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Effect of Slenderness Ratio on the Behavior of Encased Stone Column

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***Abstract*— This paper outlines the behavior of encased stone column (ESC) by making a variation in the slenderness ratio (0.5, 1, 2, 3, and 4) of ESC and relative density (30%, 60%, and 90%) of stone aggregates. The diameter of stone column was taken as 100mm and length varied as 50mm, 100mm, 200mm, 300mm and 400mm for a slenderness ratio of 0.5, 1, 2, 3 and 4 respectively. Polyvinylchloride (PVC) net was used to encapsulate the stone column and galvanized iron (GI) sheets are used as horizontal reinforcement. As the slenderness ratio increases the load carrying capacity decreases. For the present test condition, it is observed that there is a small variation in load carrying capacity for a slenderness ratio of 2, 3 and 4. Further the failure pattern of the ESC was studied with respect to the slenderness ratio. It is found that ESC, having slenderness ratio of 0.5, failed due to the rupturing of encasement. Bulging is the cause of failure for ESC having slenderness ratio of 1 and 2, whereas ESC with slenderness ratio of 3 and 4 failed due to combination of bulging and buckling effect. The improvement in load carrying capacity is more pronounced if the relative density of stone mass is higher. Circular GI strip placed as horizontal reinforcement further increases the load carrying capacity of ESC. This improvement is more visible for stone aggregates placed at higher relative density.**

Keywords*— *Stone Column; Encasement; Slenderness Ratio; Load Carrying Capacity; Horizontal Reinforcement.

I. INTRODUCTION

Among various ground improvement techniques, installation of stone column (SC) is being widely used for the construction of flexible structures like rail/road embankments, liquid storage tanks, factories etc. on soft soils. When SC's are inserted in soft soil, problem may arise due to the squeezing of stones into the adjacent soil and dispersion of soil mass into the stone aggregates, which results in the contamination of stone aggregates, reduction in the drainage function and bearing capacity of SC. Stone column behavior can be further improved by encapsulating it with suitable geosynthetics. The behavior of stone column and encased stone column has been analyzed by several researchers through model tests, field studies, theoretical and numerical analyses. The performance and behavior of geosynthetic encased SC's are studied by [1],[2],[3],[4]. The load-settlement behavior of stone columns was predicted through finite element analysis by [5]. Behavior of stone columns and encased stone columns by numerical and analytical approaches was studied by [6] Whereas [7] has attempted to predict the behavior of stone columns and encased stone columns through model studies. However, very less research has been carried out to study the behavior of encased SC having varying slenderness ratio and relative density of compacted stone aggregates. This paper describes the laboratory model tests carried out on encased stone columns (ESC) by varying the slenderness ratio as 0.5, 1, 2, 3 and 4, further the relative density of compacted stone aggregates is varied as 30%, 60% and 90%. Further the ESC is reinforced with GI discs placed at different locations. The load carrying capacity and the bulging patterns of these ESC and ESC with circular disc placed at different locations have been assessed and reported in this paper.

II. MATERIALS AND METHODOLOGY

A. Materials

The stones used for the experimental investigation are collected from the local crushing unit of Rourkela. The stone aggregates are of granite type and its size varies from 2mm to 6mm (Fig. 1). The minimum (ρ_d min) and maximum (ρ_d max) density of stone was found to be 13.93 kN/m^3 and 15.4 kN/m^3

Fig. 1. Aggregate used for the experiment.

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respectively as per IS: 2720 (Part-4)[8]. Specific gravity of stone aggregate is determined as per IS: 2720 (Part-3)[9] and found as 2.67. The angle of internal friction of stone aggregate is obtained from direct shear test and it is found out to be 51˚ (at 90% relative density). In the present study PVC net was used for encapsulation of stone column and circular GI strips were also provided as horizontal reinforcement in the stone column with a varying spacing of d, 0.5d and 0.25d, where d is the diameter of stone columns. Tensile strength test was carried out on the encasing material and the results are listed in Table 1.

Table 1: Properties of encasing and horizontal reinforcing materials

Parameters	Reinforcing material	
	GI Sheet	PVC Mesh
Displacement at peak(mm)	5.368	82.42
Strain at peak (%)	15.34	235.5
Load at peak (kN)	0.6029	0.021
Stress at peak (MPa)	25.37	0.803
Strain at break (%)	21.72	364
Load at 0.2% yield (kN)	0.288	0.0085
Stress at 0.2% yield (MPa)	12.15	0.325
Young's Modulus (MPa)	1082	39.16

B. Sample preparation

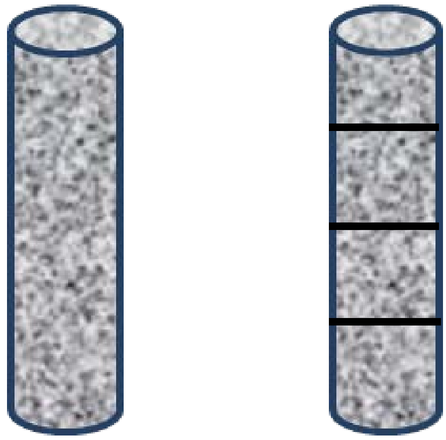
1) Encased stone column

A cylindrical profile was stitched using PVC mesh for encapsulation. The diameter of stone column was taken as 100mm and length was varied as 50mm, 100mm, 200mm, 300mm and 400mm for a slenderness ratio of 0.5, 1, 2, 3 and 4 respectively. Solid circular plate was placed below the cylindrical encasement, and then required mass of stone aggregate was poured inside it and compacted with a tamping rod to achieve the preferred relative density of 30%, 60% and 90%. UCS test was conducted on encased stone column as per IS: 2720(Part X) to study the effect of slenderness ratio and relative density of stone aggregates on load carrying capacity of ESC. Loading is done at a rate of 1.25mm/min and the load corresponding to various deformations was obtained. The stress-strain graph is plotted. Fig. 2 shows the sample under loading condition.

2) Encased stone column with horizontal reinforcement

The effect of slenderness ratio on ESC reinforced with circular strips is also considered. Circular strips of dia. 100mm was cut from the PVC net and GI sheet are used as horizontal reinforcement for the stone column provided at a spacing of d, 0.5d and 0.25d. The schematic diagram of encased stone column with and without horizontal reinforcement are shown in Fig. 3. Slenderness ratio is taken as 2 and 3 and the relative density is varied as 30%, 60% and 90% respectively and the load carrying capacity is calculated by conducting UCS test. In order to maintain the spacing of d, 0.5d, and 0.25d for SC of slenderness ratio equals to 2, the numbers of strips required are 1, 3, and 7 respectively. Stone column with slenderness ratio equals to 3 required 2, 5, and 11 numbers of strips for d, 0.5d, and 0.25d spacing respectively.

Fig. 2. Encased SC under the loading frame.



(a) (b)

Fig. 3. Encased stone column: (a) without horizontal reinforcement, (b) with horizontal reinforcement.

III. RESULTS AND DISCUSSION

1) Stress-strain behavior of ESC compacted at different relative densities

The stress-strain curves of encased stone column for different slenderness ratio, where the stone mass was compacted at different relative density is shown in Fig. 4 (a-c). From the figures, it is observed that as the slenderness ratio increases ultimate load carrying capacity of stone column decreases. It is also observed that there is relatively small variation in ultimate load carrying capacity for higher slenderness ratio. The ultimate load carrying capacity of encased stone column with a slenderness ratio of 0.5 is much higher than other slenderness ratio for all relative densities. It may be due to overlapping of dead zones from both sides. From Fig. 4 (a-c), it is also observed that ultimate load carrying capacity of stone is increased by almost 1.5 times as relative density is increases from 30 % to 90%. As relative density increases, interlocking

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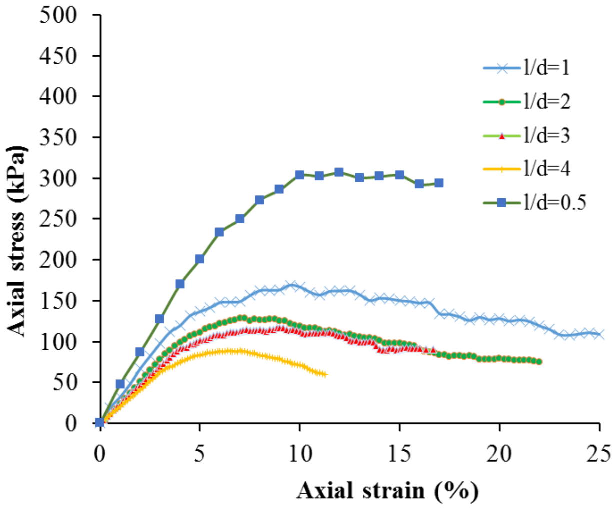
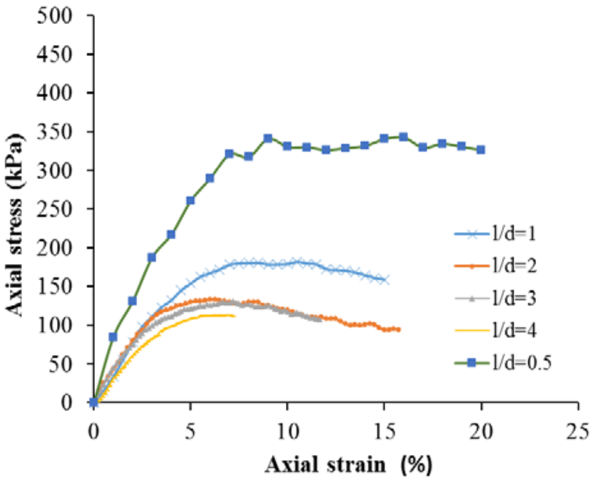
effect also increases which leads to higher load carrying capacity. Ultimate load carrying capacity for higher slenderness ratio is less, because load resistance is coming more due to friction between particles and less due to interlocking effect. The ultimate load carrying capacity of ESC for different slenderness ratios and different relative densities is given in Table 2.

Table-2 Ultimate axial stress of ESC for different slenderness ratios and different relative densities

Slenderness ratio (l/d)	Relative density (%)		
	30	60	90
	Ultimate axial stress (kPa)		
0.5	312.1	342.7	450.9
1	169.1	181.9	188.9
2	128.4	132.9	136.1
3	116.3	130.8	132.3
4	89.2	112.7	125.6



(a)



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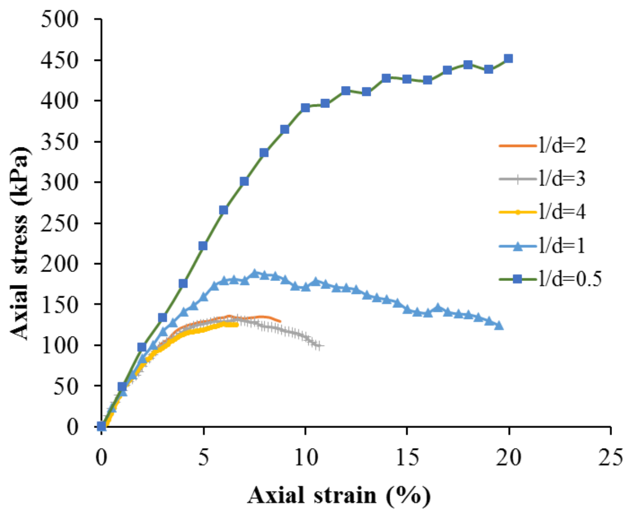


(c)

Fig. 4. Stress-strain curves of ESC for different slenderness ratio: (a) at 30 % relative density, (b) at 90 % relative density, (c) at 90 % relative density.

Fig. 5 (a) shows the failure pattern of ESC having slenderness ratio of 0.5 which fails by rupturing of encasement, whereas Fig. 5 (b) shows the failure pattern of ESC having slenderness ratio of 1, which fails by bulging effect. It is further noticed that ESC with slenderness ratio of 2 fails by bulging effect, whereas ESC with slenderness ratio of 3 and 4 fails by combined effect of bulging and buckling. Fig. 5 shows the failure pattern of ESC reinforced with GI sheet at d spacing.

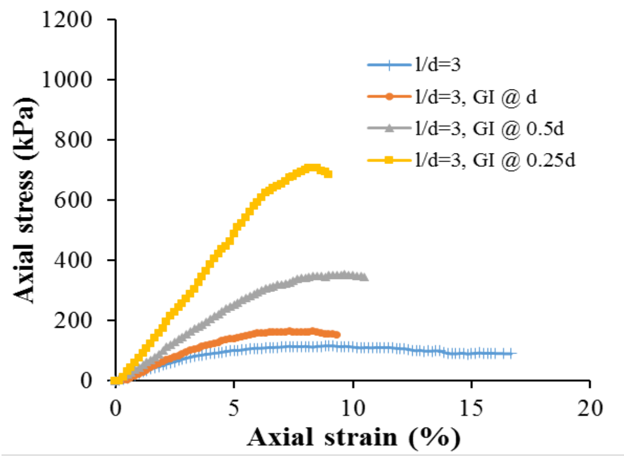
2) Stress-strain behavior of ESC with horizontal reinforcement at different relative densities

In the encased stone column, two different types of circular strip, made from galvanized iron (GI) and polyvinylchloride (PVC), is placed for three different spacing namely d, 0.5d and 0.25d. Horizontal reinforcement is provided as circular strips in encased circular stone column. It is observed that as the spacing between the circular strips is reduced, the load carrying capacity of the SC increases. The maximum failure stress is obtained for higher relative density and closer spacing between the discs. Failure is mainly due to bulging action of SC. Similarly the UCS test was carried out and the failure stress values were obtained corresponding to 30%, 60% and 90% relative densities.

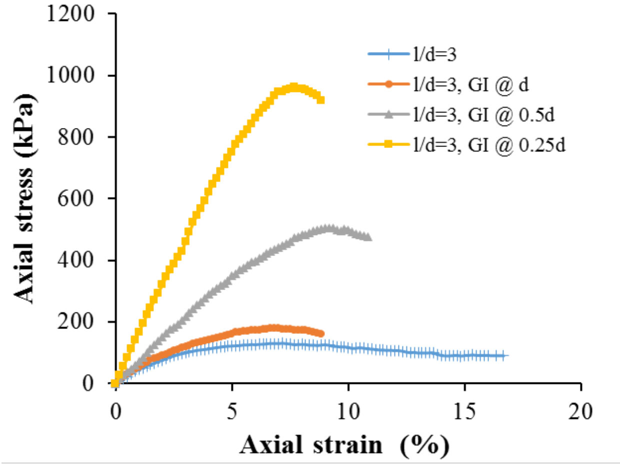
(a)

(b)

Fig. 5. Deformed shape of encasement of ESC: (a) for l/d = 0.5; (b) for l/d = 1.



(a)



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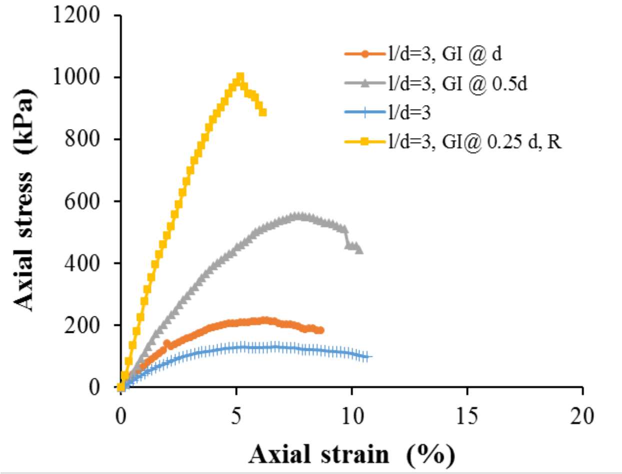


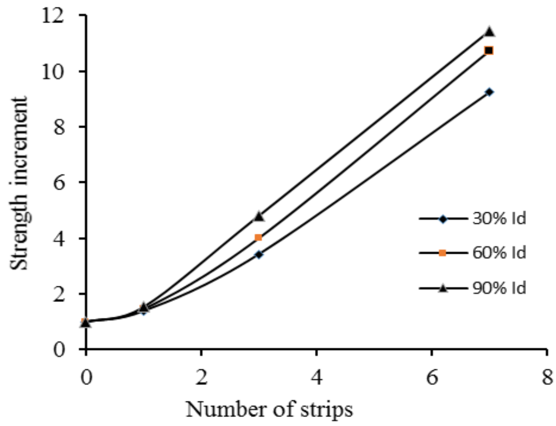
(c)

Fig. 6 Stress-strain curves of ESC with GI horizontal reinforcement for different slenderness ratio: (a) at 30 % relative density, (b) at 90 % relative density, (c) at 90 % relative density.

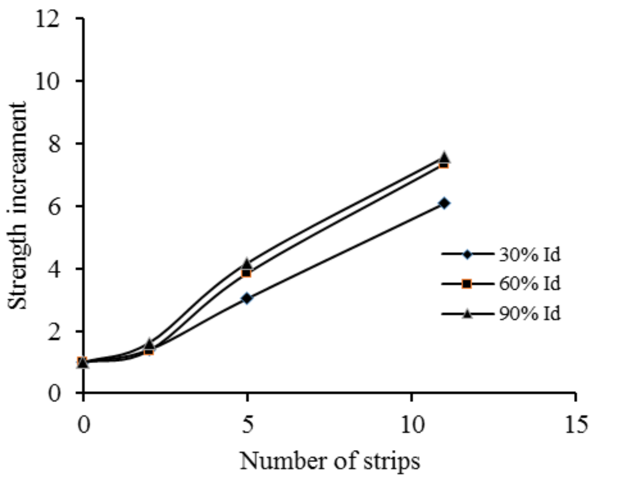
Fig. 6 (a-c) show the stress-strain curves for ESC reinforced with GI circular strips for various configuration of spacing. It is found that the failure stress for the ESC without any circular strips as horizontal reinforcement is 116.3 kPa.

The failure stress for ESC reinforced with circular disc of GI at a spacing of d, 0.5d, and 0.25d is obtained as 163.1 kPa, 353.8 kPa, and 707.1 kPa respectively. Because of the insertion of the GI disc at d, 0.5d, and 0.25d the failure stress is increased by 1.4, 3.1, and 6.1 times that of ESC with only circumferential reinforcement. The use of GI strip inside the ESC at minimum spacing makes the ESC stiffer to withstand higher load.

Fig. 7 (a-b) show the variation of strength increment with number of horizontal GI disc reinforcements. It is noticed that the strength of SC is more for 90% relative density and it increases almost linearly with the number of strips and relative density. Strength of ESC is a function of relative density of stone mass and spacing between the horizontal strip reinforcements. The load carrying capacity of ESC is directly proportional to relative density, number of strips reinforcements and inversely proportional to the spacing between the strips. ESC having higher relative density and lesser spacing between the strips has higher strength.



(a)

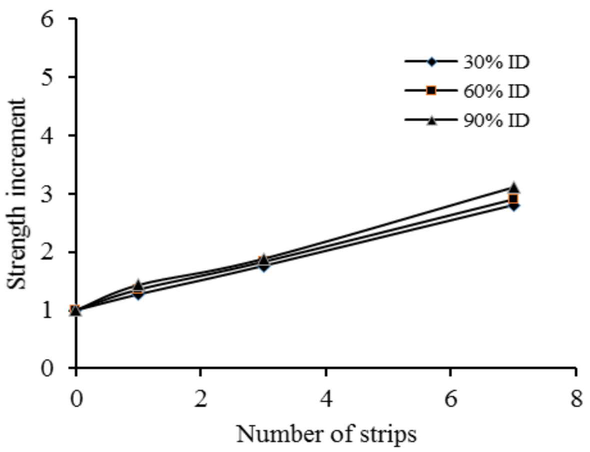


(b)

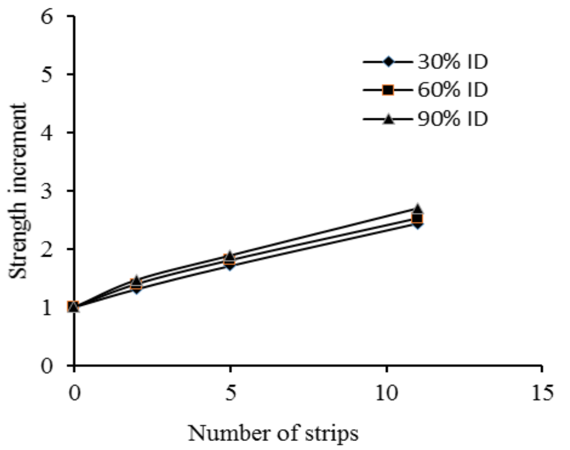
Fig. 7. Strength increment in ultimate load carrying capacity with number of GI strips reinforcement of ESC: (a) l/d = 2, (b) l/d = 3.

From Fig. 7 and 8, it is observed that strength increment for GI strips reinforcement is much higher than that of PVC strips reinforcement. This is because placement of GI strip arrests the bulging at the aggregate-reinforcement interface more effectively. Practically no bulging is found in the plane where the GI nets were provided but the PVC nets were unable to arrest the bulging.

The bulging shape of encased stone column reinforced with PVC strip is almost similar to that of ESC without horizontal reinforcement, which indicates that PVC strip are not much effective in arresting the bulging. This may be due to lower stiffness value of PVC nets. For a given relative density, slenderness ratio, and configuration of horizontal strip reinforcements the specimens with GI strip reinforcements show higher failure stress than the specimens reinforced with PVC strip. Further an increase in the slenderness ratio of the stone columns results in a decrease in failure stress, other factors remaining same. In the present test, it is observed that failure condition of encased stone column is due to combination of bending and bulging as it has more slenderness ratio.



(a)



(b)

Fig. 8. Strength increment in ultimate load carrying capacity with number of PVC strips reinforcement of ESC: (a) l/d = 2, (b) l/d = 3.

IV. CONCLUSIONS

Load carrying capacity of encased stone column with slenderness ratio of 0.5 is much higher than any other configuartion of the stone column. Higher relative density of aggregates makes the stone column much stiffer to withstand a higher load. Stone column with slenderness ratio of 0.5 fails due to the rupturing of stone aggregates; bulging is the cause of failure for encased stone column having slenderness ratio of 1 and 2, whereas encased stone column prepared with slenderness ratio of 3 and 4 fails due to combned effect of bulging and buckling. Further, placement of horizontal reinforcement increases the strength of encased stone column. In the present study, galvanized iron (GI) horizontal strip reinforcements are found more effective than polyvinylchloride (PVC) horizontal strip reinforcements. Further the improvement in load carrying capacity of horizontal reinforced encased stone column is more prominent when the relative density of stone mass is higher. GI horizontal strip reinforcements placed at a spacing of 0.25d with relative density of stone mass 90% enhance the load carrying capacity by 11.4 times over the ESC.

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