Study of Load & Settlement Behaviour of Expansive Soil Reinforced with Granular Pile Using Natural Aggregates

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Abstract. Expansive soil such as Black Cotton soil is problematic from geotechnical point of view as it is unstable volumetrically with the variation of seasonal moisture making it sensitive to deformation. Its strength decreases, compressibility increases on wetting, it possesses very small shear strength. There are several geotechnical improvement techniques available for expansive soil strata, but the use of granular piles is becoming popular in India as it improves the strength parameters, such as increases load bearing capacity, reduces settlement, takes wide spread loads and improves the rate of consolidation. In this study, experimental investigations have been done to judge the load and settlement behaviour of Black Cotton soil when reinforced with geotextile encased granular pile by varying the percentage of natural aggregates, fly ash and lime at varying L/d (length & diameter) ratio of 1.5, 2, 2.5, 3 and 3.5. The soil sample was prepared taking a mould of 150mm diameter, 175mm height and granular pile of diameter 50mm. The test results showed significant reduction in settlement on installation of geotextile encased granular pile when compared to untreated soil sample. The ultimate load increased & settlement reduced with increase in percentage of fly ash & lime with each increase of L/d ratio as well.

1. Introduction
India has large geographical diversities with soils, mountains, forest covers, rivers, terrains, deserts, etc. with that a variety of soil types also exist in different parts of our country. For example, the Black Cotton (BC) soil present in central part of India, marine clay, lithomargic clay, and laterite soil of Southern region are a few soils types. BC soil is one of the expansive soils available in our country covering 21% of land area and generally, available in tropical and arid regions. Its appearance varies from black to grayish brown colour. It is majorly originated in our Central India as well as some parts of South India, Deccan plateaus and fields along with Andhra Pradesh, Gujarat, Maharashtra, and also several areas in Odisha.

BC soil shows high plasticity, exhibit major swelling and shrinkage characteristics due to the presence of clay mineral Montmorillonite. Construction of geotechnical designs and their execution on BC soil is associated with great difficulties. As structures founded on BC soil undergoes huge amounts of settlements and deformation, due to alternate drying, wetting and ground water table variation. They possess very low shear strength, and hence, they could tend to damage structures and foundations during the execution or throughout the life of the project. Different ground improvement techniques are available for various types of soils such as, Soil Replacement, Mechanical Stabilization, Chemical Stabilization, and Stabilization using Reinforcement, Sand Drains, and Prefabricated Vertical Drains, Granular Piles or Stone columns. Several problems are not solved effectively with above solutions due...
to its time and money constraints particularly when the geological strata of expansive soils extended to large depth [1-6].
Granular piles (GP), also known as stone columns can be constructed in both cohesionless as well as soft cohesive clays by method of partial replacement of undesirable local soil with granular material of strong, dense and highly permeability. This increases the load bearing capacity, helps in significant reduction of settlement and increase consolidation rate of expansive soil. GP gain strength from lateral reinforcement and hence encasing granular piles with geotextile can increase the lateral strength. It effectively controls the swelling pressure as well. Other benefits of GP are it is sustainable, feasible, economical, and efficient. Therefore, considering all the benefits, the areas of utilization GP should be explored more.
Previously, load tests were conducted on floating GP constructed in soft BC soil and effect of pile length on load carrying capacity was studied by Siddharth Arora & Rakesh Kumar [2]. A study was done to improve the load carrying capacity of foundation in expansive soil by including fibers and geogrid encased GP material by Kundan Meshram & P.K. Jain [1]. In 2017, Mohd Furkhan & M. Kameswara Rao [3] conducted laboratory tests to understand the load carrying capacity pattern of GP provided in soft soils by varying percentages of Recycled materials in place conventional materials. Recently, Eswara Reddy Orenkanti [6] studied the response of GP in presence of encasement & combination of encasement & lateral reinforcement under compression tests.

2. Materials Used & Properties
The present work focuses on ground improvement of black cotton soil. Keeping the cost efficiency and environmental aspects in mind, various materials are being considered in the present work. The following materials are used:

2.1. Black Cotton Soil
Black Cotton soil is collected from Nachuni Village, under Balugaon, in Khorda District, from 1m depth below GL. The properties of Black Cotton soil are given in Table 1.

2.2. Natural Aggregates
Natural aggregates considered were collected from CET college campus of size between 4.75-10 mm. The properties of aggregates are shown in Table 2.

Table 1. Virgin Expansive Soil Properties

| Properties                  | Values | Properties              | Values |
|-----------------------------|--------|-------------------------|--------|
| Specific gravity            | 2.42   | Plasticity Index        | 31.83% |
| D10                         | 0.002  | Shrinkage Limit         | 21.38% |
| D30                         | 0.0061 | IS Soil Classification  | CH     |
| D60                         | 0.023  | Free Swell Index        | 100%   |
| Coefficient of Uniformity (Cu) | 10.45  | Natural Moisture Content | 21.94% |
| Coefficient of curvature (Cc)| 0.735  | Optimum moisture content| 17.80% |
| Gravel content              | 0%     | Maximum dry density     | 1.79 gm/cm³ |
| Sand Content                | 28.38% | Liquid Limit            | 60.21% |
| Silt & Clay Content         | 65.85% | Plastic Limit           | 28.38% |

2.3. Fly Ash
The fly ash used is a Class C Fly ash and is originally from NTPC, Talcher and purchased from a local vendor. The chemical properties were collected from NTCP Talcher. Fly ash is used here in place of cement as it has cementing properties when added with water, it will give workability to the natural aggregates. The physical & chemical properties are shown in Table 3.
2.4. Lime
For this project work I have used powdered hydrated lime, due to its binding and adhesive property. It acts as a binding material and imparts strength in the granular pile.

2.5. Geotextile
Geotextile is purchased from Sun textiles private limited from Kolkata. Woven Polypropylene type of geotextile is used. Properties of Woven Polypropylene geotextile are given in Table 4.

**Table 2. Properties of Natural Aggregates**

| Properties                        | Values  |
|-----------------------------------|---------|
| Specific gravity                  | 2.83    |
| Water absorption                  | 0.202%  |
| Aggregate impact value            | 25.18%  |
| Aggregate Crushing value          | 26.46%  |

**Table 3. Properties of Fly Ash**

| Properties                          | Values                  |
|-------------------------------------|-------------------------|
| Specific gravity                    | 1.82                    |
| Coefficient of Uniformity (Cu)      | 3.08                    |
| Coefficient of curvature (Cc)       | 1.02                    |
| Clay content                        | 0%                      |
| Sand content                        | 14%                     |
| Silt & clay content                 | 86%                     |
| Grain size                          | Uniformly graded        |
| Colour                              | Grey                    |
| Moisture content                    | 1.98%                   |
| Free Swell Index (%)                | 0%                      |

**Table 4. Properties of Geotextile**

| Properties                        | % by Mass |
|-----------------------------------|-----------|
| Specific gravity                  | 0.91      |
| Unit weight                       | 500 gm/m² |
| Thickness                         | 2mm       |
| Colour                            | White     |
| Breaking strength                 | 16 KN/m   |
| Elongation Break                  | 25 – 10 (%)|
| Tear strength                     | 0.42 KN   |
| Opening size                      | 0.07-2 mm |

3. Methodology

3.1. Experimental Setup
This experimental setup is similar to the California Bearing Ratio (CBR) test setup. Tests were conducted in cylindrical mould to determine the load and settlement behaviour of BC Soil reinforced with geotextile encased GP. A typical test arrangement is shown in Figure 1. All the experiments were carried out on a GP of diameter 50mm surrounded by BC Soil in a cylindrical mould of diameter 150mm and 175mm depth. The soil sample was prepared at a dry density of 1.79gm/cc and 17.8% moisture content. The soil sample was compacted with no visible air voids and GP was installed at centre of sample through replacement method and filling the hole with pile materials in layers.
The Load tests were conducted varying L/d ratio of GP (where, L is Length & d is diameter of GP) from 1.5 to 3.5 with a difference of 0.5. The diameter of GP was kept constant for all the tests, i.e. 50mm.

![Figure 1. Typical Test Setup for Load-Settlement behavior of GP in BC soil](image)

3.2. Preparation of Soil Sample
A soil sample of 5kgs BC soil was prepared with a moisture content of 17.80% in a C.B.R mould in five layers and each layer was rammed to maintain a desired bulk density of 1.52gm/cc. Soil was added in five layers and 56 number of blows were applied in order to maintain heavy compaction. Sample top was levelled by cutting off the excess. The soil sample hence prepared was kept aside for few hours after installation of GP. After that the load tests are conducted. A 150mm diameter mild steel footing plate is placed on sample top so that the entire setup acts as a composite material. The plunger distributes the axial load uniformly through the proving ring on plate and then to soil sample. The load settlement test is conducted on untreated sample. Then in the similar procedure reinforced soil samples are tested.

3.3. Installation of Granular Pile
After the preparation of soil sample, the GP with natural aggregate of size between 4.75 to 10mm, fly ash and lime paste encased in geotextile were installed by a replacement method. A Stainless steel pipe of 5cm diameter open at both the ends was smeared with grease and inserted into the BC soil sample mould up to desired length of GP. Then the pipe was pulled ensuring that the soil does not fall back. Then a piece of geotextile was rolled and stitched to a diameter of 5cm and placed vertically so as to cover the entire GP. The GP of natural aggregates, fly ash and lime paste was prepared by adding 5% water content (Rakesh Kumar & P.K. Jain 2013). Gradually the water content was increased with the increased percentage of fly ash and lime. The material was charged in three layers and compacted with a tamping rod to maintain uniformity diameter of the GP. It was made sure so that no air voids were left and continued until GP was formed. Two to three soil sample moulds were prepared and was kept for half a day and load tests were conducted in CBR setup.

3.4. Test Procedure
The test setup is similar to CBR test setup. The load was applied with plunger assembly on the mild steel circular footing plate placed on top of soil sample including the granular pile. The footing plate considered here is of the same diameter as that of mould. Through the proving ring the load was applied by a technique of constant displacement rate of 1.25 mm/min. Dial gauge was used for noting the settlement (dial gauge least count= 0.02mm). The load was applied until settlement reached a constant value. The load corresponding to settlement of footing plate was noted.
A series of load tests were performed on unreinforced soil sample and soil samples reinforced with geotextile encased GP at different depths. A mild steel circular plate of 15cm dia is taken for all the tests (i.e. keeping diameter equal with mould diameter). It is placed on the soil sample to act as footing plate and all load tests were performed. The test results were compared with the untreated soil sample. The various series of laboratory tests are clearly mentioned in the Table 5.

**Table 5. Virgin Expansive Soil Properties**

| Test Series | Combination of Tests Conducted On                                                                 |
|-------------|---------------------------------------------------------------------------------------------------|
| 1 at depth of 17.5cm (L/d=3.5) | 1. Untreated Black Cotton soil  
2. BC soil reinforced with geotextile encased 67% GP with natural aggregate + 30% Fly ash + 3% lime  
3. BC soil reinforced with geotextile encased 60% GP with natural aggregate + 35% Fly ash + 5% lime  
4. BC soil reinforced with geotextile encased 53% GP with natural aggregate + 40% Fly ash + 7% lime |
| 2 at depth of 15cm (L/d=3.0) | 1. BC soil reinforced with geotextile encased 67% GP with natural aggregate + 30% Fly ash + 3% lime  
2. BC soil reinforced with geotextile encased 60% GP with natural aggregate + 35% Fly ash + 5% lime  
3. BC soil reinforced with geotextile encased 53% GP with natural aggregate + 40% Fly ash + 7% lime |
| 3 at depth of 12.5cm (L/d=2.5) | 1. BC soil reinforced with geotextile encased 67% GP with natural aggregate + 30% Fly ash + 3% lime  
2. BC soil reinforced with geotextile encased 60% GP with natural aggregate + 35% Fly ash + 5% lime  
3. BC soil reinforced with geotextile encased 53% GP with natural aggregate + 40% Fly ash + 7% lime |
| 4 at depth of 10cm (L/d=2.0) | 1. BC soil reinforced with geotextile encased 67% GP with natural aggregate + 30% Fly ash + 3% lime  
2. BC soil reinforced with geotextile encased 60% GP with natural aggregate + 35% Fly ash + 5% lime  
3. BC soil reinforced with geotextile encased 53% GP with natural aggregate + 40% Fly ash + 7% lime |
| 5 at depth of 7.5cm (L/d=1.5) | 1. BC soil reinforced with geotextile encased 67% GP with natural aggregate + 30% Fly ash + 3% lime  
2. BC soil reinforced with geotextile encased 60% GP with natural aggregate + 35% Fly ash + 5% lime  
3. BC soil reinforced with geotextile encased 53% GP with natural aggregate + 40% Fly ash + 7% lime |
4. Results and Discussions

From the experimental investigations various Loads-Settlement curves for a series of tests varying L/d ratios are presented below. The tests were performed following the procedures according to IS: 2720(PART-16):1987. With every L/d ratio, the percentage of Fly ash and lime added were varied.

**Figure 3.** Load-Settlement Curve for GP with L/d = 3.5

**Figure 4.** Load-Settlement Curve for GP with L/d = 3.0
Figure 5. Load-Settlement Curve for GP with L/d= 2.5

Figure 6. Load-Settlement Curve for GP with L/d= 2.0
The following Load settlement curves are presented by varying the ‘L/d’ ratio by keeping the percentage of fly ash & lime constant.

Figure 7. Load-Settlement Curve for GP with L/d = 1.5

Figure 8. Load-Settlement Curve for GP of NA with 30% Fly Ash + 3% Lime
It is noticed that when the L/d ratio along with percentage of fly ash and lime is increased the settlement is noticed to reduce significantly. The ultimate load of the BC soil for any reinforced soil is noticed to be more than the unreinforced or untreated BC soil sample.
From the following curves it is also noticed that with increase in L/d ratio of the granular pile as well as the fly ash and lime content the ultimate load is increased. Hence, the Load-settlement behaviour pattern noticed is in accordance with the various literature surveys done by me and falls in place with the model tests conducted by various researchers.

5. **Conclusion**

The objective of the study is to conduct experiments to study the Load-settlement behaviour of geotextile encased granular pile in BC soil, taking various composition of granular pile with natural aggregates, fly ash and lime at different L/d ratios 1.5, 2, 2.5, 3 and 3.5. Based on the experimental investigations and results obtained it is noticed that:

1. Settlement in reinforced BC soil reduces with increased L/d ratio of GP, i.e. from 1.5 to 3.5. For GP of 53% Natural Aggregate + 40% Fly Ash + 7% Lime, the ultimate load increased by 10% as compared to GP of 67% Natural Aggregate + 30% Fly Ash + 3% Lime.
2. For increased proportion of Fly ash & lime in the granular pile material for each L/d ratio the settlement is noticed to reduce. Although, the rate of reduction of settlement for the increasing proportion of GP material is slow. Here is some observation:
   i) Granular Pile of 67% Natural Aggregate + 30% Fly Ash + 3% Lime at L/d 3.5 takes 37% more load to achieve same settlement as compared to at L/d 1.5.
   ii) Granular Pile of 60% Natural Aggregate + 35% Fly Ash + 5% Lime at L/d 3.5 takes 44% more load to achieve same settlement as compared to at L/d 1.5.
   iii) Granular Pile of 53% Natural Aggregate + 40% Fly Ash + 7% Lime at L/d 3.5 takes 37% more load to achieve same settlement as compared to at L/d 1.5.
3. Ultimate load for geotextile encased Granular Pile of 53% Natural Aggregate + 40% Fly Ash + 7% Lime at L/d 3.5, increased by 192% to achieve the same settlement when compared to unreinforced BC soil.
4. It can also be concluded that granular pile of full length gives more strength and less settlement as compared to untreated BC soil or at any depth.
5. The ultimate load is notice to increase with the increased L/d ratio of GP. Also, it is increasing for all the percentages of Fly ash & lime, even though the rate is slow but the result and pattern is in accordance with all the literature surveys made by me.

According to the laboratory tests conducted, the results comparing the performance of the geotextile encased granular piles in BC soil are in good accordance with all the literature surveys done for this study.

References

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