Analysis on the Performance of Stone Columns with Different Materials in Soil Stabilization

Samuel Thanaraj. M, Freeda Christy.C, Brema.J

ABSTRACT--- Stone column ground improvement involves adding vertical columns of stone into the ground to a depth of at least 4m below the ground surface. A layer of compacted gravel can then be put over the top of the columns, ready for the construction of new house foundations. The stone column method is quick to construct and can be done at any time of the year. Stone columns are extensively used to improve the bearing capacity of poor ground and reduce the settlement of structures built on them. A stone column is one of the soil stabilization methods that is used to increase strength, decrease the compressibility of soft and loose fine graded soils, accelerate a consolidation effect and reduce the liquefaction potential of soils. The columns consist of compacted gravel or crushed stone arranged by a vibrator. This article presents installation methods, design and failure modes of stone columns. In this study, the filler material crushed stone is replace with other locally available materials such as Marble waste, Pebbles, Concrete waste. A study on the performance of the stone column with and without encasement also undertaken. Geogrid is used for encasement to control bulging effect. A set of tests were conducted on the Load versus settlement behavior of the stone columns at laboratory by installing the stone columns of size fixed based on the length to diameter ratio. Clay soil has been taken as sample and waste marbles, pebbles wee taken and different parameters. From the previous studies of literature it was understood that bulging effect on the stone column occurs during loading on the top portion of the stone columns. Another set of laboratory tests were conducted on the stone columns with geogrid encasement to control the bulging. From the results it was observed that encasement with geogrid controls the bulging effect and the locally available materials could be used as filler material of stone columns which can be used for improving the strength of loose soils.

Key words : stone column, bearing capacity, settlement, stabilization, soft soil

1. INTRODUCTION

The rapid urban and industrial development pose an increasing demand for land reclamation, utilization of unstable and environmentally affected ground and safe disposal of wastes. In order to meet these demands, ground improvement techniques have been evolved which now emerged as a major part of civil engineering practice. Basically, these techniques involve modifications of mechanical, hydraulic, physical, cementing and chemical properties of ground.

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The construction site has to be explored the soil to the required depth and investigation of the engineering properties of soil is to be carried out. From the investigation, the safe bearing capacity is calculated. Sometimes the existing soil on a given site may not be suitable for supporting the desired facilities as buildings, bridges, oil tanks, dams and so on because of safe bearing capacity of soil may not be adequate to support the given load. In such a case, it is recommended to adopt the ground improvement techniques.

There are lots of ground improvement techniques available in practice. They are: (i) Pre-loading (ii) Soil replacement (iii) In-place densification by Vibroflotation, Compaction piles, Simple stone column, vibrostone column and vertical drains, Blasting, Soil stabilization with Grouting and injection methods, Soil reinforcements.

2. LITERATURE REVIEW

Pradip Das and Dr. Sujit Kumar Pal [2013] conducted a study of the behaviour of stone column in local soft and loose layered soil. Load tests also conducted through the compression testing machine are performed on single un-encased stone column in sandy silt soil with clay. The stone column treated soil can carry more load than untreated soil. The load carrying capacity of treated soil increase with the increase in diameter of stone column. When column area is loaded, failure of bulging occurs within the entire column area. The encased stone column in layered soil also decreases with the increasing diameter of stone column. The load carrying capacity of treated layered soil decreases with the increasing of diameter of stone column.

B. Galy et al [2012] done a research on the Influence of the vibro-stone column reinforcement on the seismic bearing capacity of a surface shallow footing. A new approach to estimating the bearing capacity of reinforced soils under seismic conditions is proposed. It is based on limit equilibrium theory, pseudo-static and pseudo-dynamic concepts and a specialized method for estimating reinforced soil properties. The parametric study presented indicates that a 1.5B treatment width on each side of the footing is sufficient to increase the original bearing capacity by 25 to 50% (depending on the Area ratio) in the case of a "partial improvement" scenario is presented here.

Jajatikesharinaik [2013], in his research on Load carrying capacity of stone columns embedded in compacted pond ash, attempted to assess the suitability of reinforcing technique by stone columns to improve the load carrying

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capacity of pond ash deposits through several laboratory model tests. The shear parameters of the compacted pond ash samples reinforced with stone columns of varying area ratios and length ratios are evaluated from triaxial compression test. In addition to this, stone columns having different area ratios and length ratios are introduced in compacted pond ash beds and the bearing capacity of the composite system is evaluated through a series of footing loading tests. Due to the confinement and sample prepared at higher compactive effort attributed to the closer packing of particles, resulting in the increased interlocking among particles.

S.N. Malarvizhi and K. Ilamparuthi [2010] have done a research on Load versus settlement of clay bed stabilized with stone & reinforced stone columns. Load tests were performed on soft clay bed stabilized with single stone column and reinforced stone column having various slenderness ratios and using different type of encasing material. Encasing the stone column with geogrid resulted in an increase of load carrying capacity irrespective of whether the column is end-bearing or floating. In case of floating columns the l/d ratio has less influence on the capacity of column for the lengths studied in this investigation. The ultimate load capacity of the reinforced column increases with the stiffness of the reinforcement. The ultimate bearing capacity of reinforced stone column and stone column treated beds are three times and two times that of the untreated bed. The encased stone column is stiffer than stone columns, thereby reducing the load on clay, consequently reducing the settlement.

3. IMPORTANT FEATURES OF STONE COLUMN TREATMENT

Fig. 1 Image of Stone column treated soil.

3.1 Influence of Soil Type: Subsurface soils whose undrained shear strength range from 7 to 50 kpa or loose sandy soils including silty or clayey sands represent a potential class of soils requiring improvement by stone columns. Subsurface conditions for which stone columns are in general not suited include sensitive clays and silts (sensitivity is 2 4) which lose strength when vibrated and also where suitable bearing strata for resting the toe of the column is not available under the weak strata.

3.2 Influence of Construction Methodology: The disturbance caused to the soil mass due to a particular method of constructing the stone columns significantly affects the overall behavior of the composite ground. The availability of equipment, speed of construction and the depth of treatment would normally influence the choice of construction technique.

3.3 Treatment Depth: The treatment depth with stone column for a given soil profile should be so determined that the stone columns extend through the most significant compressible strata that contribute to the settlement of the foundation. Average depth of stone column accomplished in India may be around 15.0 m or so, although with equipment modification, higher depths beyond 20 m may become a possibility in future.

3.4 Area of Treatment. Stone columns work most effectively when used for large area stabilization of the soil mass. Their application in small groups beneath building foundations is limited and is not being used. Thus, large loaded areas which apply uniform loading on foundation soils, such as beneath embankments, tank farms and fills represent a major area of application.

3.5 Termination: End bearing is not a specific requirement for stone columns. However, they should extend through the soft compressible strata as indicated; the soil near the ground surface has a dominating influence on settlement and ultimate bearing capacity of stone columns.

3.6 Pattern: Stone columns should be installed preferably in an equilateral triangular pattern which gives the densest packing although a square pattern may also be used.

3.7 Spacing: The design of stone columns should be site specific and no precise guidelines can be given on the maximum and the minimum column spacing. However, the column spacing may broadly range from 2 to 3 depending upon the site conditions, loading pattern, column factors, the installation technique, settlement tolerances, etc.

4. TESTS ON CLAY

4.1 Soil Sample

The soil sample is black cotton soil which is distributed in most at north of Coimbatore. A disturbed soil sample is that in which a natural structure of soil get partly or fully modified and is destroyed although with suitable precautions for natural moisture content may be preserved. Such a sample is called as representative soil sample.

The representative soil sample for the thesis was collected from Goundampalayam, Coimbatore and it was analysed for its strength properties. An open pit was made up to a depth of 1.5m below the ground surface where the representative soil samples were taken.

4.2 Experimental Work

The experimental study is carried out to estimate the load carrying capacity of a stone column. Accordingly, tests are carried out in test tank where a stone column of 50mm diameter is constructed as equilateral triangular pattern of a cylindrical tank, which is filled with soft clay of required consistency. Tank

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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. Whereas the entire area represented by the column is loaded to estimate the stiffness of the improved ground.

4.3 Experimental Set-up

Fig.2 Test Setup – Load VS Settlement

Typical test arrangement is shown in cylindrical tank of height 500mm is used as model tank. Diameter of the tank is taken as the diameter of the area of zone of influence around each column. Stone column diameter used for the test is 100mm. To study the effect of spacing the diameter of the tank was varied from 210mm to 420mm. Assuming triangular pattern and spacing to diameter ratio (s/d) as 2, 3 and 4 the model tank diameters used are 210, 315 and 420mm. In the tank clay is placed for a height of 450mm in which the stone column is installed at the Centre.

5. CONSTRUCTION OF ENCASED STONE COLUMN

The column is constructed by replacement method. A 50mm outer diameter thin open-ended seamless pipe is pushed into the clay at triangular pattern up to 30cm above the bottom of tank. The clay within the pipe is stone column snooped out using a helical auger. Encasement is first inserted into the holes and then gravels of size 2 – 10mm are charged into the hole in layers as well as tests were conducted with pebbles.

5.1 Test Procedure

After preparing the stone column & stone column with encasement, the load deformation behavior of the column is studied by loading it in a uniaxial loading frame at a strain rate of 1.2mm/minute. To load the stone column area alone a loading plate of 180mm diameter is placed exactly at the center of the stone column and the load is applied till failure. To load the entire tank area a loading plate of diameter 5mm less than the inside diameter of the test tank is placed over the sand blanket and the load is applied over the plate. Load is observed for equal intervals of settlements up to an average deformation of 12mm.

6. RESULTS

6.1 Untreated Soil

The tank with filled untreated soil and tested for its maximum load bearing capacity in a uniaxial test and the results in Table I.

TABLE I
LOAD VS SETTLEMENT OBSERVATION OF UNTREATED SOIL

Sl.No Unit	Load (KN)	Settlement (mm)
1	0	0.97
2	1.2	2.03
3	2.45	3.27
4	3.62	4.52
5	4.97	6.78
6	6.2	8.37
7	7.46	10.51
8	8.57	11.24
9	9.74	12.86
10	11.28	14.91
11	12.3	16.24
12	13.78	18.47
13	14.81	19.83
14	15.98	20.94
15	16	22.46
16	17	23.83
17	17.1	27.14
18	18.32	29.52
19	20.23	32.37

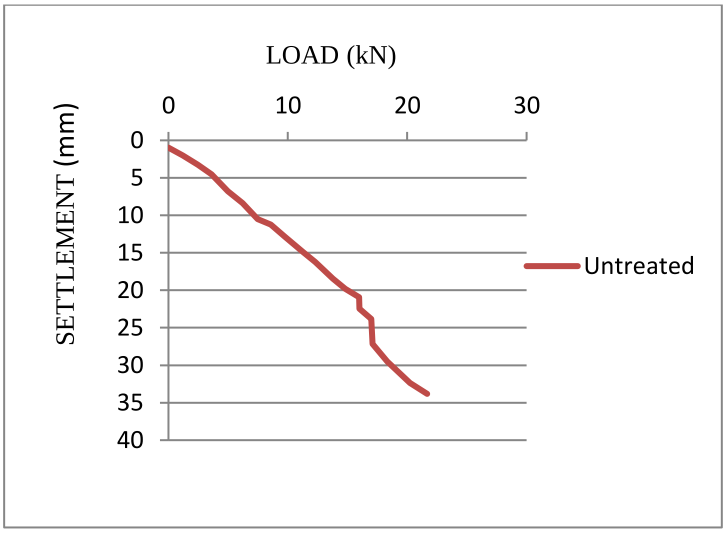

Fig.3 Load VS Settlement of untreated soil

6.2 Stone column made with aggregates

The tank with filled soil, stone column made with aggregates and tested for its maximum load bearing capacity in a uniaxial test and the results in Table II.

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TABLE II
LOAD VS SETTLEMENT OBSERVATION OF STONE COLUMNS WITH AGGREGATES

Sl.No	Load	Settlement	
		Without Encasement	With Encasement
Unit	(KN)	(mm)	(mm)
1	0	0.83	0
2	1.2	1.88	1
3	2.45	2.77	1.77
4	3.62	3.52	2.8
5	4.97	5.32	3.5
6	6.2	7.70	4.32
7	7.46	9.12	7.78
8	8.57	10.09	8.98
9	9.74	12.84	10.34
10	11.28	14.75	11.84
11	12.3	15.37	13.76
12	13.78	16.52	14.88
13	14.81	18.15	16.83
14	15.98	19.90	16.99
15	16	20.95	17.97
16	17	22.68	20.1
17	17.1	22.22	22.36
18	18.32	26.39	22.56
19	20.23	26.77	22.92
20	21.67	27.07	23.52

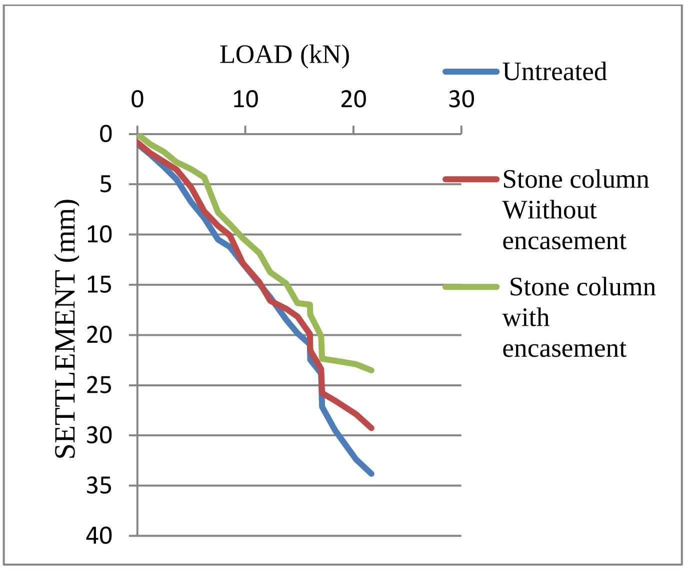

Fig.4 Comparison Load VS Settlement of Stone column with Aggregate with and without encasement

6.3 Stone column made with Waste Marbles

The tank with filled soil, stone column made with pebbles and tested for its maximum load bearing capacity in a uniaxial test and the results in Table III

TABLE III
LOAD VS SETTLEMENT OBSERVATION STONE COLUMN WITH MARBLE WASTE

Sl.No	Load	Settlement	
		Without Encasement	With Encasement
Unit	(KN)	(mm)	(mm)
1	0	0.83	0
2	1.2	1.88	1
3	2.44	2.77	1.77
4	3.62	3.52	2.8
5	4.97	5.32	3.5
6	6.2	7.7	4.32
7	7.45	9.12	7.78
8	8.56	10.09	8.98
9	9.73	12.84	10.34
10	11.27	14.75	11.84
11	12.3	16.6	13.76
12	13.77	17.4	14.88
13	14.81	18.15	16.83
14	15.98	19.9	16.99
15	16	21.53	17.97
16	17	23.4	20.1
17	17.1	25.78	22.36
18	18.32	26.53	22.56
19	20.23	27.87	22.92
20	21.66	29.27	23.52

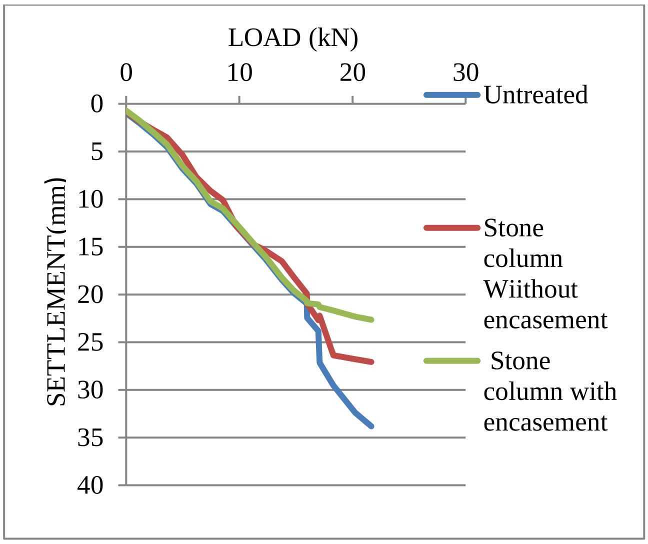

Fig.5 Comparison Load VS Settlement of Stone column with Waste marbles with and without encasement

6.4 Stone Column Made with Pebbles

The tank with filled soil, stone column made with pebbles and tested for its maximum load bearing capacity in a uniaxial test and the results in Table IV

TABLE IV
LOAD VS SETTLEMENT OBSERVATION OF STONE COLUMNS WITH PEBBLES

Sl.No	Load	Settlement	
		Without Encasement	With Encasement
Unit	(KN)	(mm)	(mm)
1	0	1.44	0.57
2	1.2	2.88	1.61
3	2.44	4.82	2.50
4	3.62	6.54	3.26

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5	4.97	7.86	5.06
6	6.2	9.89	7.44
7	7.45	10.04	8.86
8	8.56	10.22	9.82
9	9.73	13.06	12.58
10	11.27	14.66	14.49
11	12.3	16.37	15.11
12	13.77	17.52	16.26
13	14.81	19.15	17.88
14	15.98	21.90	19.64
15	16	22.95	20.68
16	17	23.68	21.41
17	17.1	24.22	21.96
18	18.32	27.39	22.05
19	20.23	27.72	22.17
20	21.66	28.92	22.62

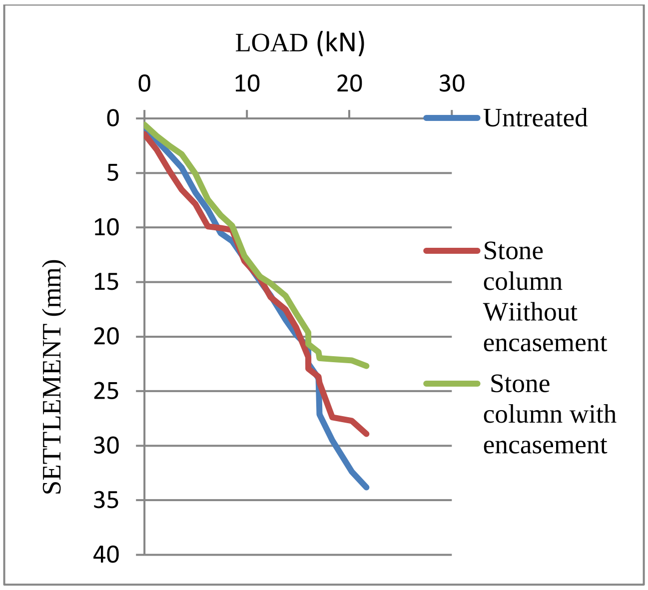

Fig.5 Comparison Load VS Settlement of Stone column with Pebbles with and without encasement

7. OVERALL COMPARISON OF STONE COLUMNS WITH AND WITHOUT ENCASEMENT

7.1 Without Encasement

The behaviour of stone columns with Load vs. Settlement with Aggregate, Waste marbles, and pebbles along with the untreated soil are shown in the graph below.

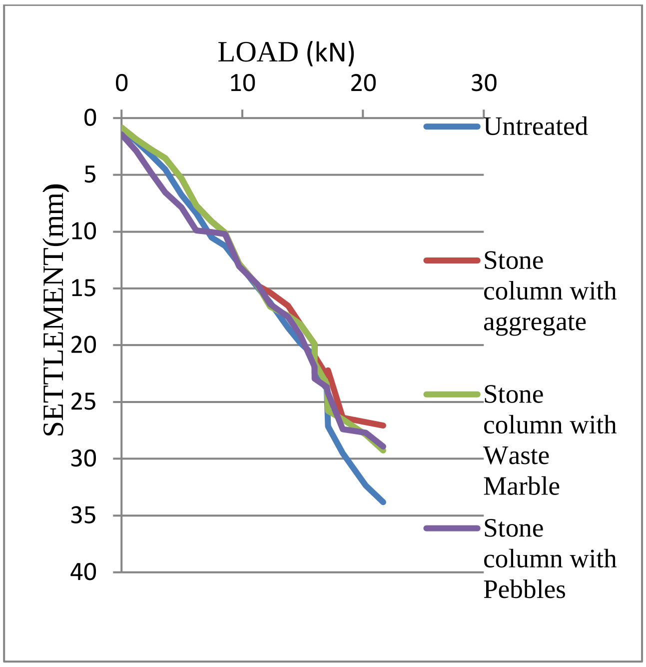

Fig 6. Comparison of stone columns of different materials without encasement

The settlement behaviour of Stone column with aggregate which is used conventionally is found to be less when compared with the other materials. The effect of settlement of other materials waste marbles and pebbles are found to be more or less equal and close to the value of column with aggregate both in the case of without encasement and with encasements. The difference in the settlement behaviours found to be nearer to each other comparatively,

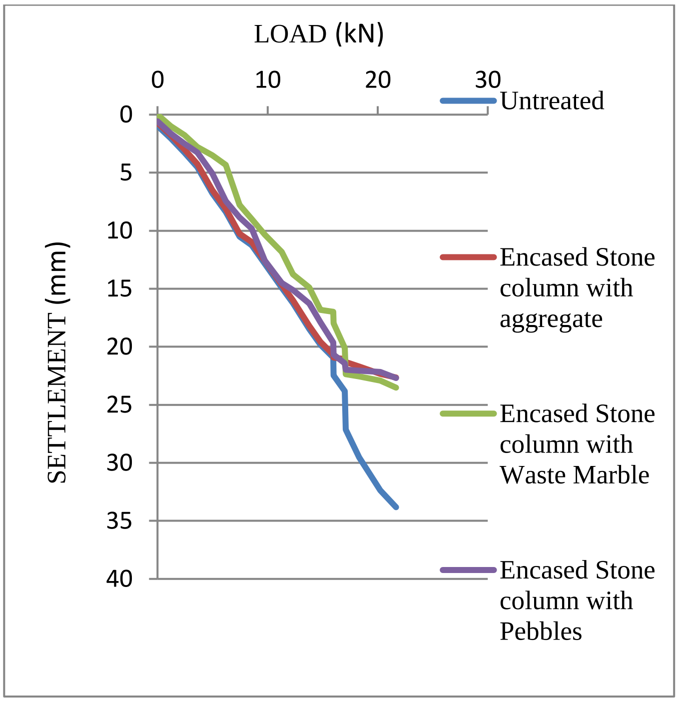

Fig 7. Comparison of stone columns of different materials with encasement

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8. ULTIMATE BEARING CAPACITY

The ultimate load is obtained from the intersection of the tangents i.e., the ultimate load corresponding to the value of the settlement where the tangent intersects. The ultimate bearing capacity of the proposed foundation q_u (f) can be obtained from the relation:

Diameter of Plate used over the triangular pattern place stone column: 300mm, Area of Plate: $0.071m^2$

For clayey soil, q_u (f) = q_u (p)

Sl. No.	Type	Ultimate Bearing capacity (KN/m^2)
1	Untreated soil	162.54
2	Stone column with marble waste	192.20
3	Stone column with pebbles	178.74
4	Stone column with Hard blue granite Aggregate	258.67
5	Encased Stone column with marble waste	264.43
6	Encased Stone column with pebbles	187.45
7	Encased Stone column with aggregates	285.72

9. CONCLUSION

Stone columns with encasement provide good results not only improving its strength and also prevent the column from bulging which was discussed in detail in the previous. Literatures. The above study was conducted to analyse weather locally available material could be used as filler material for stone columns. The following observations were obtained:

1. Among the different materials used Aggregates along with the encasement gives higher strength than other materials. The values of other materials are moderately nearer to the value of stone column with conventional material aggregates.
2. The geosynthetic encasement prevents the contamination of stone column and thus will not reduce the friction between the stone aggregates and clay bed. The encasement prevents from bulging effect on the top portions which was studied in detail from the literatures as well.
3. Pressure settlement response of geosynthetic encased stone columns generally shows linear behaviour not indicating any catastrophic failure unlike the conventional stone columns.

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