Bio-Enzyme Stabilization of Expansive Soils Sustainable And Eco-Friendly Alternative To Lime/Cement

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Abstract- *Expansive soils, particularly black cotton soils, exhibit significant swelling and shrinkage behavior due to moisture variation, causing structural instability and damage to infrastructure. Traditional stabilization techniques using lime and cement, although effective, are associated with high carbon emissions and environmental degradation. This research paper explores bio-enzyme stabilization as a sustainable and eco-friendly alternative. Bio-enzymes, derived from organic fermentation, improve soil properties through catalytic reactions that enhance particle bonding and reduce water affinity. This study reviews mechanisms, experimental findings, advantages, limitations, and field applications of bio-enzyme stabilization. Results indicate substantial improvements in strength, reduction in plasticity, and enhanced durability, making bio-enzymes a promising alternative for sustainable geotechnical engineering*

Keywords: Bio Enzyme, Lime, Cement, Sustainable, Plasticity, Strength etc

I. INTRODUCTION

Expansive soils are problematic due to their high shrink-swell potential caused by moisture variation. These soils typically contain clay minerals such as montmorillonite, which exhibit high water absorption and volume change characteristics . This leads to cracking, heaving, and structural failures in pavements and foundations.

Conventional soil stabilization methods involve lime and cement treatment. While effective, these methods:

- Produce high CO_2 emissions
- Increase construction costs
- Cause long-term environmental degradation

Recent research has focused on bio-based stabilization techniques as sustainable alternatives. Bio-enzymes have emerged as an innovative solution due to their eco-friendly nature and effectiveness in improving soil properties .

II. OBJECTIVES

- To evaluate the effectiveness of bio-enzymes in stabilizing expansive soils
- To compare bio-enzyme stabilization with lime and cement methods
- To analyze the environmental and economic benefits

III. EXPANSIVE SOILS: CHARACTERISTICS AND CHALLENGES

Expansive soils:

- Exhibit high plasticity and compressibility
- Have low shear strength and bearing capacity
- Undergo cyclic swelling and shrinkage

These properties make them unsuitable for construction without stabilization.

IV. CONVENTIONAL STABILIZATION METHODS

4.1 Lime Stabilization

- Reduces plasticity and increases strength
- Works through pozzolanic reactions

4.2 Cement Stabilization

- Improves compressive strength and durability
- Forms cementitious compounds

Limitations

- High carbon footprint
- Energy-intensive production
- Long curing time

- Environmental concerns .

V. BIO-ENZYME STABILIZATION

5.1 Definition

Bio-enzymes are organic, non-toxic liquid formulations derived from fermentation of plant extracts, sugars, and agricultural waste .

5.2 Common Bio-Enzymes

- TerraZyme
- PermaZyme
- DZ-2X
- Eko Soil Enzyme

VI. MECHANISM OF BIO-ENZYME STABILIZATION

Bio-enzymes act as catalysts that modify soil behavior through:

6.1 Cation Exchange

- Reduces thickness of adsorbed water layer
- Decreases soil plasticity

6.2 Particle Bonding

- Enhances inter-particle bonding
- Increases soil density and strength

6.3 Reduction of Water Affinity

- Makes soil less susceptible to moisture variation

6.4 Biochemical Reactions

- Accelerate chemical reactions between clay particles and organic ions

These processes improve compaction and mechanical strength

VII. EXPERIMENTAL FINDINGS

7.1 Strength Improvement

- Unconfined compressive strength increased up to **131%** in treated soils

7.2 Plasticity Reduction

- Significant reduction in plasticity index and shrinkage

7.3 Compaction Characteristics

- Increase in maximum dry density (MDD)
- Reduction in optimum moisture content (OMC)

7.4 Swelling Reduction

- Improved resistance to volume change

7.5 Bearing Capacity

- Increase in California Bearing Ratio (CBR) values

VIII. CONCLUSION

Bio-enzyme stabilization presents a promising, sustainable alternative to conventional lime and cement stabilization techniques. It significantly improves the engineering properties of expansive soils while minimizing environmental impact. Although further research is required for large-scale implementation and standardization, bio-enzymes have strong potential to revolutionize geotechnical engineering practices toward greener infrastructure development.

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