Strength and Settlement studies on basalt fiber reinforced marginal soil

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Abstract. Laboratory soil tests had conducted footing settlement studies analysis for sand and soil, but still a research gap exist that not many studies were done for reinforced and stabilized earth. In thus study, an attempt is made to analyze the load vs. settlement characteristics of various reinforced soils using an small size square reaction tank of 50x 25x18 cm. Various reinforced soils such as Basalt fiber in 2\% reinforcement and optimum moisture content for this proportions is found to be 10\% and soil in the reaction tank is filled with this OMC and kept for 48 hours for mellowing. A 5-ton capacity loading frame is used for loading, settlement characteristics measurements were using precise dial gauges and load settlement curve were drawn.

1. Introduction

Soil stabilisation is mostly done in weak soils. This helps to increase its strength and improves the performance of the structure. Many studies are being done on this concept by adding several components to the existing soil. Reinforcing the soil under the footings is one such method which gained attention\cite{1}. Geogrids are widely used in several cases to reinforce the weak soils such as soft clay. This is generally done when the subgrade is weak. Some different methods are also proposed to improve the bearing capacity of soils like soft clay. One such method is to partially remove the existing weak soil and replacing it with granular soil. This may be considered as the partial replacement. Based on the required bearing capacity and the allowable settlement of the soil this replacement is done\cite{2}.

For stabilization of weak soils, various methods such as vibro-flotation, compact soil using piles or explosion, excavation and replacement, well point system, reinforced earth are usually employed. Ineach case, predicting the apt method always depends on several factors such as soil condition, the required degrees of compaction, construction process, maximum depth of compaction, timetimeline for completion of a project, availability of equipment and materials, etc.

Many studies are being done to improve the characteristics of soil especially in black cotton soil. Studies state that index properties of black cotton soil are improved when treated with granite dust and lime \cite{3}. Further the index properties of expansive soils are also improved by adding flyash into it\cite{4}. Studies are also done to improve the engineering properties of black cotton soil with GBFS\cite{5}. Stabilization of black cotton soil is done by using novel SiO\textsubscript{2} combination as a stabilization agent \cite{6}. Some high swelling soils are also stabilized using Lignosulfonate and Metakaolin\cite{7}.
Using some traditional techniques to improve soil condition often contributes some problems ranging from economical to environmental issues, such as to construct a foundation in soils with very poor bearing capacity is not always compatible with the overall cost of construction of the project[8]. So rather than investing huge amount in construction of footings, soil stabilisation techniques can be adopted which reduces the cost of construction of footings. And these processes can be easily adopted[9, 10].

Bearing failure and settlement are the two dependable factors in the process of stabilisation of soils. Based on these two factors the design of footing is done. The bearing failure is always checked using the plastic theory and the settlement by elasticity concept[11].

The overall load-settlement behaviour is the important factor in designing the footings on cohesion less soils under axial compression loading. The load settlement is first used in estimating the settlement at a given load and secondly it is used to interpret the failure load or the bearing capacity of the soil [12].

2. Materials and methodology

2.1 Basalt

It is a volcanic rock usually dark in colour, fine grained and comes under igneous rock. It composes minerals as plagioclase, feldspar, calcic and pyroxene[13]. It mostly form an extrusive rock such as lava flow. Usually fine graded particles are formed due to rapid cooling of lava on the surface. This rock underlines most of the surface of earth. Most areas with ocean basins are also underlain by basalt[14].

When compared to many rock types basalt is the one which underlies most of the earth's surface. Especially most of the Earth's basins are underlain by basalt. Although basalt is much less common on continents, lava flows and flood basalts underlie several percent of Earth's land surface. Basalt is a very important rock[15].

2.2 Use of basalt fibre

The basic qualities of basalt fibre are it has high abrasion chemical resistance. It also have high compressive strength. Some other physical properties of basalt fibre are it can be made into very fine fibres, super fine fibres and ultrafine fibres[16]. These fibres are considered surpassing based on its special properties as heat, sound insulation and thermal stability, new range of composite products and materials properties, durable and resistant to vibration. These fibres can be anticipated as a completely very new range of composite materials and products[17]. However these products are given such importance because they do not have any reaction with water or air. Non-combustible nature and expulsion proof, non-reactive to any contactive chemicals, indirectly zero damage to the environment adds these fibres to the list of important material. Many applications of asbestos can be replaced by basalt fibre. Basalt fibre has three times of reinforced plastics. More over 1 kilogram of basalt reinforcement is equal to 9 kilograms of steel approximately[18].

2.3 Applications

Basalt fibre is used in a wide range of possibilities, as basalt plastic reinforcement bars, in heat insulation materials glass and wool etc[19]. now a days basalt fibres are even used as aggregates in concrete, ballast in railways, high quality textile fibres are produced for floor tiles, for heavy industries it is used as acid resistance equipment[20]. After many mineralogical studies for this basalt fibre the FTIR spectrum is obtained and shown in Figure 1.
2.4 Index properties and Engineering Properties

Index properties of soil are specific gravity, water content, particle size distribution, in-situ density, consistency limits, relative density. Whereas engineering properties are permeability, shear strength and compressibility. To determine these properties of soil standard tests are done as per IS for example SP-36, Part 1[21] and the results are tabulated. These properties are determined for the sample to be filled in the small scale reaction tank.

The ratio of weight of the soil solids to the ratio of equal amount of water is considered as the specific gravity of the soil sample. A volumetric flask is used to perform this experiment in the laboratory. With the use of this volumetric flask the volume of soil is found and then this weight is divided by equal volume of water.

Liquid limit is obtained at the point where the soil transfers from the natural solid state and then it starts to behave like a semi solid particle. It can also be defined as a small shearing strength which helps to withstand the ability of flow as of water when mixed with water. A graph is plotted for the shear strength by taking no. of blows on abscissa (logarithmic scale) and then the water content in the sample on the ordinate. Plastic limits are obtained by rolling the soil samples to the point where the diameter reaches approximately to 3mm and then the water content added to the sample is measured where the soil crumbles on reaching the diameter of 3mm. plasticity index is obtained with the values of liquid limit and plastic limit.

| Table 1. Index properties of Standard soil |
|------------------------------------------|
| Specific Gravity                         | 2.23  |
| Natural water content                    | 25%   |
| Liquid limit(WL)                         | 34.10%|
| Plasticity index                        | 11.84%|
| Liquidity index                         | 23.14%|
2.5 Particle size distribution characteristics
The initial soil classification of the soil is either dry or wet based on the particle size analysis. The size of the soil particles has a significant effect on the engineering properties of the soil. The formation of the soil by weathering process, the larger size particles has resist the disintegrated effects caused during weathering wear-tear process. Larger the particle size, larger will be stability and strength of the soil[22]. The $D_{10}$ is termed as the effective size of the soil in mm and it is least finer size of the soil retained. The ratio of, $D_{10}$ and $D_{60}$ gives the uniformity coefficient ($Cu$) which in turn is a measure of the particle size range[23].

The coefficient of uniformity is given by,

$$Cu = \frac{D_{60}}{D_{10}}$$

![Figure 2. Liquid limit of Standard soil](image-url)
To obtain the relationship among the moisture content of the soil and the dry density of the soil proctor compaction test is done. This experiment is done as per Indian standards. The experimental instrument consists of a cylindrical metal mould of internal dia 10.15cm and height od 11.7cm, it also have a detachable base plate, a collar of effective height of 5cm and a rammer of 2.5kg. Compaction is done on the soil sample, this increases the bulk density of the soil by removing the air voids[24]. The theory used for this process is that the dry density of the soil depends on the moisture content in the soil for any compactive effort[25]. When almost all the air is driven out and the soil is compacted at a high moisture content the maximum dry density is obtained this is also called as MMD. The moisture content present in the soil for this MMD is called as optimum moisture content of the soil which is denoted as OMC. A graph is plotted between water content added to the soil on abscissa and dry density on the ordinate we can obtain the MMD and OMC of the soil sample[26].

Figure 3. Grain size Distribution of standard soil

3. Proctor compaction test

Figure 4. OMC for standard soil and soil + 2% basalt fiber
3.1 Shearing characteristics
To find the cohesion of the soil and the angle of internal friction of the soil direct shear test is used. Both cohesion and angle of internal friction are called as soil shear parameters they are denoted as \( c \) and \( \varphi \) respectively. When ever a structure is dependent on the soil shearing resistance then the property of shear strength is considered as the important soil property. OMC and MMD are used to prepare the soil sample inside the shear box. Then a constant load is applied on the sample to find the values of cohesion and angle of internal friction[27]. Then the shearing load is applied on the soil by increasing it at a constant rate and is applied to the point where failure occurs. This load at failure when divided with the area gives us the shear strength for the soil sample[28]. The arithmetic equation is given as

\[ \tau = c + \sigma \tan(\varphi) \]

the loads are changed and then applied on different samples, a straight lined graph is obtained which has the slope equal to the angle of internal friction and the intercept which is equal to the cohesion. This experiment is considered as the easiest and the most quickest method to determine the shear strength parameters of the soil. The sample preparation is also very easy in this experiment[29].

| Table 2. Direct shear for standard soil and soil + 2% Basalt fiber |
|------------------|------------------|
| \( C(\text{N/cm}^2) \) | 1.661 | 0.703 |
| \( \phi \) | 11 | 8 |
| \( \theta \) | 40 | 41 |
| \( \sigma_1(\text{N/cm}^2) \) | 14.1687 | 12.225 |
| \( \sigma_3(\text{N/cm}^2) \) | 6.873 | 7.9695 |
| \( \sigma(\text{N/cm}^2) \) | 11.154 | 10.991 |
| \( \sigma(\text{N/cm}^2) \) | 3.829 | 2.248 |

3.2 Unconfined compressive strength\((qu)\)
It is the compressive stress at which the unconfined cylindrical sample fails under a very simple compression test[30]. Unconfined compression test is used to calculate the undrained and unconsolidated shear strength of the soil[31]. A dial guage is provided on the instrument and a compression device is also constituted. The compression setup is for load and then the dial guage is used to note the deformation. The load will be taken for different readings of the dial guage starting from \( \varepsilon =0.005 \) and is increased by equal by value of 0.005 at each step. By dividing the area by \( (1 - \varepsilon) \) the corrected cross sectional area is calculated and then by dividing the load with the corrected area the compressive stress for each step is calculated.

![Figure 5. Stress strain curve for standard soil and soil+2% basalt fiber](image-url)
3.3 Footing settlement studies

The reaction tank used in this study is of size 50x25x18cm. The soil is filled upto a depth of 45cm with the density of 1800 Kg/m$^3$. The soil is compacted by a heavy rammer with the blows of 7 for each layer providing an energy equivalent to light compaction effort of Proctor test[32]. The soil is mixed by using mixture machine with optimum moisture content and left for 48 hours’ maturation[33, 34]. The soil is mixed in the concrete mixer machine large volume of soil to be mixed, the fiber and stabilizing agents are directly added to soil and allow to rotate for 2 minutes to obtain even mixing, after which water is added upto optimum moisture content level and mixing is continued for 5 minutes[35, 36]. The soil is taken out in a tray and closed with polythene sheet to avoid water escape, this is kept for 4 hours for mellowing. Then the soil is filled in even layers in the reaction tank with a compaction energy of 6 kilo/joules. This setup is kept for 24 hours by properly covering the top surface to avoid moisture escaping. Before the study is conducted the moisture content, density, is measured and noted.

Figure 6. Small Reaction Tank In 5 ton Capacity Loading Frame
3.4 Load vs settlement curve

Load is applied to the soil using a plate of size 10 cm X 10 cm loaded by the loading frame with 5ton cylinder. This test is conducted as a stress controlled test in which the applied loading rate is controlled by using servo motor operated by a pressure gauge. Load is measured using sensitive 10 ton load cell calibrated before every test.

![Load vs Settlement curve for standard soil+2% Basalt fiber](image)

**Figure 8.** Load vs Settlement curve for standard soil+2% Basalt fiber
4. Conclusion

In this research effort is taken to analyse the reinforcement characteristics of basalt fiber and the strength increased it provides to prevent footing settlement. For standard soil the load vs settlement describes the settlement increased and where in the addition of 2% basalt fiber the settlement curve is linear and strength increased. The permeability value for soil + 2% basalt fiber is 0.0218 mm/sec. The study and linear variation in the curve shows that the basalt fiber prevents uneven settlement and makes the settlement linear with respect to time. There are few limitations in this study which includes the settlement duration, resting period of the soil inside the tank before testing but yet it gives accurate results in predicting the settlement characteristics of the reinforced soil.

5. References

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