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Smart Subbase: Glass-Powder and Cement-Reduced Laterite Fusion

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ABSTRACT
There is a rising demand for sustainable materials because the road construction industry plays a major role in resource depletion, greenhouse gas emissions, and environmental deterioration. In order to improve engineering properties and lower cement usage, this study investigates the stabilization of lateritic soil using Portland Pozzolana Cement (PPC) and waste glass powder. Eleven percent PPC and two percent glass powder were used to stabilize lateritic soil samples from the Kazhakuttam region of Kerala. Significant gains in strength and load-bearing capability were demonstrated by laboratory tests such as the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). For subbase applications on low-volume roads, the CBR exceeded 75% and the UCS above 2.25 MPa, both of which meet IRC 37 standards for using subbase in low-traffic roads.[1]

The research also evaluated pavement design optimization utilizing IIT PAVE software, showcasing the capability to lessen the thickness of the Wet Mix Macadam (WMM) layer while maintaining structural integrity. Providing geotextiles on top of the stabilized subbase along with side drains , waterlogging above the subbase can be reduced to a great extent. The focus was on sustainability and cost efficiency by partially replacing cement with glass powder, which significantly reduced material costs and lowered the carbon footprint related to cement production. This method of stabilization is innovative in the fact that it combines resource optimization, waste management, and this method is very efficient, and therefore, met with great satisfaction for environmentally clean construction works. The research demonstrates the possibility of its application in scales as well as in adaption to regions that are rich in lateritic soil.

Keywords: Lateritic soil; waste glass powder; Portland Pozzolana Cement (PPC); sustainable construction; geotextile drainage system

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I. INTRODUCTION

The increasing focus on both sustainable and economically friendly geo-technical engineering has augmented the requirement towards effective resource utilization and environmental protection.Lateritic soils in Kerala poses significant challenges for road construction because of their poor engineering properties. Traditionally, it is done with the use of stabilizers like cement, but it has lately been done with waste glass powder instead. The goal of the research is to enhance the environmentally friendly stabilization of lateritic soils for low volume road (LVR) construction by employing waste glass powder as a partial cement replacement.[2]

The study bridges the gap of data regarding usability of waste glass powder in engineering lateritic soil limits for compressive strength and California Bearing Ratio (CBR). It also takes into account the economic advantage of improving the compressive strength and the bearing ratio and the thickness reduction of the Wet mix macadam (WMM) layer which was calculated based on IIT Pave. All these in combination require the application of sustainable materials and practices which is promoted in this study to facilitate efficient road subbase stabilization in an environmentally sustainable manner.

The procedure includes the sampling of lateritic soil and carrying out index and engineering property tests such as grain size analysis, Atterberg limits, specific gravity, and CBR, and Unconfined Compressive Strength (UCC). Preparation of the stabilization mix is done by blending stabilizer cement (9-12% by weight of soil) and glass powder (2% by weight of soil). Mix design and performance test considers the improvement of the process of stabilization in Low Volume Road construction.[3-4]

Among the several anticipated contributions of this study is the feasibility of using waste glass powder as a means of reducing the amount of cement used while, at the same time, maximizing soil strength and enhancing pavement sustainability. The research is anticipated to provide a reference for the industry in the construction of low-cost, resource-based, and sustainable road infrastructure.

I Soils of Kerala

Geological foundation of Kerala is characterized by Precambrian Archaean rocks and sedimentary, tertiary, and quaternary deposits. The region has undergone five phases of major tectonic uplifts and two phases of coastal subsidence. Additionally, the majority of the land is hilly with barely a slender coastal strip being in sight.

Extensive erosion over time, in addition to Miocene-age subsidence onto the margin of the continental shelf, has shaped the current topography. Sea-level fluctuations, of more than 150 meters, indicate that the current sea level is a feature of comparatively recent times.

In Kerala area, lateritic soils are present in quaternary and tertiary sedimentary deposits, as well as in subsurface crystalline deposits, which suggests extensive erosion and the process of lateritization. The improper application of laterite in the subbase and base courses of pavements has exacerbated local geotechnical issues. Tectonic activity, as well as stream erosion from the highlands, has led to the deposition of diverse geological materials in low topography regions, resulting in lithological inconsistency. Soils of Kerala are of various types, including coastal alluvium, mixed alluvium, acid saline soils, Kari soils, lateritic soils, red soils, hill soils, black cotton soils, and forest soils.

II Lateritic Soil

Lateritic soil occurs typically in hot and humid tropical environments, including regions of India, Africa, Southeast Asia, and Australia. It forms through intense weathering, in which heavy rainfall washes away soluble minerals, leaving behind iron and aluminum oxides that supply the reddish-brown hue to the soil. Though leached and hence nutrient-deficient, lateritic soils are high in iron and aluminum.

On top of acidic rock formations, lateritic soils are strongly indurated and zoned, and the intensity of induration increases with iron content. They typically occur at 10 to 100 meters above sea level, in strips between mid-altitudes and coastal regions. Lateritic soils are typically mounds or low hills with irregular slopes. One of the most noticeable features is that they are strongly plastic, and this results in strong volume changes with changes in moisture, and this makes construction difficult. Stabilization methods enhance their quality for use in infrastructure construction.

III Composition of Lateritic Soil

Lateritic soil contains iron and aluminum oxides in abundance, and minerals such as quartz, kaolinite, and clay minerals. It depends on where the location is, the climate, and the region's geological history. Lateritic soils do not contain organic matter and may not contain basic nutrients such as nitrogen, phosphorus, and potassium. Though difficult for agriculture, with proper care and fertilization, lateritic soils may produce some crops.

Derived through weathering rock residue in arid, tropical conditions, laterite possesses an open, pitted surface composed of high amounts of iron, aluminum, and titanium oxides. Strength and hardness result from the iron minerals' close packing. Although with good drainage characteristics in its in-place condition, remolded laterite can be claylike and plastic upon wetting and is restricted for use in particular construction applications. Laterite was first tested from the mid-1970s as a low-volume bituminous-surfaced road base course and was still used considerably in road layer applications.

IV Lateritic Soil in Kerala

Lateritic soil in Kerala is mostly found in the midland and highland tracts, particularly in districts such as Thiruvananthapuram, Kollam, Alappuzha, Kottayam, Thrissur, and Kannur, occupying approximately 50% of the area. These soils are of three types:

Soils with less than 30% gravel and thickness between 60 to 150 cm, mostly occurring at the foot slopes of laterite mounds.

Lateritic soils of 30% to 80% gravel, occurring in the side slopes and crests of laterite hills.

Afterwards soils with less than 50 cm thickness, occurring in northern regions such as Malappuram, Kozhikode, and Kannur, characterized by indurated laterite exposures.

Significance of Laterite Stabilization for Road Construction

Soil stabilization in road construction is essential to increase shear strength and structural load-bearing capacity. This is especially where the underlying soil is not strong enough to meet construction requirements. Stabilization processes, including the addition of cement, enhance the shear strength of the soil, reduce permeability and compressibility, and increase the load-bearing capacity of the soil, finally increasing the lifespan of the pavement and foundation. Permeability and compressibility also decrease through stabilization, making the soil more suitable for use in construction.

II. Materials and methods

This section outlines the materials and test procedures employed to achieve the study's objectives. The experimental plan, visualized in the accompanying flow chart provides a concise overview of the study's methodology

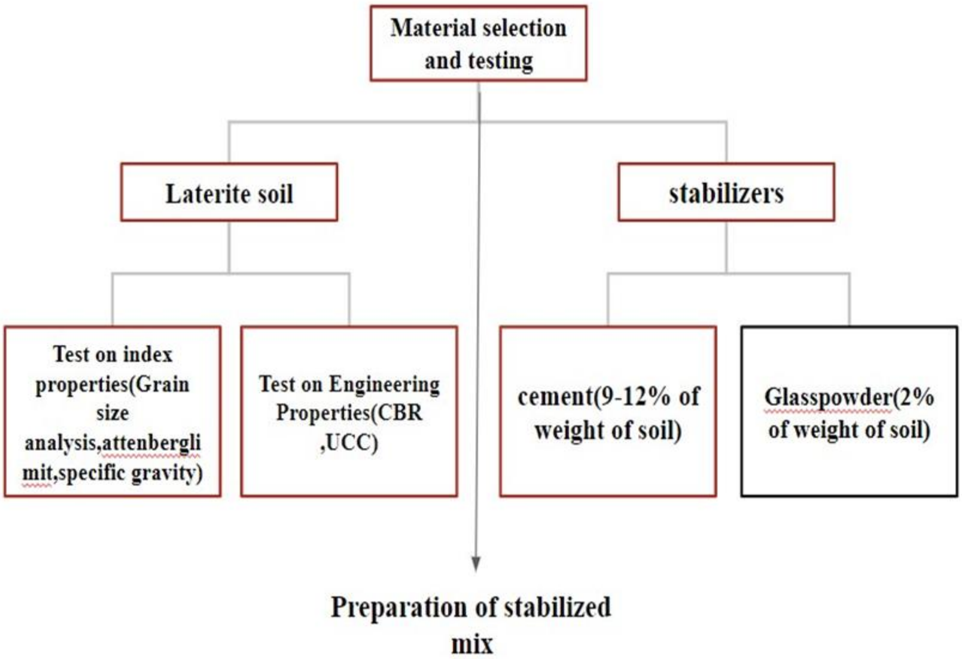

Figure 1 Research Flow chart

Lateritic soil

The soil sample used for the study was obtained from a burrow pit of 1.5m depth from various part of Thiruvananthapuram which falls under the Kazhakuttam series of Trivandrum district as per Soil Survey Organisation, Agriculture Department of Kerala.

Figure 2 Laterite soil

2.1.2.Cement

Ramco PPC Cement is a type of Portland Pozzolana Cement known for its enhanced durability and resistance to aggressive environments. It incorporates pozzolanic materials, which improve the strength and longevity of concrete, making it ideal for various construction applications, including road subbases.

Table 1: Chemical properties of PPC cement

All values are in % by mass unless otherwise stated.

Chemical Requirement	Values (Ramco PPC)	Requirement as per IS 1489: Part 1 - 1991
Magnesia (MgO)	1.29	Max 6.0
Sulphur trioxide / Anhydride (SO_3)	2.16	Max 3.5
Ratio of percentage of lime to percentage of silica, alumina and iron oxide	0.92	0.80 – 1.02
Ratio of percentage of alumina to that of iron oxide	1.25	Min 0.66
Insoluble residue	1.35	Max 5.0
Total loss on ignition	2.08	Max 4.0
Chloride content	0.023	Max 0.10

2.1.3. Glass Powder(75 microns)

Figure 3 Glasspowder

Table 2 Chemical Composition of GlassPowder

Compound	Value %
SiO2	71.1
CaO	9.2
Fe2O3	0.16
Al2O3	0.95
MgO	4.4
Na2O	12.6

2.4 Laboratory Test

Tests on unstabilized soil

Different tests were performed on the unstabilized soil to understand its inherent characteristics and behavior of the original lateritic soil. These tests gave information about parameters like compaction properties, plasticity index.

Grain Size Analysis (IS 2720 Part 4)

Particle size distribution of the lateritic soil was determined as per IS 2720 Part 4. The test is used to find the particle size distribution in a soil sample by passing the soil sample through a series of sieves with progressively finer mesh sizes. Each portion of soil held up on each sieve is noted, which makes calculation of the percentage of particles in a particular range of sizes possible. This information is important for the soil classification and determination of engineering properties of the soil for road base stabilization.

Atterberg Limits (IS 2720 Part 5)

This test identifies the plasticity properties of the soil, including its liquid limit, plastic limit, and plasticity index, thus enabling the soil to be classified according to its behavior towards varying moisture contents. The soil's Atterberg limits were determined in line with IS 2720 Part 5 - Methods of Test for Soils: Determination of Liquid and Plastic Limit. The liquid limit was calculated by utilizing the Casagrande apparatus, as seen in Figure 4. These are utilized in identifying the workability and stability of the soil in relation to moisture variation, an important aspect to study soil stabilization in road subbase construction.

Figure 4 Liquid Limit Test on unstabilized soil

Compaction Test (IS 2720 Part 7)

This test determines the maximum dry density and optimum moisture content of soil. The compaction of soil is carried out at different moisture contents to determine the dry unit weight-moisture content relationship. Compaction test was conducted as per IS 2720 Part 7. The results are highly important to determine the suitability of the soil and the compaction requirements required to stabilize road base.

California Bearing Ratio (CBR) Test (IS 2720 Part 16)

The CBR test is used for finding the load-carrying capacity of the soil, which is an important factor in the construction of pavement.Compact a sample of the soil and impart a load for determining the penetration resistance of the soil. According to IS 2720 Part 16 -, the test was performed. Through the test, useful information concerning the soil strength and the capability of the soil as a material for use in road construction subbase can be obtained.

Unconfined Compressive Strength (UCS) Test (IS 2720 Part 10)

The Unconfined Compressive Strength (UCS) test assesses the maximum compressive stress that a cohesive soil can withstand in the absence of lateral support, which is required to determine its load-carrying capacity and overall stability. The soil specimen is cylindrical and is subjected to vertical loading until failure, thus providing valuable information on the inherent strength characteristics of the soil. The UCS test was conducted in accordance with IS 2720 Part 10 - This parameter is vital for understanding the behavior of soil under compressive loading in foundation and subgrade applications.

Stabilizing with Cement

Lateritic soil specimens were treated with different percentages of cement in percentage weights, i.e., 9%, 10%, 11%, and 12% levels including control soil samples. For comparing the influence of cement stabilization in modifying the soil geotechnical properties, compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests were conducted for all the specimens.

Tests were performed as per particular Indian Standards:

California Bearing Ratio (CBR) Test: IS 4332 Part 5 - Methods of Test for Stabilized Soils: Determination of CBR for Soil-Cement Mixtures.Unconfined Compressive Strength (UCS) Test: IS 4332 Part 6 - Testing methods for the stabilized soils - Determination of the compressive strength of Cement-Stabilized Soils.The given parameters provide guidelines for establishing the strength, compacted properties, and load resistance of cemented stabilised soil to be utilized as road subbase material.

Glass and cement powder stabilization.

Lateritic soil samples were stabilized with various percentages of cement (i.e., 9%, 10%, 11%, and 12% by weight) and equal percentage of 2% glass powder as a fraction of the weight of the soil in the unstabilized samples. With an aim to determine cement and glass powder stabilization's effect on the engineering parameters of the soil, Unconfined Compressive Strength (UCS) and California Bearing

Ratio (CBR) tests were conducted on all the samples. The samples were tested according to applicable Indian Standards:

California Bearing Ratio (CBR) Test: IS 4332 Part 5 - Test Methods for Stabilized Soils: Determination of CBR for Soil-Cement Mixtures.

Unconfined Compressive Strength (UCS) Test: IS 4332 Part 6 - Specification for Methods of Testing Stabilized Soils: Determination of the Compressive Strength of Cement-Stabilized Soils.

The stabilization technique, a blend of glass powder and cement, is attempting to boost the load capacity, compaction value, as well as strengthening lateritic soil, thus rendering it reliable for application as a road subbase.

III. Results and Discussion

3.4.1 Tests on unstabilized soil

Index properties of soil

The particle size distribution of the soil, Methods for Particle Size Distribution of soils is as shown below

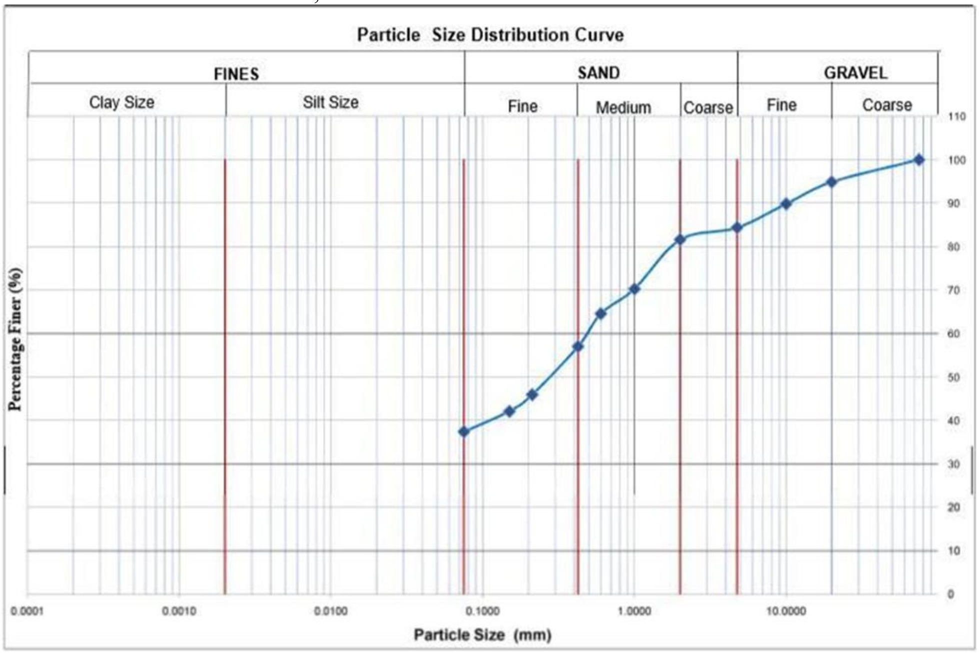

Figure 5 Particle size Distribution curve

Table 3: Index properties of unstabilized soil

Gravel (%)	16
Sand (%)	47
Fines (%)	37
Classification of soil	SC
Specific gravity	2.54
Liquid limit, LL (%)	53
Plastic limit, PL (%)	23
Plasticity Index, PI (%)	30

Compaction Characteristics Of Unstabilized Soil

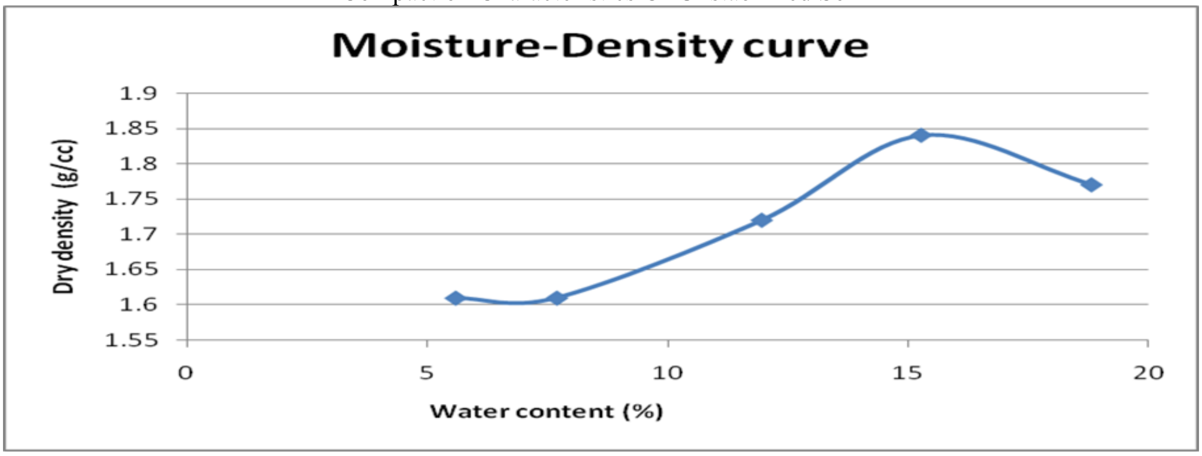

Figure 6 The moisture density relation of unstabilized soil

Table 4: Compaction test results of unstabilized soil

Optimum moisture content, OMC (%)	15.30
Maximum dry density, MDD (g/cc)	1.83

Unconfined compressive strength test on unstabilized soil
The unconfined compressive strength of unstabilized soil was found to be 635 KPa.

California Bearing Ratio Test on unstabilized soil

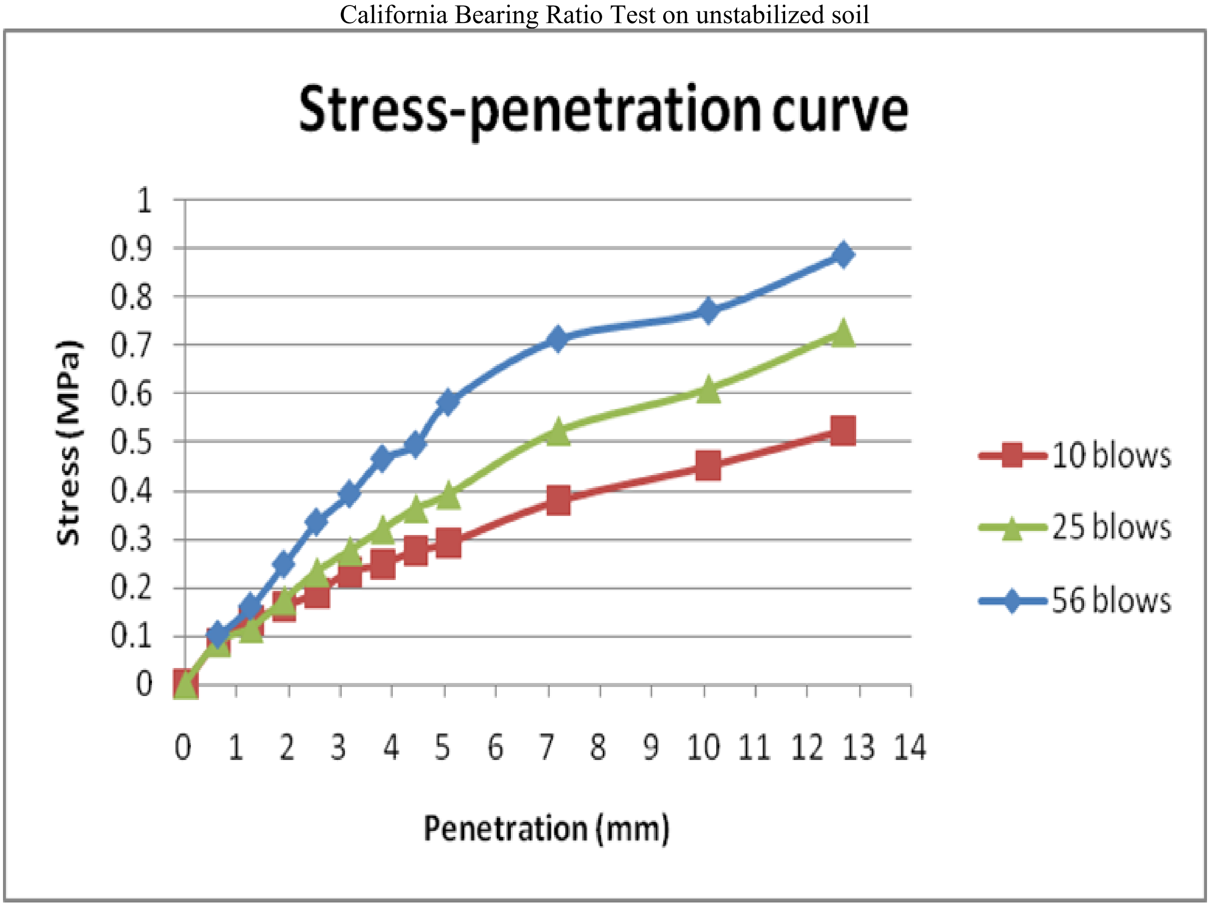

Figure 6 Moisture- Density Relation of unstabilized Soil

CBR specimens were casted at optimum moisture content and compacted using 56, 25, 10 blows per layer. Stress penetration graph of specimen at different number of blows are as shown

Table 5: CBR test result of unstabilized soil at different blows

No. of blows per layer	CBR (%)
10	2.82
25	3.81
56	5.64

3.4.2 Results of stabilized soil with cement and Glass powder

Cement: Added to enhance the soil's strength.

- Glass Powder: Incorporated to reduce the required amount of cement, improving sustainability.

Stabilization Details:

- Cement Content: Tested at 9%, 10%, 11%, and 12% by weight of soil.
- Glass Powder: Kept constant at 2% by weight of soil.

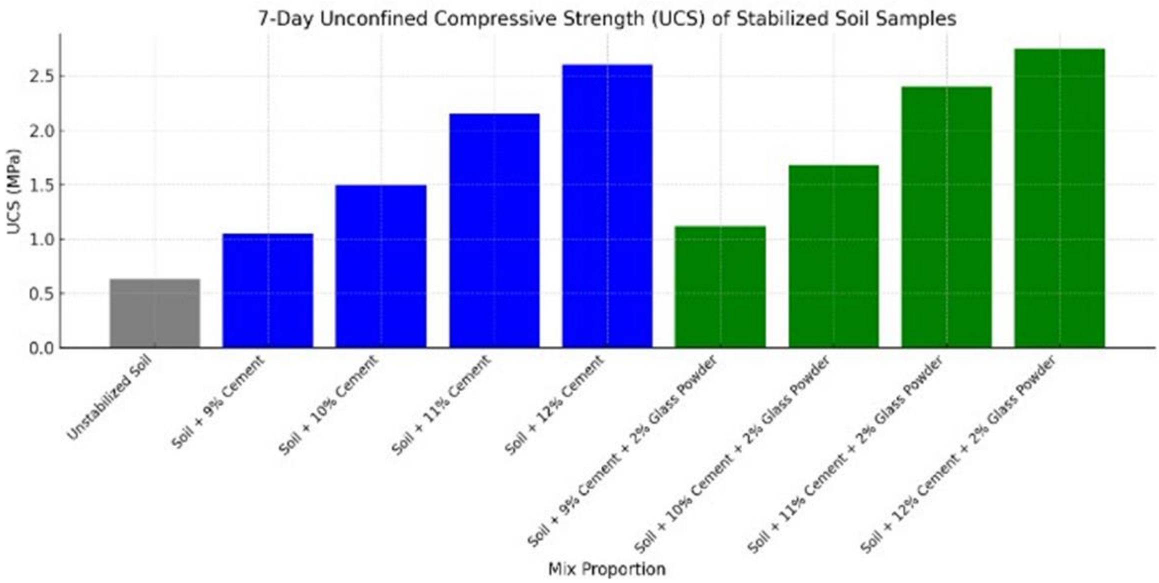

Figure 7 UCS Comparison

Table 6:7-Day UCS Results for Different Stabilization Mixes

Mix Proportion	7 day UCS(MPa)
Unstabilized Soil	0.635
Soil + 9% Cement	1.05
Soil + 10% Cement	1.50
Soil + 11% Cement	2.15
Soil + 12% Cement	2.60
Soil + 9% Cement + 2% Glass Powder	1.12
Soil + 10% Cement + 2% Glass Powder	1.68
Soil + 11% Cement + 2% Glass Powder	2.40
Soil + 12% Cement + 2% Glass Powder	2.75

Table 7 CBR Comparison for stabilized and unstabilized soil

Condition	CBR %	Stabilizer used
Unstabilized soil	5.64	None
4 day soaked (cement only)	61.57	11% cement
4 day soaked (cement+glass powder)	78.15	11%cement,2%glass powder

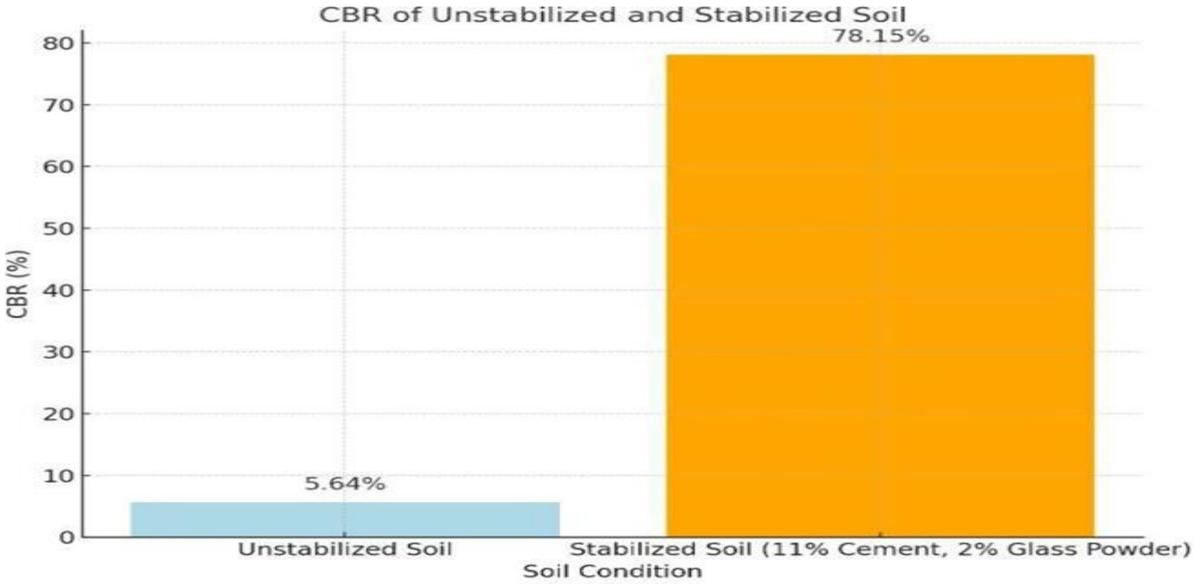

Figure 8 CBR Comparison

Pavement Design and Analysis

Considering a road stretch of 1 km length having a width of 7.0m having a design traffic of 2 msa, with subgrade CBR strength of 5%,Low-volume roads generally cater to traffic loads of less than 2 MSA over the design life

Innovating Rural Roads: IRC 37 vs. IIT PAVE Optimization

Figure 9 (Conventional vs optimized road)

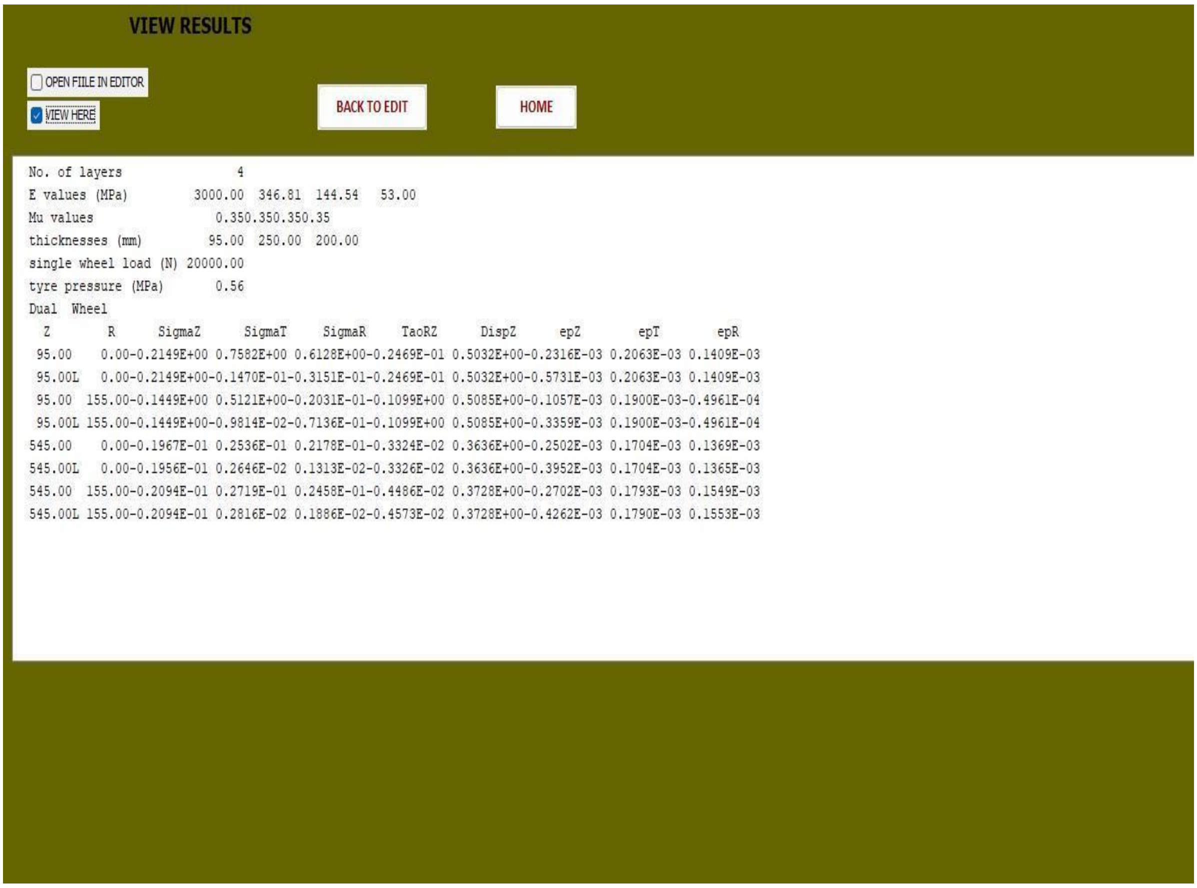

Figure 10- IIT Pave calculation (IRC 37-Conventional) Source: IITPAVE Software Output (IIT Kharagpur – MoRTH Initiative)

Table 8-Strain Limits (Conventional)

IRC37-2018 Strain Limits Layer -wise Assessment				
Layer	**Location of strain**	**Permissible strain as per IRC 37**	**Actual strain(IIT Pave)**	**Remarks**
Bituminous Layer	**Bottom of layer**	**4.929×10^{-4}**	**2.0×10^{-4}**	**PASS**
Stabilized subbase	**Bottom of layer**	**9.6×10^{-4}**	**2.5×10^{-4}**	**PASS**
Subgrade	**Top of subgrade**	**9.6×10^{-4}**	**3.9×10^{-4}**	**PASS**

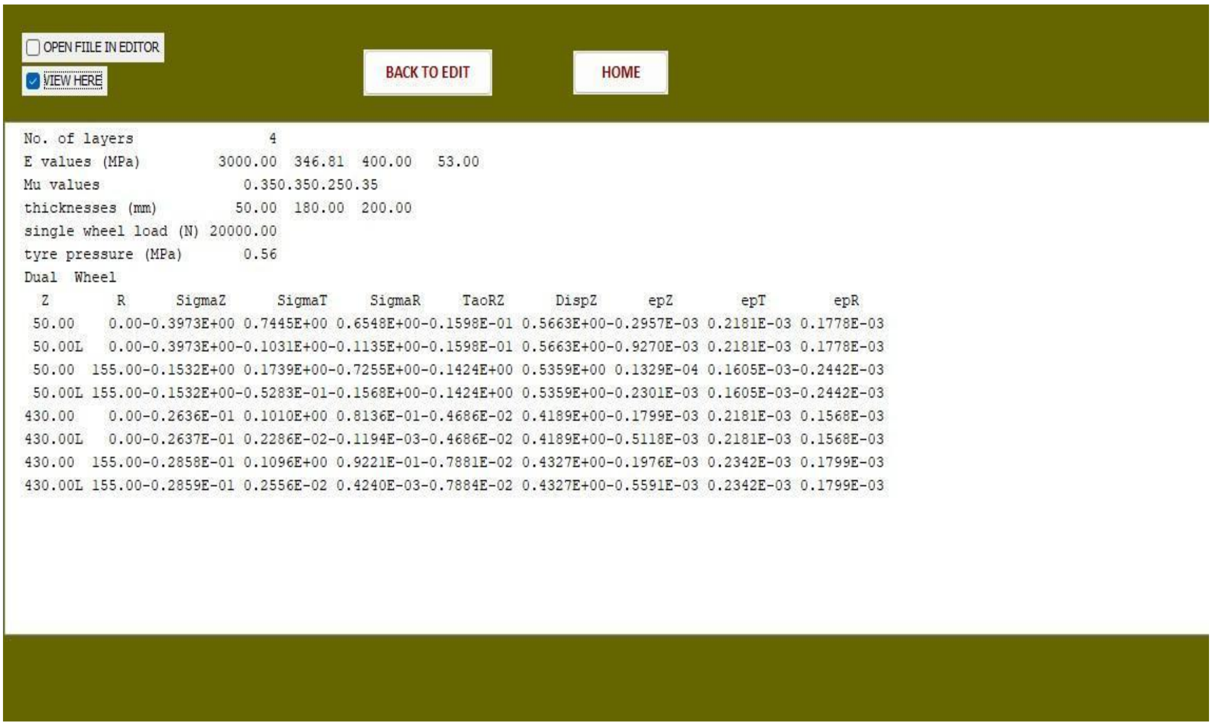

Figure 11-IIT Pave calculation (stabilized road)Source: IITPAVE Software Output (IIT Kharagpur – MoRTH Initiative)

Table 9-Strain Limits(Stabilized road)

IRC37-2018 Strain Limits Layer -wise Assessment				
Layer	**Location of strain**	**Permissible strain as per IRC 37**	**Actual strain(IIT Pave)**	**Remarks**
Bituminous Layer	**Bottom of layer**	**4.929×10^{-4}**	**2.1×10^{-4}**	**PASS**
Stabilized subbase	**Bottom of layer**	**9.6×10^{-4}**	**1.79×10^{-4}**	**PASS**
Subgrade	**Top of subgrade**	**9.6×10^{-4}**	**5.1×10^{-4}**	**PASS**

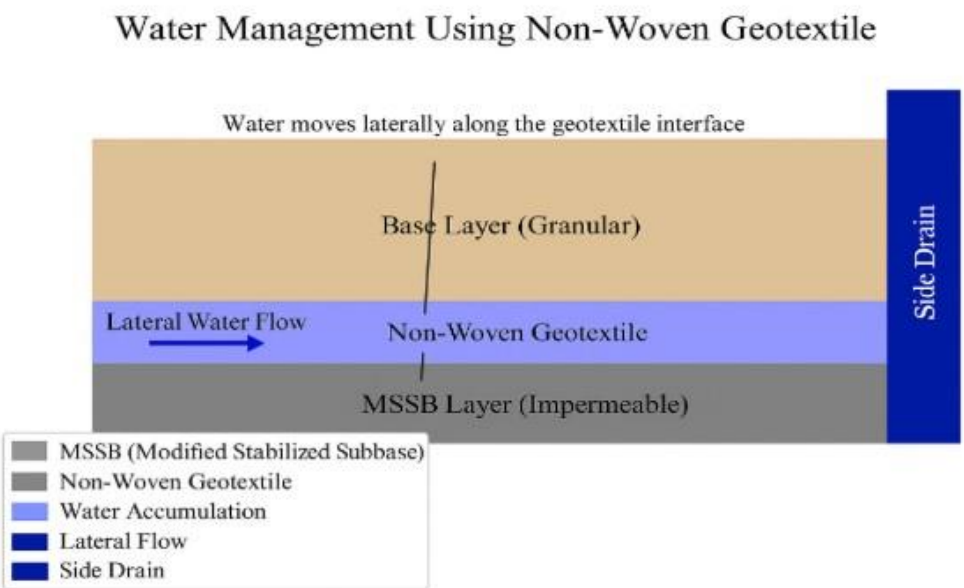

Figure 12-Water management using Non woven Geotextiles

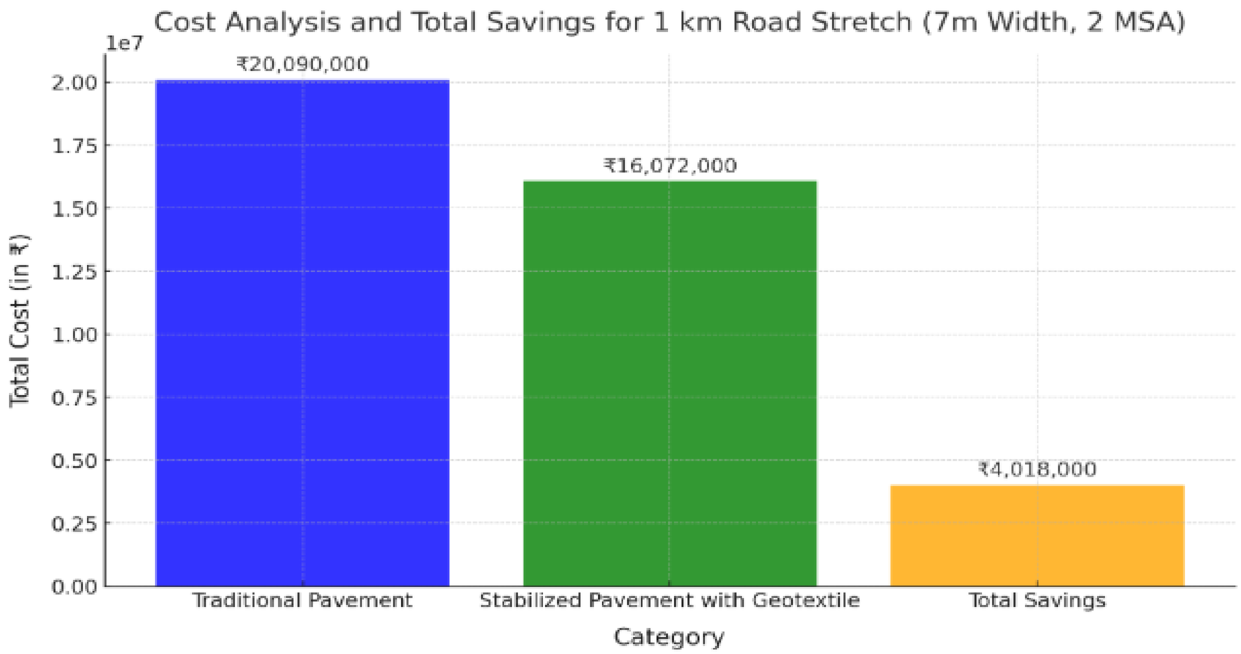

Figure 13 Cost Analysis

IV. Implications

In Kerala and other areas where lateritic soil is prevalent, the findings of this research have important implications for the future of road building. This study offers a sustainable alternative to traditional subbase materials by showing the viability of stabilizing lateritic soil with a combination of cement and waste glass powder. Waste glass powder use alleviates the reliance on cement, which lowers the associated environmental costs, and offers a viable method for recycling industrial waste, resolving environmental problems related to glass disposal and cement production.

This method has the potential to change business practices and spur future research into sustainable materials for infrastructure construction. The environmental consequences are significant, in addition to financial benefits. Using glass powder encourages recycling and contributes to low-carbon development by lowering the carbon footprint of cement manufacture.[3-5]

The rise in CBR value of 78.15% after soaking signifies a dramatic increase in load-carrying capacity, which results in a decrease in total pavement thickness. It has been established that the best combination of 11% cement and 2% glass powder yields UCS value greater than 2.25 MPa as recommended by IRC 37. This improvement in strength makes the stabilized soil suitable for low volume road subbase applications, with increase in pavement life and decrease in frequency of maintenance.[3-5]

This research has the potential to guide policy decisions and establish new standards for sustainable road construction materials, particularly in areas with abundant lateritic soil

Limitations

- The study has some limitations despite the promising results. The laboratory environment where the experiments were carried out might not completely represent field conditions, where traffic loads, weather fluctuations, and durability over long periods could affect the stabilized soil's performance. The curing process used in this research, with closed plastic bags and damp jute bags, might not exactly replicate actual curing conditions, which could influence the gain in strength with time.
- Also, the study obtained a best combination of proportion but could vary for sites depending upon differences in composition at different places. Long-term behaviour of stabilised lateritic soil under climatic variations in form of heavy rains and frequent variation in temperatures experienced in the Kerala region warrants testing through field trial.

- The findings of the study corroborate the utilization of cement and glass powder-stabilized lateritic soil for application in various transportation infrastructure and geotechnical works. It is most appropriately suitable for Low-Volume Roads: With increased strength and resistance to loading, it can suit rural roads as well as secondary roads where both economic and sustainability-oriented options become a prime necessity.

- Subbase Layers: The enhanced engineering characteristics enable reduction in the Wet Mix

Macadam (WMM) layer thickness, minimizing the cost of construction.

● Pavement Rehabilitation Works: The soil stabilization can be used in rehabilitative works in upgrading road facilities by strengthening the weak subgrade.

● Sustainable Construction Projects: Utilization of waste glass powder supports green building principles, favouring resource utilization and minimizing use of traditional resources.

V. Conclusion

● This study concentrates on the stabilization of lateritic soil from Trivandrum, Kerala, using 11% Portland Pozzolana Cement (PPC) and 2% waste glass powder to improve its applicability as a subbase material for low-volume roads. The laboratory testing conducted on the stabilized lateritic soil included various important soil tests to evaluate its suitability for road construction. These tests were the Unconfined Compressive Strength (UCS) test, California Bearing Ratio (CBR) test, and permeability test .The UCS test assessed the soil's shear strength, the CBR test measured its load-bearing capacity, and the permeability test established the soil's resistance to water infiltration. Based on the results obtained, it can be concluded that the stabilization of lateritic soil with PPC and waste glass powder significantly improves its strength, durability, and acceptability as a subbase material for low-volume roads. The findings fit with international practices and standards in geotechnical engineering, upholding the use of this method for sustainable and cost-effective road construction. The study results are summarized as follows:

● Strength Gain: Laboratory testing verified that the stabilized blend(11%cement and 2% glasspowder by weight of soil) recorded a 7-day Unconfined Compression strength(UCS) of more than 2.25 MPa, according to IRC 37 subbase specifications.

● CBR test with 11% cement and 2% glass powder by weight of soil resulted in a remarkable strength gain, with CBR from 5.64% (untreated) to 78.15%, and also saving cement content and increasing sustainability

● Pavement Layer Optimization: WMM layer thickness was reduced from 250 mm to 180 mm, and BT from 95 mm to 50 mm without compromising structural performance by using IIT pave software.

● Stabilization with 11% cement and 2% glass powder decreased soil permeability to 1.1×10^{-5} cm/s at 28 days, preventing water infiltration but aggravating drainage issues beneath BM/BC layers. To counteract this, a non-woven HDPE geotextile was used over the subbase to provide lateral drainage, stop water ponding, and improve long-term pavement performance, augmented by side drains for efficient water management.

● Financial Feasibility: For a 1 km, 2 MSA road, the approach yielded around 20% cost savings and maintenance savings, as shown in Figure 13.

● Environmental Sustainability: Substitution of 2% of cement with glass powder lowered cement consumption by 15%, reducing CO_2 emissions by 1.8 kg for each 100 kg of soil treated—fostering low-carbon and sustainable development.

These results establish that cement and waste glass powder stabilization can maximize road construction by
enhancing sustainability, reducing material needs, and increasing the strength of soil. The research favors the application of this method to low-volume roads in Kerala and other such areas with lateritic soils
Recommendations for Future Research and Applications:
1. Field Implementation: Conduct large-scale field trials to validate laboratory findings under real-worldconditions.
2. Long-Term Performance Evaluation: Assess durability under different climatic conditions and traffic loads.
3. Alternative Stabilizers: Explore the effectiveness of other industrial byproducts such as fly ash or rice husk
ash for further optimization.
4. Environmental Impact Analysis: Conduct a life cycle assessment to quantify the ecological benefits of usingwaste glass powder.
5. Scaling for Higher-Traffic Roads: Investigate the applicability of stabilized lateritic soil for medium-andhigh-traffic roads
Conflict of Interest
The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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