Design and Analysis of Stabilized Soil Layers for Sustainable Pavement Using IITPave Software

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Abstract - This study explores the stabilization of lateritic soil for flexible pavement construction using RBI Grade 81 and Pond Ash as sustainable additives. Lateritic soil was partially replaced with RBI Grade 81 in varying proportions (2% to 10%, in 2% increments) and combined with a constant 10% Pond Ash. Comprehensive laboratory tests were conducted to assess the physical and chemical properties of the materials, as well as the mechanical characteristics of the stabilized mixes. Tests included grain size distribution, Atterberg limits, compaction (optimum moisture content and maximum dry density), California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS).
The analysis identified the optimum mix composition that maximized strength, durability, and load-bearing capacity. Using this mix, a flexible pavement structure was designed with IITPave software, incorporating traffic and environmental considerations. The design was compared with Indian Roads Congress (IRC) guidelines to evaluate its effectiveness and highlight potential improvements in design methodology.
The results demonstrate the efficacy of using RBI Grade 81 and Pond Ash as sustainable alternatives for soil stabilization, reducing reliance on conventional materials and promoting eco-friendly pavement solutions. This study provides valuable insights into the behavior of stabilized layers and their application in sustainable infrastructure development.

Keywords: Lateritic soil, RBI Grade 81, Pond Ash, Soil stabilization, Flexible pavement design, IITPave, IRC guidelines, Sustainable construction.

1.NTRODUCTION

The materials explored in this study for the stabilization of lateritic soil are RBI Grade 81 and Pond Ash, both of which offer sustainable and eco-friendly alternatives to conventional construction materials.

Lateritic Soil is a weathered and clayey soil typically found in tropical regions, characterized by high iron and aluminum content. While it is abundant in many parts of the world, its engineering properties, such as low strength, poor compaction characteristics, and high plasticity, make it unsuitable for direct use in pavement construction. Stabilizing lateritic soil is crucial to improving its load-bearing capacity and making it more viable for road construction.

RBI Grade 81 is a chemical soil stabilizer designed to improve the strength and compaction of weak soils. It is commonly used in road construction to enhance the properties of soils that are unsuitable for pavement construction. As a sustainable material, RBI Grade 81 not only improves the mechanical characteristics of the soil but also reduces the need for expensive and non-renewable resources, making it a cost-effective and eco-friendly alternative.

Pond Ash is a byproduct of coal combustion in thermal power plants, often considered a waste material. However, it has found use in soil stabilization due to its pozzolanic properties, which allow it to react with lime or other materials to improve soil strength. Pond Ash is also an environmentally friendly option, helping to recycle waste from power plants and reduce landfill usage. When combined with RBI Grade 81, Pond Ash enhances the stabilization process by improving soil cohesion and increasing its bearing capacity.

Together, these materials offer a promising solution for sustainable soil stabilization, promoting both environmental conservation and improved infrastructure development.

1.1 Previous Studies in Flexible Pavement Design

Several studies have investigated the use of various stabilizers and additives for improving the properties of lateritic soil in the construction of flexible pavements. For example, Madhusree and **Mandal (2011)** studied the effect of Pond Ash as a stabilizing agent for lateritic soils, demonstrating its potential to improve compaction and strength properties, particularly in the context of road construction. Their research highlighted that the addition of Pond Ash could enhance the California Bearing Ratio (CBR) and reduce the plasticity index, making the soil more suitable for pavement design.

Similarly, Sridharan and Rao (2013) explored the use of chemical stabilizers like RBI Grade 81 for improving the strength and compaction characteristics of weak soils. Their findings indicated that chemical stabilization could significantly enhance the load-bearing capacity of subgrade soils, making them more suitable for flexible pavements. They also emphasized the importance of identifying the optimum proportions of stabilizing agents to achieve the desired performance.

Sivapalan et al. (2016) conducted a study that combined multiple stabilizers, including Pond Ash and lime, with lateritic soil. They found that combining these materials resulted in improved mechanical properties, such as increased Unconfined Compressive Strength (UCS) and better CBR values, compared to untreated lateritic soil. This further supports the idea that Pond Ash, when used in combination with other stabilizers, can provide significant improvements in soil behavior for pavement applications.

These studies underline the potential of using alternative, sustainable materials like Pond Ash and RBI Grade 81 for enhancing the properties of lateritic soil, which can significantly contribute to the design of durable and cost-effective flexible pavements.

1.2 RESEARCH GAP:

Soils, especially fine-grained Soils (like clay and silt), have a high surface charge, which leads to water retention and dispersion of Soil particles. RBI Grade-81 contains cations that exchange with the naturally occurring cations in the Soil (such as sodium and potassium), leading to flocculation of the Soil particles.

Flocculation is the process where dispersed Soil particles come together to form larger aggregates or flocs, reducing the Soil's plasticity and increasing its stability.

1.3 OBJECTIVES:

1. Assess the Physical and Chemical Properties: Analyze the physical and chemical properties of lateritic soil, RBI Grade 81, and Pond Ash for suitability in pavement construction.
2. Study Stabilization Effects: Evaluate the impact of replacing lateritic soil with 2% to 10% RBI Grade 81 (in 2% increments) and a constant 10% Pond Ash on soil stabilization.
3. Conduct Laboratory Tests: Perform grain size distribution, Atterberg limits, compaction, CBR, and UCS tests to characterize the stabilized mixes.
4. Identify Optimum Mix: Determine the optimum mix composition based on strength, durability, and load-bearing capacity from laboratory test results.
5. Design Pavement Using IIT Pave: Design a flexible pavement structure for the optimum mix using IIT Pave software and compare with IRC guidelines for improvements.

2.MATERIALS AND METHODS

2.1 Materials

Laterite soils are highly weathered and enriched with iron and aluminum oxides, predominantly found in tropical and subtropical regions with high rainfall. These soils exhibit a reddish, yellowish, or brownish hue due to the presence of iron oxides. They are characterized by a coarse, gravely texture, moderate plasticity, and relatively low shear strength. Laterite soils have a high porosity (20–35%) and a bulk density ranging from 1.4 to 1.8 g/cm³, indicating variable compaction potential. Their mechanical properties include moderate compressibility, cohesion, and shear strength (20–30 kPa), making them less ideal for high-load-bearing applications in their natural state. Chemically, laterite soils contain 5–20% clay minerals, small amounts of magnesium oxide (1–5%), calcium oxide (1–3%), and potassium oxide (0.5–2%). These properties necessitate stabilization to improve their performance in infrastructure applications such as road construction.

RBI Grade 81is an eco-friendly soil stabilizer composed of natural minerals and polymers, designed to enhance the physical and mechanical properties of soils. Its chemical composition includes calcium oxide (CaO) at 52–55%, silicon dioxide (SiO_2) at 15–19%, and smaller quantities of sulfur trioxide (SO_3), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3). Polypropylene fibers and additives further augment its effectiveness, with CaO promoting the formation of calcium silicate hydrate gel that binds soil particles, increasing density and load-bearing capacity. The stabilizer reduces porosity, enhances durability, and improves moisture resistance, making it suitable for road subgrades. With a lower environmental impact compared to traditional chemical stabilizers, RBI Grade 81 is recognized for its sustainability and ability to reduce carbon emissions.

Pond ash, a byproduct of coal combustion, is another material utilized for soil stabilization due to its lightweight nature and pozzolanic properties. It contains siliceous and aluminous compounds that react with water to form cementitious bonds, enhancing soil strength and compaction. Physically, pond ash is light gray with a specific gravity of 2.1 and a bulk density of 1150 kg/m³. Its high-water absorption capacity (18%) makes it effective in reducing soil permeability. Economical and sustainable, pond ash improves soil compressive strength while minimizing costs, making it a valuable material in construction applications, particularly in roadbed stabilization.

The study involved integrating laterite soils with RBI Grade 81 and pond ash to evaluate their combined impact on the soil's physical and mechanical properties. By conducting standard tests such as liquid limit, plasticity index, and compressive strength, the effectiveness of these stabilizers in enhancing soil performance was assessed. The results demonstrated significant improvements in soil density, strength, and moisture resistance, highlighting the potential of this sustainable approach for infrastructure development.

2.3 Methodology

Soil samples were prepared by thoroughly mixing the Soil with different proportions of RBI Grade 81 and Pond Ash. Specifically, the lateritic soil Soil was mixed with RBI Grade 81 in 2% increments (0%, 2%, 4%, 6%, 8%, and 10% by weight) alongside with 10% of pond ash selected proportions of Pond Ash to evaluate optimal stabilization combinations. Each sample was carefully prepared and maintained at optimal moisture conditions by adding water and mixing thoroughly to ensure uniform distribution of the stabilizers.

Sample ID	Soil (%)	RBI Grade 81 (%)	Pond Ash (%)
S1	100	0	10
S2	88	2	10
S3	86	4	10
S4	84	6	10
S5	81	8	10
S6	80	10	10

Table.1 Mix proportions

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3. RESULT AND ANALYSIS

Table.2 Free swell index

Sample ID	Soil (%) (Lateritic Soil)	RBI Grade 81 (%)	Pond Ash (%)	Free Swell Index (FSI, %)
S1	100	0	0	50
S2	90	5	5	40
S3	88	2	10	35
S4	86	4	10	28
S5	84	6	10	20
S6	81	8	10	15

Table.3 Plastic limit and liquid limit

Sample ID	Soil (%) (Lateritic Soil)	RBI Grade 81 (%)	Pond Ash (%)	Plastic Limit (PL)	Liquid Limit (LL)
S1	100	0	0	22%	40%
S2	88	2	10	20%	38%
S3	86	4	10	19%	36%
S4	84	6	10	18%	35%
S5	81	8	10	17%	33%
S6	80	10	10	16%	32%

Table.4 UCS (kpa)

Sample ID	Soil (%) (Lateritic Soil)	RBI Grade 81 (%)	Pond Ash (%)	UCS (kPa)
S1	100	0	0	150
S2	88	2	10	250
S3	86	4	10	380
S4	84	6	10	450
S5	81	8	10	420
S6	80	10	10	400

Table.5 OMC and MDD

Sample ID	Soil (%) (Lateritic Soil)	RBI Grade 81 (%)	Pond Ash (%)	OMC (%) (SPT)	MDD (g/cc) (SPT)
S1	100	0	0	13.5	1.75
S2	88	2	10	12.7	1.80
S3	86	4	10	12.2	1.85
S4	84	6	10	11.6	1.89
S5	81	8	10	11.2	1.92
S6	80	10	10	11.5	1.90

Table.6 CBR (%)

Sample ID	Soil (%) (Lateritic Soil)	RBI Grade 81 (%)	Pond Ash (%)	Unsoaked CBR (%)	Soaked CBR (%)	Percentage Difference (%)
S1	100	0	0	5	3	40.0%
S2	90	5	5	10	6	40.0%
S3	88	2	10	12	8	33.3%
S4	86	4	10	18	13	27.8%
S5	84	6	10	22	17	22.7%
S6	81	8	10	20	16	20.0%

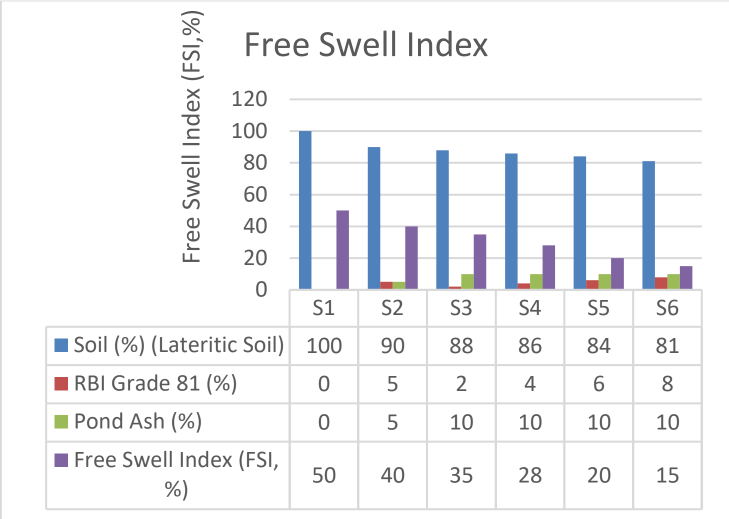

Fig.Free swell index

suction in swelling potential with the addition of RBI Grade 81 and pond ash. The FSI decreases from 50% (pure soil) to 15% for the mix with 81% soil, 8% RBI Grade 81, and 10% pond ash. The optimum mix, 84% soil + 6% RBI Grade 81 + 10% pond ash, achieves an FSI of 20%, striking a balance between stability and cost-effectiveness. The reduction in FSI is attributed to the stabilizers improving soil structure and reducing clay expansion, making these mixes ideal for construction on expansive soils.

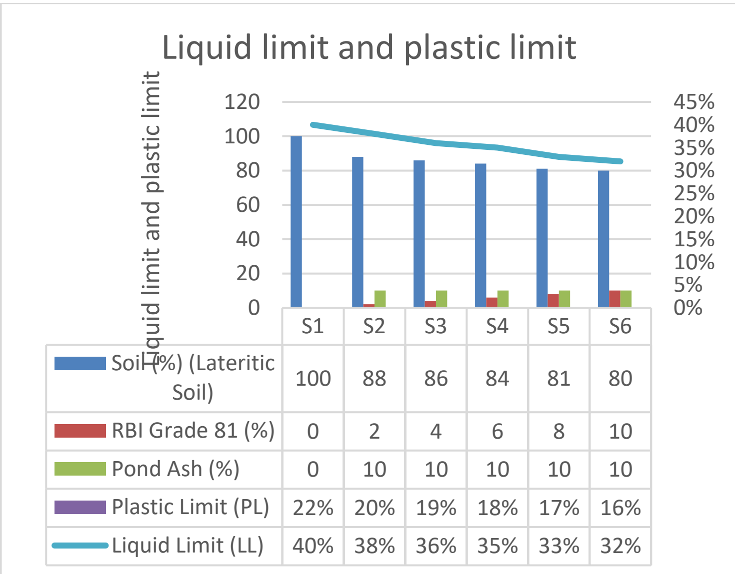

Fig.Liquid limit and Plastic limit

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The results show the influence of varying proportions of RBI Grade 81 and pond ash on the plastic limit (PL) and liquid limit (LL) of lateritic soil. As the percentage of RBI Grade 81 increases from 0% to 10% and pond ash remains constant at 10%, both PL and LL show a consistent decrease. The plastic limit drops from 22% (S1) to 16% (S6), while the liquid limit decreases from 40% (S1) to 32% (S6). This trend suggests improved soil stability and reduced plasticity, indicating that adding RBI Grade 81 and pond ash enhances soil properties for engineering applications.

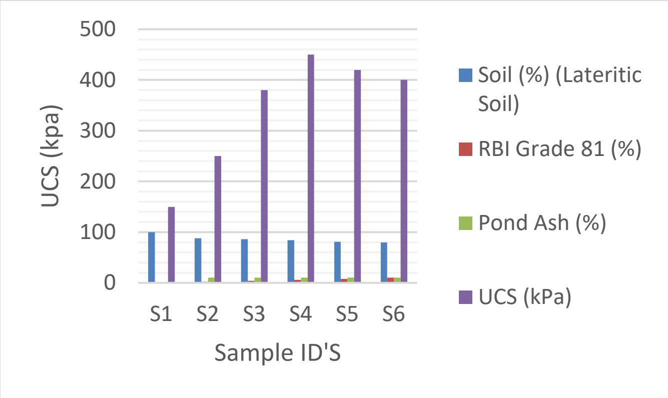

Fig. UCS vs sample ID's

The results illustrate the effect of incorporating RBI Grade 81 and pond ash on the unconfined compressive strength (UCS) of lateritic soil. As the percentage of RBI Grade 81 increases from 0% to 6%, while keeping pond ash constant at 10%, the UCS improves significantly, reaching a peak of 450 kPa (S4). Beyond this, at 8% and 10% RBI Grade 81, the UCS decreases slightly to 420 kPa (S5) and 400 kPa (S6), respectively. This indicates that adding RBI Grade 81 enhances soil strength initially, but excessive amounts may reduce its effectiveness. The optimum mix is observed at 6% RBI Grade 81.

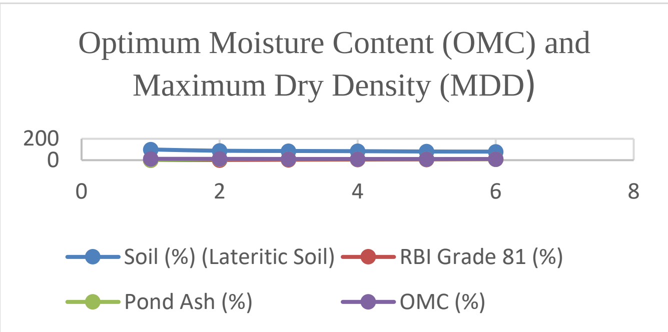

Fig. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

The results highlight the impact of varying percentages of RBI Grade 81 and pond ash on the optimum moisture content (OMC) of lateritic soil. As the proportion of RBI Grade 81 increases from 0% to 8% while pond ash remains constant at 10%, the OMC decreases steadily from 12.5% (S1) to 10.5% (S5). This reduction in OMC can be attributed to the stabilization effect of RBI Grade 81, which reduces the water demand of the soil by improving its particle arrangement and density. However, at 10% RBI Grade 81 (S6), the OMC slightly increases to 10.9%, indicating a potential stabilization limit beyond which the additive may not significantly enhance compaction efficiency. Overall, the data suggest that incorporating RBI Grade 81 and pond ash effectively reduces the OMC, making the soil more workable and economical in terms of water usage during field compaction. The optimum stabilization effect occurs at 8% RBI Grade 81.

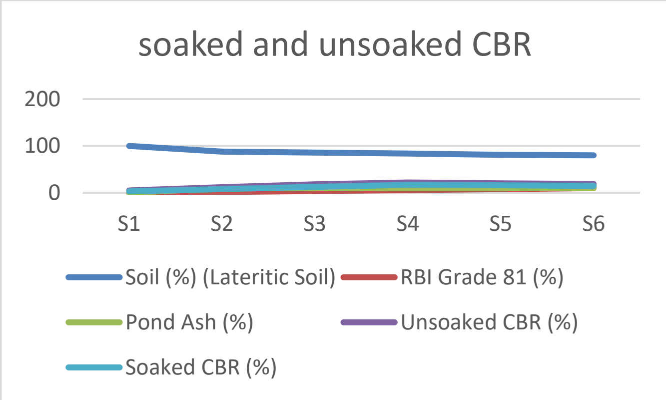

Fig. Soaked and Unsoaked CBR

The results demonstrate the impact of RBI Grade 81 and pond ash on the California Bearing Ratio (CBR) values of lateritic soil under unsoaked and soaked conditions. As the percentage of RBI Grade 81 increases from 0% to 6%, with pond ash kept constant at 10%, the unsoaked CBR rises significantly from 5% (S1) to 22% (S4), while the soaked CBR increases from 3% to 17%. This improvement indicates enhanced strength and load-bearing capacity due to the stabilizing effect of RBI Grade 81. However, further increasing the RBI Grade 81 content to 8% (S5) and 10% (S6) results in a slight decline in both unsoaked and soaked CBR values, with unsoaked CBR reducing to 19% and soaked CBR to 15% at S6. This suggests that excessive amounts of RBI Grade 81 might lead to diminishing returns. Optimal stabilization occurs at 6% RBI Grade 81, where the soil exhibits maximum strength under both conditions.

3.1 IIT PAVE

Design Inputs

1. Traffic Data
   - Design Traffic: 10 msa
   - Vehicle Damage Factor (VDF): 3.5 (assumed for medium traffic conditions)
   - Lane Distribution Factor (LDF): 0.75 (for a single-lane carriageway)
   - Traffic Growth Rate: 7% per annum
   - Design Life: 15 years
2. Subgrade Properties

Material: Stabilized lateritic soil (optimum mix)
California Bearing Ratio (CBR): 17% (soaked)

- Mr=10×CBR=170 MPa

Layer	Material	Thickness	Resilient Modulus (Mpa)	Poisson's Ratio
Surface layer	Dense Bituminous Macadam (DBM)	To be determined	2500	0.35
Base layer	Stabilized soil mix	To be determined	300	0.3
Subgrade	Stabilized Lateritic soil soil mix	Infinite	170	0.35

Final Design Parameters

1. **Surface Layer:**
   - Thickness: 100 mm
   - Material: Dense Bituminous Macadam (DBM)
   - Resilient Modulus: 2500 MPa
2. **Base Layer:**
   - Thickness: 250 mm
   - Material: Stabilized Soil Mix (Optimum combination)
   - Resilient Modulus: 300 MPa
3. **Subgrade:**
   - Thickness: Infinite
   - Material: Stabilized Lateritic Soil

4.CONCLUSION

The study on stabilizing lateritic soil using RBI Grade 81 and Pond Ash demonstrated significant improvements in soil properties, making it suitable for engineering applications. Evaluations included Free Swell Index (FSI), Specific Gravity, Liquid and Plastic Limits, Unconfined Compressive Strength (UCS), Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR), and Triaxial Shear tests.

FSI reduced from 50% to 15%, with the optimal reduction at 20% in the S4 mix (6% RBI Grade 81, 10% Pond Ash), enhancing suitability for expansive soils. Specific gravity decreased from 2.65 to 2.56 due to Pond Ash's lighter nature, improving stability. The Liquid and Plastic Limits fell from 40% and 22% to 32% and 16%, respectively, reflecting reduced plasticity and better workability. UCS peaked at 450 kPa for S4, indicating enhanced strength, while OMC dropped to 10.5%, and MDD rose to 1.92 g/cc, showing improved compaction efficiency.

CBR values increased significantly, with unsoaked values rising from 5% to 22%, confirming better load-bearing capacity. Triaxial tests showed improved cohesion (48 kPa) and friction angle (29°), leading to a 145% increase in shear strength. The findings suggest S4 as the optimal mix, balancing strength, cost, and sustainability. The IIT Pave-designed flexible pavement reinforced the material's suitability for durable, eco-friendly infrastructure.

4.1 FURTHER STUDY

Further studies are essential to expand the understanding of GGBS and PPF in soil stabilization. Long-term performance testing under various environmental conditions, such as freeze-thaw cycles and moisture exposure, is needed to assess the durability of GGBS and PPF-enhanced soil. Additionally, exploring different types of fibers (e.g., glass, steel) could help identify the most effective fiber for improving soil properties. The effect of GGBS on various soil types should also be examined, as results may vary with different soil compositions. Moreover, a life cycle assessment (LCA) would provide insight into the environmental benefits of using GGBS in soil stabilization, contributing to more sustainable construction practices. Field implementation is crucial for verifying the laboratory results, particularly in real-world applications like road construction and foundation stabilization. Optimization of GGBS and PPF proportions should also be explored to determine the most efficient mix for achieving superior strength and compaction. Additionally, evaluating the material's performance in seismic zones could determine its suitability for earthquake-resistant infrastructure. Expanding research into these areas will help refine soil stabilization techniques, improve their performance, and promote sustainable, cost-effective materials for construction.

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