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Preparation Of Soil Improvement Using Biological Stabilization Treatment

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ABSTRACT

The use of biological processes for ground improvement, particularly bio cementation, is a relatively new area and a potentially sustainable alternative strategy. The most commonly investigated biological soil improvement procedures are Microbially induced calcium carbonate precipitation (MICP) and Enzyme induced calcium carbonate precipitation (EICP). MICP and EICP improve soil by facilitating calcium carbonate precipitation via urease enzymes generated by bacteria cells or plants. Plant derived crude urease enzymes can be used as an excellent alternative to commercially available urease enzymes. A comparative study of the efficiency of both MICP and EICP indicated that EICP can be an excellent alternative to MICP due to its precipitation efficiency ease of controlling the precipitation rate. The results of UCS values of treated EICP samples in different types of soils showed an increase in strength parameters.

Biological stabilization, an eco-friendly technique for improving soil properties in construction projects. Unlike traditional methods that rely on chemicals or mechanical intervention, biological stabilization utilizes living organisms or their byproducts to enhance soil characteristics. The approach offers numerous advantages, including sustainability due to its reliance on natural processes, reduced environmental impact by eliminating harmful chemicals, and self-healing capabilities through ongoing microbial activity. The abstract then highlights the primary applications of biological stabilization in fortifying soil strength and bolstering erosion resistance. Finally, it acknowledges the limitations of this developing technology, including the ongoing research on long-term performance data and the dependence on specific soil properties for optimal effectiveness.

Key words: MICP, (Microbially induced calcium carbonate precipitation) EICP, (Enzyme induced calcium carbonate precipitation) Crude urease enzyme, Soil improvement, Calcium Carbonate.

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INTRODUCTION

Soil improvement techniques modify soil properties for construction or long-term performance. These techniques can improve strength, compressibility, permeability, or groundwater conditions. Biological stabilization treatment is a novel and sustainable approach to soil improvement. It utilizes microorganisms to enhance soil properties and promote ecosystem health, addressing challenges of soil degradation and promoting sustainable development.

1. Soil Degradation: A Pressing Threat

Soil degradation, marked by a decline in quality and productivity, is a critical global issue with cascading environmental, social, and economic consequences. Intensive agricultural practices, deforestation, urbanization, industrial activities, and improper land management all contribute to soil erosion, compaction, nutrient depletion, and contamination. These processes not only threaten agricultural productivity and food security but also exacerbate biodiversity loss, water pollution, and climate change.

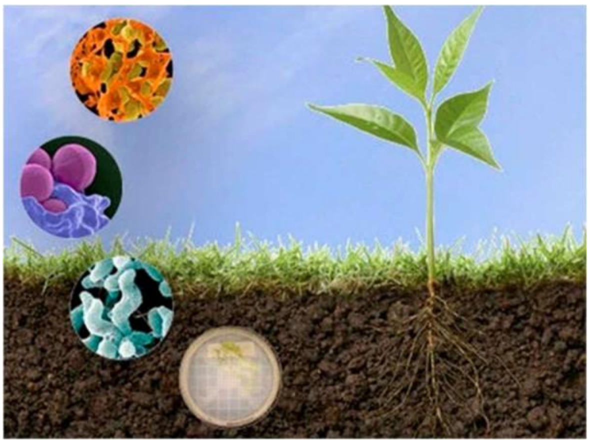
2. limitations of Conventional Methods

Historically, conventional soil stabilization methods have relied on mechanical, chemical, or structural interventions to address soil degradation and improve stability. Techniques like mechanical compaction, chemical stabilization with cement or lime, and structural reinforcement with geosynthetics or concrete have been common in infrastructure development, construction, and land rehabilitation projects. While effective in some contexts, these methods often come with high energy inputs, environmental impacts, and long-term maintenance costs, highlighting the need for more sustainable alternatives.

3. A Shift Towards Biological Solutions

Biological stabilization treatment represents a paradigm shift in soil management, emphasizing the power of microorganisms to enhance soil structure, fertility, and resilience. By harnessing the metabolic activities of beneficial microbes, biological treatments offer eco-friendly, cost-effective, and sustainable solutions to soil improvement challenges. These treatments aim to promote soil aggregation, enhance nutrient cycling, remediate contaminants, and mitigate erosion through natural biological processes, ultimately restoring soil health and functionality.

4. The Microbiological Engine.



At the core of biological stabilization lies the intricate interplay between microorganisms and soil particles. Bacteria, fungi, algae, and archaea interact with soil organic matter, minerals, and water, catalyzing biochemical reactions that influence various soil properties. Processes like organic matter decomposition, mineral weathering, nitrogen fixation, and carbon sequestration mediated by microorganisms contribute significantly to soil stabilization, nutrient cycling, and overall ecosystem function.

5. A Diverse Toolkit: Techniques and Approaches

Biological stabilization encompasses a diverse array of techniques and approaches tailored to specific soil improvement goals and environmental contexts. Key techniques include bio cementation, bio stabilization, bioremediation, and biochar amendment, each leveraging distinct microbial processes to achieve desired outcomes. Bio cementation, for instance, involves the precipitation of calcium carbonate by uratolytic bacteria, which binds soil particles together, enhancing cohesion and stability. Bio stabilization, on the other hand, utilizes microbial exopolysaccharides to promote soil aggregation and reduce erosion susceptibility.

6. Innovation at the Forefront

Advancements in microbial ecology, genetic engineering, and biotechnological applications have expanded the scope and efficacy of biological stabilization treatments. Researchers are exploring novel microbial strains with enhanced capabilities for soil improvement, as well as innovative formulations of microbial inoculants and organic amendments. Genetic engineering techniques pave the way for the design of customized microbial consortia optimized for specific soil conditions and improvement goals, fostering tailored solutions to address soil degradation challenges.

Biological stabilization bursts onto the scene as an innovative technique for soil improvement in construction, placing itself at the forefront of sustainable practices. This abstract delves into its potential to revolutionize the field.

7. Sustainability Benefits Beyond the Environment

One of the primary advantages of biological stabilization treatments is their environmental sustainability. Unlike conventional methods that often rely on synthetic chemicals or energy-intensive processes, biological stabilization harnesses natural microbial processes that are inherently eco-friendly. By minimizing reliance on external inputs and reducing carbon emissions, these treatments contribute to environmental conservation and climate change mitigation efforts.
Furthermore, biological stabilization promotes soil biodiversity, enhances ecosystem services, and fosters long-term soil health and resilience, aligning with principles of sustainable development and environmental stewardship.

8. Applications Spanning Industries

Biological stabilization treatments offer versatile solutions with applications across various sectors, including agriculture, forestry, infrastructure development, environmental remediation, and urban planning. In agriculture, these treatments can improve soil fertility, water retention, and crop productivity, supporting sustainable intensification and resilience to climate variability. In forestry, biological stabilization techniques facilitate reforestation efforts, enhance soil regeneration, and mitigate erosion risks in degraded landscapes. Moreover, in infrastructure development, biological stabilization can reduce construction costs, enhance durability, and promote green infrastructure solutions, contributing to more resilient and sustainable built environments.

9. Socioeconomic Considerations and Empowering Communities

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The adoption of biological stabilization treatments can have significant socioeconomic benefits, particularly in rural and resourceconstrained communities. By improving soil productivity and ecosystem services, these treatments enhance livelihood opportunities for farmers, promote food security, and reduce dependence on external inputs. Furthermore, community-based approaches to soil management empower local stakeholders, build social capital, and promote inclusive decision-making processes. Engaging communities in the design, implementation, and monitoring of biological stabilization projects fosters ownership, builds resilience, and ensures the relevance and sustainability of interventions tailored to local needs and priorities.

10. Bridging Knowledge Gaps: Future Research Directions

Despite the promising potential of biological stabilization treatments, several knowledge gaps and research challenges remain. Further research is needed to elucidate the intricate mechanisms underlying microbial-mediated soil processes. This will allow for the optimization of microbial consortia for specific soil conditions and improvement goals. Additionally, research is crucial to assess the

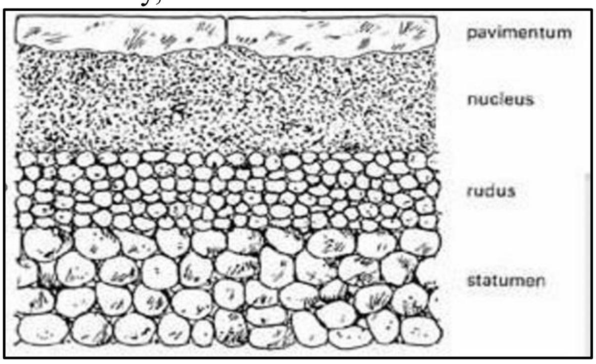


Figure 1 Layers of soil

BENEFITS OF USING SECONDARY RAW MATERIALS IN SOIL STABILIZATION

1. Improved Water Content-Density Relationship: Lime modifies soil texture through flocculation (particle clumping), increasing void ratio and decreasing dry density. This also raises the optimal moisture content for compaction.
2. Reduced Plasticity Index: Lime treatment significantly reduces plasticity in most clay soils. This results from a decrease in the liquid limit and an increase in the plastic limit.

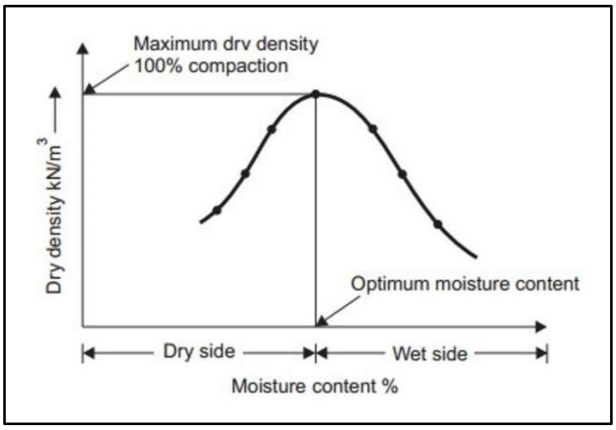


Figure 2 Relationship Between moisture content and Dry Density

3. Increased Shear Strength: Lime treatment enhances the material's capacity to withstand repeated load cycles without failure, improving its fatigue resistance.
4. Enhanced Durability: Lime-treated soils exhibit greater durability against the detrimental effects of wet-dry and freezethaw cycles, ensuring long-term performance.
5. Increased Strength: Research has shown that lime addition improves the strength properties of both uncured and cured soils.
6. Role in Strength Enhancement: Lime mortars, used for centuries in construction, demonstrate the strength and reliability of lime-treated materials despite lower strength compared to cement mortars. Lime treatment also increases wet

compressive strength and reduces water absorption.

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$$

$$2NH_3 + 2H_2O \rightarrow 2NH^+_4 + 2OH^-$$

$$CO_2 + H_2O \rightarrow HCO_3^- + H^+$$

$$HCO_3^- + H^+ + 2OH^- \rightarrow CO_3^{2-} + 2H_2O$$

$$Ca_{2+} + CO_{32-} \rightarrow CaCO_{3\downarrow}$$

$$CO(NH_2)_2 + 2H_2O + Ca^{2+} \rightarrow 2NH_4^+ + CaCO_{3\downarrow}$$

LITERATURE REVIEW

- This paper by Murtala et al. (April 2015) explores the potential of bio-mediated soil improvement (BMIS) for geotechnical applications, highlighting its advantages in terms of execution and environmental sustainability. The review examines the soil microorganisms involved in BMIS and factors influencing their activity and compatibility with soil particles. The paper concludes by discussing potential applications of BMIS in geotechnical engineering and challenges associated with its field implementation.
- This paper by Negi et al. defines soil improvement as the modification of soil properties through chemical and physical methods to enhance its engineering performance. The primary goals are to increase bearing capacity, reduce permeability, and improve workability. The paper emphasizes the importance of stable soils for construction projects. Unstable soils can compromise structures. The paper focuses on various methods for modifying soil properties and their improvement using lime.
- Takeshi (2023) explores three key issues regarding material reuse in Japanese geotechnical applications. Firstly, the paper examines the current state of using excavated soils, highlighting recent efforts to assess their environmental suitability due to potential contamination concerns. Secondly, it emphasizes the growing importance of traceability in ecogeotechnics. Finally, the paper discusses challenges in utilizing disaster waste generated by the 2011 earthquake and tsunami, focusing on efficient separation of usable soil from debris for geotechnical applications.
- Wuana et al. (2023) review potential sources, chemistry, and health risks of heavy metals in polluted soils. They discuss common methods for remediating these metals, including immobilization, soil washing, and phytoremediation. These techniques are highlighted as promising advancements for cleaning up contaminated sites. Remediation is crucial to reduce associated risks, restore land for agriculture, improve food security, and minimize landuse change issues.
- Singh (2023) investigates the risks posed by heavy metals (Cd, Cu, Pb) to human health and ecosystems due to their introduction into soil and groundwater systems. The paper identifies industrial waste and leachate from landfills as potential sources of contamination. The study emphasizes the importance of understanding soil interactions with heavy metals for remediation strategies. Batch and leaching column tests are used to assess these interactions in compacted clay liners, commonly used in landfills.
- Ping Wang, Jiang-shan Li, Hua-fang Wang; present that to concentrate the impact of EDTA washing remediation on building properties of overwhelming metals debased soil, bunch tests were led to gauge the pH, penetrability, restrict water substance, compressibility and shear quality of lead

sullied soil washed by EDTA; Comes about demonstrated that pH and attachment diminished as the grouping of EDTA expanded; and as far as possible expanded from 21.8% to 23.0% and fluid breaking point expanded from 41.6% to 43.3% as convergence of EDTA expanded from 0 to 0.15mol/Infinitesimal tests come about demonstrated that the mineral substance of montmorillonite (from 7.87% to 0.07%), elite and albite diminished and quartz expanded by 11.09% as EDTA focus expanded.

1. Principles of Biological Stabilization:

Biological stabilization involves the use of microorganisms and their metabolic processes to modify soil properties. The key principle revolves around the interaction between microorganisms and soil particles, leading to alterations in soil structure, composition, and stability. Microorganisms such as bacteria, fungi, and algae play pivotal roles in processes like organic matter decomposition, mineral weathering, and nutrient cycling, contributing to soil improvement.

2. Techniques of Biological Stabilization:

Bio cementation: Microbially induced calcite precipitation (MICP) is a prominent bio cementation technique wherein urea and calcium sources are introduced into the soil, triggering microbial activities that result in the precipitation of calcite, thereby binding soil particles and enhancing cohesion. Bio stabilization: This technique involves the application of organic materials or microbial inoculants to promote soil aggregation and reduce erosion susceptibility. Microbial products such as exopolysaccharides act as binding agents, binding soil particles together and imparting stability.

3. Advancements and Innovations:

Genetic Engineering: Advancements in genetic engineering have enabled the development of microbial strains with enhanced capabilities for soil stabilization. Engineered microbes can exhibit improved metabolic pathways for mineral weathering or produce specific compounds conducive to soil aggregation. Bioremediation Coupled with Stabilization: Integrating bioremediation processes with stabilization techniques offers a dual benefit of soil improvement and contamination mitigation. Microorganisms capable of degrading pollutants can be employed alongside those promoting soil stabilization, addressing environmental concerns while enhancing soil quality.

4. Applications and Effectiveness:

Erosion Control: Biological stabilization treatments have shown effectiveness in mitigating soil erosion by enhancing soil cohesion and aggregate stability. Applications in slope stabilization, roadside rehabilitation, and mine reclamation have demonstrated significant reductions in erosion rates. Infrastructure Development: Bio cementation techniques have garnered attention for their potential in infrastructure development. Soil improvement through MICP has been explored for applications in foundation construction, underground tunneling, and pavement reinforcement, offering sustainable alternatives to conventional stabilization methods.

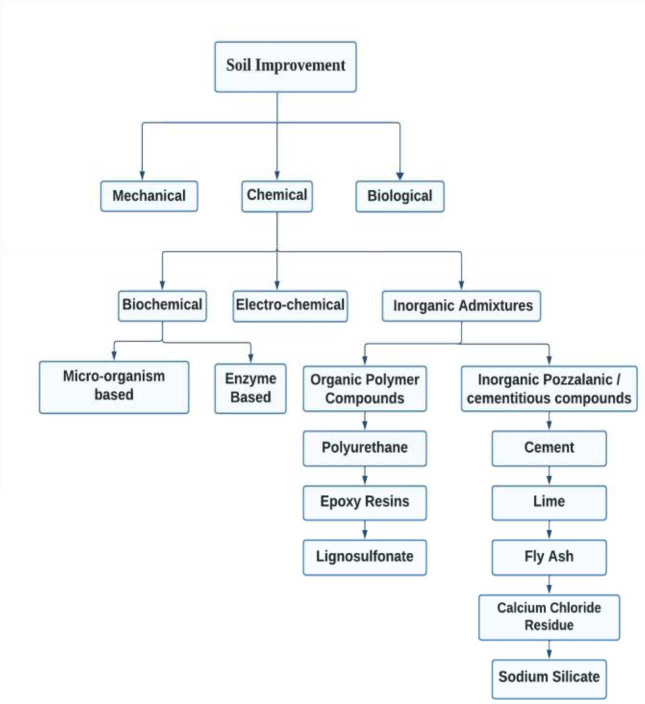
Research Objectives

1. This research work will help to fulfil the infrastructural demand for the growing country like India.
2. With these research development activities has to be carried out on the weak and problematic soil due to the shortage of competent land space.

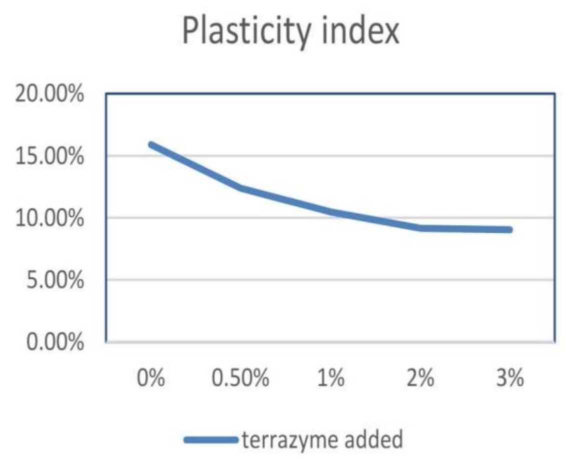
3. By using this research, we can push forward the increasing awareness of environmental issues, there has been a remarkable shift toward "green" and sustainable technologies.

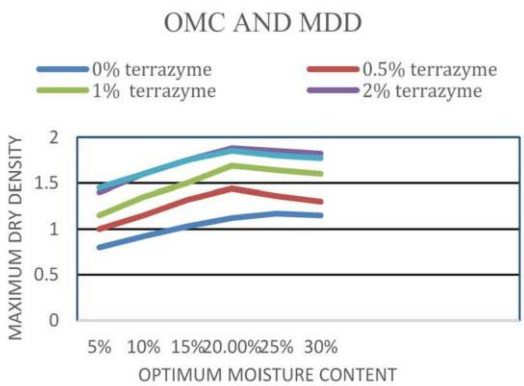
Research methodology

In this technique, calcium carbonate precipitation has been induced inside the soil matrix by microorganism through their metabolic process to improve the engineering properties of soil. This technique is also called as microbial induced carbonate precipitation or MICP.



1. Collection of soil sample- normal ground (collected 5kg soil by digging 3m depth.
2. Engineering properties of soil sampleMaximum dry density (MDD), optimum moisture Content (OMC), liquid limit (LL), plastic limit (PL), grain size, IS classification
3. Selection of Bacteria and batch cultivation- Sporosarcina Pasteurii, Bacillus
4. Quantitative analysis of calcite precipitation.





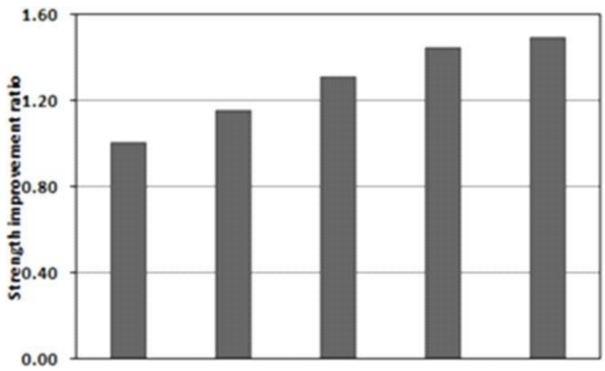


Figure 3 Precipitation

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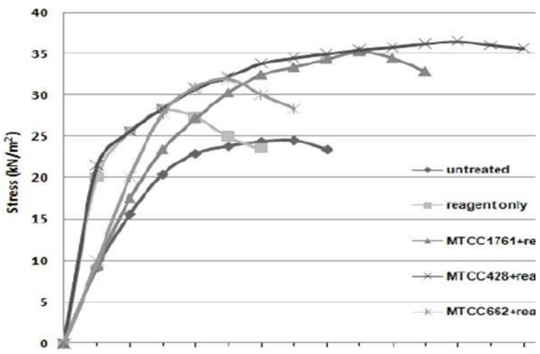

DESIGN MIX

Total weight of soil- 3kg

Weight of mould- 4.8 kg

1. Weight of mould + sample + 2% water- 7.05kg
2. Weight of mould + sample + 4% water- 7.12kg
3. Weight of mould + sample + 6% water- 7.21kg
4. Weight of mould + sample + 8% water- 7.38kg
5. Weight of mould + sample +10% water- 7.32kg

1. Cut of container- 43.32gm rCut of container + sample- 54.14gm
   Cut of container + sample after drying- 4.
   53.6gm
2. Cut of container- 33.51gm
   Cut of container +sample- 44.08gm
   Cut of container + sample after drying- 5.
   43.6gm
3. Cut of container- 42.25gm
   Cut of container + sample- 48.72gm

Cut of container + sample after drying- 48.01gm

Cut of container- 49.47gm
Cut of container + sample- 57.77gm
Cut of container + sample after drying - 56.77gm

Cut of container- 31.93gm
Cut of container + sample- 43.49gm
Cut of container + sample after drying- 42.33gm

Table 1 Soil Properties

No	Water Content (W%)	Bulk density (γ)	Dry density (γd)
1	5.25%	22.5	21.37
2	7.68%	23.5	21.54
3	8.98%	24.1	22.11
4	10.13%	25.8	23.42
5	12.59%	25.2	22.38

Sieve analysis

Total weight of soil- 1 kg

Sieve size - (4.75>2.36>1.18>>600μ>300μ>150μ>75μ>Pan)

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Sieve C_1	Sieve size C_2	Mass of each sieve C_3	Sieve + retained soil C_4	Mass of soil retained (C_4-C_3)	Percentage of each C_{5}/W_n*100	Cumulative percentage of R_n	Percentage
1	4.75	.340	.502	.162	16.2	16.2	83.8
2	2.36	.324	.386	.062	6.2	22.4	77.6
4	1.18	.300	.412	.112	11.2	33.6	66.4
6	600	.296	.37	.074	7.4	41	59
7	300	.298	.317	.019	1.9	42.9	57.1
8	150	.290	.529	.239	23.9	66.8	33.2
9	75	.288	.301	.013	1.3	68.1	31.9
10	Pan	.416	.735	.319	31.9	100	0

Metal	Concentration, mg/L	
	A	Base-1
Al	2.74	60.4
Ca	719	420
Fe	24.1	3.19
K	7800	1.55
Mg	337	2.13
Mn	2.11	< 1
Na	169	31000
P	< 1	2.94
Rb	11	< 1
Si	318	63000
Zn	3.05	< 1

Table 2 Metal concentration in product-A and Base-1

Metal	Concentration, mg/L	
	A	Base-1
Cl-	1150	14.5
NO^{3-}	Not detected	Not detected
SO_4^{2-}	664	27.8

Table 3 Inorganic anions in product-A and Base-1

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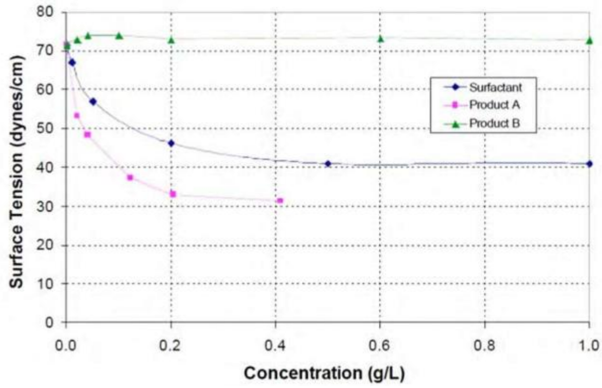

Figure 4 Surface tension test results of products A, B and SDD

Wavelength (cm^{-1})	Functional Group
1,120	C-O
1,220	tertiary butyls
1,350	C-OH
1,300	CH2=CH, CH-OH
1,460	C-H bend

Table 4 Interpretation of peaks in FTIR spectra for the enzyme stabilizer

The summary of Atterberg limits, increase in dry density, friction angle, cohesion and R-value are given in the Table 5.

Soil No.	Type AASHTO/ USCS	L.L			P.L			P.I.	Max. dry density (pcf)	Angle of internal frication (Degrees)	Cohesion (kPa)	R-Value
		1*	2*	3*	1	2	3	3	3	3	3	3
1	A-2-4/ GC	26.2	24.3	-7.3	17.6	19	8	-38.4	5.2	-3.7	6	27.3
2	A-2-4/ GP	24.2	--	--	17.4	--	--	--	-7.7	12	-5	-43.5
3	A-2-4/ SW-SC	22.1	--	--	16.9	--	--	--	0.5	-6.8	14.7	-23.3
4	A-2-4/ GW	22.5	--	--	16.2	--	--	--	-0.1	-0.2	36.2	1.4
5	A-2-4/ SP	29.3	28.7	-2	19.3	20	3.6	-13	-4	6.7	20.5	--
6	A-2-4/ GW-GC	26.9	26.7	-0.7	21.5	18.9	-12.9	44.4	1.6	-10.5	64.2	7.7
7	50 % Soil 5 +50% ¾ inch class-II AB	--	--	--	--	--	--	--	1.4	-3.7	20.1	14.7
8	75 % Soil 6 +25% ¾ inch class-II AB	--	--	--	--	--	--	--	4.4	-4	38.9	-13.2
9	50 % Soil 1 +50% ¾ inch class-II AB	--	--	--	--	--	--	--	0.6	-10.7	59.5	-10

1* untreated, 2* treated and 3* % increase

Table 5 Summary of laboratory test results

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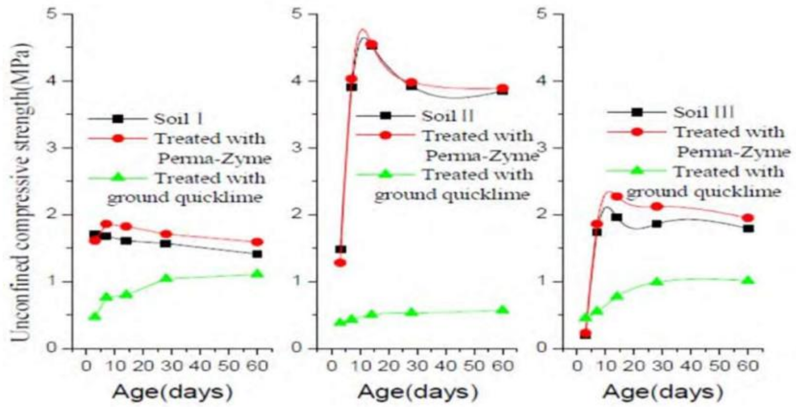

Figure 5 Relation of unconfined compressive strength and curing time under air-dry

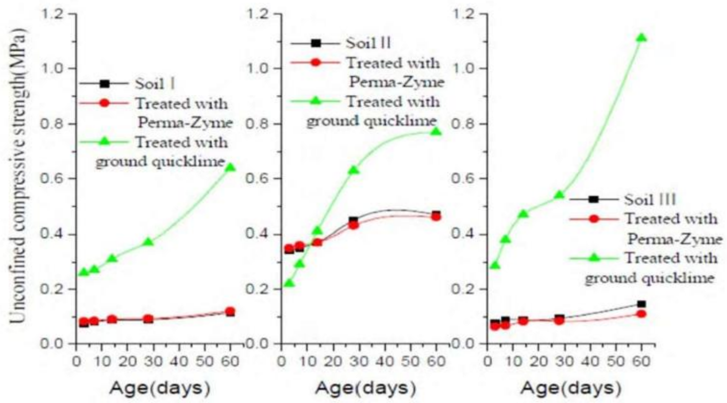

Figure 6 Relation of unconfined compressive strength and curing time in sealed glass

CONCLUSION

- The above studies show varying results from very modest improvement to significant improvement. Therefore, the published claims or results by the manufacturer of these enzymes cannot be trusted without independent laboratory testing. But at the same time the laboratory tests are criticized for not replicating the field conditions.

- Biological stabilization treatments offer holistic solutions for addressing complex socio-environmental challenges while promoting social equity, environmental sustainability, and cultural resilience.

- By embracing principles of inclusivity, biodiversity conservation, resilience-building, and policy coherence, these techniques can contribute to the achievement of multiple sustainable development goals.

- Through collaborative partnerships, community engagement, and policy integration efforts, biological stabilization holds promise as a transformative approach to advancing human well-being and planetary health in a rapidly changing world.
- But if the product does not show significant results in the controlled laboratory conditions then it is more difficult to attain desired results in lesser favourable conditions in the field. Its only when laboratory testing shows significant results then the next question would be how much improvement is required to validate its use in the field.

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