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Parametric studies on cemented stone column using demolition waste materials

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Abstract. With rapid urbanization and industrialization in the recent times, the available useful land is diminishing for development of the commercial, industrial and transportation purposes particularly in the urban areas. This has necessitates the use of land having weak strata particularly soft soil deposits. To minimise the construction problems associated with these soils, ground improvement is done quite frequently on the sites. Amongst the numerous ground techniques adopted to improve properties of the weak soils; use of stone column is one such approach used widely for several applications in the fields. The concept of stone column installation involves replacement of 10-35% of weak soil with another gravelly material to form a stiffer composite mass of granular cylinder.

In the present study, an exhaustive laboratory testing work was undertaken to study the improved strength properties of soft clay soils collected from Nagpur city, Maharashtra State, India on insertion of stone column. Stone columns are placed single and in group with triangular arrangement. Demolition waste material is attempted as a replacement to the natural aggregate with marginally small doses of cement for stone column preparation. Further the effects of varying length (L) to diameter (D) ratios (i.e. L/D ratio) of stone columns on the strength properties were analyzed.

Study shows an overall improvement in the load carrying capacity of clay beds on insertion of stone columns. Laboratory testing program confirms the possible use of demolition waste for stone column construction as the strength improvement is nearly 60 – 75% of the natural aggregate stone column.

Keywords: Stone column, demolition waste, strength properties

1 Introduction

In 1830, probably for the first time, stone column technique was used by the French Military Engineers as support system to the heavy foundation in soft marine sediments. Reviewed literature shows that, studies on stone columns use were limited till 1950's but lateron the technique became widely popular especially in Europe and United states.

In the conventional constructions, processed stone or coarse grained materials (sizes varying from 75 mm to 2 mm) are used with partial replacement of unsuitable soil (≈ 20% – 35%). Typically the stone column diameter is 60 – 90 cm and its length is 5 – 10 m depending upon the conditions and requirements at the site [1, 2]. The technique proved to be advantageous as it increases load carrying capacity of weak grounds. Also, reduction in total and differential settlements of structures is seen.

Depending upon the condition of soils, we can construct stone columns either as end bearing columns resting on firm stratum underlain the soft soils or floating column wherein the tip of column embedded within the soft soil layer. In both the types, if the column length is more than five times the diameter, bulging is observed in the top portion (depth ≈ 2 to 4 times the shaft diameter) [2].

The magnitude of bulging depends upon applied loaded form i.e. when load is applied through rigid foundation base over an area greater than column diameter; it increases the vertical and lateral stresses in the surrounding soils. The larger bearing area together with the additional support of stone column results in less bulging and greater ultimate load capacity with less settlement. The local bearing type of failure (mostly punching type) is also reported in some cases especially when stone columns are placed in a group.

To improve effectiveness of stone column by restraining the lateral bulging under loading, some of techniques proposed by the researchers are;

a. provision of skirting around the stone column or group of stone columns,
b. geotextile encasement of the column,
c. use of several reinforcing geofabric
d. incorporation of randomly distributed reinforcing fibers in sandy fill material,
e. stone column with vertical nails (small-diameter steel bars)
f. stone columns strengthened by additives

Limited studies are available on the use of cement [3, 7 and 10] and waste [8, 11 and 12] materials for stone column construction.

In the present work, demolition wastes (DA) is used as replacement to the natural aggregate (NA) for stone column models with cement (4 %). The test program was done in two phases viz material testing and model (small and large scale) tests. Here, results of large scale model tests are discussed. The nominal mix proportion used in test model preparation is given in the Table 1.

Table 1: Mix proportion adopted for stone column model

Sr. No.	Material	Specification	Mix Proportion
1	Coarse Aggregate	Passing through 20 mm IS sieve and retained on 10 mm IS sieve	50%
2	Fine Aggregate	Passing through 4.75 mm IS sieve	50%
3	Coarse sand	Retained on 2 mm IS sieve	25% of (1+2)
4	Cement	Ordinary Portland Cement	4% of (1+2+3)
5	Water	Potable Water	5% by volume

The addition of cement (4%), the behavior of column becomes semi-rigid. This has helped to minimize the lateral bulging under axial loading and intern increases the carrying capacity of unit cell of stone column.

The collected soil and aggregates (natural and demolition) was processed as per IS code provisions in the laboratory and their properties were examined. The properties of soil, natural aggregate and demolition aggregate are tabulated below in the Table 2 & 3 respectively. Total five combinations for model preparations were planned namely – 100% NA, 100% DA, 25%NA + 75% DA, 50% NA + 50% DA, 75% NA + 25% DA.

Table 2: Physical and Mechanical properties of soil

SR. NO.	SOIL PROPERTIES	RELEVANT IS CODES	RESULTS	TYPICAL RANGE*
1	Natural Moisture Content (%)	IS 2720 (Part 2): 1973	18.24	10-60
2	Specific Gravity	IS 2720 (Part 3): 1980	2.40	2.4-2.9
3	Clay: % (< 0.002 mm)	IS 2720 (Part 4): 1985	80.12	-
4	Silt: % (0.002 – 0.075 mm)		19.88	-
5	Soil Classification	IS 1498: 1970	CH	-
6	Liquid Limit (%)	IS 2720 (Part 5): 1985	50.72	26-85
7	Plastic Limit (%)		24.42	15-50
8	Shrinkage Limit (%)		11.80	9-25
9	Plasticity index (%)		26.30	10-44
10	Free Swell Index (%)	IS 2720 (Part 40): 1977	35	15-40
11	Cohesion, C_u (kN/m^2)	IS 2720 (Part 13): 1986	32.35	20-65
12	Frictional angle, Φ_u (°)		13.30	7-22
13	Bulk Density (kN/m^3)	IS 2720 (Part 8): 1983	18.88	14-20
14	Maximum Dry Density (kN/m^3)		15.38	14-20
15	Optimum Moisture Content (%)		21.15	12-40
16	Unconfined compressive Strength, q_u (kN/m^2)	IS 2720 (Part 10): 1991	50.85	25-70
17	Activity	SP 36-1-1987	0.325	0.2 - 4
18	Modulus of Elasticity (kN/m^2)	IS 9221:1979	3100	500 - 6000
19	Poisson Ratio, μ		0.40	0.3 - 0.5
20	Test bed moisture content (%)	--	28	-
* values are referred from past available literatures				

Table 3: Properties of natural and demolition aggregate [14, 15]

SR. NO.	PROPERTIES	RELEVANT IS CODES	NA	DA	TYPICAL RANGE*
1	Specific gravity	IS 2386 (Part 3): 1963	2.96	2.59	2.5-3.0
2	Water absorption (%)		1.28	3.69	1.65-6.0
3	D_{10} (mm)	IS 2386 (Part 1): 1963	10.64	9.72	2-11
4	D_{30} (mm)		14.35	14.36	7-15
5	D_{60} (mm)		19.90	19.31	14-20
6	Coefficient of curvature (C_U)		1.871	1.098	1.5-2.2
7	Coefficient of uniformity (C_C)		0.972	1.98	0.8-1.2
8	Gradation symbol		GP	GP	--
9	Size range (mm)	--	2-14	2-14	--
10	Maximum dry unit weight (kN/m^3)	IS 2386 (Part 3): 1963	18.46	15.69	17-22
11	Minimum dry unit weight (kN/m^3)		15.54	13.73	14-18
12	Minimum void ratio (%)		37.00	39.65	--
13	Maximum void ratio (%)		47.50	47.19	--
14	Los Angeles Abrasion Test (%)	IS 2386 (Part 4): 1963	12	32.52	11-15
15	Aggregate Impact ValueTest (%)		10.90	31.98	9-15
16	Aggregate CrushingValue Test (%)		10.53	20.17	8-14
***values are referred from past available literatures**					

2 Test Results

The axial compressive strength of stone column models prepared with different mix proportions on 7 days curing was tested. The maximum strength is observed for column with NA. However, result is promising for the mix 25% NA + 75% DA amongst all other combination, where the observed strength is 97% of NA column strength.
All the tests on stone column models embedded in soil were done in a large tank of size 60 × 60 × 90 cm. Before test conduction, various steps followed are preparations of soils bed (desired density 90 to 95%) in layers, creation of borehole in soil bed and inplace column casting, etc. The typical test setup is as shown in the Fig. 1.

The load-settlement observations of all test models for various L/D ratios are presented in the Fig 2. The method double tangent was used to determine the ultimate load intensity from the curve. It was observed that, on insertion of stone column, the load carrying capacity of the soil increases. The load-settlement curve for virgin soils during the test was somewhat parallel to the ordinate axis; on insertion of column the curve shift horizontally and steadily becomes parallel to horizontal axis. This shows the effects of semi-rigid column insertion in the clay, which make the system slightly stiffer than the earlier one.
The result for combinations when compared shows, the strength improvement is more for NA column. For the mix proportion, 25% NA + 75% DA, the improvement in load intensity is at par with NA column especially for L/D ratio 6 & 8.

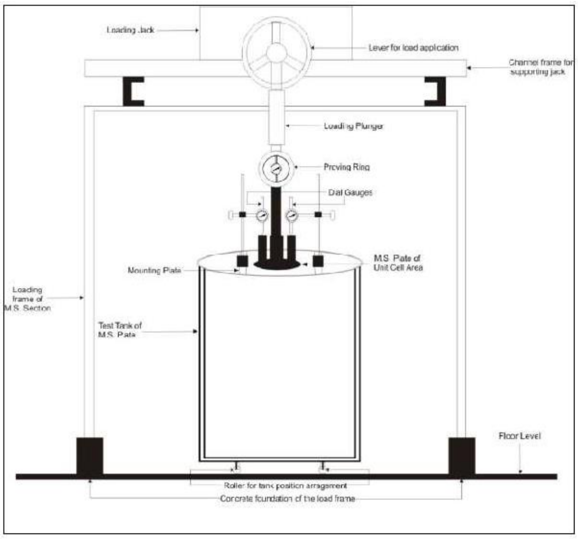
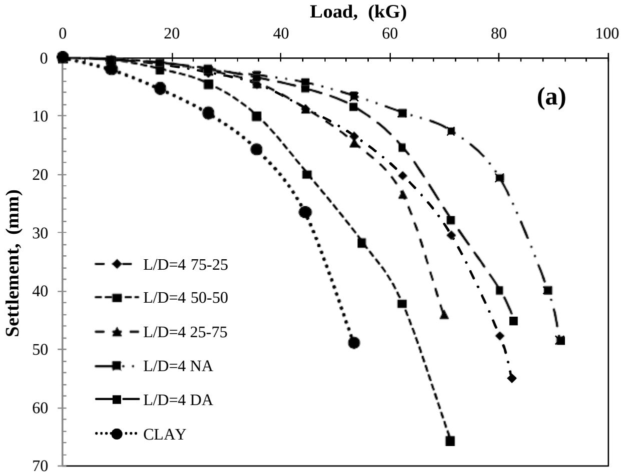
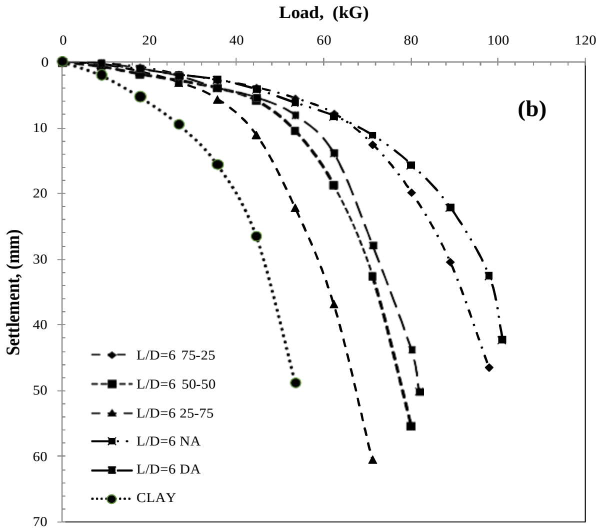


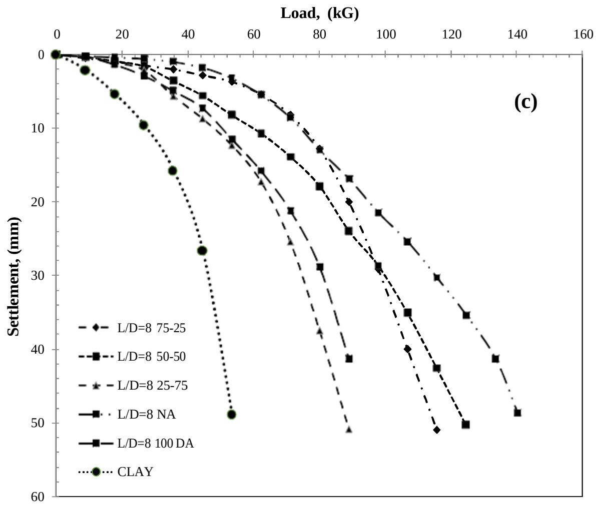
Fig. 1 Test Setup



(a) L/D ratio 4



(b) L/D ratio 6



(c) L/D ratio 8

Fig. 2 Load-settlement curves for stone column tested in large tanks

3 Conclusions

- An experimental program was carried out shows noticeable increase in the load carrying capacity of soil with stone columns insertion.
- With cemented stone column, the lateral bulging reduces on axial loading as the mix column mix became semi-rigid which helps in increasing capacity of column.
- In case of column with demolition aggregates, the strength achieved is between 60 – 75% of that observed for column with natural aggregate. This observation confirms the possible use of demolition aggregates in stone column constructions.

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