International Journal of Civil Engineering and Technology (IJCIET)
Volume 8, Issue 8, August 2017, pp. 1218–1226, Article ID: IJCIET_08_08_131
Available online at http://http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=8
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

 Scopus Indexed

AN EXPERIMENTAL STUDY ON MARINE CLAY PERFORMANCE USING REINFORCED STONE COLUMN WITH LIME SOIL COLUMN

S. Siva Gowri Prasad
Assistant Professor, Department of Civil Engineering,
GMR Institute of Technology, Rajam, Andhra Pradesh, India

K. Praveen Sai
P.G Student, Department of Civil Engineering,
GMR Institute of Technology, Rajam, Andhra Pradesh, India

Ch. Vasavi
P.G Student, Department of Civil Engineering,
GMR Institute of Technology, Rajam, Andhra Pradesh, India

ABSTRACT

Stone columns have proved to be a useful technique for supporting flexible structures resting on soft soils. However, in the case of very soft soils, stone columns have encountered excessive settlements due to insufficient lateral resistance offered by the soft soil against bulging of the columns upon loading. The bulging may be reduced to a great extent by reinforcing the columns by encasing them with geo-textile. In this proposed work, to improve the strength parameter of the week soil, the silica manganese slag is used as the column material along with the induced lime soil. To verify the strength parameter of the column, encasement is provided at different lengths of D, 2D, 3D & 4D. The load carrying capacity of the reinforced stone column with reinforcement length of 4D has increased by 147% compared to the plain clay bed.

Key words: Stone column, lime-soil (LS), Sand, Marine clay, Silica manganese Slag (SG), Geotextile reinforcement.

Cite this Article: S. Siva Gowri Prasad, K. Praveen Sai and Ch. Vasavi, An Experimental Study on Marine Clay Performance using Reinforced Stone Column with Lime Soil Column. *International Journal of Civil Engineering and Technology*, 8(8), 2017, pp. 1218–1226
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=8

1. INTRODUCTION

India is peninsula country, covered with water on three sides and there is a large amount of area coming under coastal region. The soils which exist in these coastal regions are weak and expansive in nature formed by the deposits of soft marine clays. Due to high compressibility and low bearing capacity of the soft natural soil in the coastal area, the construction of flexible pavements and railroad embankments is the challenge on the soft natural soils. Stone columns are the most common technique adopted to improve the strength of the soft soil and extensively used to support structure on soft soil by increasing the bearing capacity. To reduce bearing capacity and settlement problems, soil improvement may be considered by using stone-columns. Installing the stone column in the soft soil is not adequate, due to its confinement offered by the surrounding soil and causes failure like bulging, shear failure and excessive settlements.

S. Murugesan et al. [1] investigated the qualitative and quantitative improvement of load capacity of individual encased stone column through laboratory model tests. This test indicated a clear improvement in the load capacity of stone column due to encasement with geosynthetics having higher modulus resulting in stiffer response, this encasement impacts lateral confinement to stone column enabling a stiffer and stronger response. Ranjan Mohapatra et al. [2] studied the behavior of geosynthetic-encased granular columns (EGC) under vertical loads. The main objective of this paper is to quantify the effect of encasement on the lateral load capacity of EGCs. Several direct shear tests are performed on granular columns with and without encasement in a shear box having plan dimensions of 305 x 305 mm. The results from these tests are discussed in terms of the increase in the shear strength due to geosynthetic encasement and the strength envelopes for understanding the influence of the encasement. Siva Gowri Prasad et al. [3] investigated on floating stone columns reinforced with geotextile with different encasement lengths of D, 2D, 3D, 4D and concluded that the load carrying capacity increases by replacing the stone aggregate with silica-manganese slag and also with reinforcement length of 4D. Mahmoud Ghazavi et al. [4] studied the ultimate load carried by soft soil increase by using ordinary stone columns (OSCS) and concluded that the ultimate load and stiffness of the treated soil can be further increased by use of vertical encased stone columns (VESCS). Yoo et al. [5] have conducted full-scale load tests on isolated geogrid-encased stone column (GESC) to investigate the effect of encasement, settlement response and bulging of conventional stone column. This study shows that the additional lateral confinement to the encased columns prevents the radial column failure and the performance of the geogrid-encased column can be assessed. Ali et al. [6] carried out the tests on long floating and end-bearing single and groups of columns with and without reinforcement to evaluate the relative improvement in the failure stress of the composite ground due to different types of reinforcement and concluded that the bulging may be reduced to a great extent by reinforcing the columns either by encasing them with geosynthetics or by placing horizontal circular discs of geo-synthetics within the columns at regular interval. Yang et al. [7] studied the bearing mechanism of geo-synthetic-encased stone column composite ground, using large-scale model tests and the effects of geo-synthetic encasements of different lengths. Based on the model tests, the stress concentration ratio of the column, bearing capacity of composite ground, column deformation, axial and radial stresses of the columns, and failure modes of composite ground improved by different columns were analysed. The results show that fully-encased stone column composite ground has a higher bearing capacity and have a higher stress concentration ratio. Gandhi et al. [8] evaluated the behavior of stone column by varying the spacing, shear strength of soft clay, moisture content and the test results indicate that the failure is by bulging of the column with maximum bulging at 0.5 to 1 times the column diameter below the top. Marina Miranda et al. [9] studied the influence of the geotextile encasement on the behavior of soft soils improved with fully penetrating encased columns. This influence is analyzed by means of measuring soil column stress distribution, pore pressures and soil deformation during the consolidation process. For this purpose, a horizontal slice of a representative "unit cell" has been analyzed by means of small-scale laboratory tests. Finally the settlement reduction factor is around 0.6 when the soil is treated with encased columns and 0.8 for soil with non-encased columns. Malekpoor et al. [10] studied the behavior of compacted lime-soil (CL-S) rigid stone column in soil and concluded that CL-S column increase the load carrying capacity and reduces the settlements of soft soil. Mohamed et al. [11] have done the investigations on lime treated soft clay soil from Idku City, Egypt, where high organic matters of about 14% exist. Lime was added in the order of 1%, 3%, 5% and 7% by weight and laboratory experiments have conducted after 7, 15, 30 and 60 days including the mineralogical and microstructural examinations. The results indicate that soft clay soil of high organic content of 14% can be stabilized satisfactorily with the addition of 7%lime. Maki et al. [12] studied the group efficiency of 16 model stone and lime columns installed in soft clay consist of 2, 3 and 4 columns. The results illustrated that the group efficiency decreases with increasing the number of stone columns, also the stone columns provided higher efficiency than lime columns in the soil of shear strength (cu= 8 kPa), but the lime columns provided higher efficiency than stone columns in soil of cu= 14 kPa. Mansoor Khan et al. [13] investigated the effects of floating columns in clayey soil with silty deposits by developing small scale laboratory models. A comparison is made among lime and granular columns whereby the results of the treated ground are compared to the untreated ground. The effects of granular/lime columns on soils of different shear strengths (low-medium- high) and slenderness ratio (L/D) of columns are investigated. Based on the results, it is concluded that the granular columns gave higher strength than lime columns in the soil of low shear strength, whereas the lime columns gave more strength than granular columns in soil of higher shear strength. In this present study, soft marine clay is improved by using the stone columns of silica-manganese slag and lime soil columns.

2. MATERIALS & PROPERTIES

Basic materials used for this study are Marine clay, Silica-Manganese slag, lime, clayey silt, Sand, Geotextile. Marine clay is collected from Visakhapatnam port trust. The soil is highly compressible inorganic clay and need to be improved. The properties of marine clay are given below. Clayey silt sample is collected from Rajam, Srikakulam (Dist.) Andhra Pradesh, India. The soil sample is collected at a depth of 2m from the ground surface. The particle passing through 4.75mm IS Sieve is used in this study. The properties of marine clay and clayey silt are given in Table 1

Table 1 Properties of Marine clay and clayey silt

S.NO	Property of soil	Value	
		Marine clay	Clayey silt
1	Gravel	0	2 %
2	Sand	15	34 %
3	Silt & clay	85	64%
4	Liquid limit (W_L)	61.5%	45%

5	Plastic limit (W_p)	20.78	20.8%
6	Plasticity Index (I_p)	40.72	24.2%
7	Optimum Moisture Content (OMC)	27%	17.2%
8	Maximum Dry Density (MDD)	1.47 g/cc	17.52 kN/m^3
9	Specific gravity	2.5	2.65
10	Shear strength	12.5kPa	22 kPa

Lime is used as stabilizing material to increase the strength, durability and compressibility of the soil as well as decreases the plasticity index and swell potential of the soil.

Silica-Manganese slag is used as the stone column material, which is produced during the primary stage of steel production. It is collected from Sri Mahalaxmi Smelters (Pvt.) Limited near Vijayanagaram and the aggregates of sizes between 4.75 mm and 6.75 mm have been taken for the present study. The properties of Silica-Manganese slag are given in Table 2.

Table 2 Physical properties of Silica-Manganese slag

Property	**Value**
Specific Gravity	2.82
Water absorption (%)	0.7
Density (g/cc)	1.54

Compaction tests has been done for different properties of soil and lime and 10% lime is selected for mixing to the soil where we got the maximum dry density. The compaction test results for different lime proportions are shown in the Figure 3.

Table 3 OMC and MDD for Soil with different Lime proportions

Proportion of Lime in %	**OMC (%)**	**MDD (kN/m^3)**
8	20	1.61
10	25	1.78
15	20	1.65
20	25	1.56

Sand is used to fill the air voids between the aggregates in stone column and also used as a blanket of 20mm thickness on the clay bed. This sand is sieved from 4.75mm sieve. This is clean river sand collected from Nagavali river.

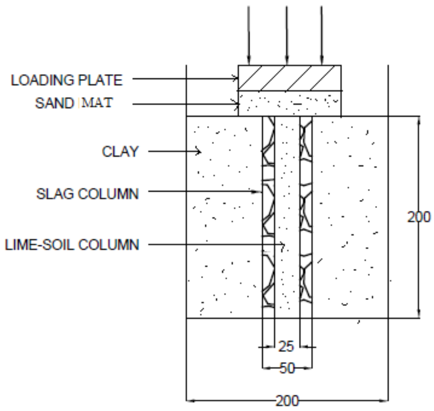
Geotextile is used as the reinforcing material for encasing the stone column and is collected from Ayyappa Geo-textile installers, Vishakhapatnam. This sheet is stitched to form the tube for encasing the stone column. Mass of the geotextile is 100g/m^2 and Tensile strength is 4.5kN/m.

3. EXPERIMENTAL STUDY

Model tests are conducted on Clay bed, Plain stone column with Lime Soil (LS column), combined Slag + Sand column and Lime-Soil column (LS+SG) and a series of reinforced LS+SG column. The reinforcement is provided with geotextile with different encasement lengths of D, 2D, 3D and 4D. The air dried and pulverized clay sample was mixed with required quantity of water. The moisture content (44%) required for desired unconfined compressive strength of 12.5kPa was determined by conducting several vane shear tests on cylindrical specimen of 76mm height and 38mm depth. Slag and Sand are used as the stone column material in proportions of 60:40. The proportion of Slag and Sand are selected such that the voids in the aggregates (40%) are filled with the Sand. The complete test setup and schematic diagram of loading frame with a typical stone column diagram is shown in Fig.1 and a different mode of application of reinforcement is shown in Fig. 2.

3.1. Preparation of Soft Clay Bed

The air dried and pulverized clay sample is taken and it is mixed with required water content of 44%. The clay is thoroughly mixed to a consistent paste and is filled in the tank in 50 mm thick layers to the desired height (H) of 200mm by hand compaction such that no air voids are left in the soil. Before soil is filled in to the tank, the silicon grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. After compaction of clay bed, it was covered with wet gunny cloth and left for 24 hours for moisture equalization and was tested.



1(a)   1(b)

Figure 1(a) Test setup with loading   **Figure 1(b)** Schematic diagram of loading frame

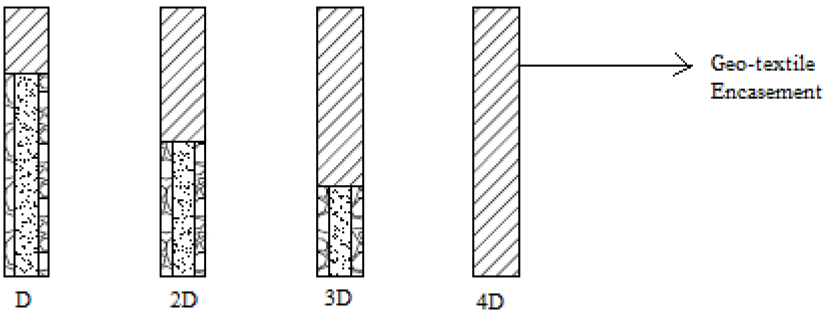


Figure 2 Different modes of application of reinforcement for encasement lengths of D, 2D, 3D, 4D

3.2. Construction of Plain Lime Soil (LS) Column

Before construction of column, grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. A PVC pipe of outer diameter 50 mm and 1 mm thick was placed at properly marked center of the tank. Before placing the pipe, grease is applied to the inner and outer surface. Around this pipe, clay bed was then filled in the tank in

50 mm thick layers to the desired height of 200mm by hand compaction such that no air voids are left in the soil. The lime soil column was casted in steps by compacting the lime soil column material by using a 5 mm diameter steel rod with 30 blows from a height of fall of 100 mm. After compaction of each layer the pipe is lifted such that there will be 5mm overlap between the two layers and withdrawing the casing pipe simultaneously for every 50 mm of depth along the length of column. After completion of construction of lime soil column it is covered with polythene cover for 24 hours to develop proper bonding between the lime soil and the soft soil.

3.3. Construction of LS+SG Column

Before construction of stone column, grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. A Perspex pipe of outer diameter 50 mm and 1 mm thick was placed at properly marked center of the tank and hallow pipe of outer diameter 25 mm and 1 mm thick was placed with in the 50 mm diameter pipe at marked center. Before placing the pipes, grease is applied to the outer and inner surfaces. Around 50mm diameter pipe, clay bed was then filled in the tank in 50 mm thick layers to the desired height of 200mm by hand compaction such that no air voids are left in the soil. The stone column was casted in 50mm thick layers in the two pipes (50mm & 25mm) by compacting the stone column material by using a 5 mm diameter steel rod with 15 blows from a height of fall of 100 mm. After compacting the initial 50mm layer in the two pipes (50mm & 25mm), the outer 50mm diameter pipe is raised slowly to a height so that there will be 5mm overlap between two layers. Slag is poured in the 50mm diameter pipe and compacted to a depth of 50mm. The inner 25mm diameter pipe is then raised to a height so that there will be 5mm overlap between the inner lime-soil layer and pipe and filled with another 50mm layer in the 25mm diameter pipe with lime soil and compacted. The same process of construction of slag column and soil-lime column was repeated up to 200mm length. After completion of construction of the column, it is left covered with polythene cover for 24 hours to develop proper bonding between the lime soil and the soft soil.

3.4. Construction of Stone Column with Geotextile Encasement

Before construction of stone column, grease is applied in the inner surface of the tank for reducing the friction between the soil and the tank. A PVC pipe of outer diameter 50 mm and 1mm thick was placed at properly marked center of the tank after applying the grease to the outer surface around this pipe. Clay bed was then filled in the tank in 50 mm thick layers to the desired height of 200mm by hand compaction such that no air voids are left in the soil. For construction of fully reinforced (4D) stone column, the pipe is reinforced with geotextile and placed at the center of the cylinder and the above procedure was followed for construction of the stone column and the lime - soil column. For constructing the stone column reinforced for length of 3D, the process of compacting the stone column is continued up to the remaining unreinforced length of D and the pipe is taken out. The pipe is encased with the geo-textile for a length of 3D and the pipe is placed in position and then the stone column is casted in steps of 50mm layers similar to the construction of unreinforced stone column. For the other reinforced lengths of D, 2D the same procedure is followed. After completion of construction of stone column, it is left covered with polythene cover for 24 hours to develop thixotropic gain.

3.5. Clay Bed/Stone Column Testing

The Clay bed/Stone column to be tested is taken and a sand blanket of 20 mm thick was laid on the surface of clay bed. A steel circular disc of 12 mm thick and having diameter of 100 mm which is double the diameter of stone column is placed at center of the bed and is subjected to strain controlled compression loading in a conventional loading frame at a rate of settlement of 0.24 mm/min. For every 1mm settlement, corresponding loads are noted up to 20 mm settlement.

3.6. Post Test Analysis

After completion of the test, the stone aggregates were carefully taken out and a thin paste of Plaster of Paris was poured into the hole to get the deformed shape of the column and kept it for 24 hours. The soil outside the stone column was carefully removed and the hardened Plaster of Paris is taken out and the deformation properties are studied.

4. RESULTS AND DISCUSSIONS

Tests were conducted on Plain Clay bed, LS column, LS+SG column, reinforced LS+SG column for an encasement length of D, 2D, 3D, and 4D. The Load carrying capacity & settlement is determined by drawing a double tangent to Load - Settlement curve. Fig. 3 shows the Load-Settlement curves of Clay bed and Stone columns having different encasement lengths.

The ultimate load carrying capacity of the LS column and LS+SG column have been increased by 11% and 93% respectively as compared with clay bed. The load carrying capacity of the SG+SL column have been increased by 5%, 12%, 19%, 28% by reinforcing with the encasement lengths of D, 2D, 3D and 4D respectively.

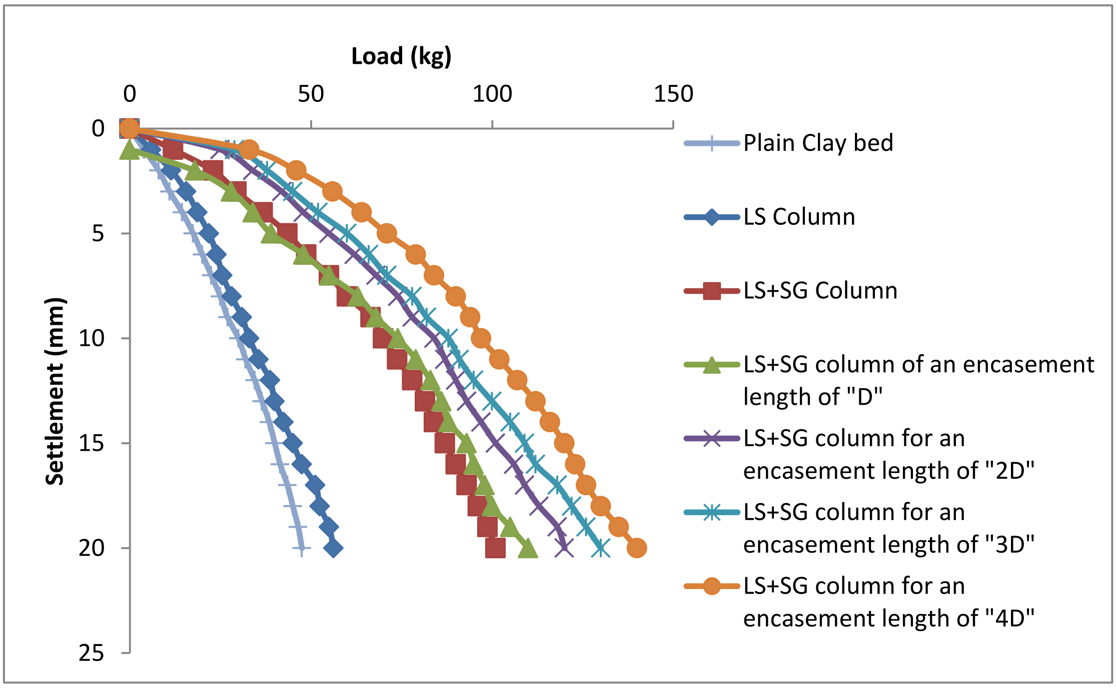


Figure 3 Load-Settlement curves of Clay bed and Stone columns having different encasement lengths

4.1. Bulging Analysis

When the clay bed is improved with plain LS column, (LS+SG) column, the maximum bulging of 11.2mm, 8.5mm occurs respectively and is found at the middle of the stone column.

When the stone column is reinforced with different encasement lengths of D, 2D, 3D & 4D, the maximum bulging of 7.4mm, 3.9mm, 3.4mm and 1.9mm were found respectively and the bulging occurs at depth just below the reinforcement depth. When stone column is loaded in soft soil, bulging occurs due to lack of confinement. Fig. 4 shows the bulging of deformed stone columns of different encasement lengths and Fig.5 shows the deformations of different stone columns.

Figure 4 Bulging of Stone column for LS column, SG+LS column, Reinforced LS+SG columns with encasement lengths of D, 2D, 3D and 4D respectively

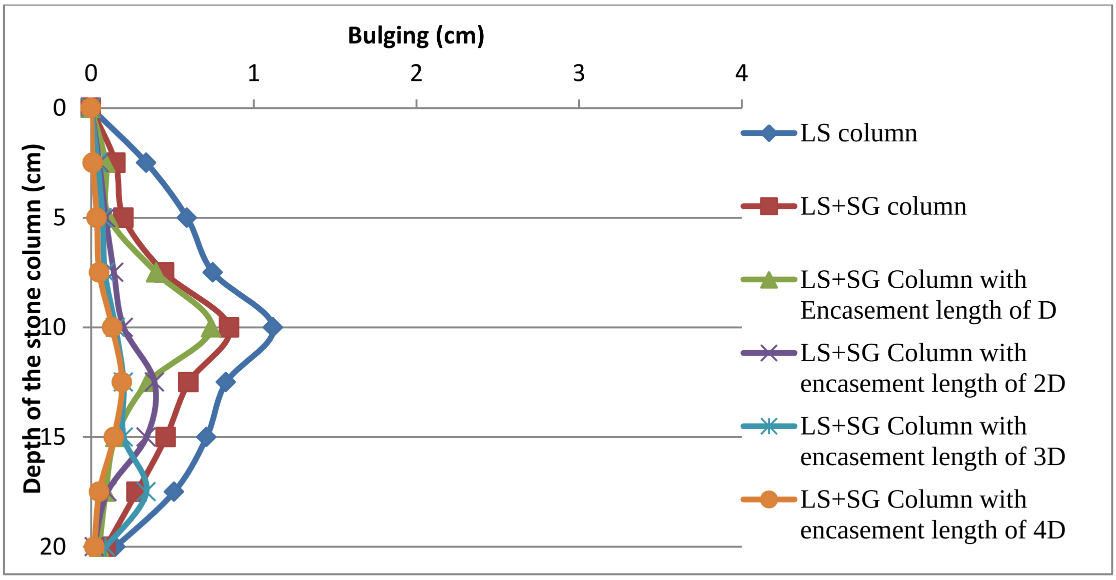


Figure 5 Deformations of unreinforced and reinforced stone columns

5. CONCLUSIONS

From the above experimental studies following conclusions are drawn

- The load carrying capacity is increased by improving the clay bed with the lime-soil column by 92%.
- Load carrying capacity of the lime-soil column with reinforcement is increased by increasing the reinforcement length from D to 4D by 22%.
- Maximum bulging has been found at half of the length of lime-soil column for unreinforced column and for all reinforced columns, bulging is found just below the reinforcement depth.

- The settlement is decrease with inclusion of lime-soil column and also with the reinforcement. This decrease in settlement for full reinforcement length is about 40% when compared to the plain clay bed.

REFERENCES

[1] Murugesan, S., & Rajagopal, K. (2007). Model tests on geosynthetic-encased stone columns. *Geosynthetics International*, **14**(6), pp. 346-354.

[2] Mohapatra, S. R., Rajagopal, K., & Sharma, J. (2016). Direct shear tests on geosynthetic-encased granular columns. *Geotextiles and Geomembranes*, **44**(3), pp. 396-405.

[3] S. Siva Gowri Prasad, P.V.V. Satyanarayana, B.Anil kumar "Improvement of Marine Clay Performance Using Silica-Manganese Slag Stone Column Reinforced with Geotextile*", International Journal of Engineering Research and Development*, **12**(9), pp. 16-21, October 2011.

[4] Ghazavi, M., & Afshar, J. N. (2013). Bearing capacity of geosynthetic encased stone columns. *Geotextiles and Geomembranes*, 38, pp. 26-36.

[5] Yoo, C., & Lee, D. (2012). Performance of geogrid-encased stone columns in soft ground: full-scale load tests. *Geosynthetics International*, **19**(6), pp. 480-490.

[6] Ali, K., Shahu, J. T., & Sharma, K. G. (2014). Model tests on single and groups of stone columns with different geosynthetic reinforcement arrangement. *Geosynthetics International*, **21**(2), pp. 103-118.

[7] Ou Yang, F., Zhang, J. J., Liao, W. M., Han, J. W., Tang, Y. L., & Bi, J. B. (2016). Characteristics of the stress and deformation of geosynthetic-encased stone column composite ground based on large-scale model tests. *Geosynthetics International*, pp. 1-13.

[8] Ambily, A. P., & Gandhi, S. R. (2004). Experimental and theoretical evaluation of stone column in soft clay. Evaluation of Stone Column in Soft Clay, pp. 1-6.

[9] Miranda, M., Da Costa, A., Castro, J., & Sagaseta, C. (2017). Influence of geotextile encasement on the behaviour of stone columns: *Laboratory study*. *Geotextiles and Geomembranes*, **45**(1), pp. 14-22.

[10] Malekpoor, M. R., & Poorebrahim, G. R. (2013). Behavior of Compacted Lime-soil Columns. International Journal of Engineering-Transactions B: Applications, **27**(2), 315.

[11] Sakr, M. A., Shahin, M. A., & Metwally, Y. M. (2009). Utilization of lime for stabilizing soft clay soil of high organic content. Geotechnical and Geological Engineering, **27**(1), 105.

[12] Maki J., Mohammed Al-Waily (2012). Laboratory Investigation on Efficiency of Models Stone and Lime Column Groups. Journal of Kerbala University, **10** (4), 268.

[13] Mansoor Khan., Shabir Hussain (2016). A Comparative Study of Ground Improvement by Lime and Granular Columns. 8th International Civil Engineering Congress (ICEC), pp. 23-24.

[14] H. K. Sarvaiya and C. H. Solanki, A Study on Effect of Length of Geosynthetic Encasement Material On Floating Stone Column, International Journal of Civil Engineering and Technology, 8(6), 2017, pp. 977–985.

[15] H. K. Sarvaiya and C. H. Solanki, A Study on Effects of Geosynthetic Encasement on Floating Stone Column. International Journal of Civil Engineering and Technology, 8(1), 2017, pp. 891–899.