Improvement of Bearing Capacity of Black Cotton Soil Using Stone Column With and Without Encasement of Geosynthetics

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Abstract – *Laboratory model footing tests has been carried out on embedded, single stone columns with and without encasement of geosynthetics of different grades in black cotton soil. Experiments are conducted to find out the effect of encasement and the performance of single column arrangement keeping diameter and length of the stone column varying. The model tests are conducted in a steel cylindrical tank of diameter 250 mm and height of 300mm, the small scale model footing tests are conducted on unreinforced and reinforced black cotton soil. Unreinforced tests are carried out and then reinforced with quarry dust column encasement are conducted. The parameters studied in this study include the number of encased reinforcement (columns) for embedded, depths. The study also evaluated the behavior of encased reinforced quarry dust columns with unreinforcement. Because of serviceability requirement in actual foundation application, the test results are evaluated in terms of the load improvement ratio and the settlement reduction factors (SRF) at two levels of settlement are investigated. The test results showed that the inclusion of quarry dust columns can appreciably improve the load carrying capacity of black cotton soil with reduction in settlement. Load improvement ratio and settlement reduction factor of reinforced black cotton soil are analyzed. Properties such as, behavior of single type of columns and encasement effect on improvement of strength characteristics of black cotton are observed. Load versus settlement response of the stone column and encased stone column are studied in the laboratory.*

***Key Words*: Improvement, Bearing Capacity, Black Cotton Soil, Stone Column, Geosynthetics etc.**

1. INTRODUCTION

The availability of land for the development of commercial, industrial and transportation etc. are scarce particularly in urban areas. This necessitated the use of land, which has weak strata. Due to ever increasing necessity of land, the need to use marginal sites with poor engineering properties has become mandatory. The use of stone columns has proved to be an economical and technically viable ground improvement technique for construction on soft soils. The stone columns are usually designed for carrying vertical loads from the structures.

Ground improvement is the modification of foundation soils or project earth structures to provide better performance under operational loading conditions. Ground improvement methods are used increasingly for new projects to allow utilization of sites with poor subsurface conditions and to allow design and construction of needed projects despite poor subsurface conditions which formerly would have rendered the project economically unjustifiable or technically not feasible. Vibro-Replacement extends the range of soils that can be improved by vibratory methods. This is done either by using the dry or the wet top feed vibrators which are forced into the ground. The aggregates are then allowed to take the place of the displaced soil which exerts a pressure on the surrounding soil hence helping to improve the soil's load bearing capacity.

Improvement of strength and compressibility characteristics of soft and /or loose soil or heterogeneous fill by installation of stone column as load bearing member has been identified as an effective means of ground improvement technique.

Need for engineering ground Improvement arises when a project encounters difficult foundation conditions. Possible alternate solutions are:

- Avoid the particular site.
- Design the planned structure accordingly.
- Use a soft foundation supported by piles.
- Design a very stiff structure which is not damaged by settlements.
- Remove and replace unsuitable soils.
- Attempt to modify the existing ground.

Ground improvement is one of the most applicable methods for improving soil condition and since past to now human kind had pursued ground improvement at site. This method is assessed more useful and economic than other methods. Ground improvement have numerous method and the suitable method is selected according with soil type, bearing condition and structure type.

1.1 Principle of stone column:

The principle of stone column is to replace loose material by compacted stone, together with densification and reduction in compressibility of the surrounding ground to form a composite material. Because the stone columns will deform under applied load, the capacity of the columns depends on the degree of stiffening achieved in the surrounding soil as well as on the internal friction of the columns.

In fine soils the stone columns will act as drainage paths to accelerate the rate of consolidation-proved that the drained water can be dispersed.The improvement of a soft soil with stone or sand columns can be accomplished using various excavation, replacement and compaction techniques. The principal construction methods and typical site conditions where the techniques are used are as follows:

Vibro-Replacement (wet): In the vibro-replacement (wet) method, a hole is formed in the ground by jetting a probe down to the desired depth. The uncased hole is flushed out and then stone is in increments and densified by means of an electrically or hydraulically actuated vibrator located near the bottom of the probe. The wet process is generally used where borehole stability is questionable. Therefore, it is suited for sites underlain by very soft to firm soils and a high ground water table.

Vibro-Displacement: The vibro-displacement method is a dry process sometimes referred to as vibro-replacement (dry). The main difference between vibro-displacement and vibro-replacement is the absence of jetting water during initial formation of the hole in the vibro-displacement method. To be able to use the vibro-displacement method the vibrated hole must be able to stand open upon extraction of the probe. Therefore, for vibro-displacement to be possible soils must exhibit excess undrained shear strengths with a relatively low ground water table site.

2. OBJECTIVE:

Need for engineering ground Improvement arises when a project encounters difficult foundation conditions.

The main objective of the study is as follows

1. To study the effect of quarry dust column encased with geosynthetics in improving the strength characteristics of black cotton soil.
2. To study the load bearing capacity of geosynthetics encased quarry dust columns with single columns.
3. To predict the settlement reduction factor of reinforced ground with the unreinforced ground.
4. Soil is good in compression and weak in tensile strength and even soil don't have tensile strength naturally therefore the weakness of soil takes place to reduce the weakness of soil reinforcement is made and its improved strength characteristics is studied.

The goal of this thesis work is how to increase shear strength and to provide required minimum bearing capacity, restrict total and differential settlements to accept magnitude of proposed loading and provide acceptable long term performance.

3. SCOPE OF WORK:

The purpose of this research was to investigate the performance of stone column encased with Geosynthetics, which is a new concept and to study the strength characteristics of black cotton soil when used as a foundation material for floating, embedded depth, under different saturation condition. The research presents results of observations obtained from tests using single columns for floating and embedded footing on a black cotton soil which is essentially reinforced. Reinforced soil performs satisfactorily under monotonic loading, well-established literatures are available with respect to geosynthetics encasement. The geosynthetics-enwrapped stone columns subjected to static loads finds a tremendous potential in restoring the column for practical usage as in many of the field situation the static loads comes into play. Studies and observations show that the settlements are greatly reduced and the load carrying capacities of encased columns are increased appreciably. These results triggered a series of studies to determine the load-settlement behavior of both the unreinforced and reinforced soil under different condition. Any decision to effectively use an improvement technique requires a clear understanding of material behavior subjected to static loading. Hence in the present investigation the efficacy of using the geosynthetics as encasement to the stone column is investigated and experiments are conducted to know the load-settlement behavior of single columns with different length and diameter of columns under different reinforcement parameters.

4. Materials:

4.1 Black cotton soil:

The black cotton soil is collected from the new railway station site of bypass road, near Hiremangalure village, Chikmaglore. The soil sample was collected by open excavation, from a depth of one meter below natural ground level leaving the surface soil. The soil is oven dried and used after sieving through IS 4.75 mm sieve, properties of the black cotton soil is summarized in table 4.1

Figure 4.1: Black cotton soil site

Figure 4.2: Black cotton soil

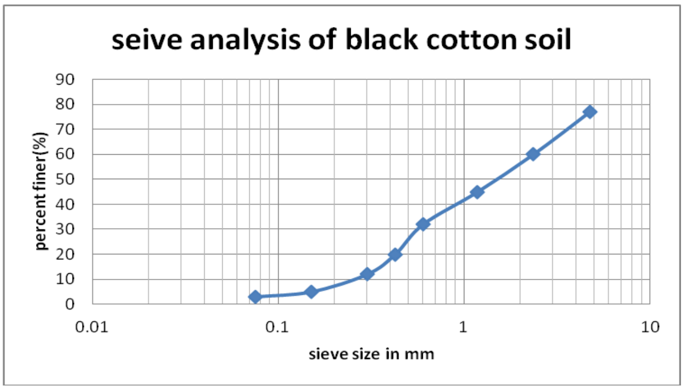

Chart 4.1: Sieve Analysis of black cotton soil

Table 4.1: Properties of black cotton soil

A .Index properties of soil

Water content	21.66%
Specific gravity	2.44
Liquid Limit	63.29%
Plastic Limit	26.41%
Plasticity Index	36.88%
Shrinkage Limit	22.49%
Free swell index	84%

The soil classification based on Index properties belongs to "**CH**" group in which Inorganic clay with high compressibility.

B. Engineering properties of soil

OMC	19%
MDD	15.30kn/m^3
Undrained cohesion	0.02kn/m^2

4.2 Quarry Dust as Fine Aggregate:

From quarry industry, the quarry dust production goes as waste. The quarry dusts are sieved until the fine aggregate achieved is close to sand fine aggregates. The quarry dust sieved through IS 2.36mm used for experimental work. The quarry dust is collected from the construction site near East West Institute of Technology in Bangalore.

Figure 4.3: Quarry dust

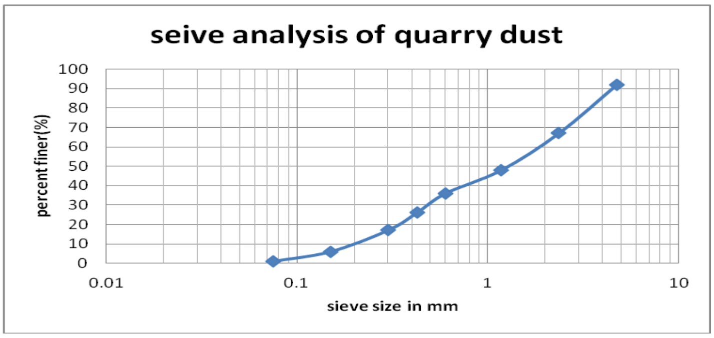

Chart 4.2: Sieve analysis of quarry dust

Table 4.2. Properties of quarry dust

Specific gravity	2.53
Coefficient of Uniformity	10.00
Coefficient of curvature	0.650

4.3 Lime:

The lime is used which will directly get in the market .And the lime is stored in place to prevent its carbonation.

4.4 Geosynthetics

For our project work different grades of geotextiles and geogrids are used.

a. Geotextiles (non oven) of different grades

i. PE-1202EF
ii. PE-1302EF

Figure 4.5: Geotextiles

Table 4.3: Properties of geotextiles as per company details.

PROPERTY	PE-1202EF	PE-1302EF	UNIT
Mass per unit area	200	300	g/m^2
Thickness	1.20	2.00	MM
Grab tensile strength	485	816	N
Grab elongation at break	131	110	%
Trapezoidal tear	129	220	N
CBR puncture	1585	3013	KN

b. Geo grid

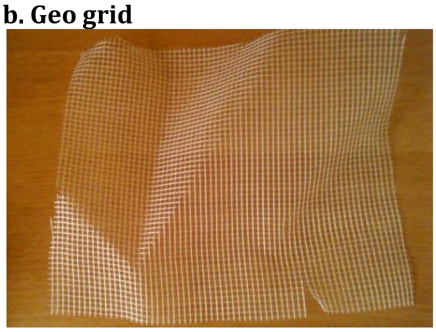

Figure 4.6: Geogrids

Table 4.4: Properties of geogrids as per company details

Weight	45	g/m^2
Mesh size	2.5*2.5	mm
Coating content	18	%
Tensile strength	400(MD)	N/5cm

5. Experimental work and methodology

5.1 Methodology:

1) The Model footing test is conducted for different lengths of quarry dust columns with geosynthetics as encasement for various D/B ratios where 'D' denotes the diameter of test tank and 'B' denotes the diameter of the circular model footing. The results are observed for different diameter columns.
2) The model footing test is conducted for single quarry dust columns encased with geosynthetics for embedded depth, floating depth & intermediate depths.
3) Load settlement characteristics of black cotton soil using quarry dust columns wrapped with geosynthetics is analyzed for single arrangement and encased columns using model footing tests.
4) Based on the experimental results conclusions are drawn for D/B ratios of 1, 2, and 3 and for different length and for different pattern of arrangement of quarry dust columns.

5.2 Preparation of black cotton soil deposit:

Oil is applied in the tank wall to reduce any friction between soil and tank wall. Required quantity of soil is mixed with 20% water content to maintain the density of 15.3kn/m^3 and thoroughly mixed soil is filled in the tank in 3 layers using rainfall technique.

5.3 Construction of quarry dust Column:

The column is constructed by dry method. The enwrapped mild steel fabricated single and group columns of requisite length are placed in the bottom centre of the tank for SINGLE Column. Fabricated columns are removed carefully without disturbing the surrounding soil and keeping the cylindrical hole intact.

Table 5.1: Table of length and diameter used for project

LENGTH(MM)	DIAMETER(MM)
300	30
300	25
300	20
225	30
225	25
225	20
150	30
150	25
150	20

5.4 Testing Procedure:

Accordingly, tests are carried out in test tank where a stone column of 8mm diameter is constructed at the center of a cylindrical tank, which is filled with black cotton soil mixed with 20% water to maintain low dry density. Tank diameter is chosen to represent a required spacing between the columns. To estimate the load carrying capacity of the column, column area alone is loaded. .

1) A circular steel test tank of diameter 250mm and height 150mm is used as model test tank. The side

walls of the tank were made smooth by coating with a lubricating gel to reduce the boundary effects.

2) The black cotton soil which is used for work is kept for 24 hours to reach its maturity period.
3) The required weight of soil sample is calculated for the lowest density of 15.30kn/m^3 as obtained from the compaction test results is mixed thoroughly with 20% water content and filled in 5 layers into the test tank using rainfall technique. Using tamping rod the void spaces present in the sample are removed.
4) The soil sample is filled into the test tank with maintaining its density throughout the procedure.
5) The different diameter of hole is created at the center without disturbing the density of soil in the tank.
6) A cylindrical hole enwrapped with the geosynthetics is formed in the test tank.
7) The quarry dust is then filled into the hole of different diameter and different through a cone made of paper.
8) The circular model footing of 75mm dia is placed exactly on top of the constructed quarry dust column.
9) The footing was placed exactly at the centre of the loading jack to avoid eccentric loading. Calibrated proving ring is used to measure the load transferred to the footing. The load was applied in small increments at constant rate of strain1.25mm/min. Each load increment is maintained constant until the footing settlement stabilized:
10) Three dial gauges are fixed on footing and deformations are measured through dial gauges (Dg_1, Dg_2, and Dg_3). The Load improvement ratio and settlement reduction factor are calculated for different settlement levels.
11) The above procedure is repeated for different lengths of encased quarry dust columns and for different diameter of arrangement of quarry dust columns.

6. RESULTS AND DISCUSSIONS

To evaluate the beneficial effects of providing quarry dust columns encased with geosynthetics in black cotton soil earth, experiments are conducted on embedded, floating columns constructed in black cotton soil earth subjected to monotonic loads. The effects of single stone columns of different length in different diameter of arrangement are found out.

We made the combinations of black cotton soil + quarry dust +lime with varying percent of quarry dust and lime and unconfined compressive and direct shear tests are conducted and for the maximum combination the direct shear test is conducted with encasement of the geosynthetics.

Table 6.1: Properties of different combinations with respect to unconfined compressive strength test

Lime and quarry dust (%)	Q_u (N/mm^2)	c_u (N/mm^2)
5	0.039	0.020
10	0.053	0.026
15	0.060	0.030

Table 6.2: Properties of different combinations with respect to direct shear test.

Lime and quarry dust (%)	C (N/mm^2)	Ø degree
5	0.0017	20
10	0.0032	22
15	0.0042	27

Apart from all the specification of stone column material, decided to study the below combination of material.
Black cotton soil +quarry dust (15%) + lime (15%)
For the above combination encasement is made and direct shear test is conducted.

Encasement	Lime and quarry dust (%)	C (N/mm^2)	Ø degree
Geo grid	15	0.006	18
PE-1202EF	15	0.0077	15
PE-1302EF	15	0.0084	21

a) Geogrids

Lime and quarry dust (%)	C (N/mm^2)	Ø degree
5	0.0032	15
10	0.0044	12
15	0.006	18

b) PE-1202EF

Lime and quarry dust (%)	C (N/mm^2)	Ø degree
5	0.0045	11
10	0.0058	13
15	0.0077	15

c) PE-1302EF

Lime and quarry dust (%)	C (N/mm^2)	Ø degree
5	0.0057	16
10	0.0069	19
15	0.0084	21

To bring out the effect of inclusion of encased stone column on the performance of circular footing, experiments are conducted both on unreinforced and reinforced black cotton soil earth under monotonic loadings.

6.1 Model footing test results:

The load deformation behavior of the encased stone column is studied by loading it in a Triaxial loading frame at a strain rate of 1.25mm/minute. To load the stone column area alone a circular model footing of 75mm diameter is placed exactly at the center of the column and the load is applied. Settlement is observed for equal intervals of load up to an average deformation of different settlements.

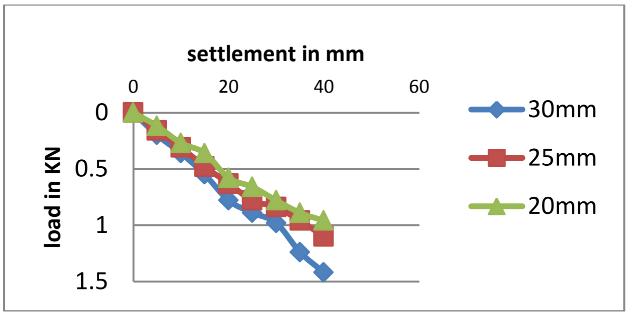

Chart 6.1: Load - Settlement characteristics graphs of unreinforced black cotton soil for 300mm length and different diameters and for 40mm settlement.

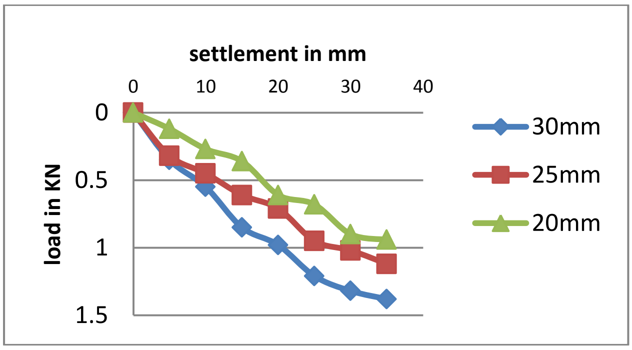

Chart 6.2: Load - Settlement characteristics graphs of unreinforced black cotton soil for 225mm length and different diameters and for 35mm settlement.

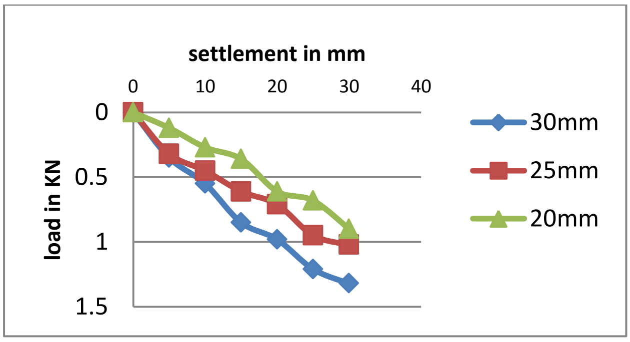

Chart 6.3: Load - Settlement characteristics graphs of unreinforced black cotton soil for 150mm length and different diameters for 30mm settlement.

Improvement of strength due to contribution of geosynthetics encasement.

A .Geogrids

Length mm	Diameter mm	Failure load KN		Contribution KN	Improvement in strength %
		without	with		
300	30	1.42	1.93	0.51	35.87
300	25	1.10	1.64	0.54	49.25
300	20	0.96	1.24	0.28	29.02
225	30	1.37	1.89	0.52	37.42
225	25	1.12	1.72	0.60	53.13
225	20	0.94	1.48	0.54	57.23
150	30	1.32	1.79	0.47	35.84
150	25	1.01	1.54	0.53	52.22
150	20	0.90	1.32	0.42	47.66

B .PE1202EF

Length mm	Diameter mm	Failure load KN		Contribution KN	Improvement in strength %
		without	with		
300	30	1.42	1.81	0.39	27.56
300	25	1.10	1.49	0.39	35.45
300	20	0.96	1.1	0.14	14.50
225	30	1.37	1.78	0.41	29.93
225	25	1.12	1.61	0.49	43.75
225	20	0.94	1.34	0.40	42.55
150	30	1.32	1.68	0.36	27.27
150	25	1.01	1.42	0.41	40.59
150	20	0.90	1.24	0.34	37.77

Load improvement ratio: It is the ratio of load of reinforced to the load of unreinforced soil. The effect of length of quarry dust column on load carrying capacity is measured in terms of load ratio, the improvement in load ratio corresponding to two settlement levels are analyzed at 20mm settlement and 30mm settlement.

Load improvement ratio is given by equation,

LIR $= Q_r / Q_{ur}$ measured for 20mm and 30mm settlement levels.

Where,

Qr = Load of reinforced soil in KN.

Qur = Load of unreinforced soil in KN.

Settlement Analysis:

A suitable foundation system should satisfy the settlement criteria. A week ground treated with quarry dust column will settle less than an untreated ground; hence the settlement reduction factor is the main objective in the ground improvement technique.

Settlement reduction factor (β) can be calculated by the relation

$\beta = (S_0 - S_r) / S_0$

Where,So = Settlement of unreinforced soil in mm compared to unreinforced soil.

And Sr = Settlement of reinforced soil in mm compared to unreinforced soil.

7. CONCLUSIONS

From above discussions following conclusions are drawn

- It was concluded that stone dust and lime gives maximum strength at 15% composition when compared to 5% and 10%.
- In the present study indicated that geosynthetics encased black cotton soil,lime and stone dust column of PE1302EF has shown better cohesion with 0.006N/mm^2.
- Improvement of bearing capacity is observed in encased stone column in all 300mm, 225mm and 150mm lengths and in 30mm, 25mm and 20mm diameter and for 40mm,35mm and 30mm settlement. It is observed that the bearing capacity of 30mm diameter 300mm length and for 40mm settlement is higher.
- The smaller diameter of the stone column has lower bearing capacity than larger diameter stone column.
- Geogrid encasement increases bearing capacity of stone column in which it gives Improvement in strength upto 57.23% because bulging behavior of stone column decreases.
- Geotextile of higher strength in which PE1302EF increases bearing capacity of stone column it gives improvement of strength upto 67.32%.
- There is considerable reduction in settlement when the stone column encased with geosynthetic.
- The marginal percentage reduction in settlement is greater in larger diameter and longer lengths of column

REFERENCES

[1] Ahmet Demir1, et al.,(2013), "An experimental study on behaviour of geosynthetic reinforced stone columns".2nd International Balkans Conference Of Civil Engineering,BCCCE,23-25 May2013,Epoka University.

[2] Ali, K et..al (2010), "Behaviour of reinforced stone columns in soft soils: an experimental study".Indian GeoTechnical conference 2010, Geotrends

[3] Chungsik Yoo, A.M.ASCE (2010), "Performance of Geosynthetic-Encased Stone Columns in Embankment Construction:Numerical Investigation".A.M.ASCE1J.Geotech.Geoenviron.Eng.2010.136:1148-1160

[4] Gupta.R and A. Trivedi (2010), "Behavior of model circular footings on silty soils with cellular supports".

[5] Hamed Niroumand, et al.(2011), "Soil Improvement by Reinforced Stone Columns Based on Experimental Work". EJGE VOL.16[2011],BUND,L

[6] Joel Gneil,Abdelemalek Bouazza (2008), "Improvement of soft soils using geogrid encased stone columns".

[7] J.A Black, Sivakumar, et al.,(2007), "Reinforced Stone Columns in Weak Deposits: Laboratory Model Study".

[8] Kameshwar Rao et al., (2012), "Comparative study of experimental and theoretical load carrying capacity of stone column with and without encasement of geosynthetics" IJAET ISSN:2231-1963

[9] Murugesan.S and Rajagopal.K (2009), "Shear load tests on stone columns with and without geosynthetic encasement".Geotextiles and Geomembranes 24(2012) 349-358 ASCE(20),

[10] S. Murugesan and K.Rajagopal (2007), "Model tests on geosynthetic-encased stone columns".ASCE9(1),30-35

[11] Mohammed Y. et.al., (2010), "Improvement of soft clays by end bearing stone columns encased with geogrids".

[12] Mereena K.P. et.al., (2009), "Triaxial compression of clay reinforced with quarry dust fibre column".

[13] Sujit kumar Dash, Mukul Chandra Bora (2013), "Influence of geosynthetic encasement on the performance of stone columns floating in soft clay".

[14] Y.F. Leung, A, Klar(2010), " Theoretical Study on pile Length Optimization of Pile Groups and Piled Rafts " Geotech.Geoenviron, Engg, 2010.136:319-330[14]

[15] Zahmatkesh. A & Choobbasti.A.J (2010), "Settlement evaluation of soft clay reinforced by stone columns, considering the effect of soil compaction"