Alteration of CBR Values in Soft Soils Using Enzymatic Lime

Greeshma Nizy Eujine, S. Chandrakaran and N. Sankar

Abstract Natural soil samples were treated and cured with lime, enzyme and enzymatic lime. The cured samples were subjected to various laboratory tests. The optimum dosages were calculated based on the results of Unconfined Compressive Strength Tests. Later samples were mixed with optimum dosages and compacted in Proctor moulds and were subjected to CBR tests at different stages of curing. Significant improvement was observed in enzymatic lime stabilized soils over lime stabilized and enzyme stabilized soils. CBR tests were also done by varying the percentage of clay in the soil specimens. In all tests enzymatic lime stabilized soils exhibited superior improvement of properties.

Keywords CBR · Enzyme stabilization · Ground improvement
Lime stabilization

1 Introduction

During the construction of highways, most often good earth is brought from ex situ or the in situ clayey soil is compacted. In the case of compacted soils, the monsoon season moistens the soil subgrade and the performance of the pavement, or in other words affects its CBR. The CBR or California Bearing Ratio is a measure of pavement stability/thickness or a technique of strength comparison between treated and untreated soils. The CBR of stabilized soils ends to be higher than of untreated soils. In this paper CBR values are compared to study the effect of enzymatic compound extracted from sugar molasses, on soils stabilized with lime.

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While numerous research works are and have been done to understand the behavior of soil–lime mixtures in the presence of other salts/chemicals, no literature has been found on enzymatic lime soil stabilization. On the other hand a number of case studies have been reported (Vedula et al. 2002) stating that sugar molasses enzyme by itself improves soil properties. The scope of the paper includes observation of the changes in CBR values of cured lime and enzyme treated soil systems and the possible savings in pavement design and construction.

2 Mechanism of Stabilization

As mentioned, the paper describes the use and effect of chemical agents lime and a bioenzyme on the index properties of stabilized soils. The utilization of lime in soil modification is not a novel technology. It is a traditional means in a variety of construction applications since the time of Romans and has never entirely disappeared. When used in soil, lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood 1993).

It alters the clay surface mineralogy, producing a reduction in plasticity and moisture holding capacity, and an improvement in soil stability. But the disadvantages of lime stabilization include lime carbonation and sulfate salt reactions which may lead to disintegration of bonds on aging. To account for the negative impacts, a number salts and chemicals have been added with lime to soil and tested. Among these already tried and proved agents include cement, fly ash, rice husk, etc.

It was hence decided to mix an enzyme with lime for the purpose of soil stabilization and to study its effects on soil properties. Enzymes are organic molecules that catalyze very specific chemical reactions if conditions are conducive to the reaction. They are typically used in low concentrations as they are not consumed by the reactions they make possible. Enzyme additives attach with large organic molecules that are attracted to the clay mineral's net negative surface charge (Scholen 1992). The enzyme used in the work like other enzymes is costly and a method to reduce the amount of enzyme, while obtaining the same degree of improvement, if achievable would be greatly advantageous. And since lime and enzyme use the same mechanism of cation exchange to improve soil properties, the idea to add both lime and enzyme together in the soil and to investigate the alterations in soil properties seemed feasible.

3 Materials Used and Methodology

The materials used in the present study is a natural clay soil obtained from Pantheerancavu, 12 km south of Calicut, lime purchased from local market in Kunnamagalam at Calicut and bioenzyme acquired from Avijeet agencies, Chennai.

Table 1 Engineering properties of soil

Property	Value
Liquid limit (%)	79
Plastic limit (%)	48
Shrinkage limit (%)	27
Bulk density (kN/m^3)	13.25
Optimum moisture content (%)	32
Soil type	Kaolinitic
Unconfined compressive strength (kPa)	64
Clay content (%)	22.17

Table 2 Properties of bioenzyme

Property	Value
Boiling point	212 F
pH	2.8–3.5
Vapor pressure (mmHg)	As water
Melting point	Liquid
Vapor density (Air = 1)	1
Solubility in water	Infinite
Evaporation rate	As water
Specific gravity (H_2O = 1)	1.00–1.10
Appearance and odor	Lt. gold liquid, characteristic odor

The physical properties of soil used are given in Table 1 and the basic properties of bioenzyme (provided by the supplier) are given in Table 2.

4 Methodology

All the specimens tested in this study were prepared and tested using standard procedures described in the Bureau of Indian Standards—IS 2720 (Part 5):1985, IS 2720 (Part 10):1991, and IS 2720 (Part 16):1987. Soil sample was air dried for a week, pulverized manually using weights, sieved through 425 micron sieve and preserved in large containers in an enclosed room. Lime was sieved using 425 micron sieve and preserved in an air-tight container to prevent carbonation. Bioenzyme was preserved in an air-tight bottle in its original liquid form.

It is known that the Optimum Lime Content of soils vary from 2 to 6% of weight with higher percentages required for soils with higher clay content. Thus soil and lime were mixed from 0 to 10%. The variations in Liquid Limit and Optimum Moisture Content were observed for each fraction within 24 h. The minimum amount of lime that did not further reduce the Liquid Limit i.e. 3.5% was chosen as approximate Optimum Lime Content. Unconfined Compression Tests were done on soils mixed with lime in the ranges 2–5%, and cured up to four weeks in air-tight bags. The actual optimum lime content was inferred from the results of unconfined compressive strength tests.

Similar tests were also done to determine the optimum dosage of Bioenzyme in the soil. A dilution ratio chart provided by Avijeet agencies (that calculated the required dosage of Bioenzyme for a particular soil based on particle size and plasticity index) served as a reference to determine the range of optimum Enzyme Content. Literature shows that enzymes provide 80% of their final strength in three to four weeks. Hence soil specimens were mixed with Bioenzyme dosages between 70 and 90 ml/m^3, cured up to four weeks in air-tight bags and tested for Unconfined Compressive Strengths. The Optimum Bioenzyme Content was determined from the test results.

Various combinations of soil + lime + enzyme mixtures were cast, cured, and tested at the optimum moisture content of untreated soil. The amount of Bioenzyme was kept close to Optimum Bioenzyme Content predominantly in all cases and percentage lime was varied from 1 to 6%. After several trials and combinations, and comparison of unconfined compressive strength of these specimens, the optimum enzymatic lime dosage was inferred.

From the results of unconfined compression tests, the optimum dosages for soil–lime mixtures, soil enzyme mixtures and soil enzyme lime mixtures were chosen. The CBR tests were performed at these dosages.

5 Results of CBR Tests

A series of experiments were conducted to understand the variation in CBR values of soil lime, soil enzyme, and soil enzyme lime mixtures. The optimum dosages were 3% lime for soil–lime mixtures, 80 ml/m^3 Bioenzyme for soil enzyme mixtures and 70 ml/m^3 Bioenzyme + 1.75% lime for soil enzyme lime mixtures. It was observed that the CBR values increased in comparison to the CBR values of untreated soils. Tables 3 and 4 describe the modification of unsoaked and soaked CBR of natural clay treated with the three stabilizing agents. The CBR values

Table 3 Variation in CBR of soil treated with stabilizers (unsoaked)

Specimen type	CBR values w.r.t period of curing in weeks			
	1	2	3	4
Untreated soil	3.6			
Soil–lime mixture	5.8	8.5	12.9	16
Soil enzyme mixture	4.2	6.2	10.1	13.2
Soil enzyme lime mixture	7.1	14.3	16.3	19.6

Table 4 Variation in CBR of soil treated with stabilizers (soaked)

Specimen type	CBR values w.r.t period of curing in weeks			
	1	2	3	4
Untreated soil	2.7			
Soil–lime mixture	4.2	6.2	8.5	11.5
Soil enzyme mixture	3.8	4.0	5.2	6.8
Soil enzyme lime mixture	4.3	10.2	12.0	13.4

increased up to 5 times when treated with lime alone, up to 3 times when treated with enzyme alone and more than 6 times when treated with enzymatic lime under unsoaked conditions

Figures 1 and 2 describe the load verses penetration curve of unsoaked and soaked CBR samples of untreated and stabilized soil samples at four weeks curing. It is observed that the enzymatic lime-stabilized soils gave higher CBR values under both unsoaked and soaked conditions. Although the improvement remains marginal, it is to be noted from Tables 3 and 4 that the CBR of enzymatic lime stabilized soils at two weeks curing is higher than the CBR of lime treated and enzyme treated soils at four weeks curing. Several studies have been done on lime and enzyme treated soils. However studies on enzymatic lime treated soils have not yet been done.

Yong (2007) studied the effect of lime on Marl Clay and reported that CBR reduced up to 78% under soaked conditions. While in this paper it was observed that CBR reduced up to 29% for lime treated soil, almost 50% for enzyme treated soils and nearly 32% for enzymatic lime-stabilized soils. Bell (1996) found that expansive clays respond more quickly to the lime treatment. In this case montmorillionitic clay has responded quite well to all three additives. The lime in the presence of enzyme has enhanced the soil properties better than lime-stabilized

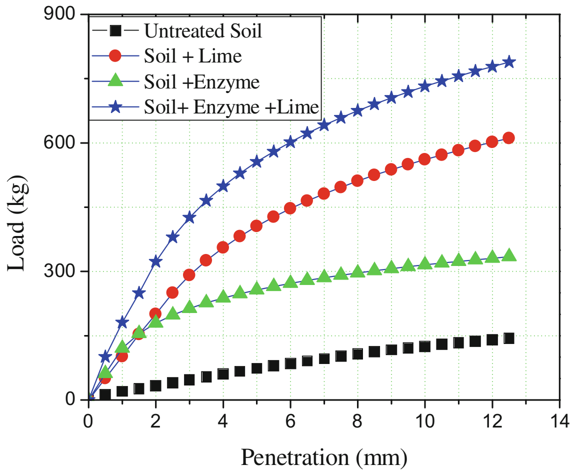
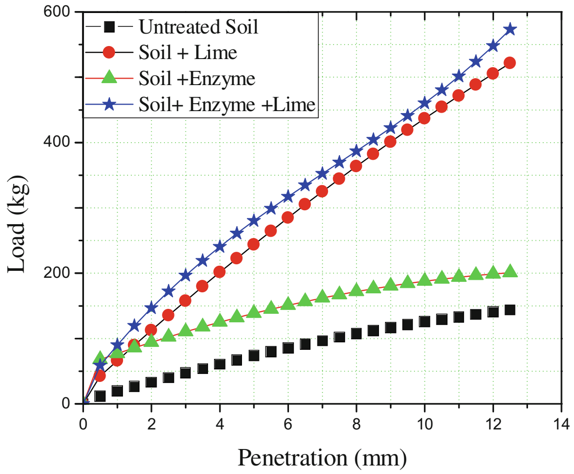


Fig. 1 Load verses penetration graph for soil samples under soaked condition (at 28 days)

Fig. 2 Load verses penetration graph for soil samples under soaked condition (at 28 days)



soils. Nugent et al. (2009) evaluated the interactions between exo-polymers and kaolinite clay to determine effects on the behavior of the kaolinite. The nano-scale interactions between the kaolinite and the cations and biopolymers used in the study were evaluated and it was found, inter alia, that biopolymer-induced aggregation of clay particles formed a clay-polymer interconnected network through cation bridging and hydrogen bonds. When the soil is combined with lime and enzyme, the cation bonds may be formed at an accelerated rate, bringing bout an increase in strength in shorter duration.

6 Modified Flexible Pavement

A good pavement design enables vehicles to pass through safely and economically. The granular materials are often affected by changes in moisture. The reason soil stabilization improves the pavement performance is because the changes in soil subgrade at the micro level affect the pavement behavior at a macro level (Steyn 2011). A sustainable pavement reduces the use of natural resources and energy consumption. It limits pollution and ensures a high level of user comfort and safety (Maher et al. 2006). Consider the design of flexible pavement of enzymatic lime stabilized soil subgrades, as compared to conventional lime stabilized soils.

Figure 3 describes the thickness of flexible pavement based on the CBR values of underlying subgrade and is a very rudimentary rule-of-thumb check from AUSTROADS (2001). The untreated soil used in this work has an initial CBR of 4, a pavement thickness requirement of 560 mm for an equivalent single axle (ESA) value of 4e7 (Line 1). For the same ESA, while conventional lime treatment increased the CBR to 16, requiring a pavement thickness of 285 mm (Line 2), the enzymztic lime stabilized soil with CBR value 19.6 will require a pavement

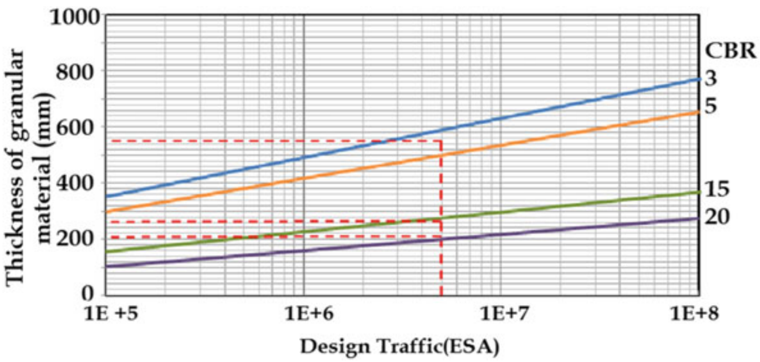


Fig. 3 Design thickness of flexible pavement on varying subgrades

thickness of only 240 mm (Line 3). A considerable savings of 45 mm is possible, along with a reduced curing period of two weeks. The use of this enzymatic lime stabilization system in the field has certain economic advantages on cost. Using local soil as much as possible instead of bringing the material from outside, the digging of the local soil and exchanging with the material brought from outside and avoiding the cost of both transportations, etc., being some. One of the most important advantages of this system is the opportunity to use and develop the local material that generally causes costs to increase, when local material needs to be exchanged with the material that is brought from outside, the opportunity to pre-mixing the material and saving construction time.

It can be concluded that using enzymatic lime stabilization for the construction of pavements, a cost saving up to 20% may be obtained as compared to lime-stabilized methods. The above cost is calculated without considering the maintenance costs which will further reduce the cost of enzymatic lime stabilized soil.

7 Conclusion

Enzymatic Lime Stabilization of soils can be used in improving the bearing capacity of the subgrade, with noticeable savings on both aggregate and disposal charges. Exposure to water has significantly reduced the CBR of all treated soils, with enzyme treated soil being affected the most. CBR of enzymatic lime treated soils have improved by more than 450% in unsoaked condition as compared to untreated soils. Economic advantages of using enzymatic lime stabilization technique include:

- Using local soil as much as possible
- Avoiding transportation cost

- Reduction in construction time
- Reduction in construction materials.

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