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# Evaluation of Shear Strength Characteristics of Root-Reinforced and Non-Reinforced Soils Using Direct Shear Test

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***Abstract: Slope instability of mine overburden dumps is a major geotechnical concern, particularly in tropical regions subjected to intense rainfall and erosion. Vegetation-based soil reinforcement offers an eco-friendly and cost-effective solution for improving dump stability. This study experimentally evaluates the shear strength behaviour of root-reinforced and non-reinforced soils using the direct shear test. Clay– dominant soil collected from coal mine overburden dumps was reinforced with Acacia mangium roots at a controlled Root Area Ratio (RAR) of 3.58%. Direct shear tests were conducted under varying normal stresses (0.5, 1.0, and 1.5 kg/cm²). Results indicate a significant increase in shear strength for root-reinforced soil compared to unreinforced soil. Cohesion showed substantial improvement, whereas changes in the internal friction angle were marginal. The findings confirm that root reinforcement primarily enhances apparent cohesion through tensile resistance and soil–root interlocking. The study demonstrates the effectiveness of Acacia mangium as a bioengineering solution for shallow slope stabilization in mine reclamation projects.***
***Keywords: Root reinforcement, Shear strength, Direct shear test, Acacia mangium, Mine overburden, Bioengineering.***

## I. INTRODUCTION

Open-cast mining generates large quantities of loose overburden material, forming unstable dump slopes that are prone to failure due to rainfall infiltration, erosion, and poor mechanical properties. Conventional stabilization methods using retaining structures or geosynthetics are often expensive and environmentally intrusive. In recent years, vegetation-based soil reinforcement has gained attention as a sustainable alternative.

Plant roots enhance soil shear strength by providing tensile resistance, increasing apparent cohesion, and improving soil structure. Species such as *Acacia mangium* are particularly suitable for mine reclamation due to their rapid growth, deep root systems, and adaptability to degraded soils. However, quantitative laboratory-based studies on root-reinforced mine dump soils under controlled conditions remain limited.

This study aims to experimentally evaluate the shear strength parameters of root-reinforced and non-reinforced soils using the direct shear test and to assess the contribution of *Acacia mangium* roots to slope stabilization.

## II. LITERATURE SURVEY

Several studies have highlighted the critical role of vegetation-based bio-engineering in improving the stability of mine overburden dumps and soil slopes. Chaturvedi et al. (2023) reviewed the effectiveness of various plant species, including *Albizia lebbeck*, *Dalbergia sissoo*, *Leucaena leucocephala*, Vetiver grass, and *Acacia mangium*, in reinforcing sandy dump soils under Indian mining conditions using direct shear and root tensile strength tests. The authors reported that India removed approximately 2048.75 million m³ of overburden to produce 745 million tonnes of coal during 2021–22, resulting in large and steep waste dumps prone to failure, with 143 fatalities reported in 23 accidents, primarily due to poor shear strength of dump material and rainwater infiltration. The study emphasized that conventional stabilization measures such as dowels and rock bolts are often ineffective in dump conditions, whereas bio-engineering provides a cost-effective, eco-friendly, and sustainable alternative. Root–soil interaction was identified as the primary stabilization mechanism, contributing to increased shear strength, reduced pore water pressure through evapotranspiration, and improved cohesion over time.

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Shear strength improvements of up to 413% were reported within six months for *Leucaena leucocephala*, while Vetiver grass roots exhibited tensile strengths as high as 75 MPa. Species selection was found to be crucial, with high survival rate, small root diameter, high root biomass, and appropriate root architecture being key factors, and the Miyawaki plantation method was recommended for rapid ecological restoration and improved factor of safety, which increased from 1.2 to 1.4 in vegetated dumps. Complementary laboratory studies by He et al. (2017) demonstrated that shear strength in unsaturated soils increases with matric suction, highlighting the importance of moisture conditions and pore water pressure dissipation during direct shear testing. Similarly, Stanisz et al. (2018) investigated root–soil composites in silt and silt-loam soils using direct shear tests and reported that shear strength enhancement increases with vegetation growth period, further confirming the significance of root reinforcement for shallow slope stabilization and erosion control.

## III. MATERIALS AND METHODS

### A. Soil Collection and Characterization

Soil samples were collected from overburden dumps of Singareni Collieries Company Limited (SCCL), Rama Gundam coalfield, India. The soil was air-dried, pulverized, and sieved through a 4.75 mm sieve. Laboratory classification tests identified the soil as sandy clay type, typical of mine dump material.

### B. Root Material

Roots of *Acacia mangium* were collected from nursery-grown plants aged 6–12 months. Both fine roots (1–2 mm diameter) and mother roots (~6 mm diameter) were used. Roots were cleaned and air-dried to preserve natural mechanical properties.

### C. Root Area Ratio (RAR)

A Root Area Ratio of 3.58% was maintained, calculated as the ratio of total root cross-sectional area intersecting the shear plane to the shear area (900 mm²). Roots were randomly distributed to simulate natural conditions.

### D. Sample Preparation and Testing

Direct shear tests were conducted using a strain-controlled shear box apparatus (30 mm × 30 mm × 20.5 mm). Two sets of specimens were prepared:

- Non-reinforced soil samples
- Root-reinforced soil samples (RAR = 3.58%)

Samples were compacted in three layers under dry conditions (0% moisture content). Tests were performed under normal stresses of 0.5, 1.0, and 1.5 kg/cm² at a constant strain rate of 2.25 mm/min. Shear stress at failure was recorded for each test.

Rooted Soil Sample After Filling Two Layers Before Performing Direct Shear Test

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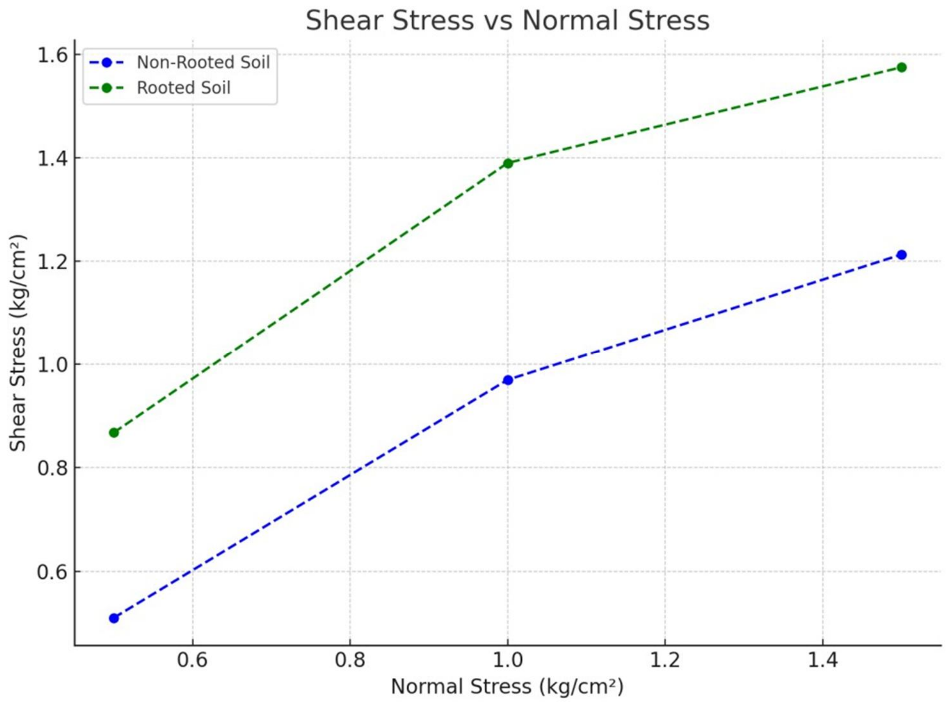
Full Setup of Direct Shear Test

Rooted Sample After Failure

## IV. RESULTS AND DISCUSSION

### A. *Shear Stress–Normal Stress Relationship*

Both reinforced and non-reinforced soils showed a linear increase in shear stress with normal stress, following the Mohr–Coulomb failure criterion. However, root-reinforced soils consistently exhibited higher peak shear stresses at all normal stress levels.




Shear Stress Vs Normal Stress Relationship of Rooted and Non-Rooted Soil

### A. *Effect of Root Reinforcement on Cohesion*

Root-reinforced soil showed a significant increase in cohesion compared to non-reinforced soil. The improvement is attributed to tensile resistance offered by roots crossing the shear plane and enhanced soil–root bonding. This confirms that roots act as natural reinforcements, similar to randomly distributed fibres.

### B. *Effect on Internal Friction Angle*

The internal friction angle showed only marginal variation between reinforced and non-reinforced soils. This indicates that root reinforcement primarily affects the cohesive component rather than frictional resistance, consistent with findings reported in earlier studies.

| Parameter | Non-Rooted Soil | Rooted Soil | % Increase |
|---|---|---|---|
| Cohesion (kg/cm²) | 0.1947 | 0.571 | 193.2% |
| Friction Angle (ϕ) | 35.11° | 35.26° | 0.43% |
| Parameter | Non-Rooted Soil | Rooted Soil | % Increase |
| Max Shear Stress @1.5 kg/cm² | 1.213 | 1.575 | 29.8% |

Comparison between Cohesion, Friction angles and Max Shear Stress

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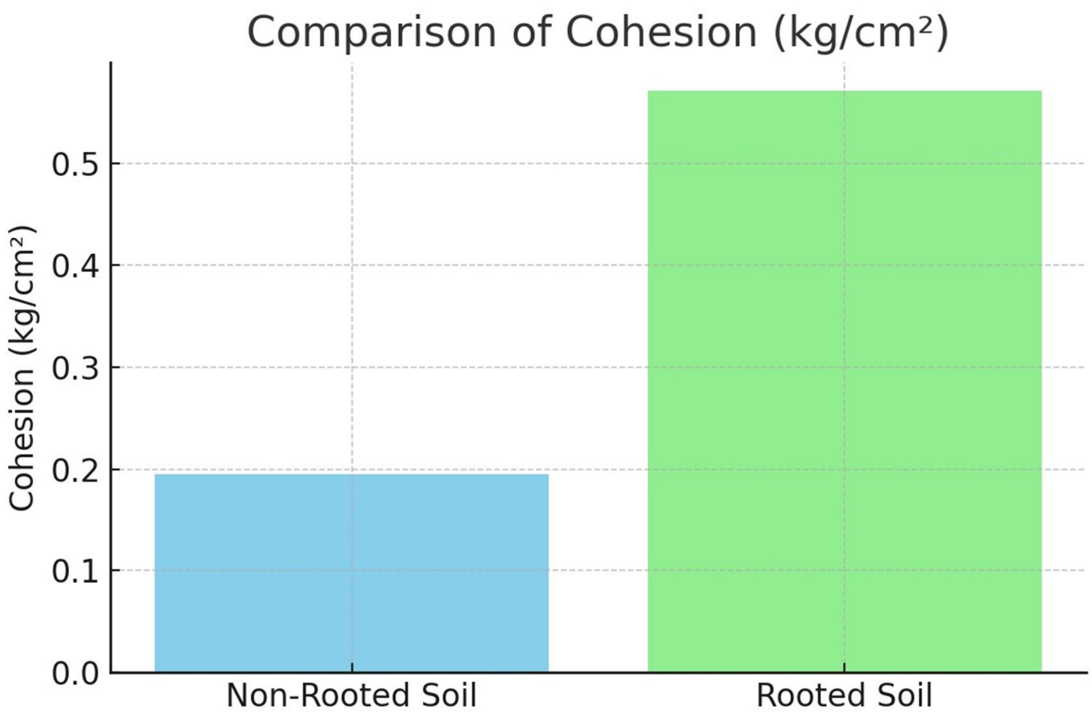
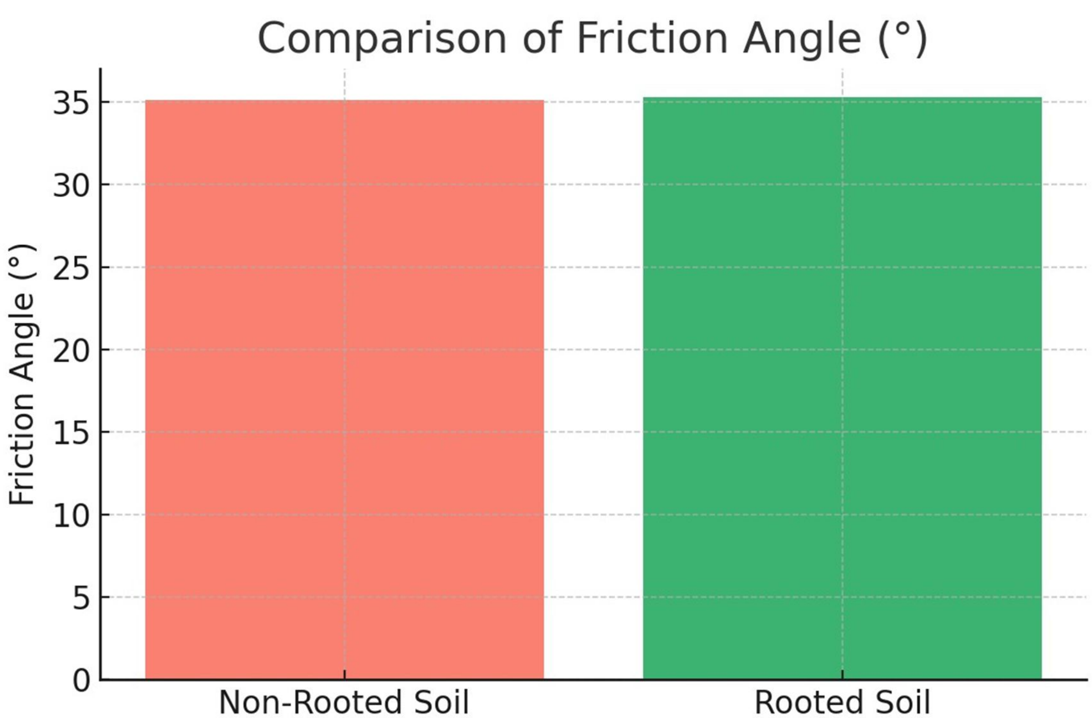
### *C. Failure Mechanism*

Visual observation revealed that root-reinforced samples exhibited delayed failure and higher resistance to deformation. Root bridging and pull-out mechanisms were observed, indicating effective interaction between roots and soil particles.




Comparison of Cohesion (kg/cm2)




Comparison Of Fiction Angle

## V. CONCLUSIONS

The experimental investigation confirms that *Acacia mangium* roots significantly enhance the shear strength of mine overburden soils. The major findings are:

1) Root-reinforced soil exhibits substantially higher shear strength than non-reinforced soil.
2) Cohesion increases considerably due to root tensile resistance and soil–root interlocking.
3) Internal friction angle remains largely unaffected by root presence.
4) Root reinforcement is most effective under low to moderate normal stresses, typical of shallow slopes.

The study supports the application of vegetation-based bioengineering techniques for stabilizing mine dump slopes and promotes sustainable mine reclamation practices.

## VI. ACKNOWLEDGEMENT

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