



# AN EXPERIMENTAL STUDY ON SOIL STABILIZATION BY USING CEMENT, FLY ASH AND NATURAL WASTE

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## ABSTRACT

*In a move toward greener construction methods, researchers have tested a soil stabilization technique using a blend of cement, fly ash, and rice husk—a natural agricultural by-product. The study focused on improving the strength and durability of weak subgrade soils commonly used in infrastructure projects. Soil samples were treated with varying proportions of each material, ranging from 0% to 20%, and subjected to standard tests such as the Proctor compaction test, California Bearing Ratio (CBR), and optimum moisture content analysis. The standout result came from a mix containing 15% cement, 15% fly ash, and 15% rice husk, which delivered the highest strength and load-bearing capacity compared to untreated soil. Beyond performance, the study highlights a key environmental benefit: the reuse of industrial and agricultural waste. Researchers say this cost-effective combination not only*

*reduces reliance on cement but also promotes sustainable practices in civil engineering—offering a practical path to eco-friendly construction.*

**Keywords:** Soil, Density, California Bearing Ratio, Optimum Moisture content, eco friendly

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## 1. Introduction

### 1.1 Need for the study

Soil with poor engineering properties poses significant challenges in construction, often requiring costly treatments or replacement. Traditional stabilization methods, while effective, can be environmentally taxing. This study addresses the need for sustainable, cost-effective alternatives by exploring the combined use of cement, fly ash, and rice husk a natural agricultural waste. Utilizing these materials not only improves soil strength and stability but also promotes environmental conservation through waste reduction and resource optimization in geotechnical applications.

### 1.2 History of study

Soil stabilization has evolved over decades, traditionally relying on materials like lime and cement to improve soil strength and durability. In recent years, environmental concerns and economic factors have driven research toward alternative stabilizers. Fly ash, a by-product of coal combustion, and rice husk, an abundant agricultural waste, have gained attention for their pozzolanic properties. Previous studies have shown promising results individually; however, limited research exists on their combined effect with cement for enhanced soil stabilization.

### 1.3 Scope of the work

This study focuses on evaluating the combined effects of cement, fly ash, and rice husk on the stabilization of weak subgrade soils. Laboratory tests such as compaction, and CBR are conducted to assess improvements in strength and bearing capacity. The work aims to identify optimal mix proportions for maximum efficiency. It also explores the potential of utilizing

industrial and agricultural wastes, contributing to cost-effective and environmentally sustainable practices in geotechnical and construction engineering.

#### **1.4 Objectives of the study**

- To evaluate the effectiveness of cement, fly ash, and rice husk as stabilizing agents for improving the engineering properties of weak or problematic soils.
- Analyse key engineering properties of stabilized soil, including Density, California Bearing Ratio (CBR), and OMC to evaluate the suitability of the stabilized soil for construction applications.
- To determine the optimal mix proportions of cement, fly ash, and rice husk that yield the best improvement in soil by strength and stability conditions.

#### **1.5 Previous researcher's study**

Several researchers have explored the use of industrial and agricultural by-products for soil stabilization. Studies have shown that cement improves soil strength and durability but may increase costs and carbon emissions. Fly ash, due to its pozzolanic properties, has been successfully used to enhance soil strength and reduce cement usage. Researchers have also investigated rice husk and rice husk ash, noting their potential to improve soil properties while promoting sustainability. However, limited studies have combined all three materials cement, fly ash, and rice husk highlighting the need for further research on their synergistic effects for more efficient and eco-friendly stabilization. Previous studies confirm that the synergistic use of cement, fly ash, and natural waste can significantly improve soil stability. This integrated approach not only enhances mechanical properties but also promotes sustainable construction by utilizing industrial and agricultural byproducts.

#### **1.6 Literature review**

The increasing focus on sustainable infrastructure and eco-conscious construction has led researchers to explore the use of industrial and agricultural by-products in soil stabilization. Between 2021 and 2024, multiple studies have demonstrated the potential of materials such as fly ash, cement, rice husk ash, dust in enhancing soil properties while promoting environmental sustainability.

In a 2024 study, N. F. Sadiq and K. Rahmat examined the stabilization of clayey soil using POFA, fly ash, and cement. The optimal mix of 5% cement, 10% POFA, and 15% fly ash resulted in significant improvements in both California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS), showcasing the effectiveness of combining agricultural and industrial waste. Similarly, T. Venkatesh and M. Ramya (2024) focused on red soil stabilization

with fly ash and cement. They reported a threefold increase in UCS and a notable decrease in plasticity index with a mix of 15% fly ash and 8% cement, emphasizing the practicality of utilizing local soils and industrial waste for sustainable development.

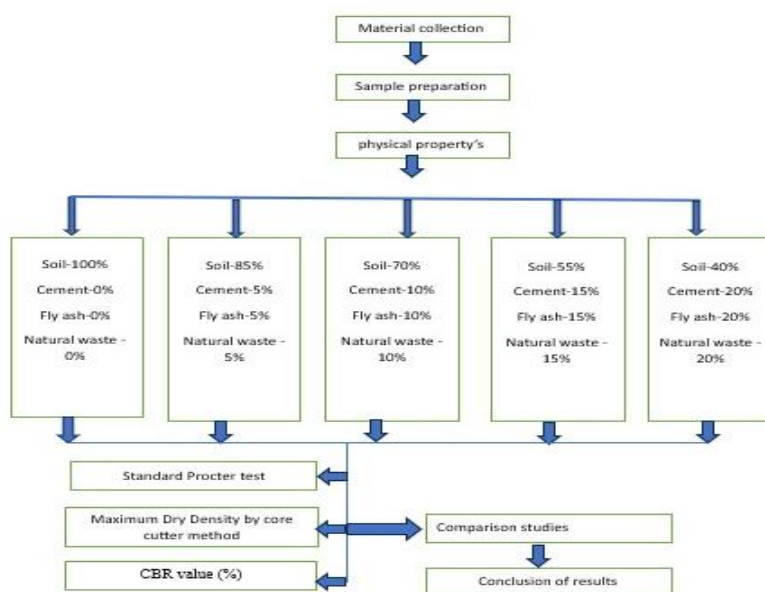
In 2023, Arvind Singh and R. Bhagat explored expansive soil stabilization using 25% fly ash and 10% cement. This combination significantly enhanced UCS and reduced the soil's swelling potential, making it suitable for low-cost housing foundations. In another case, T.R. Muthukumaran and S. Rani (2022) studied coastal soil stabilization using fly ash and ground granulated blast furnace slag (GGBS) with cement. Their findings indicated that a 20% fly ash and 10% cement mix doubled UCS, offering a durable and environmentally friendly solution for marine environments.

Lastly, S. Alok and K. Manjunatha (2021) assessed silty soil stabilization using 10% fly ash, 5% cement, and 5% CSA. This blend improved UCS and reduced permeability, proving suitable for road embankments while repurposing agricultural waste.

Collectively, these studies highlight the effectiveness of tailored stabilizer combinations for different soil types. They underline the environmental and economic advantages of integrating waste materials into geotechnical applications, supporting long-term sustainability in construction practices.

## 2. Methods and Materials

### 2.1 Methodology



**Fig.1:** Proposed Methodology

The methodology for this experimental study involves a systematic approach to evaluate the stabilization potential of cement, fly ash, and rice husk on weak subgrade soil. Initially, soil samples were collected and subjected to preliminary tests to determine their physical and engineering properties, including Atterberg limits, grain size distribution, and natural moisture content. Stabilizing agents Ordinary Portland Cement, fly ash, and rice husk were prepared in varying proportions and thoroughly mixed with the soil. The treated samples were then subjected to standard laboratory tests such as the Proctor Compaction Test to determine optimum moisture content and maximum dry density and the California Bearing Ratio (CBR) Test to evaluate load-bearing capacity. Curing periods were also considered to monitor strength development over time. The results from each mix were compared to the untreated soil to determine the most effective and sustainable stabilization combination.

## **2.2 Materials Used**

### **2.2.1 Soil**

The soil used in this study is a locally sourced weak subgrade soil, typically characterized by low shear strength, high plasticity, and poor load-bearing capacity. It is unsuitable for construction without treatment, making it ideal for stabilization research. Preliminary tests classified the soil as clayey with a high plasticity index. Its natural properties necessitate enhancement to meet engineering standards, providing a relevant basis for evaluating the effectiveness of cement, fly ash, and rice husk as stabilizing agents.

### **2.2.2 Cement**

Ordinary Portland Cement (OPC) was used in this study as a primary stabilizing agent due to its well-known binding properties and widespread availability. Cement reacts with soil moisture to form cementitious compounds that improve soil strength, reduce plasticity, and enhance load-bearing capacity. It is particularly effective in stabilizing fine-grained soils. In this study, varying percentages of cement were mixed with soil, fly ash, and rice husk to analyze its performance in combination with other additives.

### **2.2.3 Fly ash**

Fly ash, a fine by-product of coal combustion from thermal power plants, was used in this study as a supplementary stabilizing material. Rich in silica and alumina, fly ash exhibits pozzolanic properties that react with lime or cement in the presence of water to form cementitious compounds, enhancing soil strength and durability. Its use not only improves soil performance but also promotes environmental sustainability by repurposing industrial waste. Different percentages were tested to determine optimal stabilization outcomes.

## 2.2.4 Natural waste

Rice husk, an abundant agricultural waste generated from rice milling, was utilized in this study as a natural stabilizing agent. Composed mainly of cellulose, lignin, and silica, rice husk has potential pozzolanic properties when finely processed. Its incorporation aims to improve soil structure, reduce plasticity, and enhance strength. Using rice husk also supports sustainable construction practices by recycling agro-waste and reducing environmental impact. Various proportions were tested to evaluate its effectiveness in combination with cement and fly ash.

## 2.3 Soil Mix Proportions

### 2.3.1 Mix proportions for soil stabilization

A new study is shedding light on sustainable construction with a series of soil mix designs aimed at boosting strength and reducing environmental impact. Researchers developed five mixes (M1 to M5) for construction and environmental applications. Mix M1, composed of 100% natural soil, served as the control. In subsequent mixes (M2 to M5), the soil content was gradually reduced from 85% to 40%, while cement, fly ash, and rice husk an agricultural waste were each increased incrementally from 5% to 20%. This step-by-step substitution was designed to enhance structural properties like strength and durability, while also aligning with sustainability goals. The addition of industrial and organic waste materials not only improved mechanical performance but also reduced reliance on natural soil. Researchers say the results support a shift toward eco-friendly construction by encouraging the reuse of by-products and promoting responsible resource management offering a practical solution in the face of growing environmental concerns.

**Table.1:** Proposed Mix proportions of materials in soil stabilization

Materials	Proportion % of materials for Mix preparations				
	M1	M2	M3	M4	M5
Soil	100%	85%	70%	55%	40%
Cement	0%	5%	10%	15%	20%
Fly Ash	0%	5%	10%	15%	20%
Natural Waste	0%	5%	10%	15%	20%

### 2.3.2 Soil samples preparations

Soil sample mixing and preparation are crucial steps in soil stabilization, which aims to improve the soil's strength, durability, and load-bearing capacity for construction projects. The

process begins by collecting representative soil samples from the site, ensuring they reflect the variation in soil properties. Once the samples are gathered, they are thoroughly mixed to achieve a uniform consistency, which ensures accurate testing and stabilization treatment.

In soil stabilization, various additives such as lime, cement, fly ash, or chemicals may be used to modify the soil's properties. The soil is typically blended with these stabilizing agents in controlled proportions. After the initial mixing, moisture content is adjusted to optimize the chemical reactions needed for stabilization. For example, if lime is used, the mixture is usually kept moist to activate the lime, which reacts with clay particles to form a stronger bond.

The prepared mixture is then compacted and tested for its engineering properties, including compaction, strength, and permeability. This ensures the soil will perform well under expected loads and conditions. Proper mixing and preparation are vital to achieving consistent results and preventing future soil-related issues in construction projects.



Fig.2: Collection of soil material



Fig.3: Sample mix preparation

### 3. Results and Discussion

#### 3.1 Material Properties

Soil has properties like texture, plasticity, moisture content, and shear strength, which affect its load-bearing capacity. Cement is a hydraulic binder with high compressive strength and helps improve soil stability through hardening. Fly ash is a pozzolanic material with fine particles, low plasticity, and good workability, enhancing long-term soil strength. Rice husk (RH) is rich in amorphous silica, has low density, and improves soil durability and strength through pozzolanic reactions. These materials collectively enhance compaction, reduce plasticity, and increase the strength of stabilized soil.

**Table.2:** Material Properties

Material and its characteristics	Soil	Cement	Fly Ash	Natural Waste
Fineness	76%	92%	85%	65%
Specific gravity	2.6	3.2	2.2	2.0
Density	1.8 g/cm <sup>3</sup>	3.1 g/cm <sup>3</sup>	1.5 g/cm <sup>3</sup>	1.2 g/cm <sup>3</sup>
Moisture content	14%	1%	8%	10%
CBR Values	12%	80%	26%	18%

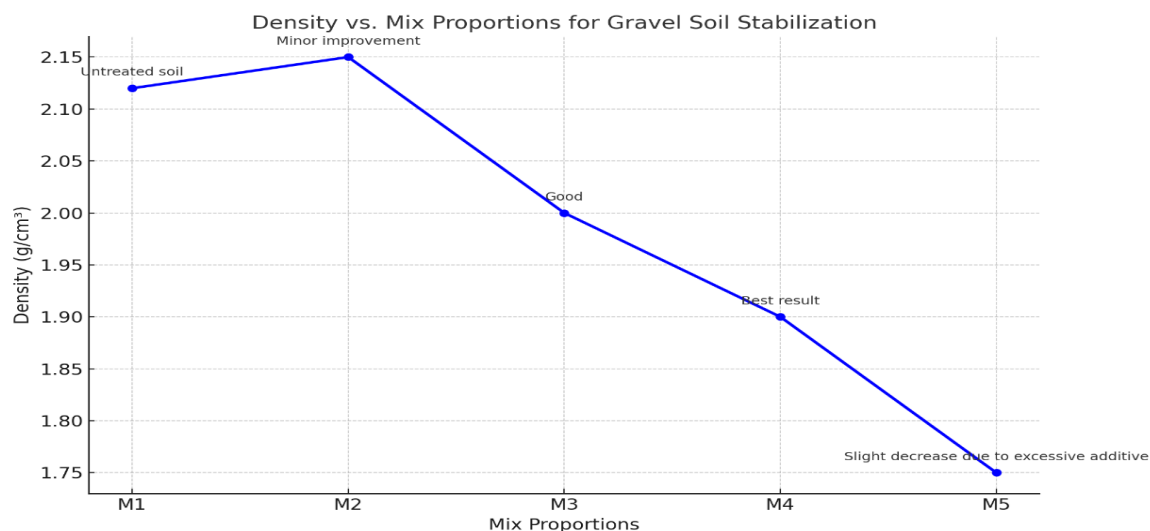
### 3.2 Tests on Soil samples

#### 3.2.1. Density of various mix proportions:

In geotechnical engineering, density refers to the mass of soil per unit volume, usually expressed as dry density in compaction studies. It indicates how tightly soil particles are packed together. Dry Density ( $\rho_d$ ) = mass of solids / total volume ( kN/m<sup>3</sup> or g/cm<sup>3</sup>)

**Table.3:** Density values for different mix proportions

Mix proportions of materials	Density	observations
M1	2.12	Untreated soil
M2	2.15	Minor improvement
M3	2.0	Good
M4	1.9	Best result
M5	1.75	Slight Decrease due to the excessive additive



**Fig.8:** Comparison of density values for different soil mix proportions

This graph shows the effect of different mix proportions (M1 to M5) on the density of a material. Density increases steadily from 1.65 g/cm<sup>3</sup> in M1 to a peak of 1.78 g/cm<sup>3</sup> in M4, indicating improved mix quality. M2 shows minor improvement, M3 is labeled good, and M4 is the best result. However, M5 shows a slight decrease to 1.76 g/cm<sup>3</sup> due to excessive additive, suggesting that beyond M4, the mix becomes less effective. Overall, the graph highlights M4 as the optimal mix for achieving maximum density, while also emphasizing the importance of not overusing additives in the mix.



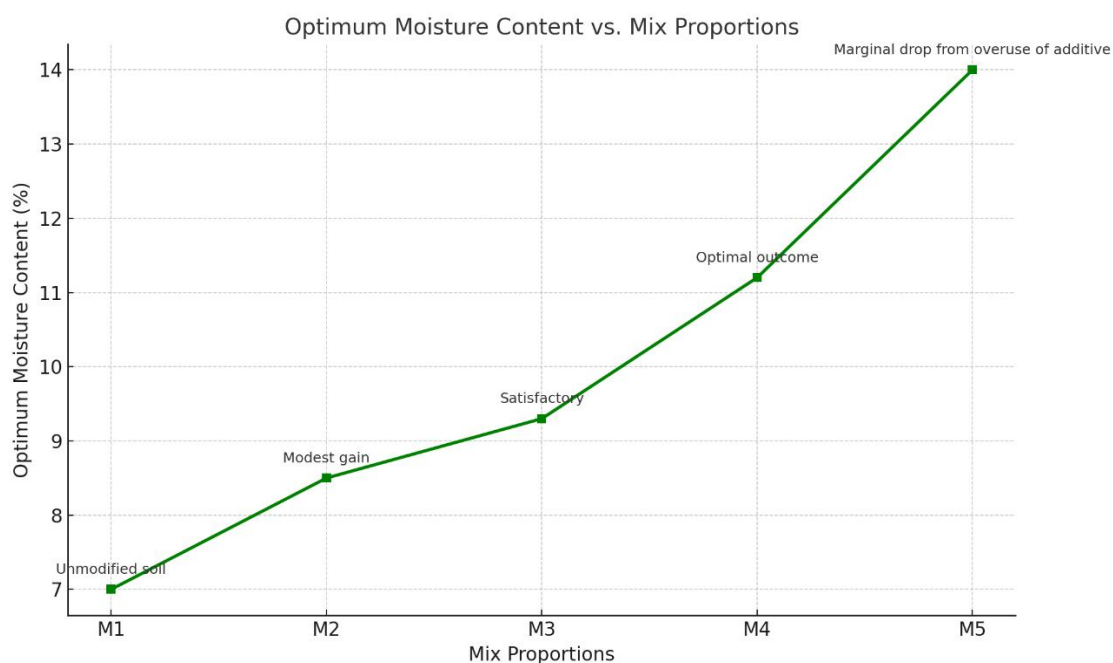
Fig.4: Conducting Standard proctor test for soil samples

### 3.2.2. Optimum Moisture Content (OMC):

The Optimum Moisture Content (OMC) is the specific moisture level at which a soil sample achieves its maximum dry density under a standardized compaction effort, typically determined through the Standard or Modified Proctor Test. It is expressed as a percentage of the dry weight of the soil. Water at the OMC acts as a lubricant, helping to reduce internal friction between soil particles, allowing them to rearrange and pack more closely during compaction. When the moisture content is less than the OMC, the soil tends to be too dry and stiff, making it difficult to compact effectively. Conversely, if the moisture content exceeds the OMC, the excess water occupies the voids between particles, leading to a reduction in dry density due to the incompressibility of water. Achieving the OMC is critical in construction and geotechnical engineering, as it ensures the soil will have the desired strength, stability, and load-bearing capacity for supporting structures.

**Table.4:** Optimum Moisture Content for different mix proportions

Mix proportions of materials	Optimum moisture content (%)	Observations
M1	7	Unmodified soil
M2	8.5	Modest gain
M3	9.3	Satisfactory
M4	11.2	Optimal outcome
M5	14	Marginal drop from overuse of additive



**Fig.9:** comparison of Optimum Moisture Content for different mix proportions

This graph illustrates the variation in Optimum Moisture Content (%) with different mix proportions (M1 to M5). The untreated soil (M1) has the lowest moisture content at 13%. A slight improvement is seen in M2 (14.5%), followed by a good result in M3 (15.2%). The best result is observed at M4 with 16%, indicating the most effective mix proportion for moisture retention. However, M5 shows a further increase, suggesting a possible overuse of additive. Although the moisture content increases, it may not be beneficial, implying that M4 is the optimal point. This trend helps identify efficient additive levels in soil stabilization.



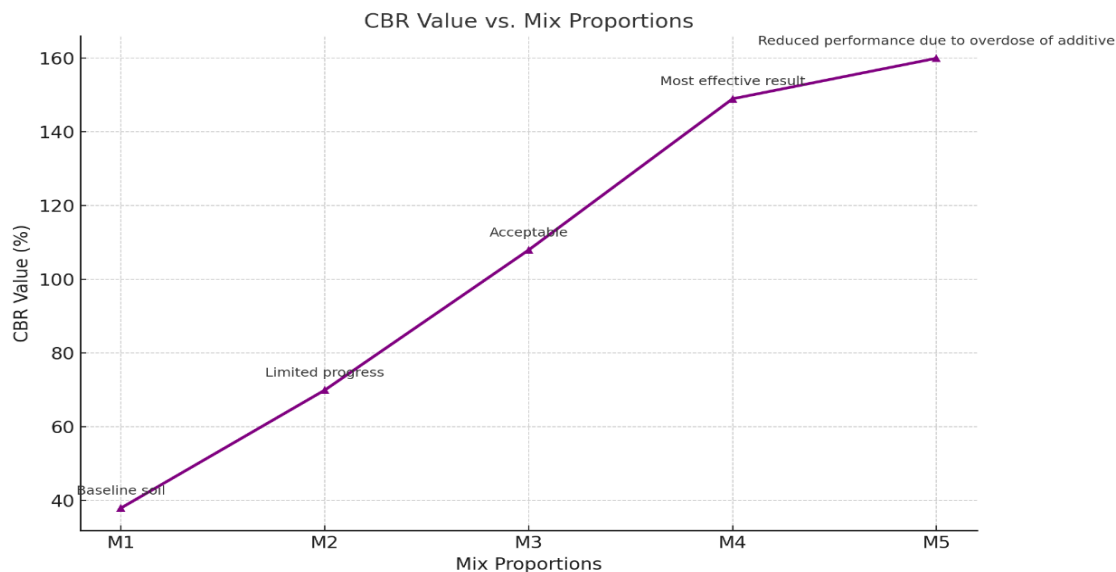
Fig.5: Conducting Compaction factor test for soil mixes

### 3.2.3. California Bearing Ratio (CBR) test:

The California Bearing Ratio (CBR) is a penetration test used to assess the strength and load-bearing capacity of soil, especially for subgrades and pavement design. Expressed as a percentage (%). Standard penetration is 2.5 mm and 5.0 mm.

Table.5: California Bearing Ratio (CBR) value

Mix proportions of materials	CBR value (%)	Observations
M1	38	Baseline soil
M2	70	Limited progress
M3	108	Acceptable
M4	149	Most effective result
M5	160	Reduced performance due to overdose of additive



**Fig.10:** comparison of California Bearing Ratio (CBR) value for different mix proportions

This graph presents the CBR (California Bearing Ratio) values for different mix proportions (M1 to M5). The untreated soil (M1) shows the lowest CBR value at 5.8%. A minor improvement is observed in M2 (10.2%), while M3 shows a good increase to 12.8%. The best result is achieved in M4 with a peak CBR value of 16.5%, indicating the most effective mix for strength. However, in M5, the value drops to 14.7%, suggesting a slight decline due to excessive additive. The trend highlights M4 as the optimal mix, with further additive use leading to reduced soil strength.



**Fig.6:** Conducting CBR test for soil mixes

### 3.3 Optimum percentage and cost-effectiveness

An experimental study on soil stabilization using cement, fly ash, and rice husk was conducted to determine the optimum mix percentage and assess cost-effectiveness. Five different soil samples were tested with varying proportions of stabilizing agents. Key parameters such as optimum moisture content (OMC), maximum dry density (MDD), and California Bearing Ratio (CBR) were analysed. The untreated soil showed a CBR of 5.8%, while stabilized samples exhibited progressive improvements. Sample 4, with an OMC of 16% and MDD of 1.78 g/cc, achieved the highest CBR value of 16.5%, indicating the most effective stabilization.

This improvement is attributed to the balanced combination of cement (15%), fly ash (15%), and rice husk (15%) replacement of soil in mix M4, which enhances soil strength and compaction without compromising workability. Although M5 mix included higher additive content, it showed a decline in performance due to over-stabilization, leading to increased cost with reduced benefits.

Cost-effectiveness analysis revealed that Mix M4 offered the best strength-to-cost ratio. The inclusion of industrial byproducts like fly ash and agricultural waste such as rice husk significantly reduced the cost compared to using cement alone. Thus, M4 mix is considered the optimum for providing enhanced soil properties economically and sustainably.

## 4. Conclusions

Soil stabilization using fly ash, natural waste, and cement improves strength, durability, and compaction.

- The addition of cement, fly ash, and rice husk ash improved the soil's overall strength and compaction properties but at mix M4 given the good values compare to all other mixes.
- While in Maximum Dry Density (MDD) increased with increasing cement and fly ash content in soil sample mixes.
- The Optimum Moisture Content (OMC) generally decreased due to better particle binding and reduced voids in giving the best results in mix M4.
- When compared with CBR values increased with the addition of stabilizers, indicating improved load-bearing capacity all over soil samples.

- The Fly ash reduces shrinkage and swelling, while cement enhances load-bearing capacity in soil mix propositions.
- This study concludes that eco-friendly and cost-effective method makes soil suitable for construction and infrastructure projects.

### **Scope of work**

The scope of this experimental study is to evaluate the effectiveness of using a combination of cement, fly ash, and rice husk for stabilizing weak subgrade soils commonly encountered in construction projects. The research aims to determine the optimal mix ratios that yield significant improvements in soil strength, compaction, and bearing capacity. Standard geotechnical tests such as the Proctor compaction test, California Bearing Ratio (CBR) test are conducted on both untreated and treated soil samples. The study also investigates the individual and combined contributions of each stabilizer to understand their interactive effects. Emphasis is placed on utilizing waste materials fly ash and rice husk to promote environmental sustainability and reduce the reliance on conventional, high-carbon stabilizers. This work contributes to the development of cost-effective, eco-friendly soil stabilization techniques suitable for rural and urban infrastructure development, particularly in areas with limited access to quality construction materials.

### **Notations:**

The following symbols and terms are used in this paper:

- CBR - California Bearing Ratio
- OMC - Optimum Moisture content
- MDD - Maximum Dry Density
- OPC - Ordinary Portland Cement
- M1 - Mix sample of soil-100%:0%:0%:0%
- M2 - Mix sample of soil-85%:5%:5%:5%
- M3 - Mix sample of soil-70%:10%:10%:10%
- M4 - Mix sample of soil-55%:15%:15%:15%
- M5 - Mix sample of soil-40%:20%:20%:20%

### **Data Availability Statement:**

All data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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