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Study on composite stone column in soft kaolinitic clay

Etudier sur la colonne composee de pierre dans l'argile de kaolinitic douce

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ABSTRACT
An improvement in the bearing capacity and reduction in settlement of soft deposits can be effected by the installation of stone column. The cost consideration for utilizing the poor and marginal sites efficiently have therefore becomes a subject of profound interest for the employment of stone column. The stone columns provide strength reinforcement to the soil and due to their relatively high modulus, a large portion of the load applied to the ground surface is transferred to them. The stone columns act as vertical drains and accelerate consolidation. From the economic point of view Composite Stone Column and Floating Stone Column gives saving of about 30 % in stone aggregate, besides marginal reduction in ultimate load capacity. i.e. 0.56 % and 1.13 %, respectively.

RÉSUMÉ
Une amélioration dans la capacité de maintiens et la réduction dans le règlement de dépôts doux peut être effectuée par l'installation de colonne de pierre. La considération de coût pour utiliser les pauvres et les sites marginaux ont efficacement devient donc un sujet d'intérêt profond pour l'emploi de colonne de pierre. Les colonnes de pierre fournissent le renforcement de force au sol et en raison de leur relativement haut modulus, une grande portion du chargement appliqué à la surface de sol leur est transférée. Les colonnes de pierre servent des égouts verticaux et accélèrent la consolidation. Du point de vue l'économique Colonne de Pierre Composés et Flotter la Colonne de Pierre donnent pour épargner d'environ 30 % dans le total de pierre, la réduction en plus marginale dans la capacité de chargement ultime. c.-à-d. 0,56 % et 1,13 %, respectivement

1 INTRODUCTION

Due to enormous population growth, a scarcity of land having sound foundation is faced for human habitation. The major problems of stability and settlement of foundation soils has forced the Geotechnical Engineers to innovate new ground improvement techniques for utilizing the weak or difficult subsoil condition. The ground improvement techniques are now sufficiently well developed to attain the desired strength and compressibility.

The introduction of shortening of drainage paths by way of sand drains also result in improvement in physical properties. It is also seen that introduction of soil reinforcement in accordance with the direction of principle "tensile strain'' improves the bearing capacity of soil. In order to reduce, in cohesive layers, the time needed to reach a high degree of consolidation, vertical drains are used in combination with preloading. In soft compressible cohesive soils, granular piles/stone columns generally are the most ideal choice from the point of view of technical feasibility as well as in terms of low energy utilization. Stone columns were introduced in France around 1830. Moderate increase in allowable bearing pressure and considerable reduction of settlement are the primary benefits of this ground improvement technique. In addition, by virtue of their high perviousness, granular piles act as free drains and permit rapid dissipation of excess pore water pressures due to static and seismic loading.

2 SCOPE

Scope of present study is to evolve experimental model study of composite stone columns, full-length stone column and floating stone column in Soft Kaolinitic Clay in the laboratory. Model study is very much useful to standardize installation technique, load-deformation behaviour, settlement rate, load resistance for unit settlement during progress of load test, shear strength and obtaining initial tangent modulus of composite soil mass.

3 SAMPLE PREPARATION AND INSTALLATION

The used notations are mentioned below
FLS: Full Length Stone Column,
FTS: Floating Stone Column,
CSAA: Composite (Diameter) Stone Column,
CSAS: Composite (Diameter & Material) Stone Column.

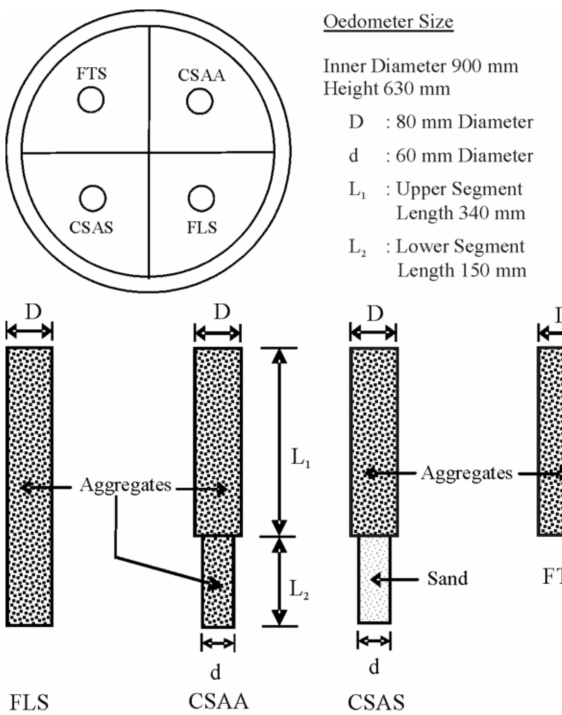


Figure 1: Schematic Diagram of Stone Columns (Plan & C/S)

Properties of Kaolinitic clay, coarse aggregate and sand used in the experimental program are described in Table-1 and Table-2 respectively.

Table 1: Properties of Kaolinitic Clay

Sr. No.	Property	Value
1	Specific Gravity	2.579
2	Liquid Limit	71.0 %
3	Plastic Limit	33.0 %
4	Shrinkage Limit	29.0 %
5	Plasticity Index	38
6	Soil Classification	CH
7	Initial Vane Shear Strength	17.77 kPa
8	Type of Clay	Kaolinite

Table 2: Properties of Coarse Aggregates and Sand

I. S. Sieve Size	Coarse Agg. % Finer	Sand % Finer
12.50 mm	100	---
10.00 mm	89	---
6.30 mm	62	---
4.75 mm	39	---
2.36 mm	5.5	100
1.18 mm	0	72
0.60 mm	---	36
0.30 mm	---	20
0.15 mm	---	0
Uniformity Coefficient (C_u)	2.571	4.419
Coefficient of Curvature (C_C)	1.116	1.082
Angle of Int. Friction (Ø)	52.35^o	37.5^o

Powdered Kaolinitic clay is mixed with water approximately double the liquid limit to form slightly stiff slurry. Slurry is passed through "a fine meshed Nylon net" to form a uniform paste of clay free from air and lump. Oedometer is filled with this slurry up to top and then allowed to consolidate under its own weight for fifteen days. Uniform load was applied to the top of perforated plate for one month. The water collected on plate is siphoned off daily. After loading, top plate is removed, the vane shear strength of the prepared soft clayey bed is measured. It was in the range of 10 to 25 kPa. After the required strength is attained, the top surface of the soil is covered with a polythene sheet so that moisture content remains same throughout the experimental schedule.

In the laboratory model, a borehole in the soft bed is made by 80mm diameter steel tube (outer casing) and 60mm diameter steel tube (inner casing), which are open at both the ends. A guide is used to hold the pipe tightly in vertical position. Simple boring method is adopted for installation of stone columns. For the installation of stone columns fixed quantity 500 gm of aggregate/sand is taken for each layer and compacted 20 times with a hammer weighing 2.6kg with height of fall of 5cm. The energy for compaction was applied 0.6176kg-cm/layer/cm^3. The consumption of stone aggregate is 4.675kg for Full Length Stone Column for a length of 490 mm.

4 TESTING PROCEDURE

After preparation of sample and before installation of stone column, vane shear strength and water content is measured preferably depthwise every time. After installation of stone column the entire area is covered with 2cm layer of sand. Bearing plate of size (10 x 10 x 0.5) cm is placed such that the centroid of the plate coincide with the centroid of the stone column. Load is applied through a jack seated on the plate. Two sets of dial gauges with sensitivity of 0.01 mm are fixed diagonally opposite to cross check the settlement and to record the settlement of the stone column. The load is applied in increments, say about 20% of the anticipated failure load. Settlement is observed for each increment of load after an interval of 0.25, 1, 2, 5,10, 20,40 and 60 minutes and thereafter hourly intervals until the rate of settlement becomes less than 0.02 mm per hour or kept for 48 hours whichever occurs earlier. Load is increased up to the total settlement of 25mm to 35mm or distinct failure pattern is obtained on the graph of load v/s settlement.

After the completion of test the load is removed slowly and vane shear apparatus measures the shear strength. To obtain moisture content profile, bore hole is made near the stone column and samples are taken depth wise.

5 PRESENTATION, ANALYSIS AND DISCUSSION

For the performance comparison of different type of stone columns in soft Kaolinitic clay, the tests performed are as follows:

1) Load - Settlement Measurement
2) Moisture Content Measurement
3) Vane Shear Strength Measurement and

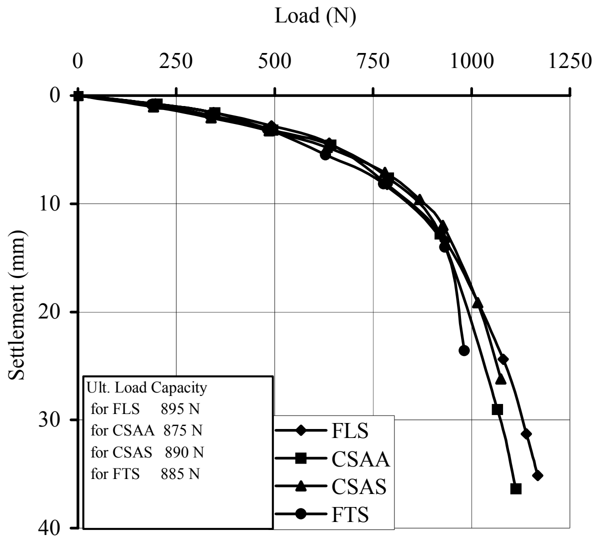


Figure 2 : Load - Settlement Curves

Load-Settlement curves shows the load resistance offering is quite high up to a settlement of 8.3mm, 8.9mm, 9.2mm and 9.5mm, moderate in between 8.3 to 15 mm, 8.9 to 14 mm, 9.2 to 14.7 mm and 9.5 to 14.7 mm settlement and after 15mm, 14mm, 14.7mm, and 14.7mm settlement resistance offering rate is quite low in FLS, CSAA, CSAS and FTS, respectively.

In the initial stage of the Load-Settlement curves when the load is about 375 N for 2 mm settlement, it is observed that the critical length of stone column is not fully mobilized in transferring the load. But when load is doubled, say about 790N, settlement increases by four times i.e. from 2mm to 8mm. This nature of curve indicates the critical length of stone columns, now fully mobilized in transferring the load.

FLS gives maximum load carrying capacity while it is minimum in case of CSAA under the same rate of loading condition. Load carrying capacity of CSAS (890N) is quite equal to that of FLS (895N) while in case of FTS ultimate load capacity is very much nearer to CSAA, but less compared to FLS and CSAS.

If we consider the Initial Tangent Modulus of FLS as standard value for comparison, it is observed that the CSAA offers more stress towards deformation during initial stage of loading, while CSAS gives minimum value of modulus, which shows that resistance towards deformation is less but it may improve with progress of loading. For FTS value of modulus is quite near to modulus value of FLS.

The reduction in settlement of CSAS compared to FLS is 25.4 %, while the decrease in ultimate load capacity is marginal (0.56%).

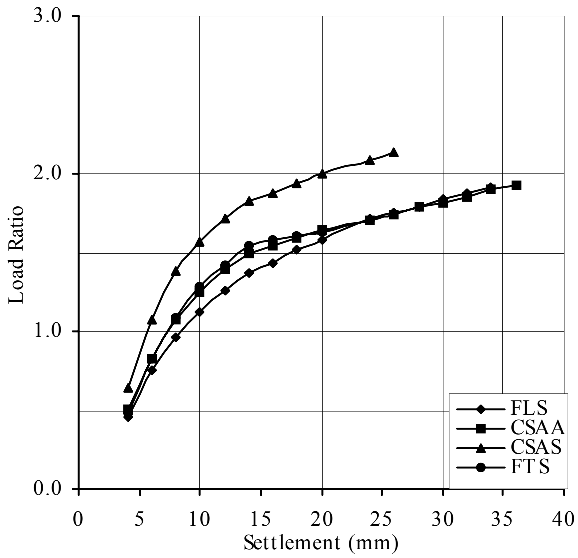


Figure 3: Settlement v/s Load Ratio

In case of CSAS, the Load Ratio (1.382) and Load Resistance (52.50N/mm) are maximum at 8 mm settlement compared to all type of stone columns, while minimum value of Load Ratio (0.963) and Load Resistance (42.50N/mm) are observed in case of FLS, which shows CSAS is quite effective in transferring the load with respect to increment of settlement. Refer figure 3 and figure 4.

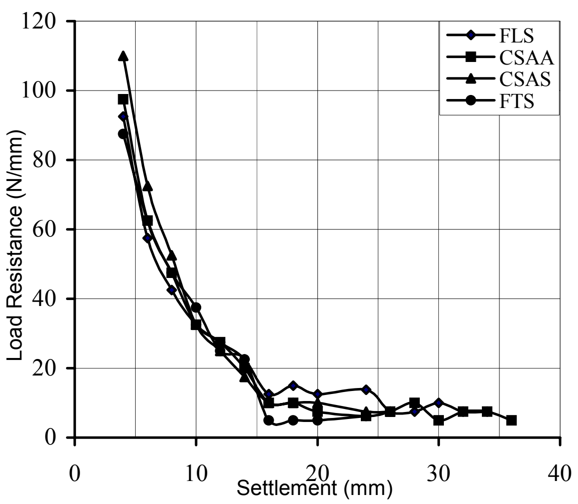


Figure 4: Settlement v/s Load Resistance

Fig.: 5 shows shear strength of virgin soil and load tested soils of all type of stone columns. Shear strength of virgin soil varies curvilinear sagging type. It means strength is higher at upper portion (5cm depth) of the soil bed and then decreases gradually up to 15 cm depth and it again increases for further depth. While all strength curves of load tested soils shows an increase in strength compared to virgin soil depthwise due to reduction in moisture content from composite soil after load test on stone column. But at 10 cm depth percentage increase in shear strength is quite more compared to other depths, and it is due to effect (phenomenon) of maximum bulging occurring in stone column at that depth. Also the maximum percentage reduction in moisture content is seen at the same depth.

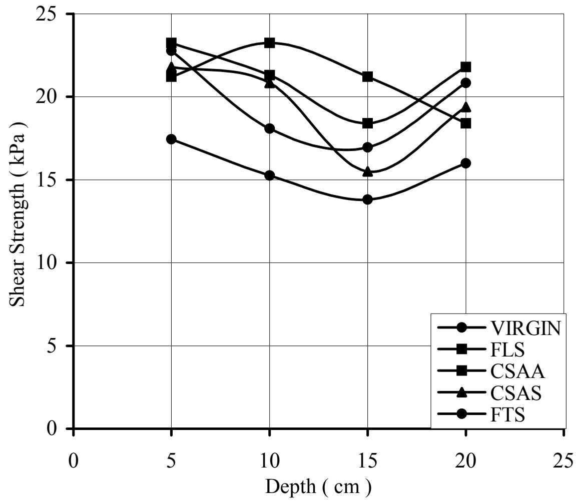


Figure 5: Depth v/s Shear Strength

Fig.: 6 shows the water content profile depthwise before installation of stone column and after the load test. Before installation of stone column, profile shows moisture content at top and bottom of virgin soil is quite same (59% to 61%). Water content increases up to 35cm depth and then it is decreases towards bottom of soil. This nature of profile is due to primary consolidation of virgin soil with provision of drainage faces at top and bottom of soil sample to get the desired strength.

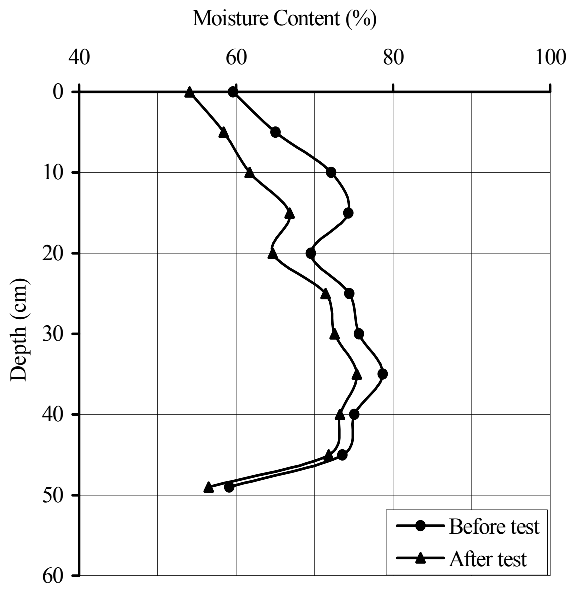


Figure 6: Moisture Content v/s Depth

The curve of moisture content v/s depth load-tested soils (CSAS) shows a higher percentage reduction in moisture content up to 20 cm depth and then it is considerably lower. Maximum percentage reduction in moisture content after load test is at 10 to 15 cm depth, which indicates that maximum bulging may occur at that depth. Refer photograph 1 and photograph 2.

The maximum reduction in moisture content takes place after load test in case of FLS due to shortening of the drainage path. Also, the final vane shear strength of soil increases up to 53.86 % at a depth of 15 cm where maximum bulging occurs.

The maximum reduction in primary consolidation time (t_{50}) is 45.6 % in CSAS compared to virgin soil. Time t_{50} reduces by 12.9 % and permeability increases by 10.57 % in CSAS. Refer Table 3.

The advantage of CSAS over FTS is the provision of lower segment made by local material (sand), which further enhances the effectiveness of drainage; it reduces time $\mathbf{t_{50}}$ by 26 % and increases permeability by 27 %. The maximum increase in permeability for CSAS is 53.8% compared to virgin soil. Refer Table 3.

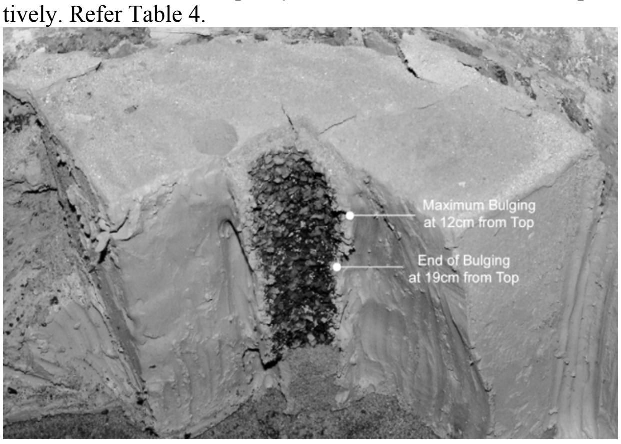
Table 3: Properties of Clay from Consolidation Test

Soil Sample	Time t50 min	Coefficient of Consolidation (CV) cm2/sec	Comp. Index (CC)	Coefficient of Permeability (k) cm/sec
VIRGIN	57	5.0228 x10-5	0.1890	1.330 x10-5
FLS	35	8.1975 x10-5	0.2660	1.829 x10-5
CSAA	33.5	8.8912 x10-5	0.2100	1.967 x10-5
CSAS	31	9.6212 x10-5	0.1818	2.045 x10-5
FTS	42	9.6608 x10-5	0.1818	1.607 x10-5

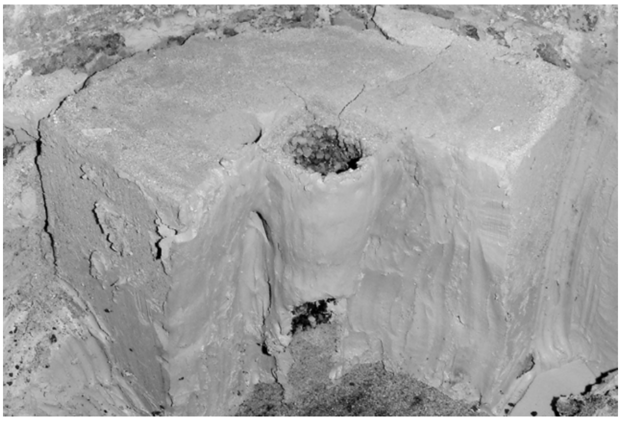
Table 4: Details of Material Consumption

Stone Column	Wt. of Material (kg)		% Consumption w.r.t. FLS	% Saving
	Coarse Agg.	Sand		
FLS	4.675	—	100	—
CSAA	4.135	—	88.45	11.55
CSAS	3.235	0.960	69.23	30.77
FTS	3.280	—	70.16	29.84

From the economic point of view CSAS and FTS gives saving of about 30 % in stone aggregate, besides marginal reduction in ultimate load capacity, i.e. 0.56 % and 1.13 % respectively. Refer Table 4.



Photograph 1 : Failure of stone column



Photograph 2 : Failure of stone column

6 CONCLUSION

Settlement expected at ultimate bearing capacity is less for CSAS compared to others.

The load ratio at any settlement is quite higher for CSAS indicating effective transfer of load.

The critical length (4.25d) is sufficient for all stone columns.

The time required for primary consolidation drops drastically for CSAS.

The provision of lower segment in composite stone columns enhances the drainage.

Though the installation of composite stone columns in field is clumsy, but from the economic point of view CSAS and FTS gives 30% saving in costly aggregates.

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