International Journal of Innovative Research in Engineering Science and Technology
May 2017 *ISSN 2320 – 981X*

BEHAVIOUR OF CEMENT GROUTED UNDER-REAMED STONE COLUMN GROUPS BASED ON MODEL STUDIES AND FEM ANALYSIS

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ABSTRACT: One of the major problems in construction sites is the presence of soft clays, loose and unstable soils. Such soils may collapse and cause distress to the structure during or after construction. Several methods are available for improving the properties of soft and unstable soils. In this work, stone column is considered as a method of improvement for load carrying capacity and reduction in settlement. Stone column technique consists of straight shafted columns filled with crushed stones and gravels. In soft clays, lateral bulging of stone column causes dispersion of stones which affects the load carrying capacity. In this work, a non-bulging material consisting of cement and crushed stones is used in stone column. Laboratory model study of such stone columns of 2.5cm diameter, area replacement ratio of 22.67% and length ratio of 8 is performed to find the effectiveness of cemented stone columns over conventional stone columns.

INTRODUCTION

Effective utilization of land has become important nowadays. Presence of soft clay deposits in construction sites poses major problems to the structure resting on it during or after construction. Various ground improvement techniques are available among which stone column technique proves to be more effective in terms of load carrying capacity and settlement reduction.

Black cotton soil makes construction difficult because of its high compressibility characteristics. Introduction of stone column can overcome this difficulty and helps in reducing the compressibility. Stone column consists of straight shafted column filled with crushed stones and gravel. The ultimate load carrying capacity of the stone column is derived from the lateral resistance offered by the surrounding soil. The method of construction of stone column consists of supplying cement or grout by bottom feed unit or pumping ready mix concrete to the bottom of the hole through feeder pipe. The use of concrete as fill material and forming rigid vertical elements is too costly. Alternately, a semi-rigid fill material consisting of cement and crushed stones is used which reduces the loss of stones into the surrounding soil.

In floating type stone columns, the stone columns are rested on a soft clay layer. However, in general, stone columns are carried to a rigid stratum passing the overlying soft clay layers.

Under-reamed Cemented Stone Column

Crushed stone aggregates in cemented stone column with cement at an optimum amount will enhance the behavior of stone column embedded in soft clay. Provision of bulb in the stem is expected to have beneficial effects due to increased bearing area and anchoring effect of the bulb.

A.P.Ambily and S.R.Gandhi presented a paper in which experimental studies were carried out to evaluate the behaviour of stone column by varying spacing, shear strength of soft clay, moisture content etc in soft clay. The results obtained were analysed using the finite element package PLAXIS. The load settlement behaviour and the ultimate axial capacities obtained from model test compared well with that of Finite Element Analysis.

Dr.S.P.Jeyapriya, Divya Darshini.K presented a paper which was intended to find the bearing capacity improvement and settlement reduction in Black Cotton soil due to the presence of under reamed portions in the cemented stone columns. A non-bulging material consisting of cement and crushed stones was used to enhance the effects of stone column. Provision of an enlarged bulb in the stem, either at the bottom of column or at some suitable intermediate levels was expected to have additional effects due to increased bearing area. Laboratory tests were conducted based on the unit cell concept. Group effects were also studied. The under-reamed cemented stone column proved to be more effective when compared with the conventional stone column.

A.P.Ambily presented a paper in which laboratory tests were carried out on a column of 100mm diameter surrounded by soft clay of different consistency. The numerical results from the FEM are compared with the experimental results. When column area alone was loaded, failure was by bulging with maximum bulging at a depth of about 0.5times the diameter of stone column. As spacing increases, axial capacity of the column decreases and settlement increases up to s/d of 3, beyond which the change was negligible. The ratio of limiting axial stress on column to corresponding shear strength of surrounding clay was found to be constant for any given s/d and angle of internal friction of stones and was independent of the shear strength of surrounding clay.

METHODOLOGY

The main objective of this paper is to study the bearing capacity improvement factor and settlement reduction factor using under-reamed cemented stone columns. Experimental studies were carried out on laboratory model setup of untreated clay bed, conventional stone column and under-reamed cemented stone column. The results obtained from untreated clay bed were compared with conventional and cemented stone columns.

Properties of Clay

The representative clay sample was collected from a 1.5 depth pit near Guest house- Government College of Technology, Coimbatore. Proper care was taken to avoid loss of moisture before testing. The properties of the clay were determined by conducting various laboratory tests such as Moisture content test, Specific gravity test, Sieve analysis, Differential free swell test, Atterberg's limits test, Standard proctor test and Unconfined compression test and summarized as shown in Table 1.

Table 1 Properties of Clay

Properties	Results
Initial moisture content	14.56%
Specific gravity	2.73
Percentage of Gravel	0
Percentage of Sand	28.7%
Percentage of Silt & Clay	71.3%
Differential free swell	50%
Liquid limit	52.80%
Plastic limit	27.78%
Shrinkage limit	12%
Plasticity index	25.02
Soil classification	CH
OMC	18.20%
MDD	1.78 g/cc
UCS	168 kN/m^2

Properties of Aggregates

Laboratory tests were conducted on the crushed aggregates to evaluate its physical and engineering properties. Table 2 shows the properties of aggregates.

Table 2 Properties of Aggregates

Properties	Results
Size range	2-10 mm
Aggregate impact value	20%
Water absorption	0.5%
Specific gravity	2.63
MDD	16.73 kN/m^2

In order to investigate the effectiveness of cemented stone column in soft clay soils, the laboratory model studies were carried out to evaluate the performance improvement with respect to increase in local carrying capacity and reduction in settlement of a single unit cell of stone column layout.

Unit cell concept

For the purpose of settlement and stability analyses, it is convenient to associate the tributary area of soil surrounding each stone column with the column. The tributary area is closely approximated as an equivalent circle. In an equilateral triangular pattern the stone columns are considered to be installed. The effective diameter of the equivalent circle for an equilateral triangular pattern of stone columns is

$$\mathbf{D_e = 1.05s}$$

where s is the spacing of stone columns.

The resulting equivalent cylinder of material having a diameter D_e enclosing the tributary soil and one stone column is known as the unit cell. The stone column is concentric to the exterior boundary of the unit cell.

The following types of unit cells were investigated:

- Unit cell of untreated soil
- Unit cell with conventional stone column
- Unit cell with cemented stone column

Table 3 Specifications of model stone column

Specifications	Conventional stone column	Under-reamed stone column
Length	20cm	20cm
Diameter	2.5cm	2.5cm
c/c spacing	5cm(2D)	9.5cm
l/d ratio	8	8
Scale factor	20	20
SC material	Aggregate (2-10mm)	Aggregate (2-10mm) + Cement (5% by weight)
Diameter of bulb	-	6.25cm (2.5D)
Size of the tank	Diameter-30cm Height-30cm	Diameter-60cm Height-60cm

The model stone column represents stone column in the field with diameter 50 cm, length 4m with spacing of 1m installed in equilateral triangular pattern.

Test setup for single stone column

- The model tank containing the clay bed reinforced with stone column is placed in the loading failure.
- Model footing of 10.5 cm is placed over the stone column with its centre placed straight below the loading plate.
- Proving ring of capacity 25 kN is used to measure the load and two dial gauges of least count 0.01 mm is fixed for recording the settlement.
- The load is then applied slowly at a strain rate of 2.5 mm/min and corresponding settlement for each load increment is noted.
- Load increments are continued until the load at failure is attained and the results are plotted.

Fig.1 shows the comparison of Load vs Settlement curves of untreated clay bed, cemented stone column, conventional stone column and under-reamed cemented stone column.

International Journal of Innovative Research in Engineering Science and Technology
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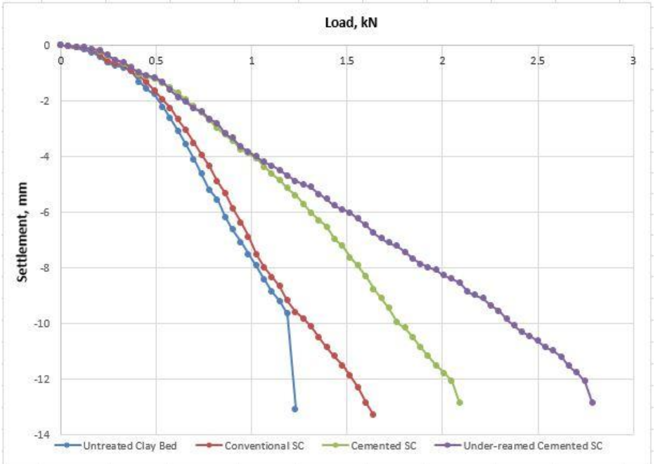

Fig.1 Comparison of Load vs Settlement curves of untreated clay bed, cemented stone column, conventional stone column and under-reamed cemented stone column

Test setup for stone column group

- The model tank containing the clay bed reinforced with stone column group is placed in the loading frame.
- Loading is applied with the help of hydraulic jack arrangement.
- Load cell of sensitivity 0.01kN and LVDTs of sensitivity 0.01mm are used to measure the settlement.
- Two settlement measuring gauges are used.
- The load is then applied in equal increments and corresponding settlement for each load increment is noted.
- Load increments are continued until the load at failure is attained and the results are plotted.

Fig.2 shows the comparison of Load vs Settlement curves of cemented stone column group and under-reamed cemented stone column group.

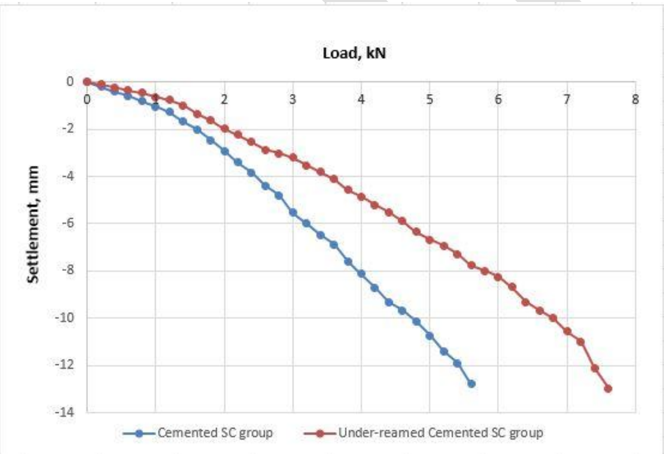

Fig.2 Comparison of Load vs Settlement curves of cemented stone column group and under-reamed cemented stone column group

RESULTS AND DISCUSSION

The curves indicate almost linear behaviour in the beginning followed by non-linear behaviour leading to continuous deformation as the load increases. The failure load Q_f of each case is determined by settlement value and listed in the Table 4.

Table 4 Failure load values

Soil-Column system	Failure Load, Q_f (kN)
Untreated clay bed	1.19
Conventional stone column	1.54
Cemented stone column	2.04
Under-reamed cemented SC	2.73
Cemented SC group (3 columns)	5.49
Under-reamed cemented SC Group (3 columns)	7.35

Bearing Capacity Improvement Factor

The improvement in the failure pressure intensity of any soil-column system is proposed to be expressed by bearing capacity improvement factor (F_b), which is

$$\mathbf{F_b = (Q_f)_t / (Q_f)_u}$$

$(Q_f)_t$ – failure load of soil – column system
$(Q_f)_u$ – failure load of untreated clay

The value of F_b for conventional stone column, cemented stone column and under-reamed stone column are 1.30, 1.72 and 2.29 respectively.

Settlement Reduction factor

The settlement reduction factor is used as a measure for improvement of the ground and is defined as the ratio of settlement of treated ground to the settlement of untreated soil.

$$\mathbf{F_s = S_t / S_u}$$

The value of F_s for conventional stone column, cemented stone column and under-reamed stone column are 0.91, 0.73 and 0.48.

Conclusion

- For improving the soft ground provision of semi- rigid type fill material for the stone column is effective.
- The model studies conducted on single unit cells using a scale reduction factor of 20 for a field stone column diameter of 50 cm diameter having area replacement ratio of 22.7% and length ratio of 8 , revealed that both bearing capacity characteristics and settlement reduction characteristics of soft clay are significantly improved by using stiffer fill material.
- The experimental study with area replacement ratio of 22.7% has proved the observation proposed by Barksdale (1983) that area replacement ratio greater than 20% is effective in improving the ground.
- The load carrying capacity of Conventional Stone Column, Cemented Stone Column and Under-reamed Cemented SC compared to untreated clay bed are increased by 30%, 72% and 130% respectively.
- The settlement reduction factor of Conventional Stone Column, Cemented Stone Column and Under-reamed Cemented SC with reference to the untreated clay are found to be 0.91, 0.73

and 0.48 respectively, which is a clear indication of improvement due to the change in the confinement provided by using stiffer fill material.

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