International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-2, December 2019

Settlement Behaviour of Soft Soil Reinforced with Geogrid Encased Stone Column under Sustained Loading

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Abstract: ***The use of stone columns in improving the bearing capacity of soft soil is well researched, but the understanding of settlement requires further studies. This paper presents the results of a series of laboratory tests carried out to study the settlement behavior of soft soil bed reinforced with ordinary stone column (OSC) and Geogrid encased stone columns (GESC). Kaolin was used as the soft soil and stones of size from 2.5 to 10 mm were used as column material. The stone columns of four different diameters were installed, by the method of replacement, into the soil having undrained shear strength of 22.5 kPa. The OSC and GESC test beds were subjected to pressure of 250 and 300 kPa. Each pressure was sustained for 24 hours and the settlement of the composite soil with time was noted. It is found that Geogrid encased stone columns have small settlement than the corresponding ordinary stone columns. The SRR (settlement reduction ratio) being a measure of ground improvement, is found increasing with the area replacement ratio. Further, at a particular sustained pressure SRR is found more for GESC than the corresponding value for OSC.***

Keywords: Kaolin clay, stone column, Geogrid, area replacement ratio, settlement reduction ratio.

I. INTRODUCTION

Stone column is being expansively used as a flexible foundation for soft soil as it is simple, economic and cost effective form of ground improvement. When ordinary stone columns are built in soft soils, they failed due to large upcoming load by increasing the diameter of the column at top length which is commonly known as bulging failure. Encasing stone columns with suitable geosynthetics is recommended in such a case (Alexiew et al. 2005). In encased stone columns, the load-bearing capacity improves by the support of the geosynthetics. The encasement around the column works as an obstacle for the movement of coarse media to move in lateral direction towards the surrounding fine soil (Murugesan and Rajagopal 2007).

Revised Manuscript Received on December 30, 2019.
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The geosynthetic encasement influence on the load carrying capacity and settlement of reinforced ground has been studied through small-scale model tests in laboratory by many (Sharma et al. 2004; Wu and Hong 2009; Gniel and Bouazza 2010; Ali et al. 2012). The numerical studies for encased columns are also presented (Murugesan and Rajagopal 2006; Malarvizhi and Ilamparuthi 2007; Khabbazian et al. 2010; Almeida et al. 2013). Raithel et al. (2002) has cited the case histories where geotextile encased stone columns were constructed to improve the soft soils below the embankments in Germany, Sweden, and Netherlands.For improving the behaviour of the soft expansive soil the geogrid can be used as reported by Kumar and Jain (2013).They found that the load carrying capacity of the granular piles increases by encasing by geogrid. The increment is more for larger diameter piles. The load settlement behaviour of encased stone column that is reported in the literature; show the short duration behaviour of the composite ground under applied loads. However, it is the long duration consolidation settlement of the ground that matters in actual field situation. Chandrawanshi, S. (2018) studied the settlement behaviour of very soft soil reinforced with stone column; in which the applied pressure was sustained for 24 hours. Displacement and replacement method of construction of stone column and the variation in compaction efforts was studied on consolidation settlement of OSC. The results show decrease in settlement at higher compactive efforts and with larger diameter of stone columns. Based on his study he developed charts (Fig.1) for designing the OSC, for the specified settlement of the composite ground, under the expected sustained pressure. These charts are useful for soils having undrained shear strength between 2.5 to 7.5kPa.

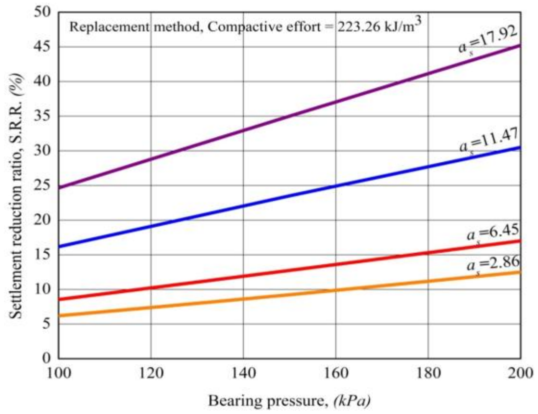

Fig.1. Design chart for selecting size of stone column for desired settlement reduction (Chandrawanshi, S. 2018).

Similar study for encased stone column has not been attempted so far. The soil of undrained shear strength below 25 kPa is well suited for provision of column encasement. The soft soil of average shear strength of 22.5 kPa was used for installation of stone columns by replacement method. The prepared test beds were subjected to pressure of 250 and 300 kPa, sustained for 24 hours and the settlement of the composite soil with time was noted. The observations of this study will be helpful in ascertaining the behaviour of encased stone columns for consolidation settlement in soft soils.

II. MATERIAL PROPERTIES

The kaolin(table- I) as soft soil and basalt rock was used for column material(table-II). The geogrid(table- III) was used for encasement material. The stone particles size between 2.5 mm and 10 mm were washed and sieved.

Table- I: Properties of kaolin

Property	Value
Specific Gravity	2.62
Liquid Limit	27%
Plastic Limit	18%
Plasticity Index	9%
Classification (IS:1498-1970)	CL
Standard Proctor test	
Optimum Moisture Content	21%
Maximum Dry Density	15.91%

Table- II: Properties of stone aggregates

Property	Value
Specific Gravity	2.66
Percentage fines (≤ 0.075 mm)	0%
Minimum size of aggregates	2.5 mm
Maximum size of aggregates	10 mm
D_{10}	2.75 mm
D_{30}	4.3mm
D_{60}	5.65 mm
C_U	2.05
C_C	1.19
Classification (IS:1498-1970)	GP
Angle of internal friction, ‘ϕ’ at relative desnsity of 66 %	44.5°

The geogrid sheet used for encasing the stone column is procured from the local market. It is commercially known as Nova curtain. From the geogrid sheets, estimated dimension of the geogrid is cut and folded to form an open-ended cylinder shape for encasing the stone column as per requirement.

Table-III: Properties of the geogrid used

Property	Value
Opening size, mm	2x2
Tensile Strength (Stiffness), kN/m	15
Thickness, mm	1
Weight, gm/m^2	260

III. EXPERIMENTAL PROGRAM

A cylindrical steel tank with internal diameter 150 mm and height 230 mm was used for the preparation of soft soil bed. A single OSC or GESC was installed in the soil, in central part and is considered to reflect the behaviour of the group of stone columns as per the unit cell theory (Barksdale and Bachus,1983). Table IV shows the tests details.

Table –IV: Details of Experimental Program

Soil bed with average undrained shear strength of 22.5 kPa	Compactive Effort	Stone column diameter	Aplied Pressure maintained for 24 hours		Tests
	(kJ/m3)	(mm)	250 kPa	300 kPa	
Soft Soil Bed	-	-	1	1	2
Soil reinforced with OSC	20.62	41.2	1	1	2
	23.2	52.5	1	1	2
	22.28	65.8	1	1	2
	20.62	77.4	1	1	2
Soil reinforced with GESC encased stone column	20.62	39.8	1	1	2
	23.2	51.3	1	1	2
	22.28	64.7	1	1	2
	20.62	76.8	1	1	2

It may be noted from the Table IV that the stone columns of four different diameters were installed into the soil. The settlement behaviour of the test beds was noted for two different applied pressures sustained for 24 hours.

A. PREPARATION OF CLAY BED

The oven dried kaolin in powder form was mixed with 40.5 % water. This amount corresponds to 1.5 times the liquid limit of the soil (i.e. 1.5 x 27 = 40.5 %). Stirring of the mix eliminated the voids and lumps from the soil. This was filled in test mould. The oil layer has been applied on the inner surface of the mould to reduce friction during load application. The porous plate of diameter 148 mm has been placed at the base of the mould and a filter paper was kept on it to obstruct the soil between the pores of lower plate during application of load. This arrangement has been done for bottom drainage. The soil was filled in layers with care to maintain a void free soil mass till top of the mould. The filled up mould was left in open air for 16 to 24 hours for self consolidation. After this filter paper was kept on the upper portion of soil bed below the brass perforated plate of diameter 148 mm which was used as a footing with a drainage media. A pressure of 185 kPa was applied gradually on the footing and was maintained for 24 hours. This state of the test bed is referred as the consolidated state which yields us the soft ground close to the natural ground with no over-consolidation pressure and is referred as soft clay bed. The laboratory vane shear test was been performed for this consolidated soil and average undrained shear strength 22.5 kPa was observed.

B. Stone Column Construction

By the use of replacement method ordinary and encased stone columns were installed. The stainless steel pipes of inner diameter 38.1, 50.8, 63.5 and 76.2 mm have been used for construction of stone columns and extractions of wet kaolin clay from prepared consolidate bed. The oil layer has been applied on the inner portion of pipe to reduce the resistance among the soil particles and pipe material. The soil removed carefully to avoid the disturbance in prepared soft soil bed. The ordinary stone column has been constructed by the filling the stone in layers of 25 mm, the pipe has been raised up by 25 mm after filling this layer. Each layer was compacted with the help of a temping rod of 0.6 kg, falling from the height of 100 mm to form stone column of uniform stiffness. The number of blows was calculated to impart same amount of energy to stone columns of different diameters. In present investigation the average compacitve energy given was 21.7kJ/m^3.

The geogrid in cylindrical form has been prepared for encasement which has stitching overlap of 5mm (Fig. 2). The cylindrical geogrid was inserted in the cavity after the soil was extracted through steel pipe. The filling of stones in the cavity has been done in the same way as was done for ordinary stone column, the final diameter of ordinary and vertical encased stone column was measured after construction. In case of OSC it was found as 41.2 mm, 52.5mm, 65.8 mm, 77.4 mm and in case of VESC it was 39.8 mm, 51.3 mm, 64.7 mm, 76.8 mm.

Fig. 2. Encased stone column of different diameter

C. TEST PROCEDURE

An exemplary test arrangement is shown in Figure 3 in which a test tank is placed on the loading platform. The platform can move up and down, at different rates, by a motorized mechanism and can apply the desired pressure on the test bed. The test tank was kept inside a bigger tank that collects the water when the test beds were subjected to consolidation pressure. The load on the test plate was measured by the proving ring. Settlement was measured by the dial gauge having least count of 0.01mm attached to one of the arm of the loading frame.

Fig.3. Loading Apparatus

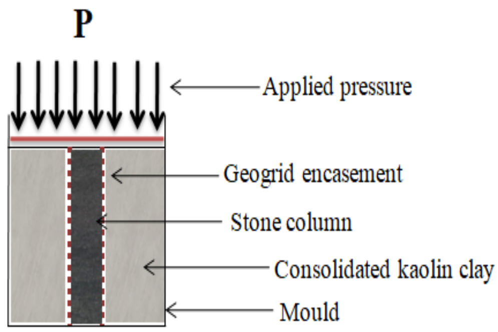

Fig. 4. Encased stone column loading

Three test series were conducted in the present investigation.

TS -1. Two soft soil test beds were prepared. One was subjected to the pressure of 250 and the other of 300 kPa. The pressure was sustained for 24 hours.

TS -2. OSC test beds having stone columns of four different diameters. For each stone column diameter of the test bed, two moulds were prepared; one subjected to the pressure of 250kPa and the other of 300 kPa sustained for 24 hours.

TS-3. GESC test beds having stone columns of four different diameters. For each encased stone column diameter of the test bed, two moulds were prepared; one subjected to the pressure of 250kPa and the other of 300 kPa sustained for 24 hours.

IV. EXPERIMENTAL RESULTS

TEST SERIES TS-1: SETTLEMENT CHARACTERISTICS OF SOFT SOIL BEDS

The settlement values were recorded with time when the settlement rate reduces to less than 0.1mm/hr and final thickness of the test bed was noted. It is noted that at any given time; the settlement for larger applied pressure is more than that for the small pressure.

The final settlement for 300 kPa pressure is 13.94 mm whereas it is 12.30 mm for 250 kPa pressure. The test series-1 is used as a reference for quantifying the performance of soft soil bed reinforced with OSC and GESC.

TEST SERIES TS-2: SETTLEMENT BEHAVIOUR OF SOFT SOIL BED REINFORCED WITH OSC

Figure 5 and 6 shows ordinary stone column settlement behaviour.

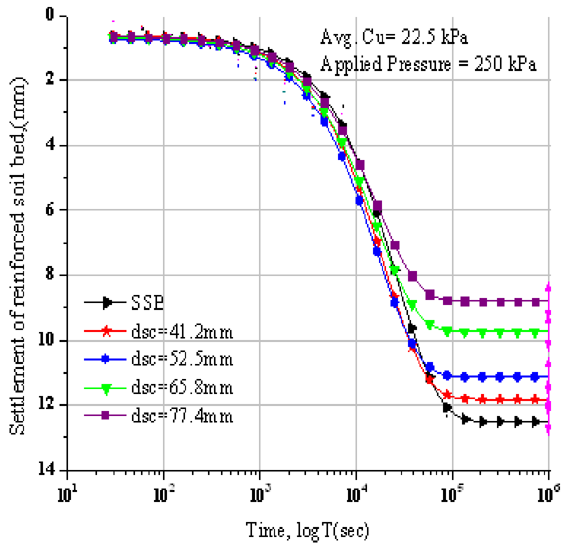

Fig. 5. Settlement vs Time for OSC at 250 kPa applied pressure.

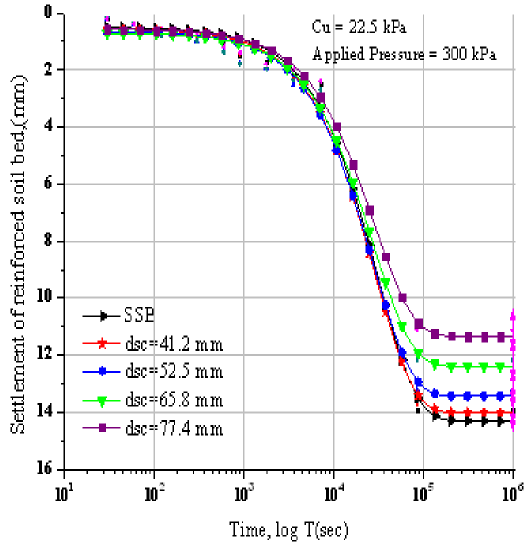

Fig. 6. Settlement vs Time for OSC at 300 kPa applied pressure.

The results indicate that on the same applied pressure the settlement decreases with increase in the diameter of ordinary stone column.

This behaviour of ordinary stone column appeared due to stress concentration ratio ‘n’ (ratio between stress in column to stress in soil). In large diameter stone column, the stress taken by the column material will be more in comparison to small diameter column, this is why large diameter of stone column is more effective to reduce settlement in comparison to small one.

TEST SERIES TS-3: SETTLEMENT BEHAVIOUR OF SOFT SOIL BED BY ENCASED STONE COLUMN

Figure 7 and 8 shows the settlement behaviour of GESC stone columns.

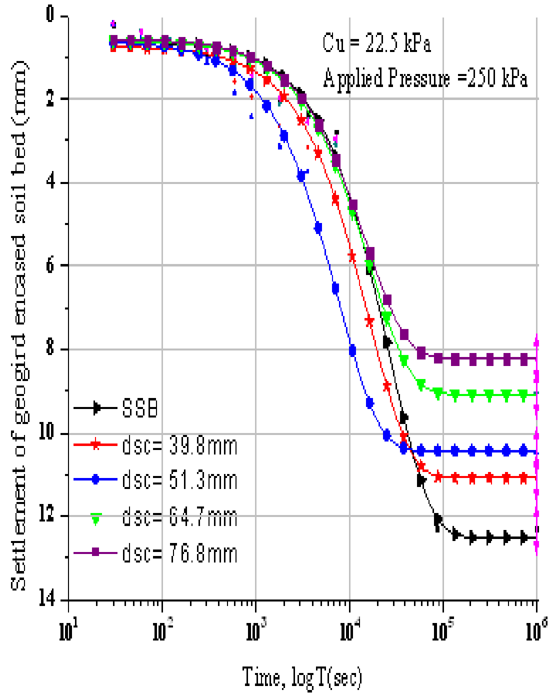

Fig.7. Settlement vs Time for GESC at 250 kPa applied pressure.

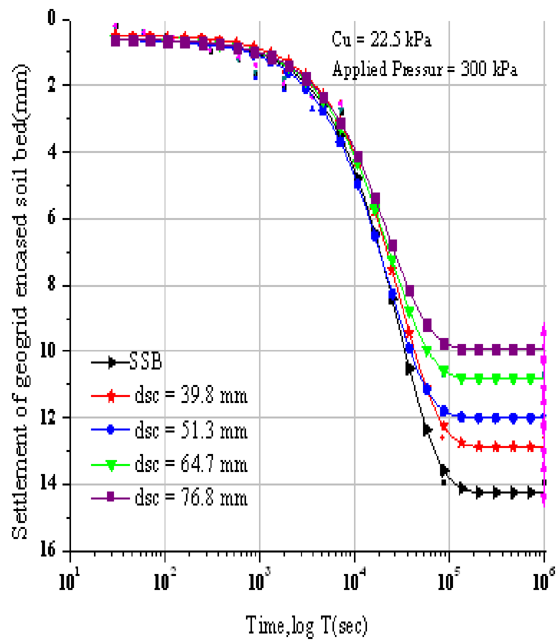

Fig. 8. Settlement vs Time for GESC at 300 kPa applied pressure.

The results indicate that for an applied pressure; the settlement of is less as the diameter of the Geogrid encased stone column increases. As the diameter of the columns increases the settlement reduction ratio (SRR) improves.

This behaviour of column is due to confinement of geosynthetic material and stress concentration ratio.

Retrieval Number: A5030119119/2019©BEIESP
DOI: 10.35940/ijitee.A5030.129219
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
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The settlement redcues by encasement is more effective than ordinary stone column.

It is noted that installation of stone column reduces the settlement. To quantify the settlement reduction, a dimensionless parameter, settlement reduction ratio (SRR) is introduced. It is defined as:

$$\mathbf{SRR = [\{h_{scb} - h_{rcb}\}/h_{scb}]\times 100}$$

where: h_{scb} = settlement of the soft soil bed for a given bearing pressure, and

h_{rcb} = settlement of the soft soil bed reinforced with stone column under the same bearing pressure.

Settlement reduction ratio is calculated for ordinary and Geogrid encased stone columns and given in table V.

Table –V: Settlement Calculations of experimental and theoretical

Type of soil bed	Diamet-er of stone column	Area Replace-ment Ratio	Settlement for different applied pressure		Settlement Reduction Ratio SRR	
			250 kPa	300 kPa	250 kPa	300 kPa
	(mm)	(%)	(mm)	(mm)	(%)	(%)
Soft soil	-	-	12.3	13.94	-	-
Soil bed with ordinary stone column	41.2	7.54	11.76	13.73	4.3	1.5
	52.5	12.25	11.13	13.2	9.5	5.3
	65.8	19.24	9.74	12.17	20.8	12.63
	77.4	26.62	8.8	11.11	28.4	20.3
Soil bed with geogrid encased stone column	39.8	7.04	11.08	12.59	9.9	9.6
	51.3	11.69	10.46	11.9	14.9	14.6
	64.7	18.6	9.07	10.7	26.2	23.2
	76.8	26.21	8.22	9.83	33.1	29.4

Under given sustained applied pressure;

(1) SRR is found increasing with the area replacement ratio.This is oberved for both OSC and GESC.

(2) The area replacement ratio in GESC is slightly less is possibly due to the resistance offered by geogrid during compaction that resist stones to spread out laterally.

V. CONCLUSIONS

The experimental work presents the performance of the ordinary and geogrid encased stone columns with different diameters constructed by imparting definite compactive effort. The following conclusions are drawn from the experimental work conducted in this study:

1) SRR in OSC and GESC is found increasing with the area replacement ratio.
2) SRR of GESC is more than OSC for the nearly same area replacement ratio for the same applied pressure.
3) SRR at higher sustained pressure is less than the corresponding value at low sustained pressure. Since only two pressures were applied in this study, hence further research on this aspect is needed.

REFERENCES

1. Alexiew, D., Brokemper, D., and Lothspeich, S. 2005 “Geotextile Encased Columns GEC: Load capacity, geotextile selection and predesign graphs.” Geotech., Spec. Pub No. 130–142, 497–510.
2. Almeida, M., Lima, B., Riccio, M., Jud, H., Cascao, M. and Roza, F. (2014). “Stone columns field test: monitoring data and numerical analyses.” Geotechnical Engineering Journal of the SEAGS & AGSSEA, 45(1), 103-112.
3. Ali, K., Sahu, J. T., and Sharma, K. G. (2012). “An experimental study of stone columns in soft soils.” Proc., Indian Geotech. Conf., Bombay, India, 625-628.
4. Barksdale, R. D., and Bachus, R. C. (1983). “Design and construction of stone columns: Volume 1” Rep. No. FHWA/RD-83/026, Federal Highway Administration, Washington DC, US.
5. Chandrawanshi, S., 2018. “Settlement Behaviour of Very Soft Soil Reinforced With Stone Columns : An Experimental Study”. Ph.D. Thesis, Maulana Azad National Institute of Technology,India.
6. Gniel, J. and Bouazza, A. 2009. Improvement of soft soils using geogrid encased stone columns, Geotextiles and Geomembranes 27, 167–175.
7. IS: 1498. 2007. Classification and identification of soils for general engineering purposes, New Delhi, Indian Standards Institution.
8. IS: 15284 Part 1. 2003. Indian standard code of practice for design and construction for ground improvement-guidelines, New Delhi, Indian Standards Institution.
9. Khabbazian, M., Kaliakin, V. N. and Meehan, C. L. (2010). “Numerical study of the effect of geosynthetic encasement on the behaviour of granular columns.” Geosynthetics International, 17(3), 132-143.
10. Kumar, R. and Jain, P.K. 2013. Expansive soft soil improvement by geogrid encased granular pile, International Journal on Emerging Technologies 4, 55–61.
11. Malarvizhi, S. N., and Ilamparuthi, K. (2007). “Comparative study on the behavior of encased stone column and conventional stone column.” Soils and Foundations, 47 (5), 873-885.
12. Murugesan, S., and Rajagopal, K.2006a . “Geosynthetic-encased stone columns: Numerical evaluation.” Geotext. Geomem., 24-6, 349–358.
13. Murugesan, S., and Rajagopal, K. 2006b. “Numerical analysis of geosynthetic encased stone column.” Proc., 8th Int. Conf. on Geosynthetics,Yokohama, Japan, 1681–1684.
14. Murugesan, S., and Rajagopal, K. 2007a. “Model tests on geosynthetic encased stone columns.” Geosynthet. Int., 24-6,349–358
15. Raithel, M., Kempfert, H. G., and Kirchner, A. 2002. “Geotextileencased columns GEC for foundation of a dike on very soft soils.” Proc., 7th Int. Conf. on Geosynthetics, Swets & Zeitlinger, Nice, France, 1025–1028.
16. Sharma, R.S., Kumar, B.R.P. and Nagendra, G. 2004. Compressive load response of granular piles reinforced with geogrids, Canadian Geotechnical Journal 41,187–192.
17. Wu, C. S., Hong, Y. S. & Lin, H. C. (2009). Axial stress-strain relation of encapsulated granular column. Computers and Geotechnics, 36,No. 1–2, 226–240.

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