Evaluation of Sustainable Methods for Embankment Stabilization

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Abstract. Technologies that can contribute to sustainable environment and enhance economic feasibility have been gaining importance all over the world. The researchers have taken advantage of locally available materials and renewable sources in order to accomplish sustainable and economic construction activities. Many research works have been carried out in the field of ground improvement towards developing techniques that causes minimum impact on the environment. Some of the conventional materials that have been used in the past for embankment stabilization are lime, cement, fly ash, silica fumes, GGBS etc. Enzymatic treatment of ground is one of the emerging multi-disciplinary solutions that targets environment sustainability through stabilization using bio-enzymes. In this method bio-enzymes, which is obtained from vegetable extracts, are used for improving the mechanical characteristics of the natural weak soil. In the current work, a comparative study has been performed for the analysis of the different techniques/materials used for improvement of embankment/sub grade resting on expansive soil. The expansive/ problematic soil is spread across a large part of central and western India and poses challenges to engineers due to its high compressibility properties. The improvement in the compressive strength characteristics of expansive soils when stabilized using materials like lime, rice husk ash, stone dust, fibre and bio-enzyme are being compared and studied in this work. On comparison it is observed when the stabilizing agent is pozzolanic in nature, curing period plays a crucial role as far as improvement factor is concerned.

1. Introduction
With advancement in technology in the past few years, the environmental sustainability has been recognized as a key initiative across the globe. The increase in population all around the world has also created a huge demand for improved and sustainable infrastructure development. Due to non-availability and increasing cost of construction materials, researchers have focused in promoting locally available materials and renewable sources for various construction activities. This has led to an extensive utilization of land for different construction purposes which resulted in scarcity of available land. Hence upgrading the engineering properties of natural weak soil and extending the infrastructure development to such soil was looked up on by the researchers. Black Cotton (BC) soils are expansive or problematic clays spread over a large part of central and western India and are unsuitable for any construction activity due to its high compressibility characteristics. These soils exhibit high swelling
and shrinkage characteristics which poses serious threats to the performance of any infrastructure. In order to facilitate construction phenomenon, BC soil was subjected to stabilization process.

Stabilization involves the improvement of the engineering parameters of weak soil so as to enhance its suitability for construction works. The widely accepted methods of refining the engineering aspect of soil is through mechanical or chemical means. Many research works have been carried out in the past on enhancing the engineering behavior of BC soil using conventional stabilizing agents such as lime, fly ash, coir-fiber, GGBS etc. [1] studied the effect of varying percentages of lime and thermal curing on strength of expansive clay and concluded that stabilized soil when cured at elevated temperatures offers maximum strength gain. [2] conducted experimental studies on problematic soil blended with lime, rice husk ash (RHA) and calcium chloride. They observed from their results that there is an optimal content of RHA and lime beyond which both Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) of the stabilized expansive soil decreased. [3] conducted experimental studies to understand the potential of using Ground Granulated Blast Furnace Slag (GGBS) as a substitute stabilizing agent to lime and cement. They summarized that although the compaction parameters decreased with increasing GGBS percentage, the strength of blended BC soil increased up to a certain limit. [4] studied the potential of using stone dust and polypropylene fibers on improving the engineering characteristics of Black Cotton soil and confirmed their feasibility in enhancing the strength parameters. The stabilization of soil using bio-enzymes has been the recent development in this area. The effect of varying dosages and curing periods in bio-modification of BC and lateritic soil was explored by [5]. Based on the experimental investigation they reported the effectiveness of enzymatic stabilization in improving the strength parameters of weaker soil. The swell shrink characteristics of expansive soil blended with bio-enzyme was estimated by [6]. Their studies revealed a decrease in swelling properties due to change in structure of soil as a result of enzyme blending.[7] explored the potential of using enzyme improved laterite soil in pavements. They summarized from their results that stabilization using bio-enzyme is ineffective in soils having higher percentages of cohesionless materials.

In the current work, it is proposed to study and compare the effect of various sustainable methods of stabilization for embankments constructed in BC soil. The BC soil blended with different enzyme proportions were tested for improvement in unconfined compressive strength. The advancement in strength parameters when treated with different stabilizing agents such as lime, stone dust, GGBS and bio-enzymes were explored and results are compared with available literature and analyzed to make recommendations on field applicability.

2. Methodology
The methodology adopted in the present study is briefed as:

a) Identification of Black Cotton soil for the current study and characterize the same
b) Determination of Unconfined compression test for two trial proportions of bio-enzyme
c) Comparison of the present studies with the available literature
d) Provide recommendations on its application to field.

The soil sample obtained from field was oven dried and were tested for index and engineering properties determination. Two trial dosages of enzyme namely, 150 and 250 ml per cubic meter, obtained by volume proportioning was fixed for the present study. The strength characteristics of bio-enzyme blended BC soil was estimated by virtue of moisture-density relationship and compressive strength test. The comparative studies were executed in order to evaluate the outcome of different stabilizing agents on BC soil. Based on the comparative studies conducted, efforts are made to provide recommendations on the applicability of the stabilizers in the field.

3. Material Characterization
For the present study Black Cotton soil was obtained from Chitra Durga district of Karnataka. The soil used for the present study was essentially gray in color and has a specific gravity of 2.63. The soil is classified as CH as per [8] and achieves a maximum dry density of 1.5 g/cc at an optimum moisture
content of 16.25%. Shear strength and Bearing resistance are the two important parameters that decides the suitability of any soil for infrastructure applications. The untreated soil has an unconfined compressive strength of 151 kPa and a California Bearing Ratio of 4.6%.

4. Experimental Studies

In the present research, the influence of Terrazyme on moisture-density relation and compressive strength of Black Cotton soil is studied and is summarized in the following sub-sections.

4.1. Effect of enzyme on moisture density relationship

The sustainable stabilizer used in the present study is Terrazyme and has a specific gravity in the range of 1 to 1.09 (as supplied by the vendor). The bio-enzyme used for the study is completely soluble in water and is not reported to be hazardous. In the present study two different dosages of enzyme is considered viz., 150ml/m$^3$ and 250 ml/m$^3$. The maximum dry density and optimum moisture content of the treated and untreated soil is estimated using Standard Proctor Compaction test and the compaction plots are presented in Figure 1. The curves obtained indicates an increment in maximum dry density along with a marginal decrement in optimum moisture content. In the absence of enzyme, the untreated soil is susceptible to swelling which inhibits the soil grains from coming close.

![Figure 1. Moisture density relationship for untreated and enzyme treated Black Cotton soil.](image)

4.2. Effect of enzyme on Unconfined Compressive Strength

From the literature it is observed that the effect of enzymes on any soil is also dependent upon curing period [9,10]. In the present study unconfined compressive strength is determined after curing for 7 and 28 days and compared. The results are presented in Figure 2. From the figure it is observed the increase in enzyme dosage will increase the compressive strength. Also, it can be inferred that the increase in strength is dependent upon the period of curing. In the initial stages of curing, the attainment in compressive strength is dependent upon the dosage. However, as curing period increases it is perceived that the influence of enzyme dosage is quite insignificant. This is because the reaction of enzyme with the BC soil is quite slow. With curing period, moisture equalization takes place and this enables uniform reaction of enzyme with soil.
Figure 2. Effect of enzyme dosage and curing period on the unconfined compressive strength.

5. Comparative Studies

To evaluate the effectiveness of different ground stabilizers, five different studies including the present work are compared. All the studies compare the performance of Black Cotton soil having similar characteristics and the details of the literature considered are presented in the Table 1.

| Literature  | Stabilizer used                              | General properties                      |
|-------------|---------------------------------------------|-----------------------------------------|
| [4]         | Polypropylene fibres and stone dust          | Specific gravity -2.6 to 2.72           |
| [2]         | Lime/ calcium chloride along with rice husk ash | Plasticity index – 30-55               |
| [3]         | GGBS\(^a\)                                   | Optimum moisture content – 23-32%       |
| [1]         | Lime and temperature effect                  | Maximum dry density – 13 to 16.5 kN/m³  |
| Present study | Terrazyme                                    |                                         |

\(^a\) Ground Granulated Blast Furnace Slag

For comparison of the results, the unconfined compressive strength of the BC soil on addition of stabilizers are studied. However, to measure the potency of stabilizer, Improvement factor as defined by [11] has been used, wherein

\[
I_f = \frac{q_{u,\text{(stabilized)}}}{q_{u,\text{(unstabilized)}}}
\]

Accordingly, the improvement factors as derived from the use of different stabilizers are compared and presented in Figure 3.
Analysis of the improvement factors reveal that the most effective ground stabilizer is lime. However, its effect is predominant at higher temperatures or in the presence of a highly reactive pozzolanic material like rice husk ash. Other than lime, the effective stabilizer is the Terrazyme which is used in the present study. This infers that the present study throws light on one of the most effective means of stabilization of expansive soil.

6. Recommendations for field applications
A broad analysis of the literature reveals that the applicability of a stabilizer is dependent upon its availability. Since the ultimate objective is to reduce the cost of construction, the stabilizer should be easily available at the location where expansive soils are there. Black Cotton soils are found mainly in Madhya Pradesh, Maharashtra and Northern parts of Karnataka. However, in these zones since temperature is in the range of 30-40°C, use of lime or Terrazyme is the most preferred solution.

7. Conclusions
The present study explores the effectiveness of Terrazyme in stabilizing Black Cotton soil. A comparative study has also been carried out to evaluate the effectiveness of different stabilizers. Accordingly, the following recommendations are made:
1. The effectiveness of Terrazyme is dependent upon the curing period rather than dosage.
2. Terrazyme has only marginal or slight influence on the optimum moisture content and maximum dry density.
3. Performance of lime is comparable to that of enzyme treated Black Cotton soil.

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