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Effect of Grouted Granular Column on the Load Carrying Capacity of the Expansive soil

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Abstract: ***Due to the scarcity of land for the construction of industrial, commercial, and transportation structures for development in urban areas, it is very necessary to use the places which have weak strata. This has become very mandatory to use the land which has poor engineering properties due to the unavailability of land. In the recent years granular columns have come under the extensive use for increasing the load carrying capacity and reducing the settlement in the expansive soil and loose sand. Nowadays to increase the stability of the foundation, granular columns are being widely used. Traditional columns are driven into the weak expansive soil stratum and maintain its stability from lateral confinement, which is generally due to the reaction from the surrounding stiffened expansive soil. However, this is not so easy to support loose soil, an additional lateral support may have to be provided to stabilize it and reduce its settlements. This study aims to overcome this weakness in soil by wrapping the granular column in geotextile layer to enhance the lateral reinforcement. In the present paper the discussion is about the variation in load carrying capacity and settlement characteristics of granular column (made up of cement fly ash and sand in a definite proportion instead of aggregates and stones) and analyzing its effect on the expansive soil by comparing its results with geotextile encased columns. In this process the study investigates the improvement of load carrying capacity of a single granular column encased with geotextile through model test.***

Keywords : Granular column; Geotextile; Expansive soil; Laboratory *Model*.

I. INTRODUCTION

Granular column is a vastly suitable technique to upgrade the poor engineering properties of ground stratum. It is generally designed to carry vertical loads imposed by the structure. It is also used to increase the strength of foundation soil or projected earth structures to provide the modified performance of weak strata under different loading conditions. In new project this is very common to utilize ground which has poor subsurface conditions to render the conditions which are formerly not allowing the project to be economically justifiable and technically feasible to carry on. Granular columns are one of them.

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Construction of these columns generally consists of water-jetting a vibrofloat into the soft clay layer to make a circular hole that extends through the loose strata to firmer soil. The hole is then filled with an imported gravel or mix to increase the bearing capacity of soil. The granular columns tend to reduce the settlement of foundations at allowable loads. Stability of these column depends on so many factors such as relative compaction of column material, confining pressure offered by surrounding soil, stress concentration ratio, loading condition, stress history of soil, gradation of column material, spacing between the columns, dimensions of granular column etc. Diameter of granular column can vary from 300 mm to 1000 mm and length can be up to 10m. In the present paper, we have discussed the variation in load capacity and the settlement behavior of granular column with intruding grouted mix inside the column instead of aggregates and stones. By stability, we are actually dealing with the load carrying capacity of the soil by comparing its result by encased column. Confining pressure offered by the soil depends on the strength of the soil.

II. OBJECTIVES

- To modify the properties of expansive soil by installing the grouted granular column made up of cement, sand, fly ash.
- To study the change in load carrying capacity of soil by installation of grouted granular column and also to find the variation of its load settlement behaviour if encased with geotextile.
- To establish a comparison between settlement behaviour of grouted granular column.

In order to perform the study literatures have been surveyed which are reflected below.

III. LITERATURE SURVEY

In this present study the literature on the granular piles/stone columns on weak soil is studied and presented in the following paragraphs. In order to increase the stiffness of granular column geo-textile encasement plays a major role, which prevent loss of mixture in nearby soft soil and it also helps in maintaining the drainage and frictional properties upto the acceptable limit as determined by the various numerical and experimental studies. Sharma et al. (2004)[21] performed tests to examine the effect of geogrid reinforced on the bearing capacity of granular piles in soft clay. They found that there is a improvement in the capacity of geogrid reinforcement and also in the engineering behaviour of the soil with the increase in the geogrids. Bulging length and diameter of the column also decreases due to the reinforcement.

This studies estimate that stress required for 3mm settlement is increased by 100 % when soil bed is reinforced with granular pile, bulge length and diameter of the pile also decreases by significant amount. Dimiter et al. (2005) [1]they provide a method to support the column laterally and which also provide the increased bearing capacity to the soil that is geosynthetic encased column, which confines the compacted granular and stone columns therefore increasing its bearing capacity and compressibility even in extremely weak stratum. Lee et al. (2007) analysed that when load is applied at the top surface of the granular column this results in deformation which is frequently followed by lateral expansion at the top surface of the column. Thus the volume of column changes and the lateral deformation in the granular column will vary under the effect of the vertical loads. The lateral support which is provided by the soil present around the column affects the total performance of the column. The support provided by the soil surrounding the column increases as the depth increases, but at the top of the column bulging failure is the most general mechanism for column failure. Khabbazian et al.(2015)[12] also suggested the same results. Zhng and Zhao (2012)[17] verified the method of installation of stone column by comparing it with two different solutions. They conducted studies to examine the changes due to effect of applied stress, geotextile encasement and spacing between the column and diameter. Settlement analysis made by specified procedure was compared by the values observed by field tests in which a good correlation was observed to establish a bond between encased and non-encased columns. They found the result that a reduction in the bulging and settlement of the column due to the high stiffness of geotextile encasement. Therefore, while designing the granular column stiffness of geotextile is considered with respect to diameter and spacing of columns because diameter and spacing of column have a huge impact on the settlement reduction. Miranda et al. (2016)[15] conducted three tests first one with non-encased column and rest two with different geo textile encasements. They observed the increased in vertical stress carried by encased column is 1.7 times of the non-encased column. stress concentration factor in encased column is also increased by 2 to 4 times the non-encased column. They also determine settlement reduction factor as 0.58, 0.62 and 0.77 for geo-textile and non-encased column respectively. Harish et al. (2016) they performed a laboratory model test on the single embedded column with and without encasement of geotextiles on different grades of expansive soil by investigating the variations in the single stone column by simultaneously varying its diameter and length. They studied the number of encasement provided for embedded depths and also the effect of encased reinforced dust. Conclusions were made depending on load improvement ratio and settlement reduction factors, and results obtained support that the intrusion of quarry dust increases the load capacity and also reduces settlement on the basis of which load settlement characteristics were investigated. For materials used in the granular column like fly ash the mechanism of reaction is totally based on these factors which was determined by Chaturvedi and Sahu (2017) [3]based on reviews they concluded that properties which influence the fly ash mechanism are effect of fine powder, pozzolanic reaction within the mix, effect due to dilution, growth in gel surface area, upgrade in the gel structure For type of fly ash these factor can function either singularly or in combined form depending on the quantity of addition. By substituting the portion of OPC by fly ash reduces the total amount of C_3A present in the mortar mixes. This reduction is termed as the dilution effect and the same become exceptional when addition of fly ash is more than the endurance limit in the technique. The other mechanism which affects the behaviour of mortar is due to the increase of sulphate resistance by pozzolanic effect. Therefore due to this pozzolanic reaction between $Ca(OH)_2$ (a byproduct of OPC hydration) a C-S-H binder matrix formation takes place as a result mortar becomes denser and stronger in addition. Sambhaji and Harihar (2018)[20]conducted a study of cemented porous material to improve the soft clay, they considered two cases one is of bulb formation at the bottom of stone column and the other one at an intermediate level of depth which is equal to 5 times its diameter which involves load tests of six unit cells in laboratory which consists of bulb cemented stone columns, they concluded that under reamed cement column were extremely effectual in enhancing the load capacity and soft clay stiffness. Kolathayar et al.(2019)[13] they studied the effect of coir geocells and high density polyethylene on the load capacity of sand bed both reinforced and unreinforced with these two materials by conducting a model test tank in the laboratory after performing various plate load tests at the system. They found that the load carrying capacity of coir reinforced system was 2 times more than the high density polyethylene geocell reinforced system. They also obtained a sustainable result for the fill material seashell with respect to sand and estimated that the mixture of 20% seashell with 80% sand gives a maximum bearing capacity.

IV. METHODOLOGY

There are three types of materials which have been used in this experiment. Expansive soil, column materials (fly ash, sand, cement) and geotextile. To find the engineering and index properties, Tests have been conducted on these materials are listed below

A. Expansive Soil

The soil which is used in present work has been transported to DTU laboratory from Obaidullaganj, Raisen district of Bhopal. The soil has been extracted from 100cm from the ground surface to eliminate the surface impurities. To achieve cohesive soil free from any impurities, it was sieved through IS 4.75mm, sieve. Visually soil can be classified as fine grained soil which is grey in color and very hard in dry state. Following tests were performed according to the code of practice to obtain the basic properties of soil.

- Liquid limit (IS: 2720,part V-1985)[10]
- Plastic limit (IS: 2720, part V- 1985)[10]
- Specific Gravity(IS: 2720,part IV/sec-I-1980 for fine grained soil)[8]
- Shrinkage limit (IS: 2720,part VI-1972)
- Standard proctor test (light compaction)(IS: 2720, part VII -1980)[11]
- Sieve analysis (IS:2720,part IV-1985 method)[9]

Table I. Physical Properties of Expansive soil

Parameter	value
Liquid Limit (%)	56.69
Plastic Limit (%)	27.06
Plasticity Index (%)	29.63
Specific Gravity	2.52
Shrinkage Limit (%)	10
Maximum Dry Density(KN/m^3)	16.2
(OMC),%	16
Classification of Soil	CH

B. Cement

Cement used in this project is ordinary Portland cement which fulfils the requirement of IS: 12269-53, grade which is obtained from high quality clinker ground with high purity gypsum.

Table II. Properties of Cement

Parameter	Value
Consistency of cement (%)	34.75
Initial setting time (min)	30
Final setting time (hrs)	10
Compressive Strength (KN/m^2)	33
Specific Gravity	3.15

C. Sand

For this project Yamuna sand was taken which was present in the concrete laboratory of Delhi Technological University at the time of experiment and its properties were evaluated by performing different tests in the laboratory which are given below. Sieve analysis is a method used to evaluate the grain size distribution of the granular material by allowing them to pass through a number of sieves of continuously smaller size and weighing the material that is retained on each sieve as a fraction of total mass of the material used.

Table III. Properties of Sand

Properties	Value
C_U	2.48
C_C	1.033
Specific Gravity	2.66

D. Fly ash

Fly ash used in this test was obtained from India Mart, all the properties of fly ash given is as per their specification. Fly ash is a byproduct generated in electric power industries from burning of pulverized coal. Fly ash, sand and cement were used to fill the stone column. Strength of granular column also depends on the type of material used and its constituents. Due to the pozzolanic reaction between Ca $(OH)_2$ (a byproduct of OPC hydration) a C-S-H binder matrix formation takes place as a result mortar becomes denser and stronger in addition.

Table IV. Constituents of Fly ash

Constituents of PFA	Value
SiO_2	48%
Al_2O_3	26%
Ca O	2.5%
Mg O	1.5%
Fe_2O_3	9%
Relative Density	2.2-2.8

E. Geotextile

Geotextile used in this test is obtained from India Mart, which is black in color of about 5mm thickness, made up of polypropylene. The texture of geotextile and its basic properties is as per the India Mart norms from where geotextile has been bought.

Table V. Properties of Geotextile

Parameter	Value
Tensile modulus of geotextile (J),KN/m	2300
Thickness of geotextile(t_g), mm	5

Sample preparation for granular column:

Three samples of cement, fly ash, and sand were prepared in ratio of 1:3 in total of nine specimen of cube (70.06*70.06*70.06) mm mould. One ratio consists of both cement and fly ash combined with three ratios of sand. Water content = (P/4 + 3), where P is the consistency of cement. All the above material is mix thoroughly and with the help of vibrating machine all the cube mould was filled with one ratio of cement and fly ash was taken with three ratio of sand along with water to prepare the mould. Fly ash is added in the sample to make the stabilization of soil economical and durable. After the preparation of granular column samples these cubes are kept for curing for 7 days which almost gives 65% of its total strength and this strength will automatically increase because soil with granular column is having 35% moisture content before its installation. Again after 7 days the cube samples have been tested in compression testing machine and the following data were calculated.

Table VI. Granular Column Sample Preparation

S.N.	Proportion (Cement and fly ash)	Load (N)	Area (mm^2)	Compressive strength (KN/mm^2)
Sample 1	40%cement + 60% fly ash	7.92	4900	1.62
Sample 2	50%cement + 50% fly ash	8.67	4900	1.76
Sample 3	60%cement + 40% fly ash	10.75	4900	2.19

In this project we have used sample 2 because its compressive strength was in range and the percentage of cement get also reduced for economy point of view this sample is best suited.

Actual compressive strength of the virgin soil at OMC is = 0.45 KN/mm^2

Combined properties of granular column:

Materials used in granular column are sand, cement, fly ash by percentage 75, 12.5, 12.5 and specific gravity 2.66, 3.15, 2.5 respectively. Specific gravity of granular column can be calculated by using the formula:

$$G_s = \frac{(P_S + P_C + P_F)}{[P_S/G_S + P_C/G_C + P_F/G_F]}$$

Where: P_S, P_C, P_F = percent by mass of sand, cement and fly ash respectively.

G_S, G_C, G_F = bulk specific gravity of each material.

Hence, the combined specific gravity of granular column is coming out to be 2.69.

Tank Preparation: A wooden tank with dimensions 45cm*45cm*45cm was used to conduct this experiment. Plastic covering was done on the inner walls of the tank so that the effect due to friction between soil and tank's wall can be neglected. Soil was sieved through IS 4.75mm size in order to get desirable cohesive soil free from grass and coarse aggregates. Some water was added by weight to the soil and it is make sure that water should mix with the soil homogeneously. Then, this tank was filled by soil in 5 layers and each layer was given 25 blows of standard proctor hammer. After preparation of tank, known amount of load was applied on the soil to determine its load settlement characteristics and from the result obtained a graph is plotted to determine the load capacity of expansive soil. This procedure was repeated three times with different conditions.

Granular Column Installation: Stone column prepared has a diameter of 3 inches (7.62 cm) and depth of 30cm and is a floating stone column. IS 15284 (Part I): 2003[6] recommended that, "to ensure bulging failure, length of stone column should be more than its critical length (= 4 times its diameter)". That is why to ensure bulging failure, length of stone column is taken 30 cm. A steel casing of outer diameter 3 inches and length 15 inches was used to make a bore hole in the soil. Test tank was filled with soil sample by maintaining its lowest density. After making the bore hole, granular column material is poured into the hole with the help of a cone made with paper and compacted to achieve sufficient stiffness.

Pouring of material and pulling out of casing was done simultaneously. A circular model footing of diameter 120mm was placed exactly on the centre of stone column to avoid eccentric loading. Load was applied on the footing simultaneously with the aid of gravimetric loading in which known amount of load is applied on the footing to calculate the settlement in the footing. Two dial gauges are fixed on the footing to calculate the settlement by calculating their average settlement for better accuracy. For different column material the above procedure is repeated till the variations in the load versus settlement is calculated.

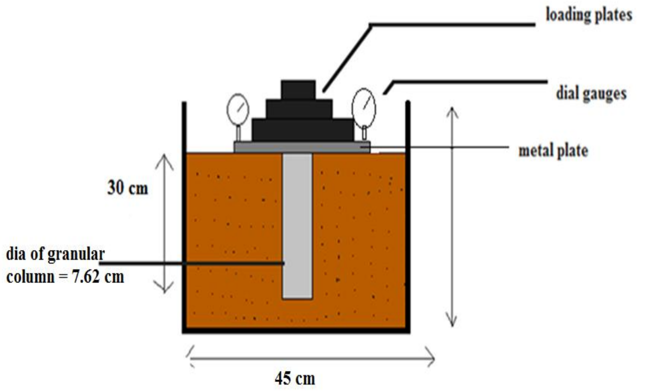

Fig. 1. Schematic diagram of the loading arrangement

Load application; A circular metal plate of diameter 12cm was placed over the granular column and two dial gauges were fixed at the two diagonal corners of the plate to calculate the average settlement for more accuracy. Thickness of the metal plate should be sufficient so that it can be able to handle the load which it going to experience. Loading was applied gravimetrically through the metal plate on the granular column. As per IS 15284 part I [6], if stone column settles more than 10 mm, it is assumed as failure of granular column and load experienced by the stone column at 10 mm settlement is said to be bearing Capacity of granular column. Loading should be applied until the value of settlement exceeds 15 mm.

Experimental Procedure: First of all, test tank was prepared as per the directions given above. One sample of soil was taken for determination of compressive strength of soil as well. After that, granular column was installed as per the instructions given above. A circular metal plate of sufficient thickness was put over the granular column. This circular plate represents the footing at actual site and used to distribute the loading between granular column and surrounding soil. Loading was applied gravimetrically by putting metal plates and concrete cubes of known weight on the metal plate. Settlement was recorded by the two dial gauges placed diagonally on the metal plate. Average value of dial gauges was used as settlement value. Loading was applied till 15 mm settlement. Load at 10 mm settlement is known as load carrying capacity of the stone column. This entire procedure was repeated three times with different conditions such as load carrying capacity of soil without column, load carrying capacity of soil with column, bearing capacity of soil with column encased with geotextile and the observations are given below.

Fig.2. Loading weights

The settlement and bearing capacity of column is calculated by conducting three experiments on the same soil by changing the fill conditions.

As per IS 15284 (part I)[6]settlement value more than 10 mm is considered as failure of granular column and load applied on stone column at 10 mm settlement is known as load carrying capacity of the granular column.

After preparing experimental setup, loading was applied gravimetrically in the form of weighing plates. Settlement was calculated using two dial gauges. Average value of two dial gauges has been taken. Loading was applied for not less than 10 mm settlement, say 14mm to 15mm settlement.

Fig.3. Expansive soil with granular column

Fig. 4.Overall laboratory setup

V. RESULTS AND DISCUSSION

In actual way load is shared between the soil and granular column. These are the results obtained. As the load is increasing settlement in the soil is also increasing. Settlement is recorded upto 15mm but the failure is estimated at 10 mm as per IS standard.

Table.VII. Load settlement calculation of soil without granular column

S.N.	Load(N)	Settlement(mm)
1	0	0
2	60.23	-0.5
3	130.74	-1.25
4	180.52	-2.12
5	300	-4.75
6	399.65	-7.2
7	445.2	-8.4
8	481.88	-10.25
9	481.88	-12.0
10	481.88	-15.05

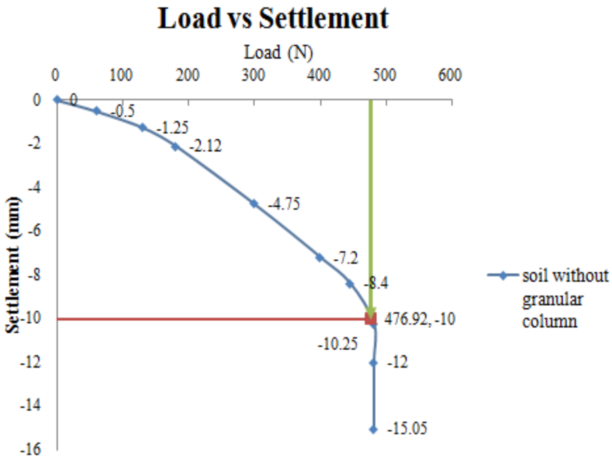

Fig.5. Load versus settlement of soil without stone column

As the load is increasing settlement in the soil is also increasing. Settlement is recorded upto 15mm but the failure is estimated at 10 mm as per IS standard.

Table. VIII .Load Settlement Calculation of column encased with geotextile

S.N.	Load(N)	Settlement(mm)
1	0	0
2	60.23	-0.45
3	150.86	-1
4	403.87	-2.5
5	542.85	-3.25
6	670.79	-4.47
7	865.45	-7.23
8	980.52	-8.49
9	1286.13	-9.55
10	1398.35	-10.24
11	1575.28	-12.95
12	1575.28	-13.85
13	1575.28	-15.28

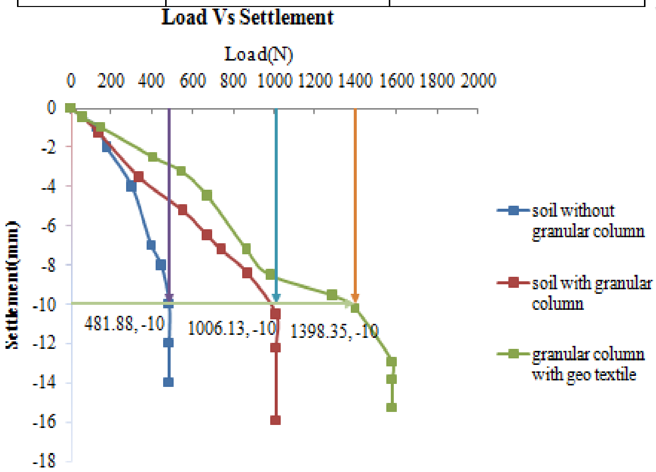

Fig.6. Comparison curve of Load versus settlement under different conditions

Load carrying capacity offered by the soil is directly proportional to the strength of the granular fill inside the column. A graph between load and settlement has been already shown above.

Variation of load carrying capacity due to change in different fill conditions is shown in the graph. Influence on the settlement due to the material used in the column on the load carrying capacity can be predicted from the graph.

As per IS 15284 part I[6], load carrying capacity of granular column is the load required for 10 mm settlement. Test has been conducted on three samples with soil without stone column ,soil with granular column, soil with geo textile wrapped granular column, load experienced by granular column at 10 mm settlement is given below. It can be seen from the table that load carrying capacity of soil increases if granular column is provided with encasement in expansive soil.These results shows that geotextile encasement have increases the load carrying capacity of soil and reduces the settlement.The load carrying capacity of all the three specimens along with their improvement percentage have been tabulated below:

Table.IX. Load carrying capacity of granular column

Types of column	Load carrying capacity at 10mm settlement (KN/mm^2)	Improvement (%)
Soil without column	42.190	-
Soil with column	86.150	104.19
Soil with column encased with geotextile	120.25	185.02

From the above results it can be said that settlement of the footing occurs due to the settlement of circular plate, which may be due to destruction of soil generated under the pressure bulb beneath the plate. The load carrying capacity of the expansive soil reinforced with granular column is higher as compare to that of the compacted expansive soil alone. This is due to the inclusion of high density grouted granular mix. As a result there is a reduction in the settlement of granular column as compare to that compacted expansive soil alone at any level of simultaneously increasing load.

Effect due to encased granular column was also observed that is the load carrying capacity of encased column is more as compare to the granular column alone, this is due to the fact that as bulging starts in the column all the tensile stresses was being carried by the geotextile encasing which reduces the failure in soil at early age .

VI. CONCLUSION

From the experiments conducted and the graphs shown above, following conclusion can be made.

- There is an improvement of 185.02% in the load carrying capacity of expansive soil by encasing the column with geotextile, and also decrease in the settlement of soil with the intrusion of grouted granular column.
- Using fly ash in granular column have several advantages i.e. it reduces the cost of soil stabilisation and increases the strength by reducing the permeability of the column as well as useful in both ground improvement and environment related problems will be derived as fly ash is a waste generated from electric power plant, produced in large amount which is approximately 7000 tons per day and its disposal is very difficult.
- A mixed failure condition is observed due to the bulging and heaving of surrounding soil during the failure of encased column.
- From this experiment it can be derived as addition of materials in appropriate ratio of fly ash and cement (fly ash more than 40%) result as a strong mixture for granular column, strength of column also depends on the types, amount and proportion in which the materials are being used. However a positive behaviour was showed by the cement when added in higher amount.

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REFERENCES

1. Alexiew, D., Brokemper, D. and Lothspeich, S., 2005. Geotextile encased columns (GEC): load capacity, geotextile selection and pre-design graphs. In Contemporary Issues in Foundation Engineering (pp. 1-14).
2. Ambily, A.P. and Gandhi, S.R., 2007. Behavior of stone columns based on experimental and FEM analysis. Journal of geotechnical and geoenvironmental engineering, 133(4), pp.405-415.
3. Chaturvedi, S.K. and Sahu, A.K., 2017. Performance of Multi blend Cement containing Fly ash, granulated blast furnace Slag and Limestone. International Journal, 12(29), pp.38-45
4. Etezad, M., Hanna, A.M. and Ayadat, T., 2014. Bearing capacity of a group of stone columns in soft soil. International Journal of Geomechanics, 15(2), p.04014043.
5. Hanna, A.M., Etezad, M. and Ayadat, T., 2013. Mode of failure of a group of stone columns in soft soil. International Journal of Geomechanics, 13(1), pp.87-96.
6. IS: 15284 (Part I): 2003. "Design and Construction for Ground Improvement - Guidelines part 1-Stone Columns".
7. IS: 2386 (Part III) – 1963, "Methods of Test For Aggregates For Concrete: Part III - Specific Gravity, Density, Voids, Absorption And Bulking".
8. IS: 2720 (Part IV) – 1980. "Methods of Test For Soils: Part 3 - Determination Of Specific Gravity".
9. IS: 2720 (Part IV) – 1985. "Methods of Test For Soils: Part 4 - Grain Size Analysis".
10. IS: 2720 (Part V) – 1985. "Methods of Test For Soils: Part V - Determination Of Liquid And Plastic Limit".
11. IS: 2720 (Part VII) – 1980. "Methods of Test For Soils: Part VII - Determination Of Water Content, Dry Density Relation Using Light Compaction".
12. Khabbazian, M., Kaliakin, V.N. and Meehan, C.L., 2015. Column supported embankments with geosynthetic encased columns: validity of the unit cell concept. Geotechnical and Geological Engineering, 33(3), pp.425-442.
13. Kolathayar, S., Suja, P., Nair, V., Krishna, S. and Tamilarasi, G., 2019. Performance evaluation of seashell and sand as infill materials in HDPE and coir geocells. Innovative Infrastructure Solutions, 4(1), p.17.
14. Martin, J.P., Collins, R.A., Browning, J.S. and Biehl, F.J., 1990. Properties and use of fly ashes for embankments. Journal of energy engineering, 116(2), pp.71-86.
15. Miranda, M. and Da Costa, A., 2016. Laboratory analysis of encased stone columns. Geotextiles and Geomembranes, 44(3), pp.269-277.
16. Murugesan, S. and Rajagopal, K., 2009. Studies on the behavior of single and group of geosynthetic encased stone columns. Journal of Geotechnical and Geoenvironmental Engineering, 136(1), pp.129-139.
17. Zhang, L., Zhao, M., Shi, C. and Zhao, H., 2012. Settlement calculation of composite foundation reinforced with stone columns. International Journal of Geomechanics, 13(3), pp.248-256.
18. Pulko, B. and Majes, B., 2006. Analytical method for the analysis of stone-columns according to the Rowe dilatancy theory. Acta geotechnica slovenica, 3(1), pp.36-45.

19. Samanta, M., Sawant, V.A. and Ramasamy, G., 2010, December. Ground improvement using displacement type sand piles. In Proceedings of the Indian Geotechnical Conference, Mumbai, India (pp. 629-632).
20. Sambhaji Golait, Y. and Harihar Padade, A., 2018. Enhancement in Effectiveness of Cemented Stone Columns for Soft Clay Ground Improvement by Providing Underreamed Bulbs. International Journal of Geomechanics, 18(11), p.04018149.
21. Sharma, R.S., Kumar, B.P. and Nagendra, G., 2004. Compressive load response of granular piles reinforced with geogrids. Canadian Geotechnical Journal, 41(1), pp.187-192.
22. Zhang, L. and Zhao, M., 2014. Deformation analysis of geotextile-encased stone columns. International Journal of Geomechanics, 15(3), p.04014053.
23. Zhang, L., Zhao, M., Shi, C. and Zhao, H., 2012. Settlement calculation of composite foundation reinforced with stone columns. International Journal of Geomechanics, 13(3), pp.248-256.
24. Zhou, C., Yin, J.H. and Ming, J.P., 2002. Bearing capacity and settlement of weak fly ash ground improved using lime fly ash or stone columns. Canadian Geotechnical Journal, 39(3), pp.585-596.

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