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Ground Improvement Using Stone Columns in Plastic (Clayey) Soils

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Abstract

Ground improvement is commonly adopted in civil engineering practice to bring down the ill effects of poor sub soil conditions on civil engineering structures constructed over them. Stone columns are one of the methods of ground improvement to enhance the engineering behaviour of soft clays. Stone columns are vertical column or inclusions of dense compact crushed stone penetrating soft clays A series of laboratory tests were performed to determine capacity of stone columns by varying simultaneously the factors IC, LL of soil and L/D of stone column over two levels each following the principles of 23 factorial experimentation which enables to quantity the relative effect of each factor as well as effect of interaction among the furthers on response of interest (capacity of stone column and critical L/D).

Keywords: *Stone Column, Index and Engineering properties, Load carrying capacity and settlements.*

INTRODUCTION

Almost all Civil Engineering structures are constructed on or in or with the soil. The load from superstructure and substructure are ultimately to be supported by the soil. Ground improvement can be done in soft or weak soils by mechanical, hydraulic and physical and chemical modification. Stone columns are vertical columns of compacted aggregate formed through the soils to be improved. The stone can be compacted with impact

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methods, such as with a falling weight or an impact compactor or with a vibro float. These are used to increase bearing capacity, improve the drainage conditions and environment control, reduce foundation settlements, improve slope stability, reduce seismic subsidence, and reduce lateral spreading and liquefaction potential, control the deformation and accelerate consolidation, permit construction on loose/soft fills.

The stone columns can be effectively used to improve the bearing capacity and to reduce settlements of a raft or footing supported in soft clays. Stone columns may either be free floating or end bearing type depending on the load transfer mechanism. Soil type, its strength and the dimensions of stone column are the other factors which will have an effect on capacity and settlement behaviour of this type of stone columns.

OBJECTIVES OF PRESENT STUDY:

1) To study the effect of Consistency Index (IC), Length/diameter ratio (L/D) of stone column, Liquid limit (LL)

2) To study the effect their interaction effect on Load carrying capacity of the stone column penetrating soft clays.

3) To study the effects on lateral and vertical extent of bulb formed owing to the bulging of stone column upon loading.

4) To develop and empirical equations to predict load carrying capacity of stone column and extent of bulging accounting for all the influencing factors, and validate the same with reported results.

REVIEW OF LITERATURE

Bryanet al (2007) described the technique, applicable soil types, settlement and bearing capacity calculations, recent research areas and an Irish case study. Where ground conditions are suitable, stone column solutions have been shown to be more cost effective than trench fill in excess of 2m depth. Murugesan and Rajagopal (2010) investigated the qualitative and quantitative improvement of individual load capacity of stone column by encasement through laboratory model tests conducted on stone columns installed in clay bed prepared in controlled condition in a large scale testing tank.

The load tests were performed on single as well as group of stone columns with and without encasement. Demiret al (2013) conducted small scale model tests in the

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lab on unreinforced and reinforced soft clay. The test results indicate that the Stone column improves bearing capacity of clay bed and decreases settlement. Kameshwarrao et al (2011) to evaluate the behavior of stone column as Vertical reinforcement to improve bearing capacity of soft clays.

The modification is in the form of introducing marginally small percentage of Sand/Stone Dust and lime to the conventional granular material. Malarvizhi and Ilamparuthi (2004) the ultimate bearing capacity of reinforced stone column and stone column treated beds are three times and two times that of the untreated bed.

MATERIALS AND METHODS

A. Materials:

The soils used in the present investigation are obtained from two different locations namely Mydukur and Kamalapuram near Kadapa, Stone columns and stone dust and all Index, Engineering properties for two clayey soils and stone dust used. By using stone columns the net safe bearing capacity, load settlement and vertical bulging of stone columns in present investigation compared with predicated quantity.

B. Methodology:

The centre of the cylindrical tank was properly marked and a PVC pipe of the diameter 20mm was placed at the centre of the tank. Around this pipe, clay bed was formed. The clay layer was tamped with a thumb frequently and gently to expel air during the process of filling. The stone required to form the column was carefully charged in the tube in the form of layers. Each layer was compacted using 12mm diameter rod attached with enlarged base. As the compaction of column was in progress, simultaneous withdrawal of PVC pipe was done. After the column was formed to the full length, test beds were left for curing for 24 hours under controlled conditions.



Fig: 1 Installation of stone columns

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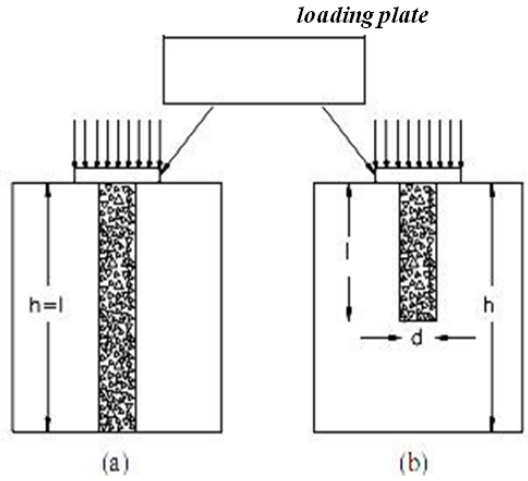


Fig: 2 Loading on Composite bed

The laboratory experiments were carried out using stone columns having a diameter of 20mm. In order get the require L/D of 2.5 and 10, the length of the stone columns is kept equal to 50mm and 200mm respectively. Certain tests were conducted on stone columns having length equal to 80mm, 120mm, 160mm and 235mm also in order to study the effect of L/D on capacity of stone column. The L/D ratios of the stone columns tested are 2.5, 4, 6, 8, and 10. Load test was conducted on raft operated by a single column of diameter 20mm for various L/D ratios on standard loading frame as a strain-controlled test. The size of the steel plate of adequate thickness and rigidity may be based on the effective tributary soil area of the stone column for a single column.

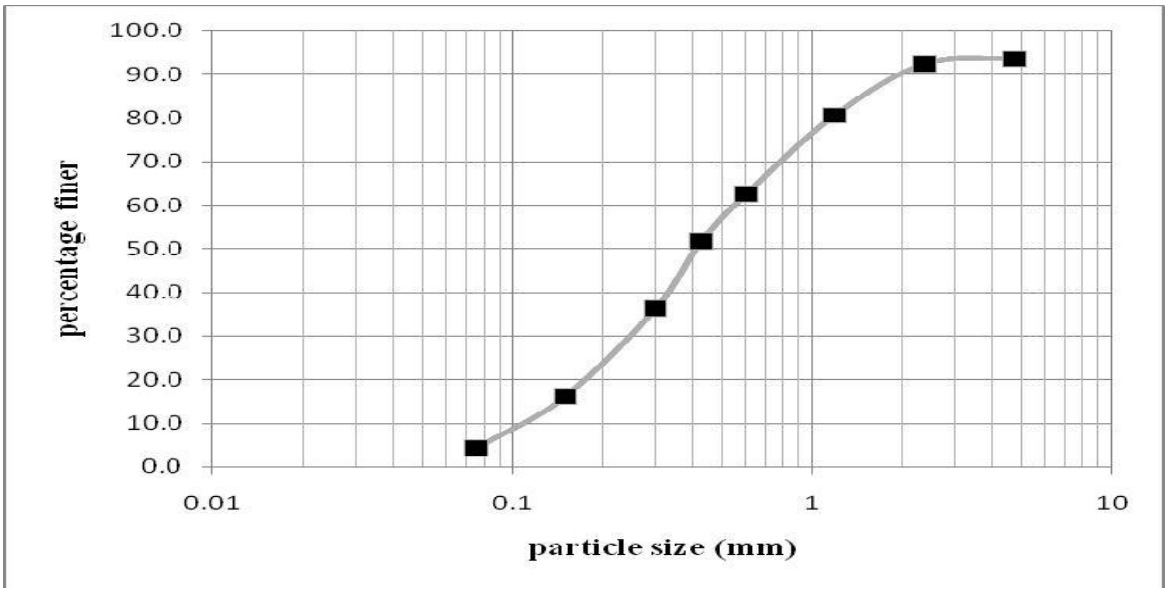
Table 1: Properties of clay tested

Property	**Soil-A**	**Soil-B**
Gravel (%)	2.65	6.4
Sand (%)	30	14
Silt + clay (%)	67.9	79.42
Liquid limit (%)	**98**	**56**
Plastic limit (%)	33.5	27.5
Plasticity index (%)	63.52	28.5
Is Classification (%)	**CH**	**CH**
Free Swell Index (%)	200	90

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Table 2: Properties of Stone Dust

Property	**Value**
Gravel (%)	5.2
Sand (%)	90.6
Silt +Clay (%)	4.2
Effective Size,D_{10}(mm)	0.12
Effective Size,D_{30}(mm)	0.27
Effective Size,D_{60}(mm)	0.57
Coefficient of uniformity, C_U	4.82
Coefficient curvature, C_C	1.03
IS Soil Classification	**SW**



Graph 1

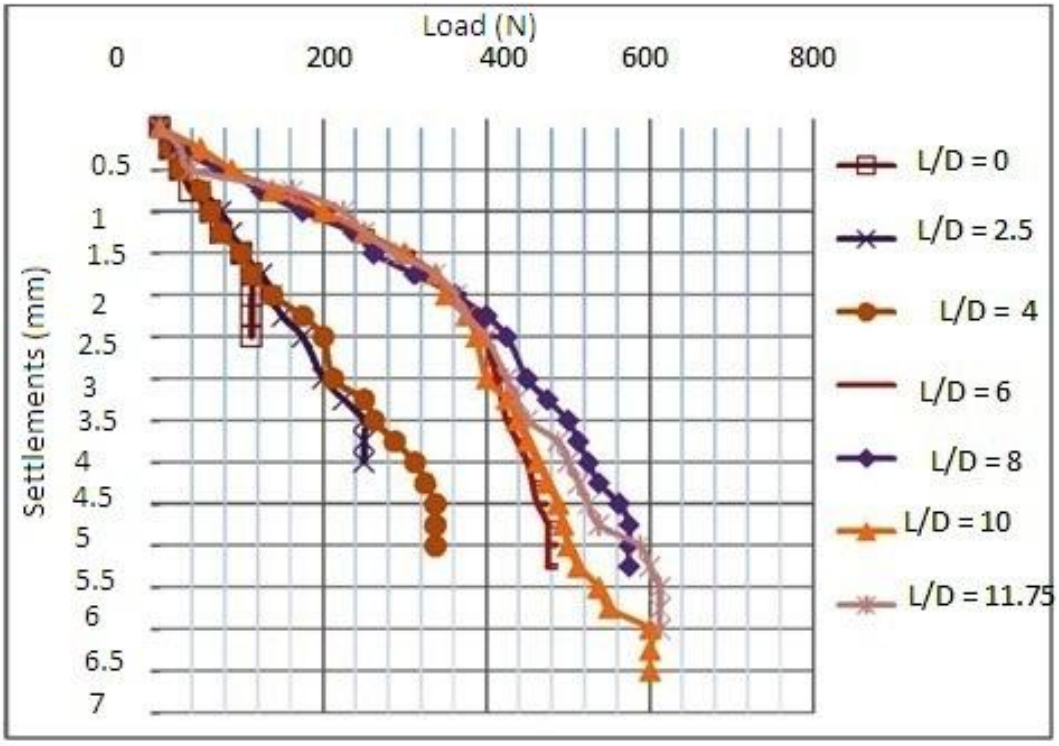
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RESULTS AND DISCUSSIONS

A series of load tests are conducted on soil bed prepared with or without stone column in laboratory in a model test tank by simultaneously varying three factors namely L/D,IC and LL each one over two levels giving rise to 23factorial experimental. The two levels chosen for L/D ratio, Consistency Index & Liquid Limit are presented below.

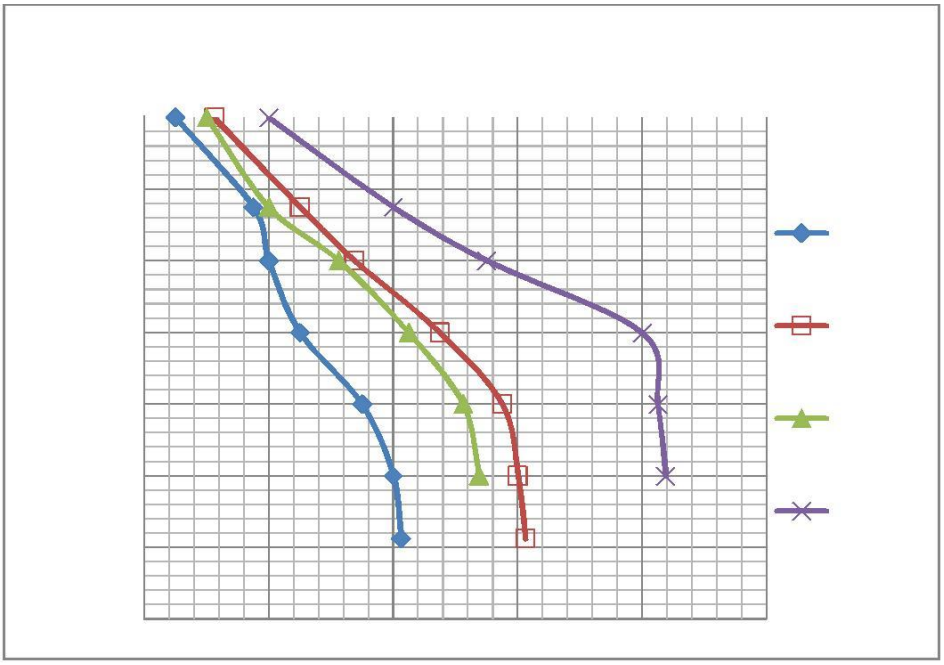
Table 3

S.NO	Factor A (L/D) ratio		Factor-B Ic		Factor-C (LL)	
	High	Low	High	Low	High	Low
1.	2.5	10	0.3	0.8	98	56



Graph: 2 Load Vs Settlements for Varying L/D ratios

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Graph: 3 Ultimate Capacity Vs Load at LL (98) for Different Ic

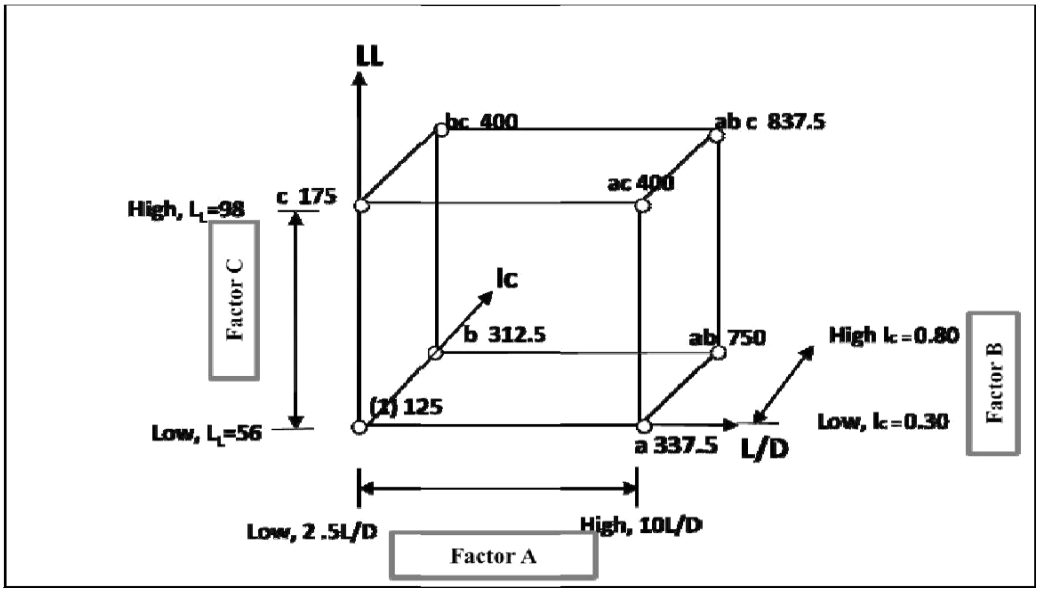
Table: 4

S.No	L/D Ratio	Load carrying capacity in N (soil A, LL= 98)				Load carrying capacity in N (Soil B, LL= 56)			
		I_C=0.30	I_C=0.50	I_C=0.65	I_C=0.80	I_C=0.30	I_C=0.50	I_C=0.65	I_C=0.80
1	0	50	100	112.5	200	18.75	56.25	62.5	137.5
2	2.5	175	200	250	400	125	137.5	150	312.5
3	4	200	312.5	337.5	550	187.5	225	300	437.5
4	6	250	425	475	800	225	325	400	725
5	8	350	512.5	575	825	287.5	450	525	737.5
6	10	400	537.5	600	837.5	337.5	475	575	750
7	11.75	412.5	-	612.5	-	337.5	-	581.5	-

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Table: 5 Ultimate capacity of Stone Column for Factorial Representation

S.No	Size of stone column in mm	Depth of the stone Stone coloum in mm	Consistency Ic	Liquid limit LL	Experimental Label	Load Carrying capacity (N)
1	2.5	50	0.3	56	1	125
2	10	200	0.3	56	a	337.5
3	2.5	50	0.8	56	b	312.5
4	10	200	0.8	56	ab	750
5	2.5	50	0.3	98	c	175
6	10	200	0.3	98	ac	400
7	2.5	50	0.8	98	bc	400
8	10	200	0.8	98	abc	837.5
9	-	No stone column	0.3	56	$_a1$	18.75
10	-	No stone column	0.8	56	$_b1$	137.5
11	-	No stone column	0.3	98	c^1	50



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In 23 factorial designs, the average effect of a factor may be determined as the change in the response produced by a change in the level of factor a verage dover the two levels of other factor. Now, the effect of the L/D ratio (Factor A) when IC (Factor B) and LL (Factor C) are at the low level is [a-1]. Similarly, the effect of L/D ratio (Factor A) when IC (Factor B) is at the high level and L L (Factor C) is at the low level is [ab-b]. The effect of L/D ratio (Factor A) when LL (Factor C) is at the high level and IC(FactorB) is at the low lev el is [ac-c]. Finally, th e effect of L/D ratio (Factor A) w hen both IC (Factor B) and LL (Factor C) are at the high level is [abc-bc]. Thus, the average effect of (Fact or A) is just the average of these four, or Effect of factor "A" on load carrying capacity of stone column is presented by

$A = {}^{1/4}(a + ab + ac + abc - 1 - b - c - bc)$

$= {}^{14}(337.5 + 750 + 400 + 837.5 - 125 - 312.5 - 175 - 400)$

A=312.58 units.

$B = 1/4\ 1(b + ab + bc + abc - 1 - a - c - ac)$

$= 14\ (312.5 + 750 + 400 + 837.5 - 125 - 337.5 - 175 - 400)$

B=315.625 units

$C = 1/4\ (c + ac + bc + abc - 1 - a - b - ab) = 14\ (175 + 400 + 400 + 837.5 - 125 - 337.5 - 312.5 - 750)$

C= 71.875 Units

CONCLUDING REMARKS:

1) Ultimate capacity and load-settlement behavior of a stone column are dependent on dimensions of the stone column represented by L/D ratio, state of soil mass and soil properties represented by Liquid limit (LL) and Consistency index (IC).

2) Ultimate capacity of a stone column increases with L/D ratio. Up to certain critical L/D, beyond which three will be no further increase in ultimate capacity with L/D.

3) Critical L/D ratio of a stone column is a function of IC of a soil and is independent of soil type. A regression model is developed to predict critical L/D ratio in terms of IC which is validated using results from literature.

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4) The effect of main factors LL, IC and L/D as well their interaction effect on ultimate capacity is quantified using the principle of 23 factorial experimentation. L/D ratio is found to have dominating influence on load carrying capacity of stone column followed by IC, interaction effect of IC&L/D (IC * L/D) and LL in that order.

The details of 23 factorial experimentation, materials used, series of tests conducted and testing procedures adapted in this investigation. Results of the load tests on stone columns are presented, analyzed.

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