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### STRENGTH AND SETTLEMENT STUDIES OF BLACK COTTON SOIL REINFORCED WITH GRANULAR PILE

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#### ABSTRACT

Ground improvement, is the modification of existing site foundation soils to provide better performance under design and/or operational loading conditions. Ground improvement techniques are used increasingly for new projects to allow utilization of sites with poor subsurface conditions. The most commonly used techniques suitable for cohesive soils and cohesionless soils have been briefly discussed in this paper. Recent advances made at MANIT, Bhopal to tackle with the problems of construction in black cotton soil have been discussed elaborately. Use of granular pile in such soils has shown that the soil strength on wetting could be improved significantly. The granular pile is found to improve the load carrying capacity of a footing to varying degree depending on the initial consistency of the soil, inclusion of fibres and encasement of the pile material by geogrid. Further, it is found that the swelling of the soil decreases by the use of granular pile in soft black cotton soil. The reduction in swelling depends on the size of the granular pile and initial moisture content in the soil; a larger diameter pile and at low initial moisture content, greater reduction in swelling is observed. Field application of both the techniques is yet to be studied. However, a case study to illustrate use of each of the above new techniques on poor soils, other than the black cotton soil, has been brought on board as illustrations.

**Keywords: Ground Improvement Techniques, Expansive Soil, Granular Piles, Swelling**

#### INTRODUCTION

India is distinguished for its geographical diversities with mountains, hills, rivers terrains, forest, wet lands, and deserts. There exists variety of soil types in different parts of the country. Some of the soils are problematic from construction point of view. The marine clay, lithomargic clay, laterite soil of Southern region and the Black Cotton (BC) soil of most of the central part of India are a few to name.

The soil classification gives valuable information regarding engineering properties such as permeability, strength, expansivity, etc. The soils are classified based on particle size distribution and consistency limits. There are two broad classes of soils namely coarse grain soils and fine grain soils. Coarse grains soils contain gravels while fine grain soils contain silt and sand. Coarse soils or Granular soils have low plasticity to non plasticity and are generally less problematic. However, fine sands and silty sands or loose deposits of sands pose problem. The phenomenon of liquefaction is observed in fine sands where water table is near to the ground surface. Among the clayey soil the black cotton soil is considered as the most problematic as it has tendency to swell and shrink due to seasonal moisture variation. In India about one-fifth of the area is covered by expansive soil. The soil behaves like a soft soil under wet/saturated condition. As a result of wetting and drying process, vertical movement takes place in the soil

mass leading to failure of structure, in the form of settlement, heavy depression, cracking and unevenness (Kumar and Jain 2012). Other type of clay which is considered problematic is dispersive clay. These are mostly found as alluvial clays in the form of slow wash, lake bed deposits and are easily erodible. They are not generally identified by standard laboratory tests such as index, grain size analysis etc. It is therefore concluded that nearly are types of soils may pose problem depending on different combination of working conditions and therefore may need improvement. The soil properties related to strength, settlement, drainage etc. need to be tailored to suit the situation in the field. A wide range of soil improvement techniques are available which may be suitable to a particular type of soil or working condition. Depending upon the loading conditions and nature of soil, a suitable technique which is also economical needs to be adopted (Hirkane et al 2014).

In this paper commonly used ground improvement techniques have been discussed and are followed by new developments particularly made to tackle the problem of construction in black cotton soil.

#### METHODS OF GROUND IMPROVEMENT

The methods of ground improvement that can be adopted depend basically on nature of strata and purpose of improvement. The methods available are as follows

**A. For cohesionless soils:**

- (i) Dynamic compaction.
- (ii) Vibro compaction.
- (iii) Grouting
- (iv) Compaction by deep blasting.
- (v) Compaction piles.
- (vi) Stone-columns.

**B. For cohesive soils:**

- (i) Preloading and Vertical Drains.
- (ii) Stone columns.
- (iii) Vacuum Dewatering.
- (iv) In-situ deep mixing.
- (v) Soil Stabilization.

Brief description of improvement techniques are as follows:

**Cohesionless soil:**

The concept of Dynamic Compaction technique is improving the mechanical properties of the soil by transmitting high energy impacts to the soil by dropping a heavy weight called pounder from a significant height. When feasible, dynamic compaction is probably the most favourite ground improvement technique in granular soils as it is usually the most economical soil improvement solution.

The Vibro compaction technique involves densification of granular soil using a vibratory probe inserted into ground. It is a deep compaction technique. The jet of water and vibratory action of probe accompanied with additional filling of sand results in to closer packing of loose sands and relative density of up to 85% can be achieved. Loose sands up to 30m depth are reported to be improved by this technique.

Compaction grouting is a ground treatment technique that involves injection of a thick consistency soil cement grout under pressure into the soil mass, consolidating, and thereby increases density of surrounding soils in situ. The injected grout mass occupies void space created by pressure densification. Pump pressure, as transmitted through low mobility grout, produces compaction by displacing soil at depth until resisted by the weight of overlying soils. Compaction Grouting when injected into very dense soils or bedrock, compaction grout remains somewhat confined, since the surrounding material is quite dense. However, when injected into under consolidated or poorly compacted soils, grout is able to "push" these materials aside. When grouting treatment is applied on a grid pattern, the result is improved compaction of displaced soils and greater uniformity of the treated soil mass.

Blast densification is suitable for large areas such as the site of the dam and is effective in saturated sands having very low clay content. The method increases the density of loose granular deposits, above or below the water table

**Cohesive Soils:**

The preloading method increases the bearing capacity and reduces the compressibility of weak ground and it is achieved by placing temporary surcharge on the ground. Surcharge generally more than the expected bearing capacity is placed. It is most effective for soft cohesive ground. The process may be speed up by vertical sand drains/prefabricated vertical drains. These drains accelerate settlement and gain in strength of the soil. Vertical drains accelerate primary consolidation only as significant water movement is associated with it. Secondary consolidation causes only very small amount of water to drain from soil; Secondary settlement is not speeded up by vertical drains.

In Stone column technique, soft soil is either replaced or displaced by making cylindrical holes and filling the holes by stones or granular materials. The technique improves the load bearing capacity of the composite ground and reduces the settlement characteristics of weak soils. This technique is useful for both cohesive soils and cohesionless soils.

Soil stabilization technique is useful for soft soils, in which mixing of different additives like, lime, cement, fly ash, stone dust etc modifies the chemical or mechanical properties of the soil. A brief description of cementitious and non-cementitious materials use in soil stabilization is as follows.

**Cementitious Materials:****Lime Stabilisation**

Clayey soils including heavy clays, moorum and other soils met within alluvial planes can be effectively treated with lime. For effective stabilisation, a soil must have a fraction passing 425 micron sieve not less than 15 percent and Plasticity Index (PI) at least 10 percent. Further, it is desirable that the percentage retained on 425 micron sieve should be well graded with uniformity coefficient not less than 5. Organic matter in the soil should not be more than 2% and sulphate content should not exceed 0.2 percent. A pH value of 10 or 11 is desired for pozzolanic reaction to take place between clay minerals and lime for the formation of cementitious compounds. Soils having organic matter and soluble carbonate/sulphate contents in excess of 2.0% and 0.2% respectively require special studies. Some materials contain amorphous silica which although has low plasticity but reacts with lime to form the necessary cementation products and should thus be considered for stabilization with lime. Material containing high Kaolinite as the basic clay mineral, usually have a fairly low PI with a high liquid limit and in such cases, lime should be considered for stabilization (Mathur et al. 2012).

**Cement Stabilisation:**

Generally granular soils free of high concentration of organic matter or deleterious salts are suitable

for cement stabilisation. For checking the suitability of soils, it would be advantageous to keep the following criterion in view.

- a) Plasticity Product (PP), expressed as product of PI of soil and percentage fraction passing 75 micron sieve should not exceed 60.
- b) Uniformity coefficient of soil should be greater than 5 and preferably greater than 10.
- c) Highly micaceous soils are not suitable for cement stabilisation
- d) Soils that are having organic content, higher than 2 percent and also those soils having sulphate and

carbonate concentration greater than 0.2 percent are not suitable for cement stabilisation.

e) Silty or fine sandy materials may exhibit a high liquid limit because of the high surface area of the particles. This material generally will not react with lime because of a lack of clay particles and can be stabilised with cement. However, cement stabilization with high doses of cement may tend to make cement stabilization uneconomical.

The selection of the stabiliser is based on plasticity and particle size distribution of the material to be treated. The appropriate stabiliser can be selected according to the criterion shown in Table 1.

Table 1 Guide to the type of stabilisation likely to be effective (Mathur et al 2012)

| Type of stabilisation | Soil Properties                          |              |         |   |         |         |
|-----------------------|--|--------------|---------|---|---------|---------|
|                       | More than 25% passing the 0.075 mm sieve |              |         | Less than 25% passing the 0.075mm sieve |         |         |
|                       | PI < 10                                  | 10 < PI < 20 | PI > 20 | PI < 6, PP < 60                         | PI < 10 | PI > 10 |
| Cement                | Yes                                      | Yes          | *       | Yes                                     | Yes     | Yes     |
| Lime                  | -  | Yes          | Yes     | No                                      | *       | Yes     |
| Lime- Pozzolan        | Yes                                      | -            | No      | Yes                                     | Yes     | *       |

The suggested application of stabilised mixtures is given in Table 2.

Table 2 Suggested Applications of Stabilised Mixtures

| Process                    | Purpose                                      | Requirement   |
|----------------------------|--|---|
| Modification sites         | Improvement of access                        | Large increase in plastic limit<br>Large and rapid decrease in plasticity   |
|                            | Rapid increase in bearing strength           |   |
| Cementation(Stabilization) | Improvement of workability and pulverization | Increase in bearing capacity and durability<br>Decrease in plasticity<br>Decrease in swell<br>Increase in strength and bearing capacity<br>CBR>80 |
|                            | Improvement of subgrade material             |   |
|                            | Improvement of base material                 |   |

**Fly Ash:** Phanikumar and Sharma (2004) studied the effect of fly ash on engineering properties of expansive soil. The soil parameters like free swell index (FSI), swell potential, swelling pressure, plasticity, compaction, strength and hydraulic conductivity of expansive soil were studied. The flyash contents were varied from 0, 5, 10,15 and 20% on a dry weight basis of the expansive soil and it was noted that increase in flyash content reduces plasticity characteristics. The FSI was reduced by about 50% by the addition of 20% fly ash. The hydraulic conductivity of the mix decreases with an increase in flyash content, due to the increase in maximum dry unit weight. When the flyash content increases there is a decrease in the optimum moisture content and the maximum dry unit weight increases. The effect of fly ash is akin to the increased compactive effort. Hence the expansive soil is rendered more stable. The undrained shear

strength of the expansive soil blended with flyash increases with the increase in the ash content.

**Non Cementious Materials:** Sridharan et al (2006) have carried out experimental study on soil- quarry dust. Quarry dust can be used with advantage to improve the engineering properties of soils. There is considerable increase in dry density on addition of quarry dust with attendant decrease in the optimum moisture content (OMC). On an average about 21% increase in dry density and 39% decrease in OMC were observed for soil-quarry dust mixes with 60% quarry dust content. This helps to find an application for industrial waste to improve the properties of local soil both in embankment and pavement constructions. Addition of any amount of quarry dust to clayey soils (highly plastic) is showed considerable increase in shear strength. The increase in angle of shearing resistance could be of the order of even 100% for

the addition of 60% of quarry dust. Increase in shear strength was observed for soils and soil-quarry dust combinations when compacted on dry side of optimum.

**Chemical stabilization:** Katz et al (2011) have to identify the mechanisms associated with one class of chemical products, a representative ionic soil stabilizer and a sodium montmorillonite clay were selected for a detailed physical-chemical study. Laboratory testing included chromatography, spectroscopy, X-ray diffraction, electron microscopy, and standard titration analyses. These tests have shown that the principal active constituents of the selected ionic stabilizer are d-limonene (a by-product of citrus processing) and sulfuric acid, which react to form a concentrated, low-pH solution of sulfonated limonene. The observed changes in clay chemistry following treatment indicated that this product would stabilize a soil by altering the clay lattice. The result is the formation of a more highly weathered, less-expansive clay structure. On the basis of this understanding of the underlying mechanisms, ionic stabilizers applied at sufficiently high application

mass ratios may improve the properties of certain soils on some highway construction projects.

**Grouting:** Huat et al (2011) have described ground improvement methods for problematic soil such as peat is deep in situ mixing method by soil-grouting columns. The conventional binders used are cementitious materials, and an introduction of a new binder, sodium silicate as an additive gives a better output on the conventional peat treatment. The effect of sodium silicate was investigated by shear strength of sodium silicate with 0%, 1%, 2.5% and 5.0% while other parameters remain constant. Based on the results there was an increasing trend in the shear strength with 1.0% and 2.5% sodium silicate compared to the conventional binder i.e. 0% sodium silicate. However, higher shear strength was achieved with 2.5% sodium silicate. Thus, this indicates that 2.5% sodium silicate was effective dosage to give a reasonable strength.

The mechanisms of peat soil stabilization under effect of sodium silicate can be explained by Following, reactions (in some conditions):

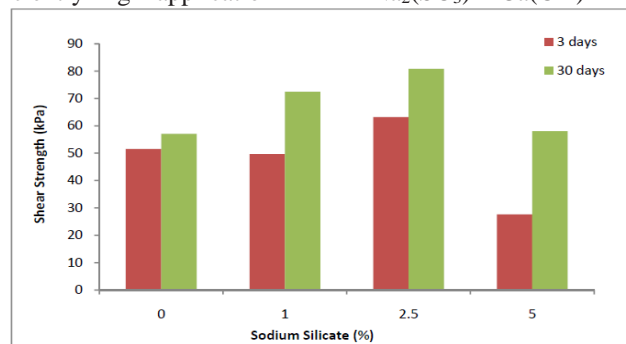
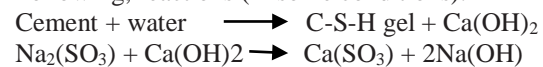


Fig. 1: Effect of sodium silicate on the reinforced peat (Huat et al 2011)

**Cohesive Non Swelling Layer:** Replacement by soils with relatively impervious material may, to a great extent offset the disadvantages of sand cushion method. The method proposed by Katti (1979) uses cohesive non-swelling (CNS) layer to reduce the effects of swelling. The heave of expansive soil underlying a CNS layer reduces exponentially with increase in thickness of the CNS layer and attains a value of no heave around a depth of 1m. The shear strength of the underlying expansive soil at the interface and below increases with the thickness of CNS layer. The method is recommended for construction of canals in black cotton soil area.

**Geosynthetic:** Hufenus et al (2006) have investigated a full-scale field test on a geosynthetic reinforced unpaved road was carried out, including compaction and trafficking, to investigate the

bearing capacity and its performance on a soft subgrade. The test track was built with three layers of crushed, recycled fill material. The 1st layer was compacted statically, whereas the 2nd and 3rd were dynamically compacted. The geogrids were instrumented with strain gauges to measure the short- and long-term deformations and the ongoing formation of ruts was assessed from profile measurements. The various geosynthetics used for this reinforced unpaved road were found to have a relevant reinforcing effect only when used under a thin aggregate layer on a soft subgrade. Under such conditions, ruts can form in the subgrade, mobilizing strains and thus tensile forces in the geosynthetic. The achievable degree of reinforcement depends on the stiffness of the geosynthetic and is limited by finite lateral anchoring forces.



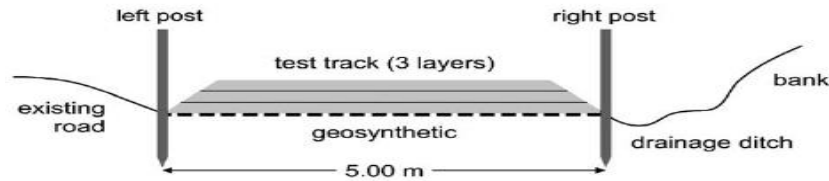


Fig. 2 Typical cross section through the test track (Hufenus et al 2006)

The traditional techniques of ground improvement like lime stabilization, cement stabilization, fly ash stabilization, etc. are not suitable because the additives (lime, cement etc.) do not proper mix with soil and do not give good results at certain depth. The polymeric geotextiles like geosynthetic, is a versatile material with attractive characteristics and advantages, and as a result, this material is now being used abundantly all over the world. At the same time these materials have got the disadvantages that it is non-biodegradable, petroleum based and is costly. So need a new technique/material which is cheap, easy laying, biodegradable, result oriented etc. Recently, introduced new methods for ground improvement i.e. stone column/granular pile and coir geotextile.

**EXPANSIVE SOIL AND THEIR PROBLEM**

Essentially expansive soil is one that changes in volume in relation to changes in water content. Here the focus is on soils that exhibit significant swell potential and in addition Shrinkage potential also exists. However, many soils that exhibit swelling and shrinking behaviour contain expansive clay minerals, that absorb water, the more of this clay a soil contains the higher its swell potential and the more water it can absorb. As a result, these materials swell, and thus increase in volume, when they get wet and shrink when they dry. Swelling pressures can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. Failure results when the volume changes are unevenly distributed beneath the foundation. For example, water content changes in the soil around the edge of any structure can cause

swelling pressure beneath the perimeter of the building, while the water content of the soil beneath the centre remains constant. This results in a failure known as end lift. The opposite of this is centre lift, where swelling is focused beneath the centre of the structure or where shrinkage takes place under the edges.

**RECENT ADVANCES IN GROUND IMPROVEMENT TECHNIQUES**

Recently, there are few techniques introduced for ground improvement, as given as follows:

- (i) Biodegradable Materials
- (ii) Stone column

**Biodegradable Material:** Coir Geotextile is readymade material, cheap, easy laying in field and biodegradable. Coir geotextiles find application in a number of situations in geotechnical/ highway engineering practice.

**Laboratory Work:** Meshram et al. (2014) have determined California Bearing Ratio (CBR) Test in laboratory and Strength Improvement Test (SIR). The paper presents the results of laboratory study conducted on black cotton soil reinforced with a layer of Coir Geotextile (CGT) placed at different depths below the loading surface in the California Bearing Ratio test mould. The CGT layer was placed in two ways- directly embedded in the clay or in between the cushion of sand layers. The placing of CGT was varied with reference to the loading face of California Bearing Ratio (CBR) plunger at 0mm, 25mm, 35mm and 45mm. The CBR test was conducted in soaked condition of the soil. In this study H2M9 type of CGT is used. The properties of black cotton soil are shown in Table 3.

Table 3 Properties of Black Cotton Soil used in study

| Test Parameter                     | Value                       |
|------------------------------------|-----------------------------|
| Gravel content                     | Nil                         |
| Sand Content (%)                   | 4                           |
| Silt and Clay Content (%)          | 96                          |
| Liquid Limit (%)                   | 50                          |
| Plastic Limit (%)                  | 22                          |
| Plasticity Index (%)               | 28                          |
| Classification as per IS 1498-1970 | CH, clay of high plasticity |
| Optimum Moisture Content (%)*      | 20                          |
| Maximum Dry Density (g/cc)*        | 1.56                        |

|                  |       |
|------------------|-------|
| Unsoaked CBR (%) | 10.07 |
| Soaked CBR (%)   | 2.26  |

**\*Light Compaction Values**

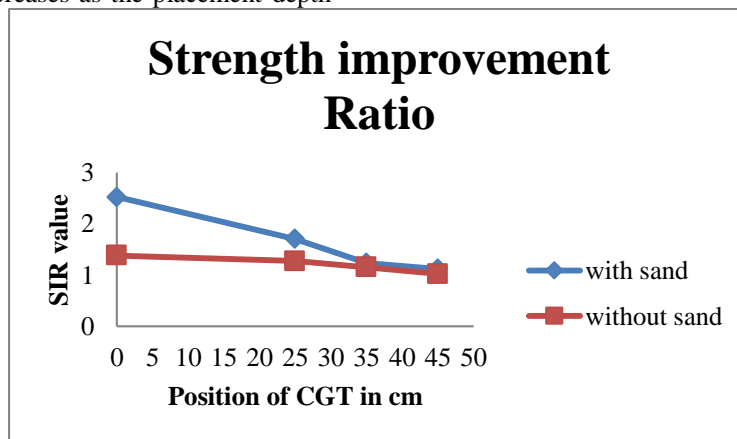
The results of CBR Test are given in Table 4.

*Table 4 Test Results of CBR*

| Depth Of Placement Of CGT | Soaked CBR (%) |           |
|---------------------------|----------------|-----------|
|                           | Without Sand   | With Sand |
| Top                       | 3.12           | 5.69      |
| 25 mm                     | 2.88           | 3.85      |
| 35 mm                     | 2.61           | 2.77      |
| 45 mm                     | 2.3            | 2.52      |

The effect of CGT inclusion on CBR of the soil is expressed in terms of Strength Improvement Ratio (SIR) which is the ratio of CBR of CGT reinforced soil to that of the raw soil. It is found that SIR is maximum when CGT is placed just at the top of the loading face and decreases as the placement depth

increases. This is true in both the cases i.e. without sand cushion and with sand cushion. Further, the SIR value is found more in sand cushion condition than the corresponding value in the other condition shown in Fig. 3.



*Fig. 3 Strength Improvement Ratio (SIR) with Coir Inclusion (Meshram et al. 2014)*

**Field observation:**

Sharma and Ravindranathan (2012) explained the field experiments on weak sub-grades (agrarian soil) with and without coir geotextile. Also discussed two case study first, the construction of a village road namely, KumbakkadChembakulam Road at Varkala Block in Trivandrum district Kerala and Second, Vellar Theru Road at Orthanadu Block in Thanjavur district Tamilnadu using H2M6 coir geotextile as a reinforcement with sand cushion. Coir netting is spread directly over the roughly leveled poor sub-grade soil (agrarian soil). In the case of clayey sub-grades it is recommended to spreading the fabric after placing a layer of sand of 10mm to 20mm thickness. The fabric is then surcharged with granular material preferably sand of 30mm to 50 mm thickness to act as a lower sub base. The fabric over the sub-grade may be spiked, if necessary, by use of J shaped wooden spikes driven at random as necessary to keep the netting in place during construction and rolling. For unsuitable and wet sub-grades, coir netting provides a satisfactory

solution to stability and drainage. The coir geotextiles placed in this location is H2M6. Lying of Coir Geotextiles and construction of bitumen layer was done after one year. After that monitoring of settlement is noted continuously, No large settlement is noticed.

**Stone Column/Granular Pile:**

Expansive soils are problematic on account of two reasons:

- (i) large variation in volume due to moisture variation and
- (ii) low shearing resistance on wetting.

Hence efforts have been made in the past to overcome volume instability and poor strength problem of this soil.

Kumar (2014) has studied the strength improvement aspect of soft expansive soil using the technique of granular pile. The main objective of the study was to investigate the load-settlement behavior of granular pile in soft expansive soil. He has used sand as granular pile material. Further to enhance the effectiveness of granular pile, nylon fibres were mixed with the sand and pile length was encased by geogrid. The experimental results

were modeled numerically using software PLAXIS (V8). The load-settlement behavior of footing resting on soil of different UCS value and corresponding behaviour of footing on granular pile

is shown in Fig. 4. The effect of different pile characteristics on load settlement behaviour is shown in Fig.5. The experimental and numerical results are shown in Fig. 6.

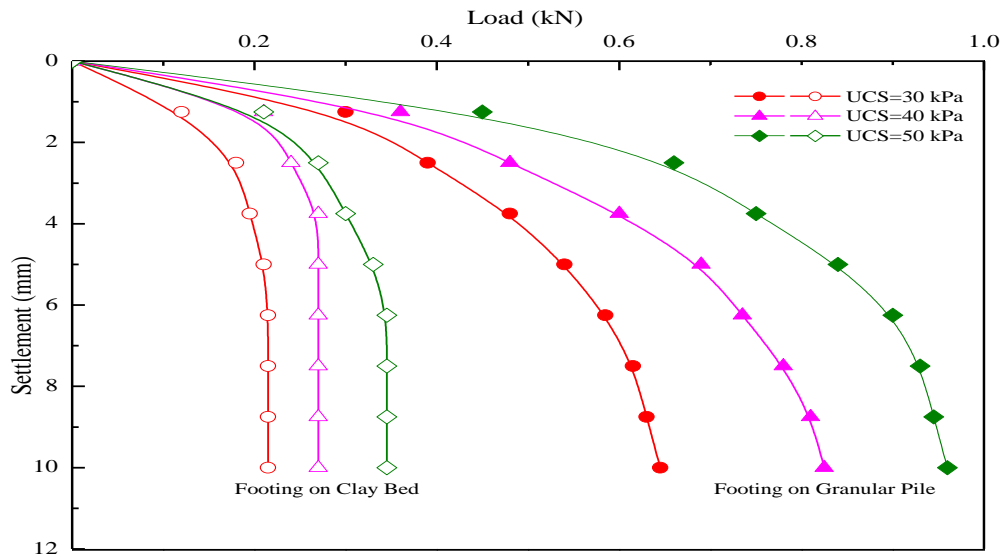


Fig. 4 Load-settlement behavior of footing on granular pile in soft expansive clay (Kumar, 2014)

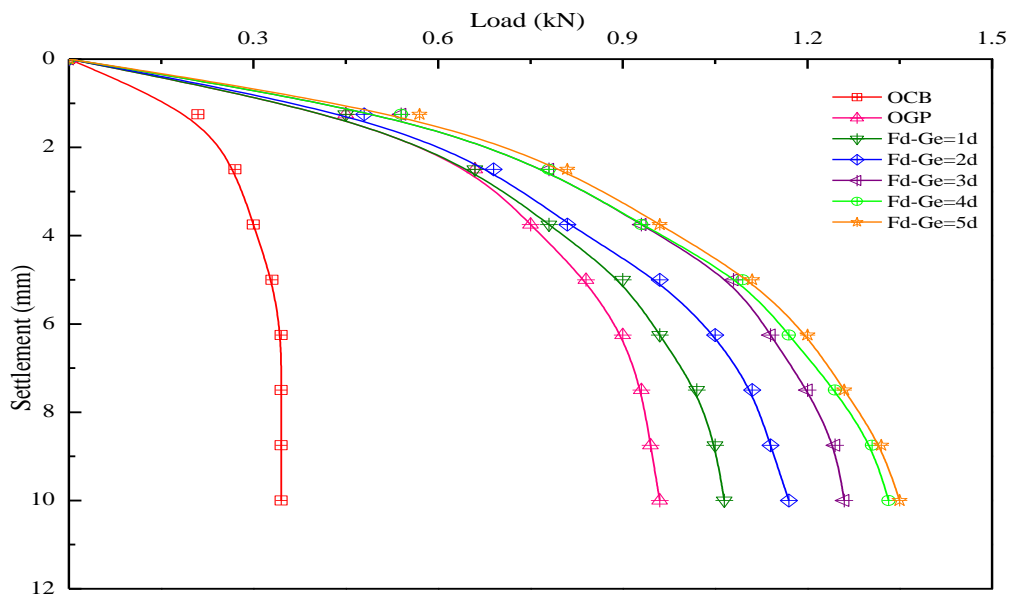
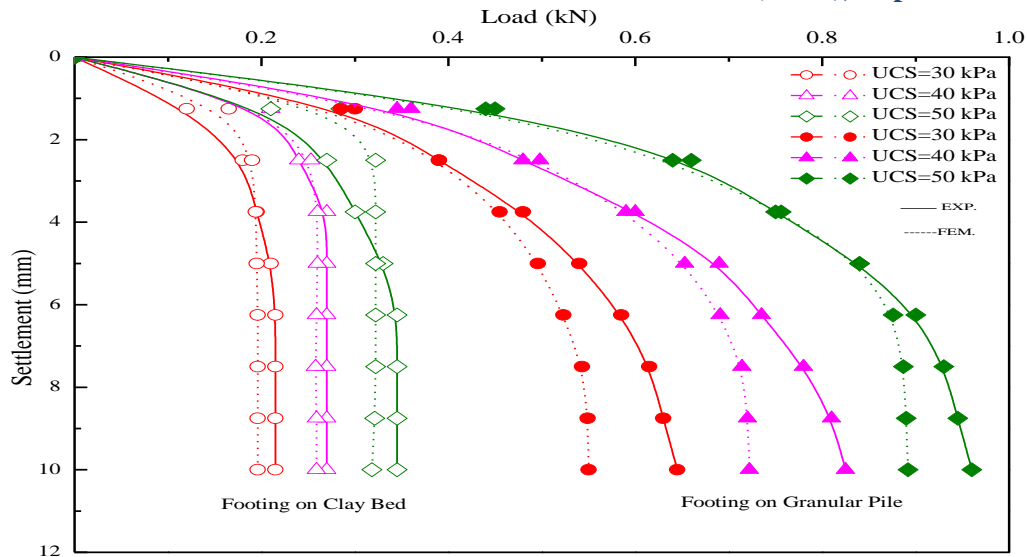


Fig. 5 Load-settlement curve for fiber mixed sand geogrid encased granular pile depth (Kumar, 2014)



**Fig. 6 Comparison of numerical and experimental load-settlement curve for varying UCS of soft soil (Kumar, 2014)**

From Fig. 2, and 3, it is concluded that the technique of granular pile is equally effective to improve strength behaviour of soft expansive clay, as is in the case of other soft clays. Further from Fig. 4 it is shown that the behaviour can be modelled numerically by FEM.

Aparna et al. (2014) have observed reduction in swelling by using granular pile/sand column at different water content. The result of an experimental study conducted for evaluating the effect of size of the sand column on swelling of expansive soil. The sand columns of diameters 25mm, 37.5mm and 50mm were made in black cotton soil test beds in a cylindrical mould of diameter 100mm. The test beds were prepared at different water contents (14, 18, 22, 26,30,36,40 and 44% by weight of dry soil) keeping the dry density of the soil as constant. The soil with sand column was submerged and the swelling of the composite material was observed. The test results show that the presence of sand column in the expansive black cotton soil reduces the swelling. The reduction in swelling depends on the size of the sand column and the initial moisture content in the soil. A column of diameter 50mm reduces swelling more than the smaller ones. For 14%

initial moisture content in the black cotton soil, the stone columns of diameters 25mm, 37.5mm and 50mm have shown reduction in swelling by 11.5%, 23% and 42% respectively in comparison to that exhibited by the raw soil. The soil with high initial moisture content shows less swelling than those with low moisture content. Thus, by manipulating the initial moisture content and the diameter of the sand column, the expansive soil reinforced with sand columns can be made volumetrically stable. It is found that the size of sand column and initial water content in the black cotton soil affect the swelling behaviour. A large size sand column reduces swelling more than by a smaller one. Swelling is also reduced with increase in water content. At 44% water content there is no swelling found in the soil. The reduction in swelling is mainly due to replacement of expansive soil by non-expansive sand and also because of presence of water in the soil. Thus if sand columns are installed in expansive soils in wet condition maximum benefit in terms of volume stability can be achieved. Effect of sand column diameter on swelling of expansive soil is shown in Fig. 7.



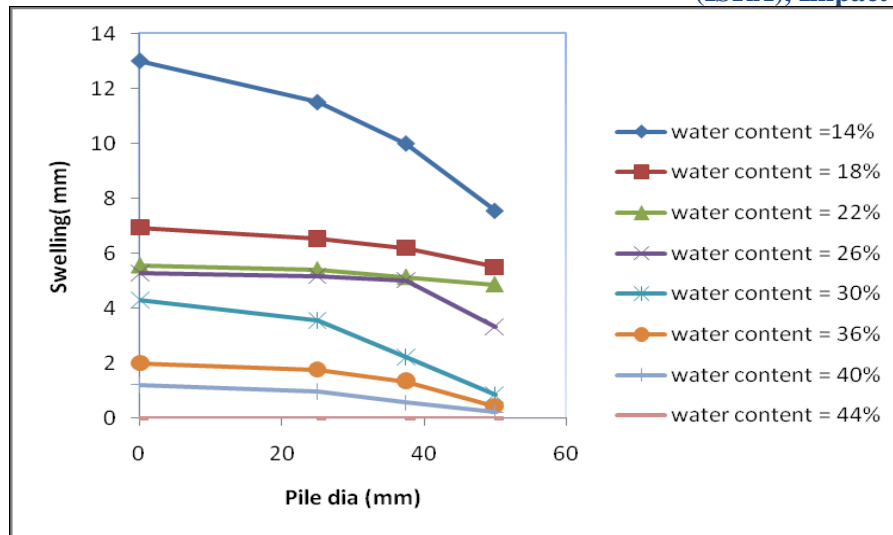


Fig. 7 Effect of sand column diameter on swelling of expansive soil (Aparna et al 2014)

The swelling behavior of expansive soil with inclusion of stone column and geotextile has been studied by Harishkumar and Muthukkumaran (2011). They reported that stone columns in expansive soil reduce the swelling pressure. With single layer of geotextile the stone column further reduces swelling pressure. Their results are shown in Fig. 8.

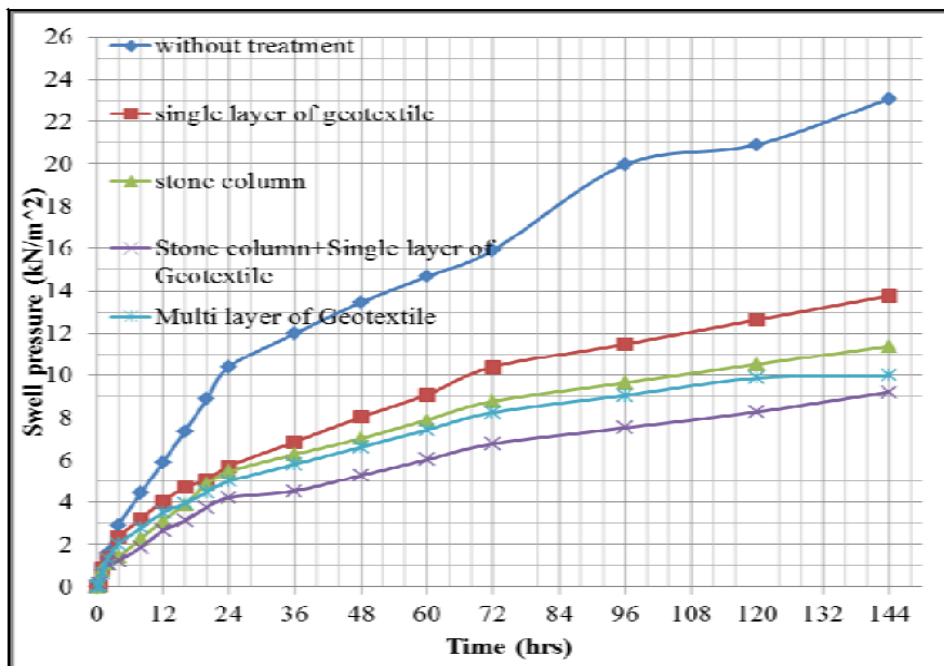


Fig. 8 Swell Pressure studies in expansive soil using stone column and geotextile layers (Harish K. and Muthuk K., 2011)

**CONCLUSION**

In short, Ground improvement is executed to increase the bearing capacity, reduce the magnitude of settlements and the time in which it occurs, retard seepage, accelerate the rate at which drainage occurs, increase the stability of slopes, mitigation of liquefaction potential, etc. Based on the soil conditions, a suitable method of ground improvement should be considered keeping in view of the economic feasibility as well as the time frame. In practice, ground improvement is widely used in a broad construction spectrum from

industrial, commercial and housing projects to infrastructure construction for dams, tunnels, ports, roadways and embankments. Study on the application of granular pile technique in soft expansive black cotton soil in the laboratory on model test tank has shown encouraging results both to increase the strength and decrease the swelling of the soil. Coir geotextile application in road construction on poor subgrade soil is under research at the moment.

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