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Performance Evaluation of Geosynthetic Encased Stone Columns

Ankit Thakur[1], Saurabh Rawat[2*], Ashok Kumar Gupta[3]
[1*] Research Scholar, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan – 173234, Himachal Pradesh, India
E-mail : ankit.thakur033@gmail.com
[2] Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan – 173234, Himachal Pradesh, India
[*]Corresponding author E-mail : saurabh.rawat@juit.ac.in
[3] Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan – 173234, Himachal Pradesh, India
E-mail : ashok.gupta@juit.ac.in

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Abstract:
This Paper shows the detailed investigation of strengthening the weak and soft soil by introducing stone column in three varieties as un-reinforced stone column and reinforced stone column i.e vertical and horizontal on sandy soil and the failure mechanism of each column is determined. During this article, experiments on three varieties of stone columns have been performed. This paper studies the results of geosynthetics reinforcement which is provided to the stone columns i.e. vertically and horizontally reinforced stone columns and the failure mechanism in all the three conditions of the stone columns is determined. The experimental testing and Finite Element Modeling have also been performed. Each of the method gives the constant end results. The results shows that the stone columns which is reinforced proved to be more effective in increasing the load bearing capacity of the soil in comparison with the stone columns which is unreinforced. The results also showed that the load bearing capacity of horizontal reinforced stone column proved to be more effective than that of vertical reinforced stone column. Also, the failure mechanism in all the three varieties is due to bulging.
Keywords: *Stones, Columns, Geosynthetics, Encasement, Finite element method.*

I. INTRODUCTION

Stone columns are used as a ground improvement technique to increase the load bearing capacity of the soil by reducing settlement. . Installation of stone column could be done by the following methods i.e replacement, displacement and rammed column method. This paper deals with the ground improvement technique which is being done by using stone column and their failure mechanism is analysed. Reinforcement is being provided so that the strength of the stone columns is increased. Finite Element Modeling has also been discussed using Plaxis 2D software.

When load is applied to the structures, the columns gets deformed and settled into the soil. Due to the deformation of the stone column the failure that occurred in the stone column is mainly due to bulging. The strength of the stone column is achieved by the movement of lateral earth pressure of the surrounding soil.

To overcome the bulging failure geotextile encased stone columns are being used. The main advantages of geotextiles are firstly the confinement of columns is done in such a way that it does not intrude in the soft soil, secondly uniform diameter of the stone columns in maintained and thirdly it improves the shear capacity of the column by providing the tensile strength of the geotextile material which results in the increased confinement of sand and gravel. Geotextiles are used as an reinforcement to the stone columns.

Reinforcements are used to acquire strength in case of terribly weak and soft soil. Thus we found that loose specimen shows higher reduction in volumetric strain as compared to the dense one **(Wu and Hong,2009)**. From the obtained results we also

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came to know that while introducing the reinforcement to the columns, the load carrying capacity of the stone columns is increased by 3-5 times. The study shows that bulging length of the reinforced stone column is reduced up to 50% than that unreinforced stone columns. With the help of this technique load carrying capacity of soil is increased and it reduces settlement. This technique is mainly used due to its low cost and versatility. It has also been found out that mainly the three factors are considered to be more effective in increasing the load bearing properties of the soil i.e. by incorporation of stiffer material in the soft soil, by incorporation of the denseness of the surrounding soil, by acting vertical drains **(Guetif et al, 2007)**.It has also been studied that the behaviour of single column and multiple columns (group of seven column) carried out by altering different parameters like spacing between the columns, different loading rates and by changing the shear strength of the soil. Columns of diameter 100mm were made in soft clay of different consistency. **(A.P. Ambily et al.)**. It is also experimented on both single and multiple stone column system using the Geosynthetic encasement. Encasement prevents the bulging out of the stone column and saves the drainage function of the stone column and also increases the friction between the aggregates and the soil surface. The results from the encasement indicated that the encased stone columns are more effective then the uncased stone columns. **(S. Murugasen et al)**. Experiments carried out the plate load tests on unit cells using a different reinforcing method i.e. installing vertical nails along the circumference of the stone column. Again, two types of loading was carried out- load on equivalent area & and load on the column area only. Its results showed that the effectiveness of stone columns improved by introducing vertical nails**. (R. Shivashankar et al.).**Wankyu Yoo et al. did the same tests on sand column i.e. sand compaction pile (SCP) or Gravel compaction pile (GCP). Geosynthetics encasement was used on these sand piles which are called Geotextile-Encased Sand Pile (GESP). Experiments were run on prototypes with different area replacement ratio and different tensile strengths. As a result failure reason for Geotextile-Encased Sand Pile (GESP) is buckling unlike that of sand compaction pile (SCP) i.e. bulging. **P. Mohanty et al**. studied the different the effect of different layers of soil. Two types of layering systems were formed i.e. stiff clay below soft clay & soft clay below stiff clay. Applied load on one column among all the columns of a multiple stone column system to study behaviour of one column among all the other columns. Result showed that the behaviour of the stone column is mere dependent on the upper layer of the soil. **Mohammed Y. Fattah et al**. observed the variation in the stone column behaviour by changing the distance between in between the column & by differing the length to diameter ratio of the stone column. As a result it was found that the stone columns are most effective when length to diameter ratio is in between 5 to 8 & spacing is approximately 2.5 times diameter. **Harish C et al**. studied the behaviour of the stone column (both unreinforced and reinforced) in the black cotton soil. Studying the effect of changing the diameter of the stone column is the major aim of this paper. And also comparing the bearing capacity of the soil reinforced with stone columns encased with different length of geosynthetics**. Shushovan Dutta et al**. did a study to create a new type of encasement that can be made from waste plastic bottles and normal stone columns were not used instead fly ash columns were created. All the columns created were end bearing columns and placed in triangular and square pattern. The method turned out to be really efficient & effective.

Finite element modelling by Plaxis 2D is used to validate the experimental results. Deformation and stability of geotechnical structures is examined by the finite element method. Though numerical modelling is mostly used for geotechnical application but its main advantage is found in those soils which shows non linear stress strain behaviour. For analysis of stability against deformation in soil problems, dimensional finite element code with availability of Plaxis version 9 is used. It can also be used for strain and axisymetric modelling. As soil is a multiphase system, having hydrostatic pore pressure which needs special techniques. The correct and elaborated modelling of actual scenario is achieved by knowing regarding the soil layers, loads, structures and additionally the boundary conditions. After implementation of finite element modelling is performed automatic mesh is generated with the help of this geometry.

II. PROPERTIES OF MATERIALS

Soil:

The soil which is used was obtained from Jaypee University of Information Technology, Waknaghat, Solan. (H.P). The Direct-shear test, moisture content test, Specific gravity test, Proctor compaction tests on soil are conducted & their consolidated results are shown in Table1.

Properties	
C	0.02 kg/cm sq.
Φ	20 degree
Water Content	3.44%
Specific Gravity	2.65
OMC	8.40%
Dry Density	1.6 g/cc

Table 1. Tests results performed on the soil.

The sieve analysis tests have been performed for the evaluation of Particle Size Distribution of granular material by permitting the material to go through the sieve which is arranged in decreasing order of 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 microns, 300 microns & 150microns. the amount of material which is passed & retained on the sieve & corresponds to that graph is plotted. the soil sample which is used in the testing is sandy soil. Particle Size distribution curve on the soil sample is shown in Fig. 1.

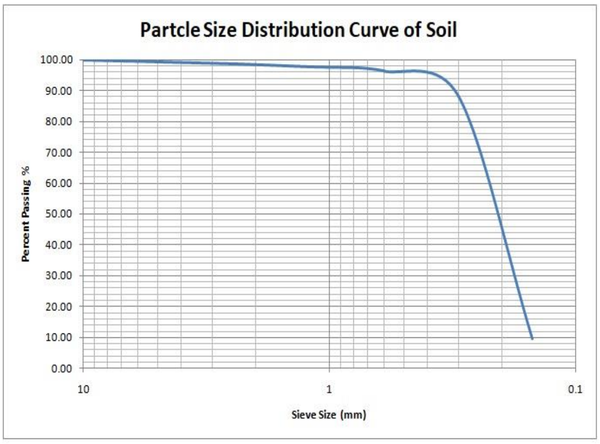

Fig. 1. Particle size distribution curve of soil sample

Aggregates:

The aggregates used for the experimental testing of the stone column can be between 6mm-40mm (K.Ali et al 2013). The aggregates passing through 10 mm sieve is taken. The aggregates which is taken is 25% of the aggregates which is retained on 10 mm sieve & 63% of the aggregates retained on 4.75 mm sieve as shown in Fig. 2.

Fig. 2. Aggregates

Geotextiles:

Geotextile is used for providing reinforcement, separation, filtration of the soil particles and drainage. This paper deals with the use of Geotextiles as an reinforcing material. Geotextiles is a permeable fabric which is used in association with soil, the ability to separate, filter & drain. The Geotextile which is used for the testing is Woven Polypropylene Geotextile which can bear large amount of load but it is not porous hence its drainage is poor. The Geotextile is used in roads, airfields, reservoirs and retaining walls. These Geotextiles improves the strength of a soil at a lesser cost and it can also be planted on very sharp slopes. The properties of Geotextile is shown in Table 2.

S.No	Property	Particular	Unit	Test Method	Quality No.
1	Tensile strength	WARP	kN/m	IS-1969	45
		WEFT	kN/m	IS-1969	34
2	Elongation	WARP	%	IS-1969	30
		WEFT	%	IS-1969	28

Table 2. Properties of Geotextile (Woven Polypropylene)

Construction of stone column

The behaviour of stone column, their resultant effects on ground and its properties are find out by casting the isolated stone column (Floating). In order to minimise the induced stresses at the boundaries of tank, such boundaries are selected which do not affect the behaviour of stone columns. The area replacement ratio is taken as 25% (K.Ali et al.,2013). By using isolated stone column approach greater area in comparison with stone column is loaded. As horizontal stresses at the lateral boundaries of column is increased due to loading the surroundings of the columns(Castro, 2017).

In construction of unreinforced stone column firstly soil is filled in different layers and each layer is having the denseness of 10 cm. 15 number of blows is provided to each layer with the rammer in order to compact the soil. When soil is filled up to the height of 20cm a hollow cylindrical shaped pipe is inserted into the modelled tank. Casting of 8stone column is done simultaneously until a height of 50 cm is reached. Aggregates which is used in the stone column are also filled in different layers, tamping rod is used to compact aggregates lightly. As aggregates are filled to the top level of the modelled tank the pipe is withdrawn simultaneously.

In construction of vertical reinforced stone column, a geotextiles encasement is to be provided. The encasement is attached to the size of hollow cylindrical shaped pipe. The soil is filled in successive layers having thickness 10cm each. Compaction is done in same manner as done in case of unreinforced stone column. As the filling of soil is reached to a height of 20cm, the pipe is inserted. The pipe enclosed with geotextile is placed in the tank. Grease is applied to the external sides of the pipe to minimise the friction. After pouring the aggregates a tamping rod is used and it is gently tamped. While tamping pipe is withdrawn simultaneously. As a result of this procedure geotextiles acts as a sac to hold the aggregates. In construction of horizontal reinforced stone column, a circular discs having diameter of 4cm is cut out from the geotextiles. The distance between two adjacent discs is 3cm.The spacing is chosen very carefully because increase in the strength of the stone column is dependent upon the spacing. As the spacing between the discs is decreased higher strength is achieved. The pipe is marked at every 3cm with a paint so as to place the disc according to specified spacing. Disc having diameter 4cm were cut out from geotextile. Placing of pipe in soil is done up to a height of 20cm from bottom. Aggregates are filled and tamping is done. After that circular discs are placed at each marked point with the help of a pipe, pipe is so chosen that the diameter of the pipe is smaller than the diameter of the casting pipe as shown in Fig. 6. Withdrawal of the pipe is done simultaneously.

III. TEST PROCEDURE

For this experiment, three unit cells have been designed of stone column (Isolated) by varying the arrangements of the reinforcement. The following tests on soil sample Specific Gravity test, Particle Size Distribution test and C-Φ limits was being carried out. For modelling of stone column, two model tanks of 300mm*300mm*550mm were made, three faces of iron and one face of acrylic sheet were created. The Fig. 3. Shows the view of isolated stone column.

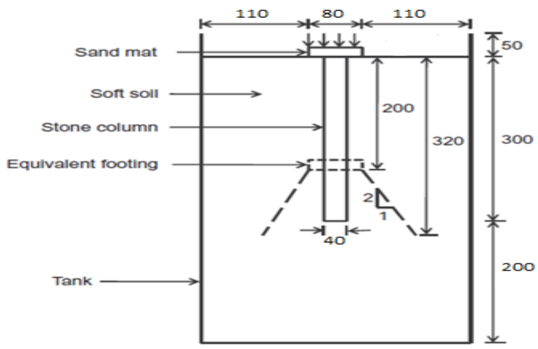

Fig. 3. Isolated stone column Schematic view

After being the construction of stone columns, the load settlement behaviour of stone column was investigated by applying the load in the vertical direction. While loading a stone column iron cylinder is being made for the testing having the following dimensions i.e. dia. 80 mm and height 20 mm. The cylindrical shaped equipment which is used for the testing, the diameter of this equipment was chosen in such a way that the dimension of the modelled tank is 3-5 times the diameter of the area which is to be loaded, so as to ensure that no forces on stone column should be exerted on the tank walls. Universal Testing Machine (UTM) is used for the testing of stone column. UTM is the machine which is used to determine the tensile and the compressive strength of material. Load is applied continuously at a rate of 1kN/min. until 60mm settlement is reached.

IV. MODEL TESTING RESULTS

Bulging at neck is the main reason of failure in all the three stone columns. The main reason of penetration in case of a floating stone columns is due to applied vertical stresses. The significant failure of stone column is observed due to the net outward force and thus it produces bending (K.Ali et

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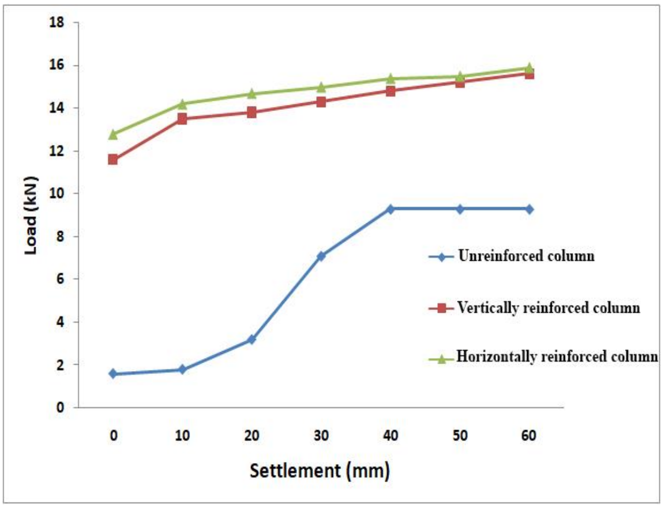
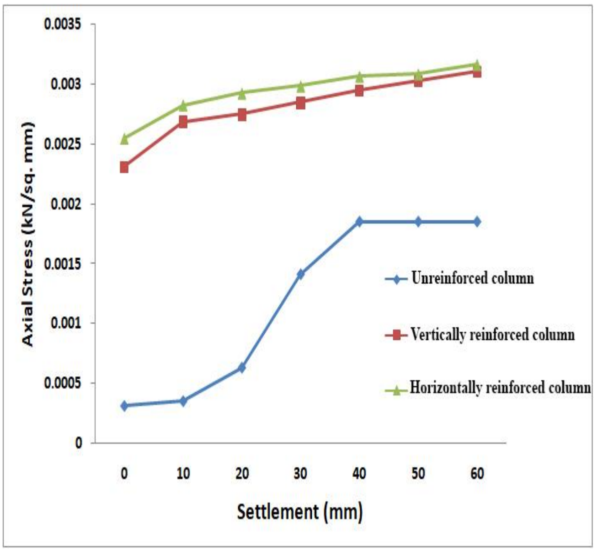
al,2013). The failure of un-reinforced stone column is found to be at lower load when compared with reinforced stone column, hence bearing capacity is increased with lesser amount. This happens as a result of geotextiles transfers load to the edges likewise to the bottom of the tank by developing the hoop stresses and by mobilizing friction.

The values are obtained from all the tests and then their average values are taken with the similar characteristics employed. This average values were reviewed since out output of the previous tests show good repeatability.



(a) Load versus settlement behaviour



(b) Variation of axial stress versus settlement from the model testing

Fig. 4.

The Fig. 4. shows the behaviour of load versus settlement and variation of axial stress versus settlement for various stone columns. The settlement of unreinforced stone columns is experienced terribly early under a load of 2 kN and at a axial stress of under 0.5 kN/mm sq. When the settlement is about 40mm, the unreinforced stone column experienced 9.8 KN load and a axial stress of 1.9 kN/mm sq. Therefore, the column constantly starts experiencing settlement without bearing any further load. As graph between the load and axial stress becomes constant, it shows that the failure of unreinforced stone column occurs at a loading of 9.8 kN. In case of vertically reinforced stone column, it does not experience any settlement upto a load of 9.8 kN and at a axial stress of 2.3 kN/mm^2, beyond this column starts experiencing settling. At a loading of 15.8 kN and at a axial stress of 3.1 kN/mm^2 a settlement of 60mm is achieved, the vertical reinforced stone column does not fail as unreinforced stone column does. Hence this shows that the load carrying capacity of the soil for vertical reinforcement provided in stone column is more than that for the stone column which is un-reinforced, but in the case of horizontally reinforced stone columns with equidistance circular discs have been placed and upto a load of 12.5 kN stone column doesn't experiences any settlement and having a axial stress of 2.5 kN/mm^2. At a loading of 15.9 kN and at a stress (axial) of 3.2 kN/mm^2 settlement of 60 mm is achieved. The horizontal reinforced stone column does not fail as vertically reinforced stone column does. Hence this shows that the load carrying capacity of the soil for horizontally reinforced stone column using circular discs is more than that of vertically reinforced stone columns. Various studies on different soils like clay shows that (K.Ali et al, 2013 and Murugesan et al,2007), the load carrying capacity of the soil having vertical reinforcement provided on stone column is more than that of horizontal reinforcement. However in our case soil is sandy in nature, the load bearing capacity of the soil which is being horizontally reinforced stone column is more than that of vertically reinforced stone column.

Failure mechanism from Model Testing

Analysis of strength increment is done while comparing the columns. The effect of varying reinforcement arrangements is to increase the load bearing capacity of soil which results in the failure of stone column at different loads. In case of floating stone column when development of significant hoop stresses takes place, early penetration of soil is experienced. Failure pattern of stone column is studied with the help of excavation of columns after loading. The expected failure pattern is found because of bulging at the neck (K.Ali et al,2013). In Unreinforced Stone columns partial excavation is started from the time of possible disintegration of unreinforced stone column as a result of complete excavation as shown in Fig. 5.(a). Failure pattern is studied by measuring the perpendicular distance from the neck and at the bottom of the column from the wall The observation made from Fig. 5.(b), value of perpendicular distance between the neck of the column and wall of the tank comes to be 14 cm. On the other side 15cm is the observed distance between the bottom of the column and wall of the tank. The results made from above observations shows, failure due to bulging is experienced by stone column as later distance is more than the former one. In Vertical Reinforced Stone Column the disintegration of stone column is prevented as reinforcements behaves as sac. Excavation of stone column is carried out, it starts from top and proceeds further towards bottom of model tank. The failure pattern of vertical reinforced stone column takes place due to bulging at the neck is shown in Fig. 5.(c). In excavation of Horizontal Reinforced Stone Column is carried out in same manner as that for vertical reinforced stone column. After some time disintegration of stone column takes place and the imprint left behind the surrounding soil is used to investigate the failure pattern. The same is shown in Fig. 5.(d). Thus it proved that the failure in all the three types of stone column occurs due to bulging at the neck as ascertained by K.Ali et al,2013. This failure pattern is according to Wood et al, it shows that the stone column bulge more in higher zone of soil as the area replacement ratio is increased, after that load is transferred to a greater depth. Before the bulging failure, a floating column could fail at end bearings, as underlying layer is weak. Thus in actual practice the most dominant failure mechanism is bulging, in case of sub surface conditions.

(a). Unreinforced stone column after load application

(b). Perpendicular distance measured from the column and the wall of modelled tamk.

(c). Vertical reinforcement column failure due to bulging

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(d). Horizontal reinforcement column failure due to bulging.

Fig. 5. Failure mechanism in Un-reinforced and Reinforced stone column.

V. FINITE ELEMENT ANALYSIS

Model Configuration

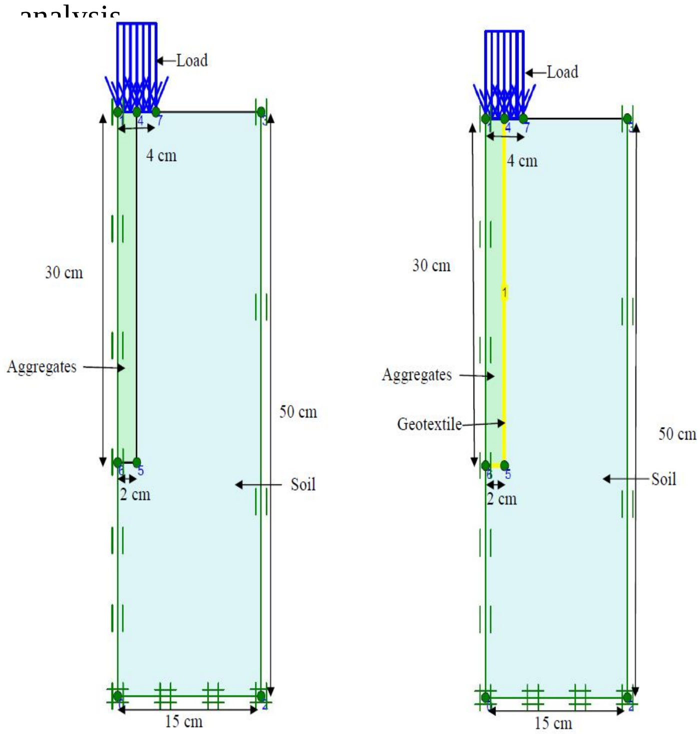
Generally for finite element analysis two methods are deployed within the industry i.e. 2D and 3D modeling. Plaxis 2D has been used for the analysis of deformation, stability in the rock mechanics and for the validation of the experimental results. The material properties used for the analysis is shown in Table 3. Mohr-coulombs criterion has been chosen. For developing the finite element model, 2D geometry model has been created in X-Y plane. Based on this finite element mesh, properties of the material and boundary conditions has also been performed by Plaxis 2D software. The pore water pressure & its effective stresses has also been generated but in our case the generation of pore water pressure is nil. The model with its geometry and boundary conditions has also been replicated for the analysis.

Properties of soil	
Poisson's ratio	0.30
Cohesion in KN/m^2	1.96
Friction angle (◦)	20
Young's Modulus in kN/m^2	20,000
Dilation angle (◦)	4
$\gamma_{saturated}$, kN/m^3	21.75
$\gamma_{unsaturated}$ kN/m^3	19.66
Properties of Aggregates	
Poisson's ratio	0.30
Cohesion, kN/m^2	0.10
Friction angle (◦)	43
Young's Modulus, kN/m^2	55,000
Dilation angle (◦)	10
$\gamma_{saturated}$, kN/m^3	23.25
$\gamma_{unsaturated}$, kN/m^3	22.78
Properties of Geotextiles	
Stiffness, kN/m	150
Tensile Yield Strength (N_p), kN/m	45
Mass per unit area, g/m^2	200
EA, kN/m	75,000
Modulus of Elasticity (E), kN/m^2	150,000

Table 3. Material Properties for Finite element analysis.

Model Configuration

The model which is being used for the analysis is shown in Fig. 6. The model with its geometry and its boundary conditions is also been replicated in the analysis.



(a). Un-reinforced Stone column. **(b).** Vertically reinforced Stone column.

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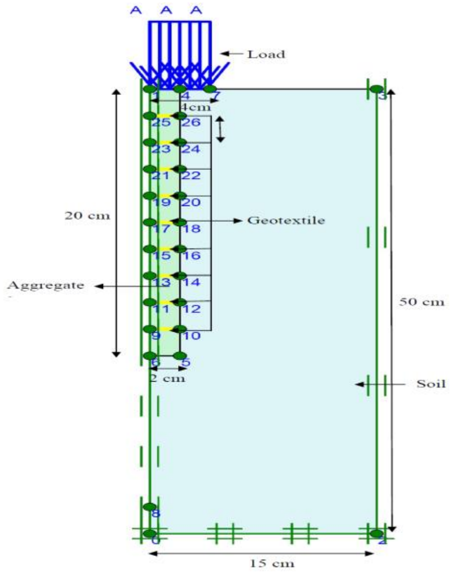


(c.) Geometry of model having structural elements in all.

Fig. 6.

Mesh Generation

While assigning the material properties and geometry of the model is characterised, then the geometry is to be divided into finite element in order to carry out the calculations of finite element. This organisation of finite elements is known as mesh. Mesh generated in Plaxis 8 software is fully a automatically generated mesh majorly in the following forms : fine, very fine, medium, coarse and very coarse. The horizontal and vertical boundaries are considered to be fixed with their particular directions. The bottom boundary of model is simulated to be a fixed boundary. Fig. 7. shows the generated initial mesh. and Fig. 8. shows mesh generation under loads.

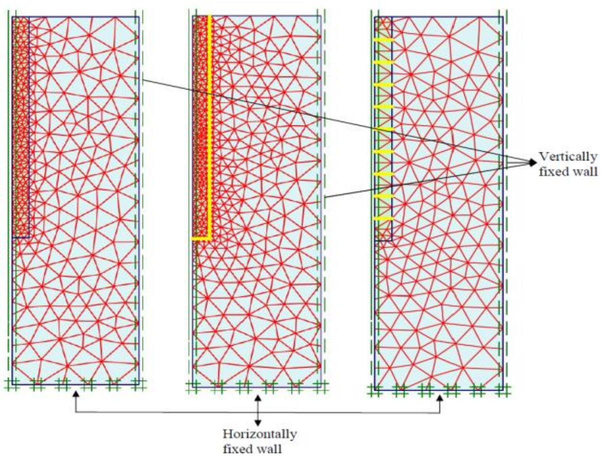
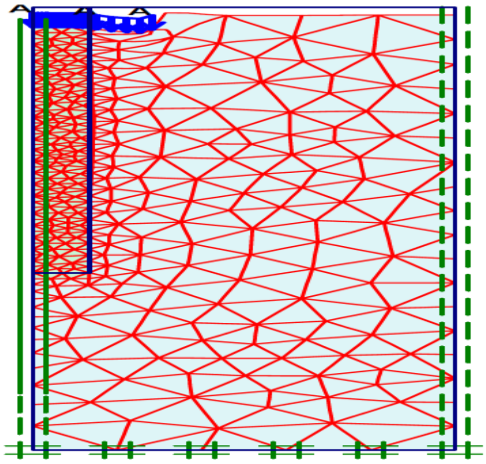
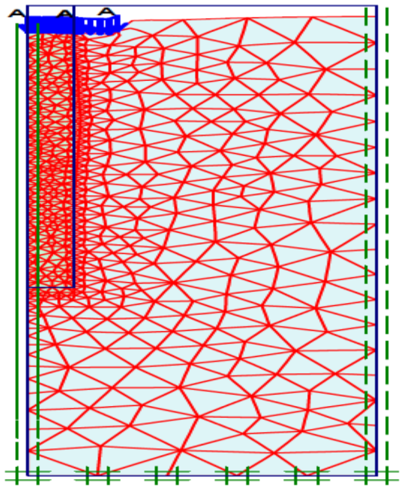


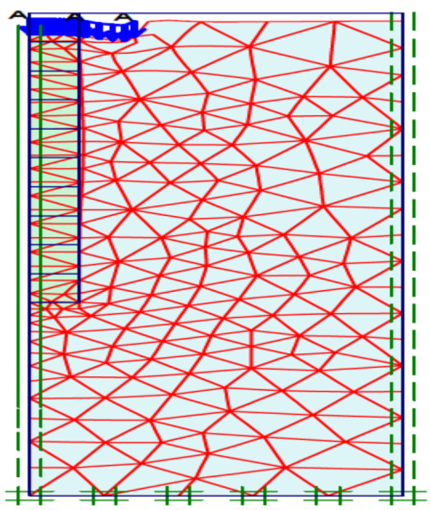
Fig. 7. Generated Initial Mesh



(a). Un-reinforced Stone Columns



(b). Vertically reinforced Stone Columns



(c). Horizontally reinforced Stone Columns

Fig. 8. Deformation under loads

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VI. FINITE ELEMENT MODELLING RESULTS

The results obtained from numerical modeling gives similar results that was obtained model testing. Behaviour of load versus settlement from Plaxis 2D is shown in Fig. 9. 2.5mm settlement is obtained at a factored load of 1.6 kN for unreinforced stone column. 1.4mm settlement is obtained at a factored load of 2.23 kN for vertical reinforced stone columns. 1.3mm settlement is obtained at a factored load of 2.23 kN for horizontal reinforced columns.

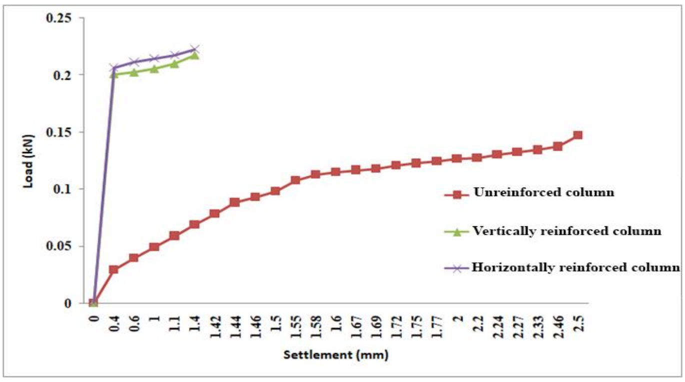
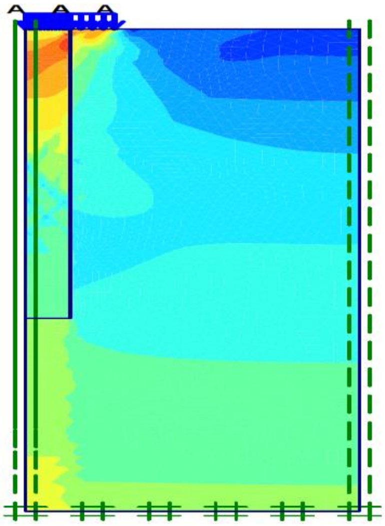


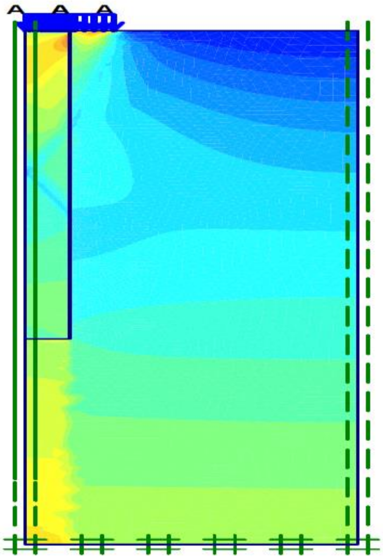
Fig. 9. Behaviour of Load versus settlement from Plaxis 2D

Stress Distribution and Loading

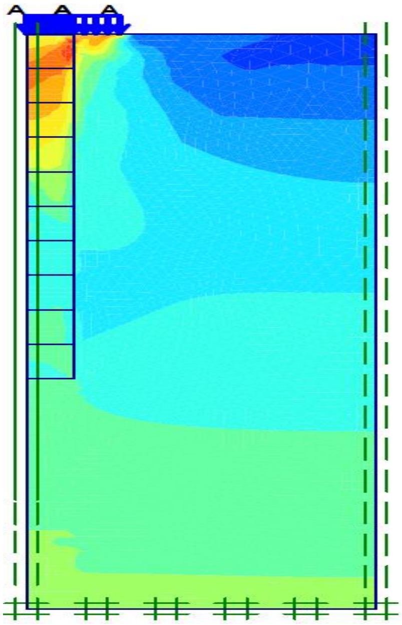
A simulated model is loaded with a uniformly distributed load as shown in Fig. 10. 60mm settlement is achieved in the model testing of stone column at a final load of 9.8 KN for unreinforced stone column, 11.9 KN for vertically reinforced stone column and 15.8 KN for horizontally reinforced stone column.



(a). Un-reinforced Stone Columns



(b). Vertical reinforced Stone Columns



(c). Horizontal reinforced Stone Column

Fig. 10. Stresses Generated under Load

When three cases are compared, stress generated shows that most prominent case of unreinforced stone column is shown by red portion whereas least distinguished portion is shown by vertical reinforced stone column . This signifies that stresses which are generated in case of un-reinforced stone columns is comparatively more than that of reinforced stone column.

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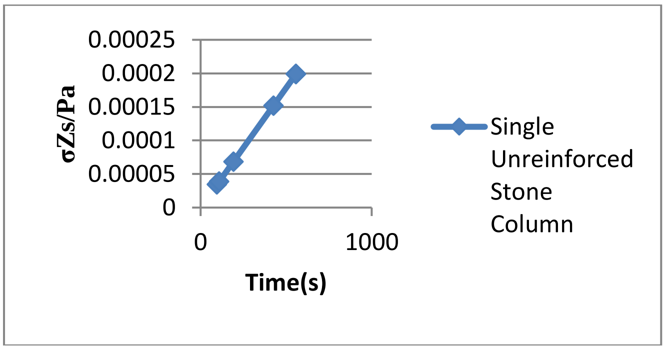
Vertical stresses

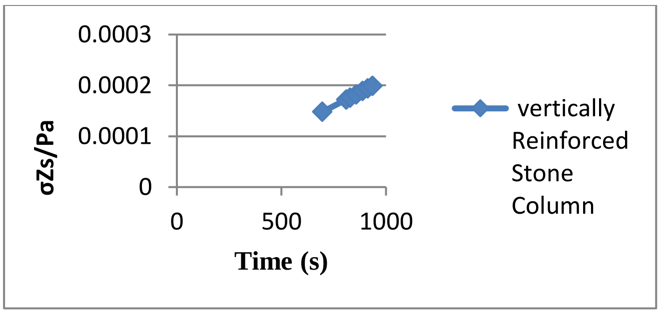
The stresses acting on columns, also put some extent of impact on soil mass as well as on columns itself thus soil-column stress distribution is the major aspect while testing, to get optimal or ideal result.

The values of the stresses acting on the soil and the column all along consolidation and compaction process are mentioned in figure respectively. In these figures 11 &12 the stresses are presented, as the ratio of the soil (σZs) and column vertical stresses (σZc) from the initial point to the ending to the increment of total applied pressure and also include changes in the time of the process. The total applied pressure at the first step was keep on increasing.

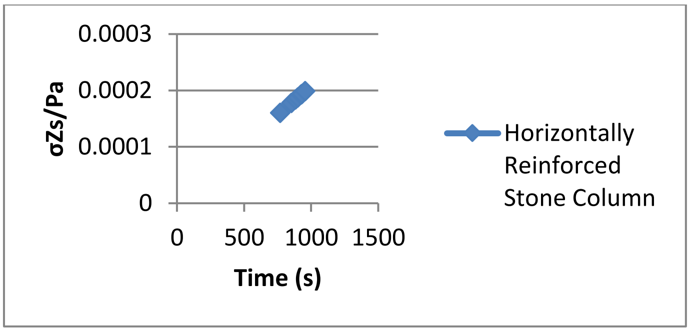
Thus, these steps or test are repeatedly performed for each case of reinforced, non-reinforced, horizontal reinforced column and vertically reinforced columns. It was seen that the reinforced column could take more stress and hence reduces in settlement of the soil while in case of non-encased or non reinforced column could not take stresses as same as reinforced column and more settlement is found. It is obvious that if we replace (geo textile) the reinforced material with other materials the changes in settlement and stress distribution can be seen.



(a)



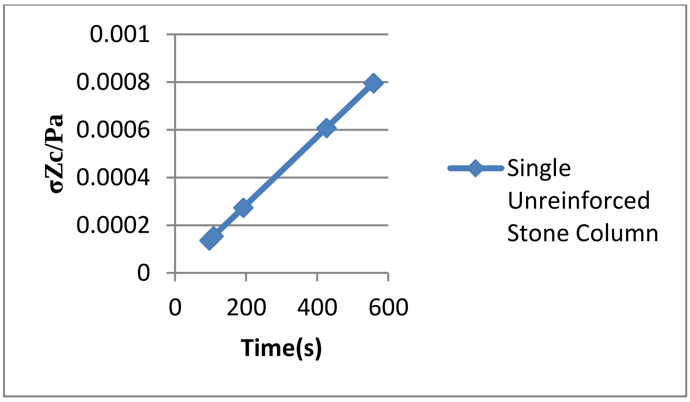
(b)



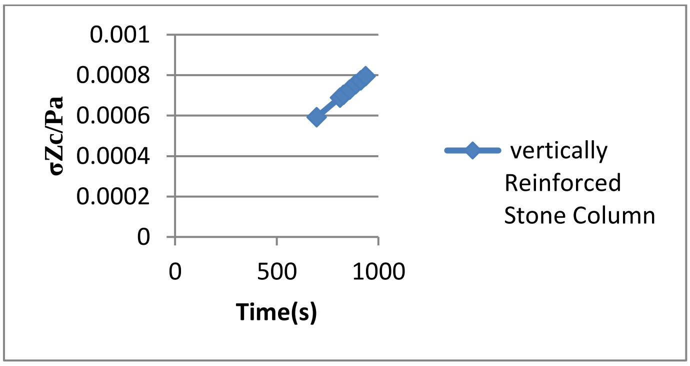
(c)

Fig. 11. Normalised vertical stress in soil with time

Thus, these steps or test are repeatedly performed for each case of reinforced, non-reinforced, horizontal reinforced column and vertically reinforced columns. It was seen that the reinforced column could take more stress and thus reduces the settlement of soil while in case of non-encased or non reinforced column could not take stresses as same as reinforced column and more settlement is found. It is obvious that if we replace (geo textile) the reinforced material with other materials the changes in settlement and stress distribution can be seen.



(a)



(b)

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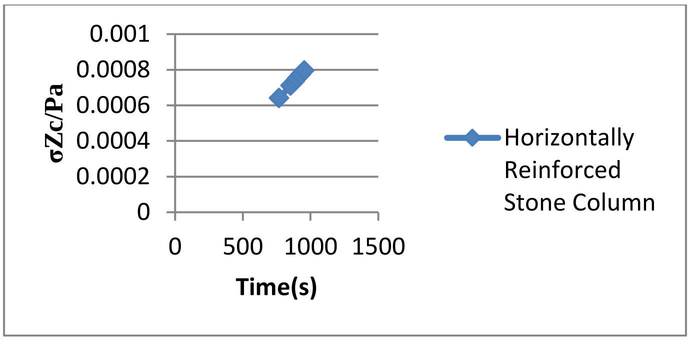
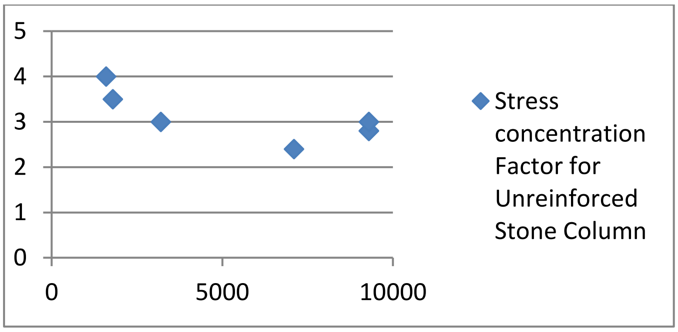


(c)

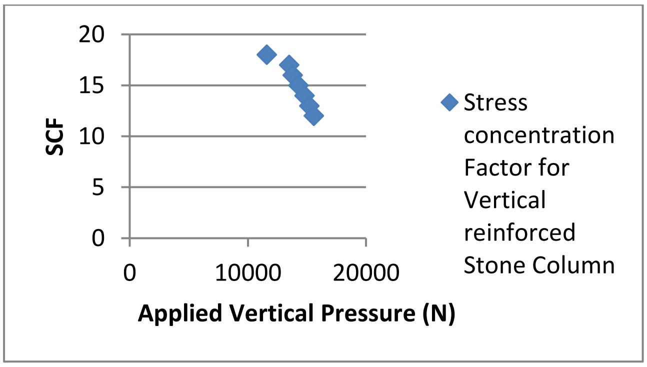
Fig. 12. Normalised vertical stress in column with time

Stress concentration factor (SCF)

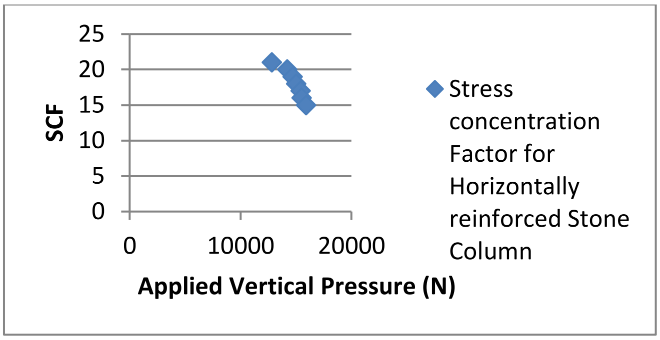
The Stress Concentration Factor (SCF) may be defined as the ratio of the highest stress to a reference stress and transfer of load between the column soil and is expressed by SCF.
The values of Stress Concentration Factor (SCF) for non-reinforced column are between 3 and 4 which is in the range of 3-10.5 which is being given by Barkdale and Bachus (1983). The Stress Concentration Factor value for reinforced column are higher being in range of 12-21. The SCF diagrams for various reinforced, non reinforced, horizontally reinforced and vertically reinforced cases are shown in Fig. 13.



(a)



(b)



(c)

Fig. 13. Incremental Stress Concentration Factor

VII. VALIDATION OF RESULTS FROM MODEL TESTING AND FINITE ELEMENT MODELLING.

The final results which are governed from model testing and finite element modeling is depicted. The relative improvement in load bearing capacity of soil is obtained from the load settlement behaviour of un-reinforced stone columns, vertical reinforced stone columns and horizontal reinforced stone columns. The quality of reinforcement pattern has been calculated by stiffness improvement factor of stone column. Validation of the experimental results is done using Plaxis 2D. Results accomplished from the tests with reinforced and non reinforced (covered or without covered) columns are compared in this portion to examine the influence of the geo-textile reinforcement. The accomplished results are introduced focusing on soil column stress distribution, contraction (devaluation) of settlement.

Combined results governed by model testing and finite element modelling is shown in Table 4. When loading magnitude is same, the settlement is 2.5mm for unreinforced stone column, 1.4mm for vertically reinforced stone column, 1.3mm for horizontally reinforced stone column and 60mm for model testing because of the following reasons :
(1). Construction of stone column is done by installation method, but its effects has not been modelled in numerical modelling.
(2). In model testing a pressure is experienced by stone column from the tank boundaries, thus the soil is forced to bulge out horizontally and it results in large settlement. In numerical modeling settlement is not affected by tank boundaries because only the vertical displacement of stone columns is specified.

Stone Columns	Applied Load (KN)	Stress (Axial) (KN/mm^2)	Settlement governed by Finite element model (mm)
Un-reinforced stone column	9.3	0.002	2.5
Vertical reinforced stone column	15.6	0.003	1.4
Horizontal reinforced stone column	15.9	0.003	1.3

Table 4. Results acquired from model testing and Finite element modeling

VIII. CONCLUSIONS

The following point wise conclusions has been made on isolated stone columns for Un-reinforced stone column, Vertically reinforced stone column and Horizontally reinforced stone column which was procured from numerical modelling and model testing.

1. From model testing results increment in bearing capacity of 61.2% for Vertically reinforced stone column and 62.2% for Horizontally reinforced stone column is achieved.
2. The stiffness improvement factor of **87.72** for vertically reinforced column and **103.6.** for horizontally reinforced column is achieved.
3. Numerical modelling results shows that the settlement of Vertically reinforced stone column is 44% less than that of unreinforced stone column and settlement of horizontally reinforced stone column is reduced by 48% than that of unreinforced stone column.
4. Numerical modelling shows that stress development for vertical reinforced stone column is maximum.
5. For sandy soils Horizontally reinforced stone columns proves to be more effective ground improvement technique.

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