Study on Response of Dual Layered Reinforced Stone Column Under Shear Loading

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Abstract. Stone columns are surely entitled for ground improvement and used on large scale by engineers these days. The vertical load capacity of stone columns reached to the ampler level by encasement of column material and using the bulging resistance due to confinement. Now, the efforts are in the direction for enhancement of shear strength of the stone column. The peripheral reinforcement is also considered for better shear strength by researchers. The objective of this paper is to study shear capacity of stone column on insertion of one extra layer of reinforcement in between peripheral layer and centre i.e. Dual Layered Reinforced Stone Column (DLRSC). In this experimental study, Geonets of small aperture openings are used as reinforcing layers due to their higher stiffness related to geotextiles. Various direct shear tests are conducted with different diameter and varying spacing between two layers of the reinforcement. Transformation in these combinations is also observed due to internal stresses generated by different values of Normal pressure. Outcomes are compared with the ordinary and single layered reinforced stone column which shows the significant amelioration to the shear strength of the stone columns.

Keywords: Stone column · Shear loading · Reinforcement · Geonet

1 Introduction

The soft soils have been ameliorated by changing the chemical properties or by changing the structural arrangement of particles which may cover two types of problems to the structures: one is the large settlement at lesser load and other is shear deformation/tilt of the structure. Fixing of such geotechnical issues for poor soils is Ground Improvement (Ghanti and Kashliwal 2008). Insertion of stone columns in the soft ground also deals with the Excessive settlement and bearing capacity problems of the soft/poor soil, hence came out as an effective tool for Soft Ground Improvement, which is in extensive application by Geotechnical Engineers now a days for many structures like Embankments, oil storage tanks and buildings on the soft clays (Gniel and Bouazza 2010; Shahu and Reddy 2014). The longitudinal load to the stone columns is transferred by the circumferential bulging of the column that provides increased stiffness to the ground (Bergado et al. 1994; Hughes et al. 1974).

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It was observed that the bulging resistance or lateral confinement from the intervening soil may not be adequate for very loose soils. Required load bearing capacity at the limiting settlement will not able to be developed by the stone column (Shahu et al. 2000). Afterwards for the more required capacity of stone column ameliorated grounds, the circumferential bulging resistance needed to be increased. Vertically loaded column with the encasement by use of various geosynthetics found much efficient in increasing the bearing stresses (Murugesan and Rajagopal 2006, 2007, 2010; Yoo and Kim 2009; Lo et al. 2010; Khabbazian et al. 2010; Pulko et al. 2011; Ali et al. 2012, 2014; Dash and Bora 2013). Further enhancement of bearing capacity and reduction in lateral bulging can be observed by the use of horizontal layers of Geosynthetics, that is due to the effect of interlocking and frictional effects of horizontal layers with stone column aggregates (Ayadat et al. 2008; Prasad and Satyanarayana 2015; Ghazavi 2018).

Lateral loading that caused Shear failure of the stone column was not in much recognition, the behavior under lateral loading for confined stone column was studied & shear strength increment was reported because of Encasing of granular material (Murugesan and Rajagopal 2009). Stiffness is the cause for the enhancement in shear strength for the smaller displacements, while on further increment in the displacements (larger displacements), the mobilization of tensile force is the cause for additive shear strength to encased stone column, which will be present /persist till the rupture of encasement (Mohapatra et al. 2016). Enhancement of shear strength for static as well as for cyclic lateral loading due the Encasement are also reported for stone column near the toe of Embankment (modeled with Unit cell shear device) (Cengiz el al. 2019). Study also shows that the grouped stone columns are more efficient for the shear strength resistance, because the confining-of intervening soil is also increased, but for the design considerations,further study is required for this aspect (Mohapatra et al. 2016).

Stone columns with vertical nails were also found effective which were inserted along the circumference of column body. Use of reinforcing nails driven around the circumference of the stone column up to a depth of 3D to 4D enhanced the performance of stone column; this is due to the increased confining of granular material (Babu and Shivashankar 2010). The installation of nails is more feasible than the geogrid that is the beneficial factor to use nails at the site (Komeil et al. 2015).

Current available study gives the insight about the shear failure of stone column, beneath the embankment. The stone columns which are on edge side of embankment are more vulnerable to failure. The literature study gives the idea of using Geonet, in place of geogrid or nailing at the circumference of the stone column. So in present study, geonets are used as reinforcing layers of stone column and behaviour of geonet reinforced stone column is discussed on application of shear loading.

2 Materials

2.1 Sand and Gravel

Soil bed was prepared by the sand collected from nearby sites in Bhopal city, which is poorly graded in nature, passing through the 4.75 mm sieve. The densities at the fully compacted and in loose state were found to be 17.36 kN/m^3 and 14.52 kN/m^3 respectively, also the density of sand at which tests were conducted was 16.1 kN/m^3.

Coarse grained soil, classified as GP, according to the soil classification system, was used as filling material for the stone column of 100 mm diameter. Other properties of sand and gravels are listed in the Table 1.

Table 1. Properties of sand and gravels used

Property	Sand	Gravel
Sp. gravity	2.64	2.68
D_{10}	0.26	2.6
D_{30}	0.38	3.1
D_{60}	0.60	4.6
C_u	2.30	1.77
C_c	0.92	0.80
$\phi°$	34°	42°

2.2 Geonets

Geonets were procured from the market. The properties of geonets used in this study are shown in Table 2, as provided by the manufacturer. The geonets used is of high density polyethylene, made with two crossover ribs. Geonets are used as reinforcement to the stone columns. For Single Layered Reinforced Stone columns (SLRSC) the layer of Geonet is placed at the Periphery of the Column, which encases the entire stone column.

Table 2. Characteristics of geonet

Characteristics	Value
Thickness	2 mm
Mass per unit area	740 gm/m^2
Peak tensile strength	8 kN/m

For Dual Layered Reinforced Stone Column (DLRSC), Two layers of Geonet are used, the first one is same as placed in SLRSC (at the periphery), which is constant for all the DLRSC samples. Second layer of Geonet is placed inside the stone column body i.e. at 0.25d, 0.5d and 0.75d distance from the axis of stone column as shown in Fig. 1 which creates spacing of 0.75 d, 0.5d, 0.25d between two layers respectively.

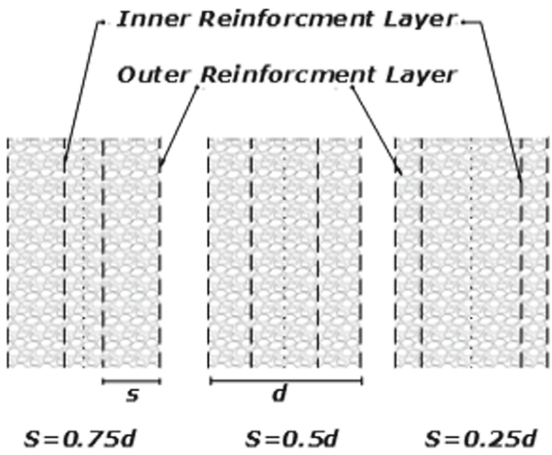


Fig. 1. Arrangement of reinforcement layers

3 Methodology

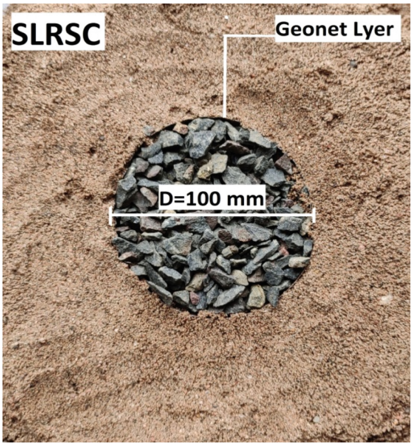
3.1 Sample Preparation

Poorly graded sand was used to make a soil bed in large shear box. Before preparing the sample with stone column, amount of sand was measured required to fill the shear box neglecting the portion equal to the volume of the stone column. So defined Pre-weighted sand was taken for each sample preparation and filled in Large Shear box, in 3 approximate equal layers. Each layer was provided a fixed amount of compaction by tamping, where the relative density for all the samples were in between 68 ± 2%.

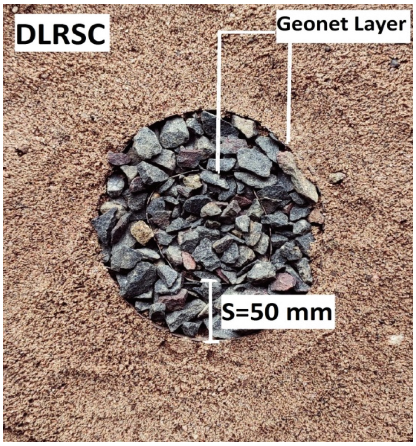
Three types of samples were prepared in the large shear box test, Unreinforced Stone Column (USC), SLRSC and DLRSC. For the USC, steel tube was placed inside the shear box and stones poured in steel tube in 5 approximate compacted layers with tamping each layer by fixed amount of compaction through fall of tamper from a height of 150 mm.

For SLRSC construction in the shear box, Geonets were placed on the inner surface of the steel tube and the stones were compacted in the similar fashion as performed for USC. After full length compaction steel tubes were pulled slowly leaving behind the Geonets in the peripheral place of the column, constructed column is shown in the Fig. 2(a).

Construction of DLRSC was done with Horizontal Layer of Geonet, which were folded to the shape of cylinder with the required diameter of 100 mm for outer layer of encasement. Similarly, for internal layer of encasement, the Geonet layer were folded to the shape of cylinder of lesser diameter 25,50 & 75 mm respectively for spacing of 0.75d, 0.5d and 0.25d respectively. Both inner and outer layers of Geonet were held in vertical position and tied with thread at the bottom to the common horizontal Base made of Geonet only, the assembly made in such a manner that both the vertical layers of Geonet with the horizontal base can stand vertically without any lateral support. This is made by using small pins as a strut between two layers. Also the joint made at the bottom end of encasement helped to keep encasement in the position. This whole assembly of Geonet layers and horizontal base was placed inside the Steel tube, which were already kept in the shear box apparatus for making stone columns. The assembly is placed such that the outer layer of encasement touches the inner periphery of the steel Tube. For DLRSC the material was also compacted in 5 layers but the compaction was done separately for both the areas i.e. the area between inner & outer layer of encasement and area encased by the inner layer of encasement. Amount of sand equal to the volume of encasement material inside the stone column was reduced for filling the DLRSC. The steel tube used was removed slowly after the compaction of material inside the stone column, one of the constructed stone column is shown in Fig. 2(b).



(a) Constructed Single Layered Stone Column



(b) Constructed Dual Layered Stone Column

Fig. 2. (a) Constructed single layered stone column (b) Constructed dual layered stone column

3.2 Test Setup

The large shear box apparatus was used for testing the shear strength of the prepared samples. The apparatus has an area of 305 × 305 mm in the plan with the effective height available for soil specimen of 150 mm. The apparatus has the predefined horizontal plan of failure at the vertical center of the specimen. This horizontal plane is maintained by the two halves of the shear box apparatus. The lower half of the box moves on the roller in the horizontal direction whereas the upper one remains in the position. Due to this assembly, the soil mass inside the box also tends to separate along the predefined horizontal plane. The strain of lower box can be measured by the Stain Gauge already positioned. Loading yoke support the top half of the shear box and connected to the load transducer which reads the resistance of the soil to the horizontal loading. The loading is applied to the specimen through a motorized device, which allows providing constant rate of loading for the test. A loading cap was used to maintain the normal load over the soil specimen by manually changing the calibrated dead weights for different normal pressure.

3.3 Procedure

To study the effect of single and double layered encasement, Stone columns were installed in the sand bed. Tests were conducted for different normal pressures of 20, 40, 60 & 80 kPa. Required normal load was applied via available top cap of the shear box. After the application of normal pressure horizontal load was applied to the lower half of the shear box, with the constant displacement rate of 1.2mm/ min. Resistance to this displacement was measured at the end of each minute from the load transducer. Test was continued for 50 min and then terminated because resistance offered by the specimen was observed to decrease significantly.

4 Result and Discussion

Lateral load to the lower half of the shear box apparatus were applied till the resistance became constant against the horizontal displacement. The sand was removed which was used to construct the soil bed and the deformation of the stone column body was observed. Failure was observed in the similar fashion as Type-2 reported by Mohapatra et al. (2016) for the high rupture strain case of encasement. In all the dual encased stone columns, outer layer of encasement had high strain values than the inner layer of encasement. The cases in which the spacing was higher between the encasements, the differences in strains of both the encasement layers was large i.e. the horizontal movement of inner layer at the failure plane started on later stage of the test.

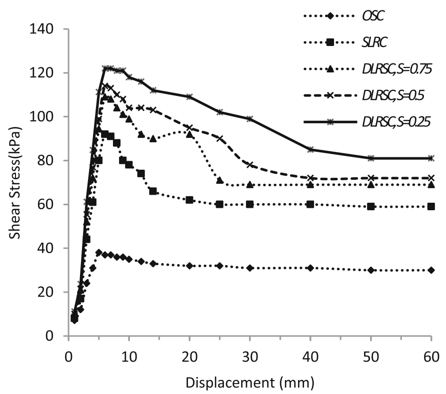


Fig. 3. Shear stress variation with horizontal displacement at normal pressure 80 kPa

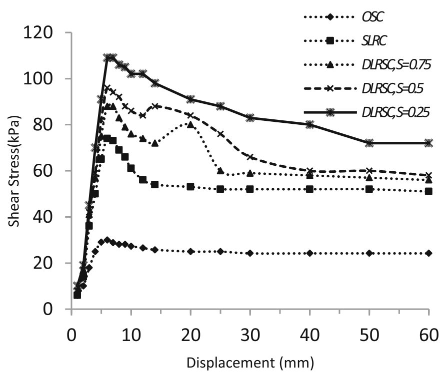


Fig. 4. Shear stress variation with horizontal displacement at normal pressure 60 kPa

4.1 Influence of Normal Pressure

Tests were performed at various normal pressure ranging from 20 kPa to 80 kPa, at each normal pressure condition on OSC use, SLRSC and DLRSC with 3 different spacing of encasement were tested. The observed values of shear resistance are shown with horizontal displacements in Fig. 3, 4, 5 and 6. SLRSC provides the confinement to the column material,due to which the shear resistance increases approximately 3 times.

Also, DLRSC is more effective than the SLRSC, more than 1.5 times of improvement observed for lower Normal stress of 20 kPa. This improvement over the SLRSC is due to additional confinement offered by the second layer of the encasement, which helps in restricting the movement of column material. As the normal stress increases towards higher side, improvement ratio reduces after 1.25 (Fig. 7). Hence, for the site where overburden pressure is less, DLRSC will be more efficient if the column beneath the earth is likely to bear the lateral load.

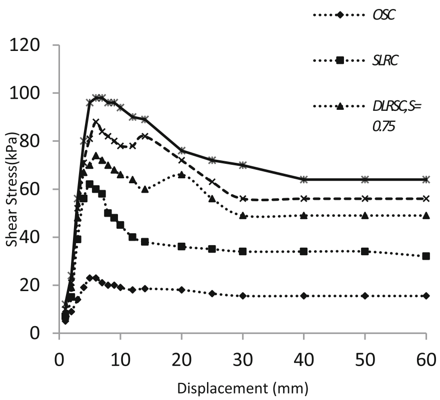


Fig. 5. Shear stress variation with horizontal displacement at normal pressure 40 kPa

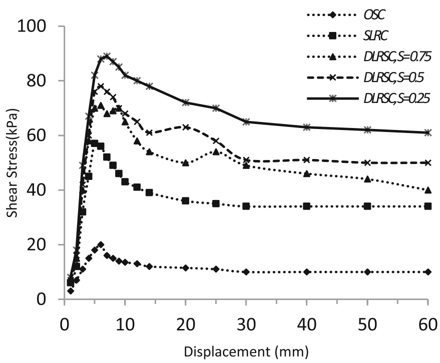


Fig. 6. Shear stress variation with horizontal displacement at normal pressure 20 kPa

Initial modulus of resistance observed was nearly same for SLRSC and DLRSC. In case of OSC, the initial tangent were tilted towards right which indicates the lesser value of initial modulus of resistance (Fig. 3, 4, 5 and 6) in all four normal pressure conditions. This shows the considerable enhancement in the stiffness of stone column due to the encasement of column.

4.2 Encasement of Column

The strain softening was observed for OSC and SLRSC at early displacements of 5–7 mm, just after the peak shear resistance, that continues till the end of the test. In case of DLRSC, for all 3 spacing conditions, some stain hardening was observed after the peak shear strength, but the resistance did not reach again after the peak resistance was offered by the stone column body. Slope of the graph of shear stress vs Horizontal Displacement after the highest point can be seen steep for case of SLRSC but in case of DLRSC it is mild, especially in the case with where spacing between encasements is 0.25d.

The gain of strength after the highest point of resistance is due to the inner layer of encasement.When the horizontal displacement occurs, gradually effect of it reaches up to the inner layer of encasement and this layer starts to act as an additive barrier which provides the strength to the column body even at higher stains. The resistance does not reach again up to the ultimate peak because when the inner layer provides the strength till that time the outer layer reaches to its creep level i.e. elongation without any increment of load.

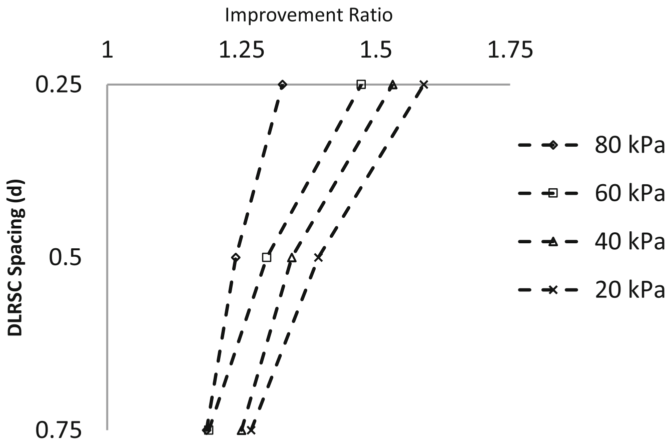


Fig. 7. Improvement ratio of DLRSC over SLRSC

4.3 Spacing of Encasement

In DLRSC, for encasement spacing of 0.75d, the additional strength mobilizes at the horizontal displacements of 20–25 mm, as the graph (Fig. 8) indicates the second local peak of shear strength. But for the 0.5d spacing of encasement this local peak of shear strength comes at earlier stage of horizontal displacement i.e. at 10–15 mm (Fig. 9). No such local peak is observed for case of 0.25d encasement spacing (Fig. 10). It indicates, as the spacing increases or inner layer of encasement is more towards the centre of stone column, contribution of this layer in resisting the lateral movement starts in the later stages of load application.

Lesser the spacing between the encasement,, continuous strength is offered to the column, as shown in Fig. 10, where no local fluctuation (Only the reduction in shear stress, no any increment for any small region) is detected. But on the other hand in Fig. 8, 9 for higher spacing between the encasement, local fluctuation (Not the constant pattern of reduction of stresses in the region of 15 to 30 mm displcaement, stresses increases and then decreases again), in strength can be seen again after the displacement of 15 mm. This loacl fluctuation occures Because of the higher spacing (S = 0.75) between geonet. When shear applies to the stone column body, firstly the outer layer of encasement starts to resist it and gives the strength to the column body. The highest point of shear stress shows the full mobilization of strength of outer layer. After the failure of outer encasement, when the shear displacement reaches to the inner layer of the encasement, this layer starts resisting the shear displacement and takes part in providing strength to the column body. Due to the restrengthning of stone column the local fluctuation occurs as the stresses increases till the full mobilization of strength of inner layer of encasement. This fluctuations are relatively high in case of large spacing (Fig. 8) then the lesser spacing case (Fig. 9). For the lowest spacing (S = 0.25) case in this study there is no fluctuation (Fig. 10) were observed. This happen because when the geonets are placed closely, after the failure of outer layer, the inner layer starts contributing to the strength immediately.

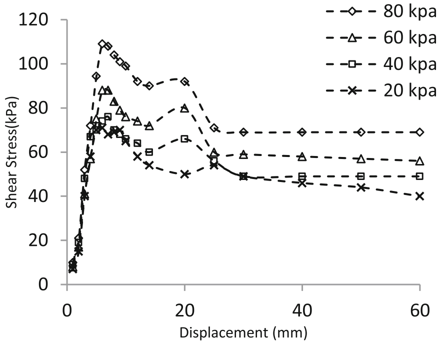


Fig. 8. Shear stress variation for DLRSC (S = 0.75d) different normal pressure

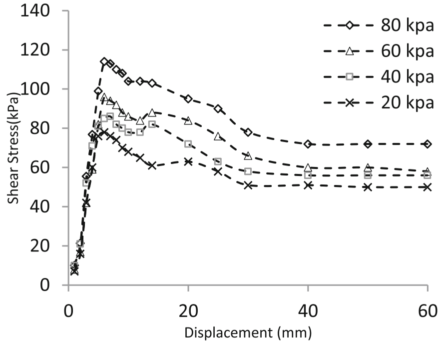


Fig. 9. Shear stress variation for DLRSC (S = 0.5d) at different normal pressure

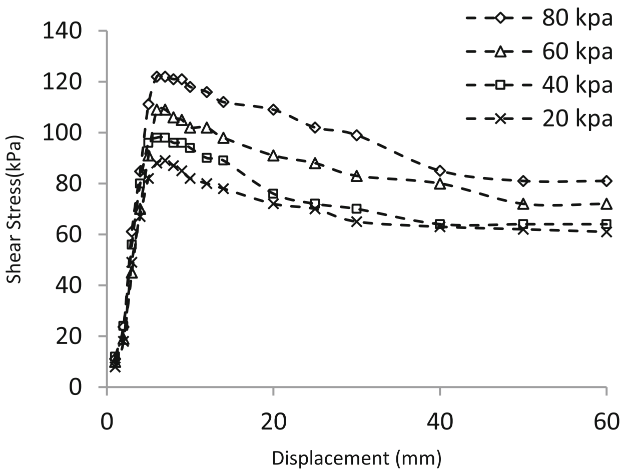


Fig. 10. Shear stress variation for DLRSC (S = 0.25d) at different normal pressure

5 Conclusion

Direct shear stress tests were conducted for many type of Stone columns installed in the Laboratory shear box setup and obtained results were analyzed. Based on the observations some conclusions are listed below:-

- Lateral strength of stone column increases due to the encasement of column material and additional shear resistance is also provided by the encasement material.
- SLRSC performs three times better than the OSC in case of shear loading.
- The peak shear strength of the DLRSC enhances substantially over the SLRSC due to provision of additional confinement of the column material by inner layer of Geonet.

- In case of DLRSC, improvement in peak shear strength from SLRSC is more than 1.5 times for lower normal stress conditions of 20 or 40 kPa and for normal stress of 80 kPa the improvement is in between 1.25 to 1.5 times.
- Lower spacing (i.e. 0.25d) between the two layers of encasement is more effective than the higher spacing (i.e. 0.75d), in case of column subjected to lateral loading.

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