Study on Effectiveness of Rigid Inclusions in Black Cotton Soil

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Abstract: *Black cotton soil is one of the problematic soils due its high shrink and swells characteristics. For the purpose of construction in such a soil, stabilisation is necessary. Among the various stabilisation methods stone columns are the one that is used to, increase the strength, decrease the compressibility of soft and loose fine graded soils, accelerate a consolidation effect and to reduce the liquefaction potential of soils. But they are not much effective for soft soils like black cotton soil. Rigid inclusions is a ground improving element and is a advanced method of stone column that is ideally suited for soft and very soft soils including peat soil. The rigid inclusions consists of cement treated aggregate, grouted aggregate or concrete columns that are often used to transfer the stress from foundation or emblent loads through very soft soils down to stiffer soils or rock layers. This paper lets you to know about the effectiveness of rigid inclusions in black cotton soil over the stone columns. The load carrying capacity of black cotton soil collected from the location of Udumalpet region, Tirupur District, Tamil Nadu, India, piled with Rigid Inclusions is compared with the stone columns of same numbers and its effectiveness is found.*

Key Words: Stone columns (SC), rigid inclusions (RI), granular mattress (GM), black cotton soil, settlement, load carrying capacity.

I. INTRODUCTION:

Black cotton soil is one of the most problematic soils due to its various physical properties and its clayey nature. In general, these soils have clay texture, average clay content being 50% and the range being 40-50%. The most important property of black cotton soil is its free shrink and swell characteristics. The most applicable and easily adopted ground improvement method used worldwide is stone column piled into the soil. Stone columns are well suited for the improvement of soft soils such as Silty Sands, Silts, Clays and Non homogeneous fills. But they are not very effective in all type of soft soils. The method introduced recently in developed countries for application in all kind of soft soil is rigid inclusions. This method is adopted nearly around 30 sites in abroad. The improvement of soft soils by rigid inclusions is used increasingly at international level. This technique allows the foundation on week soils of large civil engineering works such as: road or railway embankments, storage tanks, bridges, wind farms, industrial platforms etc.

II. STONE COLUMNS:

The stone column technique is a very efficient method of improving the strength parameters of soil like bearing capacity and reducing consolidation settlement. It offers a much economical and sustainable alternative to piling and deep foundation solutions. Vibro stone columns are designed to improve the load bearing capacity of the insitu soils and fills and to reduce differential settlements of non-homogeneous and compressible soils, allowing the use of shallow footings and thinner base slabs. It can perform Liquefaction prevention, Slope stabilization via Reinforcement and Drainage.

III. RIGID INCLUSIONS:

Rigid Inclusions is a ground improvement technique that transfers loads from the weak strata to a firm underlying stratum using high modulus, controlled stiffness columns. They are stiff ground improvement elements that consist of aggregate mixed with cement or grout, or elements made of plain concrete. The elements are stiff enough to transfer the stress from a slab, footing or embankment load through soft soil layers down to a firm soil or weathered rock layer. For rigid inclusion with granular mattress a layer of granular materials is placed above the rigid inclusions. The selection of the sizes and types of rigid inclusions to use on a project depends on the magnitude of loads being supported and the subsurface conditions.

IV. CONSTRUCTION OF STONE COLUMNS AND RIGID INCLUSIONS:

Stone columns are formed by inserting a vibrating probe to incorporate granular aggregate into ground via the resulting void and followed by compaction. Both top feed and bottom feed methods are available, depending on the availability of insitu soils and water level. And also the columns can be vibro displacement columns, vibro replacement columns or rammed columns. Even though it reduces the differential settlement and increases the load bearing capacity of the soil, they are not much effective in soft and very soft soils. Hence to overcome these disadvantages in stone columns, here we have introduced rigid inclusions.

Similar to stone columns the installation of rigid inclusion can be bottom feed or top feed and also the inclusions can be vibro displacement inclusions or vibro replacement inclusions. A bottom feed mandrel with a top mounted vibrator is advanced through weak strata to the underlying firm stratum. Granular bearing soils are densified by displacement. Concrete is then pumped to the mandrel, which opens as it is raised. The mandrel may be raised or lowered several times with the bearing depth to construct an expanded base. The mandrel is then extracted while a positive concrete head is maintained. The concrete fills the voids created by mandrel during extraction, and terminates in an upper strong stratum or is subsequently overlaid by an engineered relieving platform. The improved performance results from the reinforcement of the compressible strata with the high modulus columns.

This method consists of placing a network of inclusions to reduce the vertical load and minimize the settlement. The load is carried by the soil with the help of friction. In addition to it, when a granular layer is placed at the top of the network of piles, it reduces vertical load on the supporting soil and vertical settlement of the upper structure. The importance of granular layer thickness is to increase the load transfer intensity and to reduce vertical settlement.

V. MECHANISM:

The above installation is adopted generally in fields. In laboratory we have used a mould of volume 19088.3 cm^3 in which the soil is replaced either by stone columns or rigid inclusions. Thus the investigation is done with vibro replacement stone column and rigid inclusion on black cotton soil. The dimension of piling is found using IS codes to maintain the stress isobar within the mould. The figure 1 shows the mould with the stress isobar diagram.

The length to diameter ratio of the pile can generally vary from 1 to 9. To maintain the stress isobar within the mould the ratio is adopted as 8 in our investigation. On applying load the concrete in the rigid inclusion will fill the voids present in the soil. This makes the soil to densify, this resulting in densification. A friction force also acts between the soil and rigid inclusion materials. This helps in resisting the settlement and increases the load carrying capacity of soil. On placing the granular layer the resistance to settlement is further improved due to reduction in load transfer on the supporting soil.

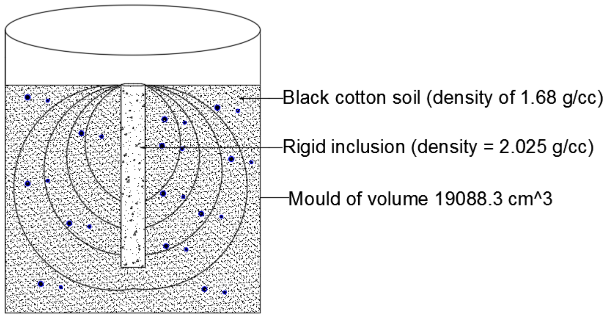

Figure 1 Mould with stress distribution

VI. EXPERIMENTAL INVESTIGATION:

Initially the black cotton soil taken from the site is tested for its characteristics in the laboratory. The soil has a specific gravity of 2.7, free swell of 40.5%, optimum moisture content of 16.3% and maximum dry density of 1.68 g/cc. Then the soil is tested with stone columns, rigid inclusions with and without granular mattress of varying numbers. The figure 2 shows the loading frame setup.

Figure 2 Loading frame setup

The testing of soil is done with the help of a loading frame setup. The setup consists of proving ring and dial gauge. The load is applied through the proving ring and applied on the soil with the help of a loading plate of 60 mm diameter based on the specification given in IS codebook. The setup of loading frame is shown in the figure 5.1.The mould used for testing is of diameter 28 cm, height of 31 cm and thickness 1 cm. The volume of the mould is about 19088.3 cm^3. The figure 3 shows the model tank.

The soil sample collected is initially dried in sun and initial water content of soil is noted. The soil, to attain maximum dry density is added with volume of water that equals to optimum moisture content of soil and mixed well.

Fig 3 Model tank

The compaction is done with help of standard proctor compaction rammer of weight 2.6 kg with a drop height of 310 mm. The compaction energy is of 6065 kg cm/per 1000 ml of soil or 595 kJ/m^3. To attain maximum dry density the number of blows required for compaction is 386 per layer, the total number of layers being three. The mass of soil required to attain maximum dry density is found to be 26 kg. The soil is compacted well and the rigid inclusions and stone columns are installed and tested for their load carrying capacity in varying numbers. The size of pile used for stone column and rigid inclusion is 26 mm diameter with a height of 200 mm to maintain the stress isobar produced due to load applied on the soil. And the spacing between the piles is twice the diameter of pile. Both the mould and loading plate used is of circular form, for maintaining uniform compaction and distribution of load to the soil respectively. The figure 3 and 4 shows the soil with one and three number of rigid inclusion.

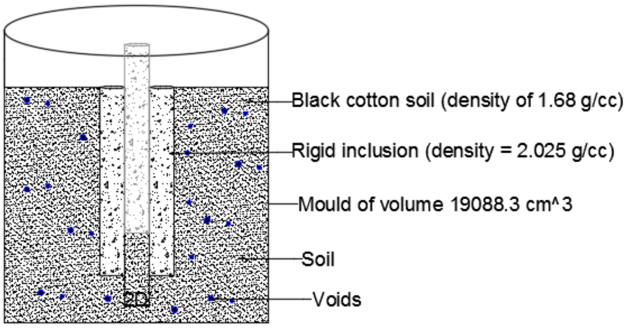

Figure 4 Schematic diagram of rigid inclusions

For stone column the aggregate used is the one passing through 12 mm sieve and retained on 10 mm sieve with a density of 1.14 g/cc. The rigid inclusion pile is made of plain cement concrete of ratio 1:4:8 and of density 2.025 g/cc. The aggregate used in concrete is the one passing through 12 mm sieve and retained on 10 mm sieve with specific gravity of 2.7.The cement used is OPC of grade 43 with specific gravity of 3.15.The fine aggregate used is of specific gravity 2.65. The water-cement ratio adopted is 0.55.

For rigid inclusions with granular mattress above the inclusions layer, for a diameter of 60 mm and thickness of 6 mm a layer of granular mattress made of aggregates passing through 2.36 mm sieve and retained on 1.75 mm sieve with density of 1.77 g/cc is laid. The figure 5 shows the soil with rigid inclusions with granular mattress.

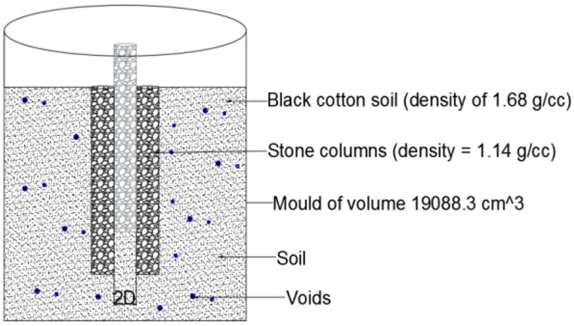

Fig 5 Schematic diagram of stone columns

VII. RESULTS AND DISCUSSIONS:

The index and engineering properties of soil such as specific gravity, consistency limits, shear strength are tested in the laboratory. Table 1 shows the characteristic of soil tested in the laboratory.

The soil is secondly tested for its load carrying capacity in the virgin clay state. Then the load carrying capacity with one, two and three number of stone columns, rigid inclusions with and without granular mattress are tested and the readings are plotted in graph with load (N) in x-axis and settlement (mm) in y axis. The figure 2 shows the test result of virgin clay and figure 3, 4, 5 shows the test result of stone columns, rigid inclusions with and without granular mattress with one, two and three number of piles respectively.

Table 1 Properties of soil

S.No	EXPERIMENT	VALUE
1	Liquid limit	57.6%
2	Plastic limit	31.58%
3	Plasticity index	20.92%
4	Shrinkage limit	16.45%

5	Liquidity index	-1.079%
6	Plasticity index	26.02%
7	Consistency index	2.079
8	pH of the soil	8.9
9	Free swell	40.5%
10	Standard Proctor compaction test OMC Max Dry Density	 16.3% 1.68 g/cc
11	Unconfined compression test q_u C_u	33.8 kN/m^2 16.9 kN/m^2
12	Vane shear test	29.43 KN/m^2

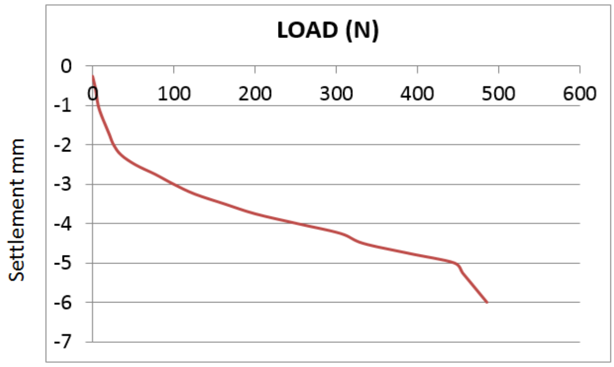

Figure 6 Load settlement curve for virgin clay

The figure 7 indicates that the settlement resistance of soil with one rigid inclusion with granular mattress is 17% greater for a 5 mm settlement and 93% greater for a settlement of 3 mm, than the one number of rigid inclusions. This also concludes that the settlement resistance of soil with one rigid inclusion with granular mattress is 48% greater for a 5 mm settlement and four times greater for a settlement of 3 mm, than the one number of stone columns.

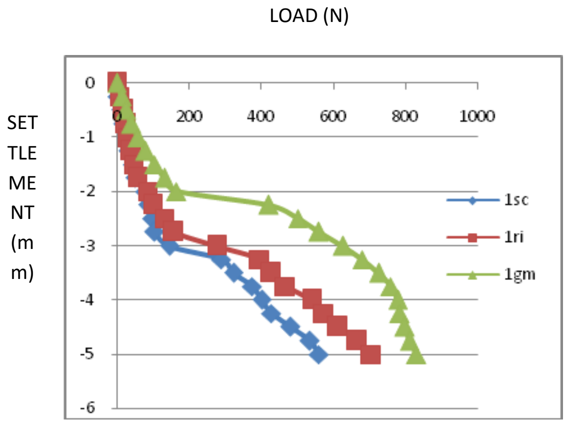

Figure 7 Comparison of one numbers of stone column and rigid inclusions with and without granular mattress

The graph in figure 8 indicates that the settlement resistance of soil with two rigid inclusion with granular mattress is 13% greater for a 5 mm settlement and 93% greater for a settlement of 3 mm, than the two number of rigid inclusions. This also concludes that the settlement resistance of soil with two rigid inclusion with granular mattress is 87% greater for a 5 mm settlement and 145% greater for a settlement of 3 mm, than the two number of stone columns

This also indicates that the settlement resistance of soil with two rigid inclusion is 90% greater for a 5 mm settlement and 6% greater for a settlement of 3 mm, than the two number of stone columns.

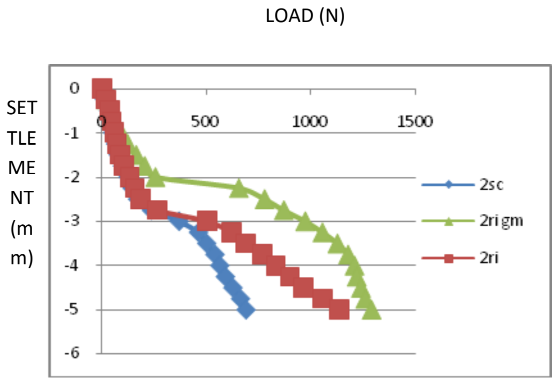

Figure 8 Comparison of two numbers of stone column and rigid inclusions with and without granular mattress

The figure 9 indicates that the settlement resistance of soil with three rigid inclusion with granular mattress is 12% greater for a 5 mm settlement and 117% greater for a settlement of 3 mm, than the three number of rigid inclusions. This also concludes that the settlement resistance of soil with three rigid inclusion with granular mattress is 113% greater for a 5 mm settlement and 129% greater for a settlement of 3 mm, than the three number of stone columns.

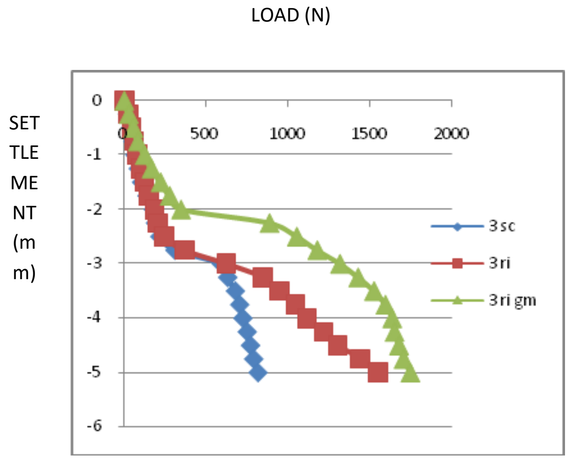

Figure 9 Comparison of three numbers of stone column and rigid inclusions with and without granular mattress

VIII. CONCLUSION:

This experimental study concludes that the soil with one number of rigid inclusions can bear the same load carried by two numbers of stone columns. The load carried by soil with three numbers of stone columns can be carried by one number of rigid inclusions with granular mattress. The settlement of soil with rigid inclusions is minimum than that of stone column and virgin clay. The minute voids present in the soil are filled by sand and cement present in the rigid inclusions resulting in more densification which is not possible with stone columns. The rigid inclusions are considered to be adaptable, effective and efficient for almost all problematic soil and are proved to be effective in black cotton soil than the stone columns. It is a quiet, vibration free and economical foundation. It also helps in increasing the load carrying capacity and allowable bearing pressure. The rigid inclusions help in construction of embankments, roads and small structures in very poor soils. Initial improvement in soil will help to prevent the tilting failure of windmills in Udumalpet region of Tirupur district, Tamilnadu, India.

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