESCs with the increase in diameter, the load carrying capacity increases. On comparing the HESC1 (S = 0.5 D) to HESC3 (S = 0.5D) and HESC2 (S = D) to HESC4 (S = D), it was discovered that with the increase in diameter from 80 mm to 100 mm, the load carrying capacity increased by 26.39% and 28.77%, respectively. The crushed stone may have more interactive shear mobilisation at the two faces of geotextile layers with larger diameters, which could be responsible for the rise in load carrying capacity with the increase in diameter. Similar results were also reported by Bonad et al., [26].

By reducing the spaces between horizontal geotextile layers or by increasing the number of layers, the load carrying capacity increases. For HESC1 (S=0.5D), the load carrying capacity increased by 9.42% compared to HESC2 (S = D). Similarly, For HESC3 (S=0.5D), the load carrying capacity increased by 7.39% compared to HESC4 (S = D). It clearly shows that HESCs with greater number of horizontal layers performs better. The increase in load carrying capacity with the increase in number of horizontal layers or decrease in spacing may be attributed to greater mobilization of shear stress between the crushed stone and horizontal layer of geotextile. Also, due to creation of small columns between the horizontal layers which restricts the lateral bulging of the column. Keeping the percentage increase in load carrying capacity and cost of geotextile in view, it is recommended that the HESC with six number of horizontal layers should be used for field applications.

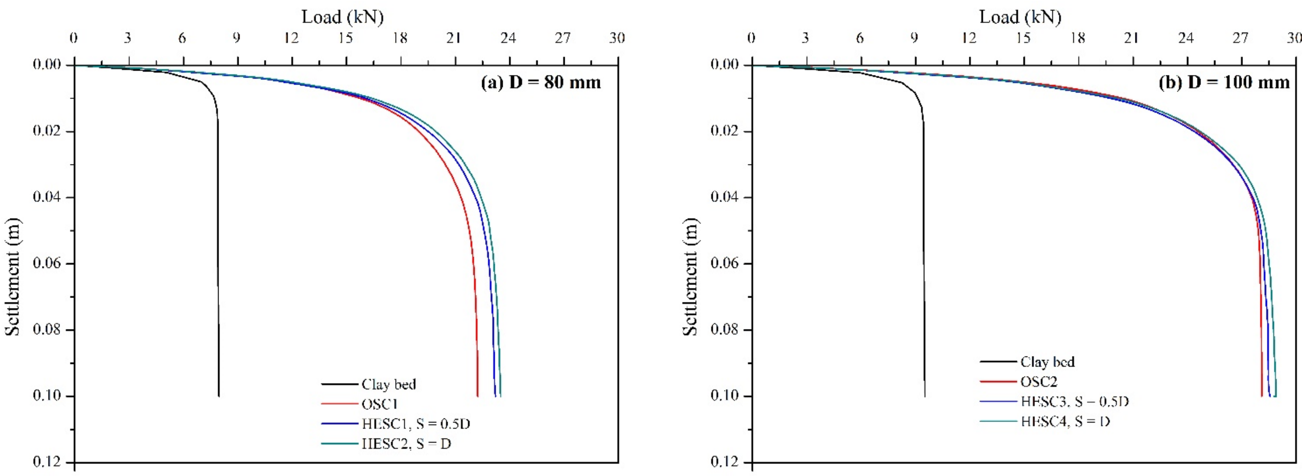

Fig. 5. Load-settlement behaviour of horizontally encased stone column (a) D = 80 mm (b) D = 100 mm

4.3. Vertically-horizontally encased stone column

The load–settlement behaviour of vertically-horizontally encased stone column of 80 mm and 10mm diameter are revealed in Figures 6a and 6b, respectively. With the combined effect of horizontal and vertical reinforcement, the load carrying capacity of the clay bed increases. On comparison with the clay bed, for D = 80 mm, for VHESC1, VHESC2, and VHESC3, the increment of 100.81%, 80.85%, and 67.87% were witnessed. Similarly, the increase was 153.9%, 122.3%, and 107.07% for VHESC4, VHESC5, and VHESC6 of D = 100 mm, respectively. The least enhancement in the load carrying capacity was witnessed for VHESC3 and VHESC6 due to the bulging and less confinement of stone column. Similar results were also reported by Bonad et al., [26].

With the increase in diameter of encased stone column, the load carrying capacity increases. An increase of 26.43% in the load carrying capacity was observed for VHESC4 (i.e D = 100 mm) compared to VHRSC1 (i.e D = 80 mm). The surface of horizontal geotextiles in VHESCs are more as compared to the vertical which lead to mobilization of high frictional forces may resulted in such observations. The effect of spacing of geotextile on the load carrying capacity of VHESCs are marginal. An improvement of 11.03% and 14.2% were seen for VHESC2 and VHESC5 compared to VHESC1 and VHESC4, respectively. The resistance offered by vertical encasement is more than horizontal reinforcement may be responsible for such observations.

4.4. Mode of failure

Figure 7 reveal the deformed shapes of unreinforced clay bed, OSC1, VESC1, HESC1, and VHESC1. Figure 7a shows the heaving of the ground near the edge of footing resting on unreinforced clay bed. The bulging of OSC and VESC1 can be seen in Figures 7b and c, when subjected to load. The maximum bulging of OSC and VESC1 occurred at a depth of 1.2D and D from the top stone column. The bulging failure mechanism of OSC1 is more as compare to VESC1. The limited bulging is seen for HESC1 as shown in Figure 7d. However, the bulging of VESC1 and HESC1 is smaller than that of OSC1. Furthermore, limited deformation between the horizontal layers occurred along the height of column in VHESC1 (as shown in Figure 7e), and the extent of the bulging became much smaller as the column height is increased.

4.5. Reinforcement Ratio (RR)

Reinforcement ratio (RR) is dimensionless parameter which can be expressed as the proportion of load carrying capacity of the reinforced stone column to the load carrying capacity of the ordinary stone column [26]. The effect of reinforcement stone column over the ordinary stone column can be easily understand with the help of RR.

RR values for VESCs of Lr = L, Lr = 0.5L, and Lr = 0.6L were in the range of 1.27-1.24, 1.20-1.18, and 1.22-1.14, respectively, as shown in Table 3. It clearly reflects that the stone column fully encased with geotextile can bear more

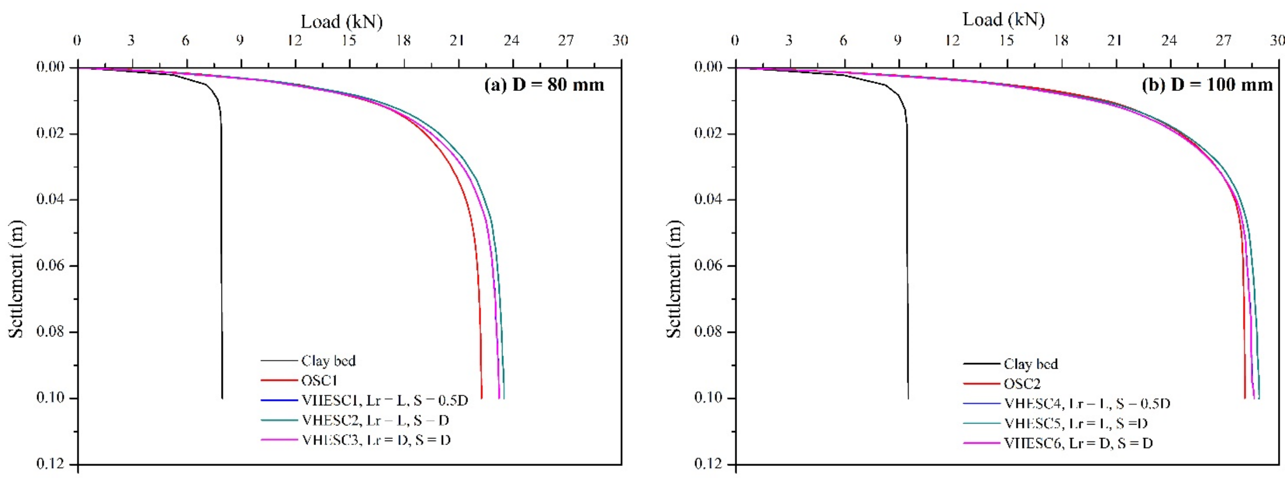

Fig. 6. Load-settlement behaviour of vertically-horizontally encased stone column (a) D = 80 mm (b) D = 100 mm

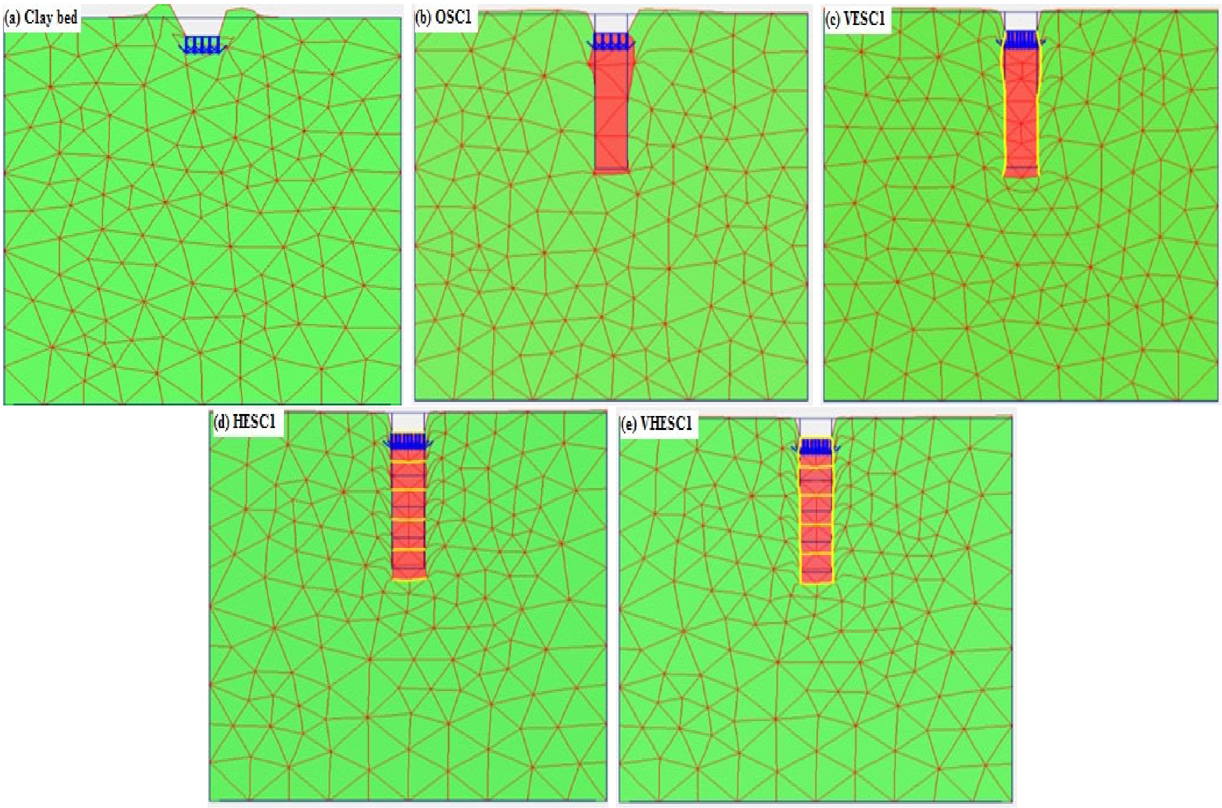

Fig. 7. Deformed shape (a) clay bed; (b) OCS1; (c) VESC1; (d) HESC1; (e) VHESC1

Table 3.
Comparison of reinforcement ratio of 80 mm and 100 mm stone column with Bonab et al. [26]

Combinations	Present study		Bonab et al. [26]	
	Diameter, mm		Diameter, mm	
	80	100	80	100
VESC1	1.27	-	1.47	-
VESC4	-	1.24	-	1.41
VESC2	1.20	-	1.32	-
VESC5	-	1.18	-	1.31
VESC3	1.22	-	1.39	-
VESC6	-	1.14	-	1.37
HESC1	1.26	-	1.29	-
HESC3	-	1.12	-	1.30
HESC2	1.38	-	1.20	-
HESC4	-	1.20	-	1.23
VHESC1	1.44	-	1.78	-
VHESC4	-	1.26	-	1.87
VHESC2	1.19	-	1.62	-
VHESC5	-	1.10	-	1.69
VHESC3	1.22	-	1.53	-
VHESC6	-	1.03	-	1.54

load compare to half or interrupted encasement. Similarly, for HESCs and VHESCs the value of RR was in range of 1.12 to 1.38 and 1.03 to 1.44, respectively. In all the case, by increasing the diameter of stone column, the effect of encasement towards performance of stone column decreases. The maximum performance of encasement was observed for VHESC1 of D = 80 mm.

4.6. Comparison of results (present study)

In this section, the load carrying capacity of VESCs are compared with HESCs and VHESCs. For D = 80 mm, for VESC1, VESC2, and VESC3, the increment of 76.49%, 47%, and 60% were witnessed compared to OSC1, respectively. Whereas, the percentage increase in load carrying capacity were 75.31% and 91.83% for HESC1 and HESC2, respectively. Similarly, the increase of 149%, 141.19%, and 145.46%, and 125.77% and 142.46% were noticed for VESC4, VESC5, and VESC6, and HESC3 and HESC4 of D = 100 mm compared to OSC2, respectively. Overall, on comparing the percentage change in the load carrying capacity of VESCs to HESCs, it is noticed that VESCs performs better than HESCs. Similarly, the combined effect of vertically-horizontally encased stone columns on the improvement of load carrying capacity were compared with vertically encased stone column. For D = 100 mm, an increase of 12.24% in the load carrying capacity of VHESC4 was seen compared to VESC4. Similarly, an improvement of 13.77% and 14.2% load carrying capacity of VHESC2 and VHESC5 were observed compared to VESC1 and VESC4 for D = 100 mm, respectively. VHESCs reinforced clay bed performs better than VESCs and HESCs reinforced clay bed because of combined effect of lateral confinement and formation of small column.

4.7. Comparison with the literature

The present results associated to reinforcement ratio of circular footing (diameter equal to diameter of stone column) rested on VESCs, HESCs, and VHESCs were compared with the reinforcement ratio (obtained experimentally) of circular footing (diameter equal to twice the diameter of stone column) rested on VESCs, HESCs, and VHESCs reported in the literature [26]. The results of the comparison are tabulated in Table 3. Table 3 reveals that the RR values of the present study are low compared to Bonab et al. [26] except for HESC2 and HESC4. In the present study, maximum performance of encasement was observed for VHESC1 of D = 80 mm. Whereas, Bonab et al. [26] documented maximum performance of encasement for VHESC4 of D = 100 mm. The bearing capacity failure of encased stone columns observed Bonab et al. [26] were local shear failure. Whereas, in the study punching shear failure of encased stone columns were observed. According to IS 15284 (2003) (part 1) [1], the stone column should be loaded over an area greater than its own because of less bulging, greater ultimate load capacity and reduced settlements. The difference in the RR values of present study and Bonab et al. [26] may be due to difference in the footing size.

5. Conclusions

In this study, Plaxis 2D was used to simulate clay bed reinforced with three different arrangements of geotextile encased single stone column. Stone column of diameter 80 mm and 100 mm and length 400 mm and 500 mm were reinforced and named as VESCs, HESCs and VHESCs depending upon the position of geotextile. The effect of length of reinforcement, spacing of geotextile layers, and diameter of stone column on the load carrying capacity of reinforced clay bed were evaluated from load-deformation curves for VESC, HESC and VHESC. From this study, the following observations are drawn.

- The load carrying capacity of clay bed improves from 23% to 55% with the inclusion of OSC. Further, by reinforcing the OSC with geotextile, the load carrying capacity of clay bed increases.
- In VESCs, the improvement in load carrying capacity of clay bed reinforced with VESCs are more as compare OSCs. The improvement in the load carrying capacity of half-length vertically encased stone columns are comparable to the fully vertically encased stone columns. Stone columns reinforced with heights (0.6 L) have a similar efficiency to half reinforced stone columns (0.5 L).
- In HESCs, the improvement in load carrying capacity of clay bed depends on the spacing between horizontal geotextile layers. By reducing the spaces between horizontal geotextile layers, the load carrying capacity increases.
- VHESC has the highest load carrying capacity followed by VESC and HESC.
- The Reinforcement Ratio values for VRSC, HESC, and VHRSC are 1.14-1.27, 1.12-1.38 and 1.03-1.44, respectively.
- The maximum performance of encasement was observed for VHESC1 of D = 80 mm. Whereas, Bonab et al. [26] documented maximum performance of encasement for VHESC4 of D = 100 mm.
- The bearing capacity failure of encased stone columns observed Bonab et al. [26] were local shear failure. Whereas, in this study punching shear failure of encased stone columns were observed.
- Over all, the inclusion of geotextile encased stone column improves the load carrying capacity of clay bed by 2 to 5 times.

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