STUDY ON SINTERED FLYASH AGGREGATE AS COLUMNAR INCLUSIONS ON SOFT CLAY

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ABSTRACT

A stone column is one of the soil stabilizing 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. Due to demand of conventional aggregate in various applications such as buildings, bridges, pavements etc., In this paper, an attempt is made to use the fly ash aggregate (FAA) waste, as column material in the place of conventional coarse aggregate (CCA) to stabilise the soil. Laboratory tests are carried out for one, two and three column of 25 mm diameter surrounded by soft clay with an entire equivalent area loaded to estimate the stiffness of improved ground. Finite-element analyses have also been performed using 15-noded triangular elements with the software package PLAXIS. The numerical results from the FEM are compared with the experimental results which showed good agreement between the results. It is found that the load carrying capacity increases with number of columns but not linearly and load carrying capacity of FAA column is comparable to that of CCA column. Hence, it is concluded that conventional coarse aggregate may be replaced with fly ash aggregate realizing the situation in which cost of column construction is to be reduced, added advantage being effective reuse of fly ash for geotechnical applications.

Keywords: *Stone column, Fly ash aggregate, Conventional coarse aggregate, Finite element method, Soft clay.*

1. INTRODUCTION

Construction sites underline by weak and compressible soils are always has been associated with excessive settlement due to poor strength. These include soft clays, expansive soils, collapsible soils, and high organic soils etc. Such soils are often found near the river banks, along the perimeter of bays and beneath wetlands. They are prone to shear failure and excessive settlements. With the increasing urbanization and industrial zones it is necessary to consider the possibilities of realizing foundations on these areas. So construction projects on these areas require suitable ground improvement technique for better performance of foundation medium. In many ground improvement techniques stone columns are the most preferable and are also widely used to increase bearing capacity and reduce the settlement of foundation medium. The increasing global demand in conventional materials like stones, aggregates, sand etc. requires the use of innovative and cost-effective materials for soil stabilizing techniques.

Flyash is a waste material from thermal power plants with present availability of more than 120 metric tonne per year in India. The problem with fly ash lies in the fact that not only its disposal require large quantities of land, water, and energy, its fine particles, if not managed well, by virtue of their weightlessness, can become airborne. Hence, disposal and management of fly ash poses challenging problems, in the form of land usage, health hazards, and environmental dangers. Hence its utilization in ground improvement will not only create abundant opportunities for its proper and useful disposal but also help in environmental pollution control to a greater extent in the surrounding areas of power plants.

Murugesan and Rajagopal (2010) evaluated the behavior of single and group of ordinary stone column and predicted that the load carying capacity increases with number of columns not in linear. Dipty Sarin Isaac and Girish (2009) studied the influence of column material in the performance of stone column by conducting model tests on soft clay and found that stones are the most effective stone column material and Quarry dust, though a waste product is effective in improving the load deformation characteristics of the soil used. Stalin and Soundara (2009) studied the influence of concrete waste in the performance of stone column through laboratory model test on stone columns installed in clay and concluded that the concrete waste can be a column material in the place of stone aggregate for the improvement of soft clay deposits. Ambily and Gandhi (2004) studied the load settlement behavior of stone column by laboratory model tests and compared the results with finite element methods. Priyadharshini and Mohan Ganesh (2005) reported that the sintered fly ash light weight aggregates can be used as replacement of conventional aggregates in concrete

Table 2. Properties of Aggregates

Properties	Conventional Coarse Aggregate	Fly Ash Aggregate
Aggregate crushing strength (%)	20.73	33.1
Aggregate impact value (%)	16.11	25.7
Aggregate abrasion value (%)	38.3	45.2
Specific gravity	2.76	2.02
Water absorption (%)	0.6	14.38
Maximum dry density (kN/m^3)	16.67	8.1

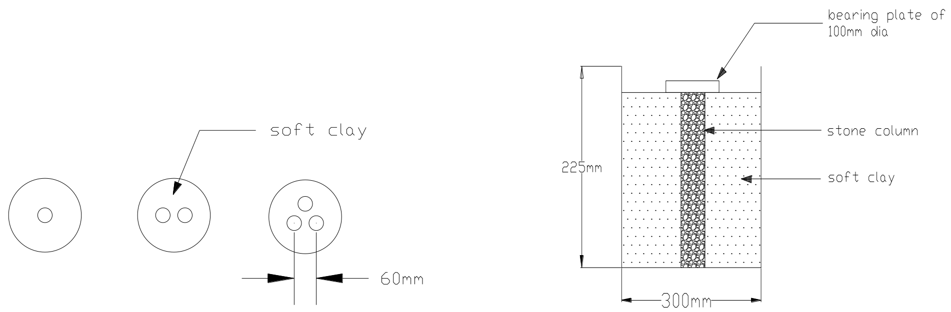


Figure 1. (a) Arrangement of Stone columns (b). Load test Arrangement.

for making some building components such as hollow and solid blocks. In this paper, attempt is made to study the performance of fly ash in aggregate form as column material in the place of conventional stone aggregate for the improvement of soft clay.

2. EXPERIMENTAL WORK

The laboratory experiments were carried out using stone column with diameter of about 25 mm and length of 200 mm. All the laboratory experiments were performed with stone columns surrounded by soft clay. The details of Physical properties of soft clay are summarized in Table 1. Conventional coarse aggregate (CCA) and Fly ash aggregates (FAA) of size varying from 5mm to 10mm were used to form the columns. The details of Physical properties of conventional coarse aggregates and fly ash aggregates are summarized in Table 2.

2.1. Experimental Set –Up

Cylindrical tank of height 225 mm and diameter 300 mm 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 25mm. Experimental set-up comprises of a cylindrical tank filled with soft clay and inserted with one, two and three column of 25 mm diameter with spacing 2.5 times diameter of the column and arranged in triangular pattern. A sand layer of 25 mm thick is placed at top as a blanket. Vertical load is applied over diameter equal to that of stone column. Sand layer of 25 mm height is placed on the clay bed around the column in the case of column alone loaded. The load was applied through a proving ring at a constant strain rate of 1.2mm/min.

Clay bed is prepared at optimum moisture content and maximum dry density. The stone / fly ash aggregate column was installed into the prepared soft clay bed through casing pipe that was already placed while filling the model tank. After placement of required quantity of aggregate, the casing pipe was withdrawn and kept ready for load testing. A schematic view of load test set up is shown in Figure 1 and 2. Load tests were carried out for single, two and three stone and fly ash aggregate columns.

2.2 Test Procedure

After preparing the stone column, the load deformation behavior of the column is studied by loading it in a triaxial loading frame at a strain rate of 1.2mm/minute. Load tests are carried out for single, two, and three columns, loading is applied through a loading plate of 100mm diameter is placed exactly at the center of the stone columns and the load is applied till failure. Load is observed for equal intervals of settlements up to an average deformation of 25 mm.

Table.3. Properties of Materials for Numerical Model.

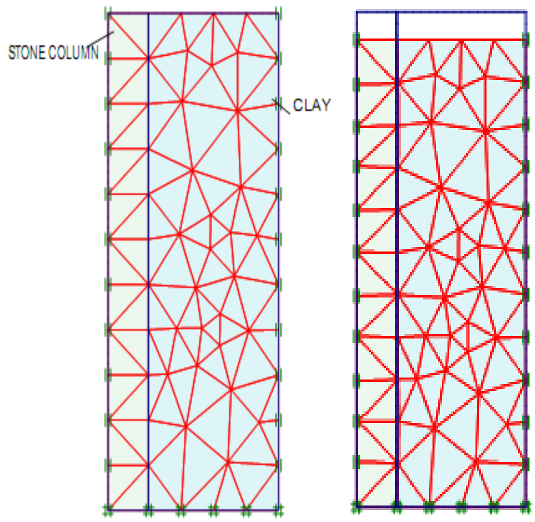
Properties	Clay	Conventional Coarse Aggregates	Fly ash Aggregates
Modulus of Elasticity (E_s)	800 kPa	40000 kPa	18000 kPa
Poisson's Ratio (μ)	0.45	0.3	0.3
Shear Strength (c_u)	6.5 kPa	-	-
Angle of Internal Friction (φ)	-	38°	42°
Dry density (γ_{dry})	12.6 kN/m^3	16.4 kN/m^3	8.1 kN/m^3
Bulk density (γ_{bulk})	17.4 kN/m^3	-	-

Table 1 Index Properties of Soft clay.

Properties	Values
Clay, %	40%
Silt, %	28%
Sand, %	32%
Liquid limit, %	52%
Plastic limit, %	24%
Plasticity index, %	28%
Specific Gravity	2.68
Free swell index, %	60%
Swell classification	High
Soil classification	CH

3. NUMERICAL MODEL

The Numerical analysis is carried out using the commercially available finite-element program PLAXIS, to compare the load settlement behavior with the model test. An axisymmetric analysis carried out using Mohr-Coulomb criterion. A drained behaviour is assumed for all materials. Fifteen noded triangular elements are used for meshing. Along the periphery of the tank (interface between the soft clay and the cylindrical surface of the unit cell), radial deformation is restricted but settlement is allowed. Along the bottom of the tank both radial deformation and settlement are restricted. The basic axisymmetric finite-element mesh and boundary conditions used to represent the stone column and the surrounding clay and the typical deformed mesh for single column is shown in Fig. 2(a). Analysis for a group of columns was also carried out as shown in Fig. 2(b) using an axisymmetric model. All the material properties used in the numerical model are summarized in table 3.



(a) (b)

Figure 2: (a) Finite-element discretization for clay with single column (b) Typical deformed mesh

4. RESULTS AND DISCUSSIONS

4.1 Comparison of Load Settlement Response for CCA and FAA Columns

Figure 3 shows that the load settlement response of conventional coarse aggregate and flyash aggregate column for single, two and three inclusions. The response is same when settlement is less than 2.5 mm, excepting soft clay + 3 CCA columns. Beyond 2.5mm settlement, the load carrying capacity of clay + CCA column is always higher than clay + FAA column. For 2.5mm settlement, the capacity of one, two and three FAA columns are 61N, 126 N and 136 N and the same is 89 N,130 N and 138 N for CCA column.The capacity values of one and two soil + FAA column are 30% and 3% lesser than one and two columns of soil + CCA. But, in three column case, the capacity of soil + FAA column is 6% lesser than the same case with soil + CCA columns (Table 4). However, corresponding to 12 mm settlement, the load capacities of one, two and three columns of FAA are 15%, 15.4% and 16% respectively lesser than that of CCA columns. The reason for the slightly lower value of clay + FAA column is possibly due to the crushing of cement mortar coated over the stone aggregate especially at higher settlements. It may be noted that the capacity of CCA and FAA are almost the same at initial settlement of the column (<2.5 mm).

Table 4. Comparison of Load at 2.5mm settlement for CCA and FAA columns.

Description		Load (N) at 2.5 mm Settlement	Load (N) at 12 mm Settlement
Virgin Clay		24	220
FAA	1 FAAC	61	285
	2 FAAC	126	402
	3 FAAC	136	488
CCA	1 SC	89	335
	2 SC	130	475
	3 SC	138	582

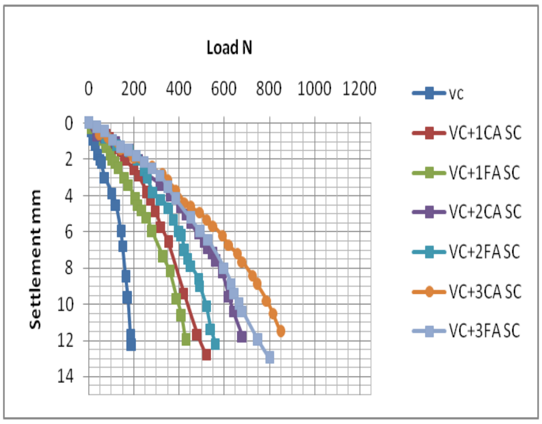
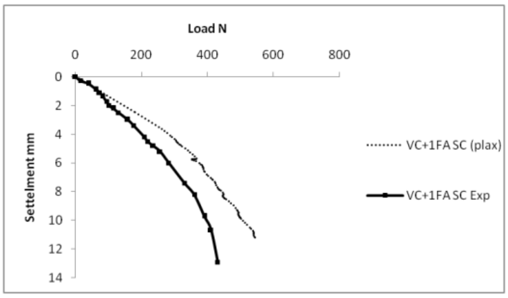


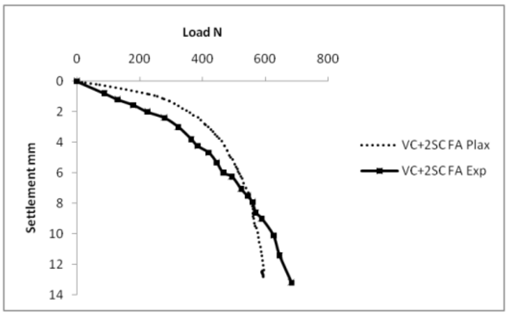
Fig 3. Comparison of Load Carrying Capacity of CCA and FAA columns

4.2. Comparison of Load Settlement Response of Experimental and Numerical Analysis.

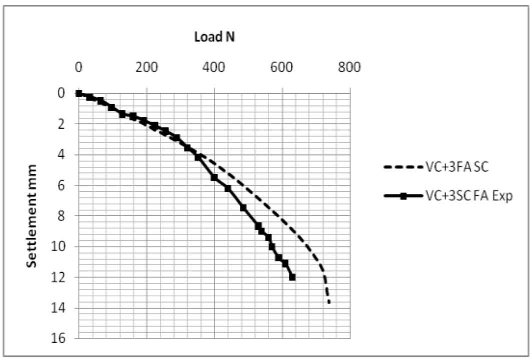
Fig.5 compares the load settlement curves from model test and finite element analysis for single, two and three column of flyash aggregate with clay having 0.4 consisitency index. The ultimate load carrying capacities obtained from the model test and software analysis are given in table 5.



(a).Single stone column



(b).Two stone column



(c).Three stone column

Fig 4. Comparison of Load Settlement Response of Experimental and Numerical Analysis

Table 5 Comparison of Load Carrying Capacity of CCA and FAA columns

Description		Ultimate Load Capacity (kPa)	
		Model Test	FEM
Virgin Clay		60	135
CCA	1 SC	222	262
	2 SC	325	355
	3 SC	345	385
FAA	1 FAAC	153	212
	2 FAAC	315	325
	3 FAAC	340	365

From the table 5 the load carrying capacity increases with increasing number of column inclusions for both conventional coarse aggregate (CCA) and flyash aggregate (FAA). The load carrying capacity from finite element method (FEM) slightly overestimste the load carrying capacity results of experimental tests.
For single flyash aggregate column the increase in ultimate load capacity is 150% for two column 100% and for three column 200%.

5. CONCLUSIONS

From the load Settlement behaviour of improved soil from experimental and Finite element analysis the following conclusions are drawn.

1) The Increase in load carrying capacity of clay treated with single, two and three column of FAA are 2.55, 5.25 and 6.65 times that of Untreated clay.

2) The Increase in load carrying capacity of clay treated with single, two and three column of CCA are 3.7, 5.4 and 6.25 times that of Untreated clay.

3) Load- settlement behaviour is similar irrespective of number of columns and column material when settlement is less than 2.5mm. Considerable variations do exist for the load- settlement curve at higher settlements (> 2.5mm). This is mainly because of the mobilization of frictional resistance offered by granular CCA or FAA aggregate during bulging.

4) The ultimate load capacities obtained from numerical results are overestimate the experimental ultimate load capacities for both CCA and FAA column.

Hence concluded that fly ash aggregate may be effectively utilized as column material in the place of conventional coarse aggregate for the improvement of soft clay.

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