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Strength and Slope Stability Analysis of Sakaleshpura Lateritic Soil Stabilized with Silica Fume and Randomly Distributed Artificial Polypropylene Fibers

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Abstract - The present Lateritic Soil(LS) is collected from Dhonigal village, Sakleshpura Taluk, Hassan District, Karnataka(s),India, where a recent natural slope failure has occurred due to human interference in March 2025. To give a rational and economic solution approach, the lateritic soil has been stabilized with 5% Silica Fume (SF)(by weight of soil). All the tests were performed in the triaxial loading frame with a strain rate of 1.25mm/min. samples intended to test immediately were test on the same day of casting where as samples intended to test with curing were tested on curing period. In order to increase the passive inclusive in the failure surface of the slopes, lateritic soil stabilized with optimum silica fume is treated with optimum percentage of Randomly Distributed Poly Propylene Fibers (RDPPF). To validate the improvement in the stability of the treated soil, Factory of safety for untreated and treated soil is determined using stability analysis of slope by method of slices for three trial slopes 1:1, 1:1.5 and 1:2. It has concluded that L.S.+5%S.F.+0.5%RDAPFF with as slope of 1:5 shows 39% improvement of its stability on compared with Lateritic soil alone where as Lateritic soil treated with 5% silica fume shows lower factor of safety on compared with above combination. Hence addition of fibers to treated soil shows good improvement in the factor of safety and stability analysis.

Key Words: Lateritic soil, Silica fume, Polypropylene fiber, Strength, Slope stability, Factor of safety.

1. INTRODUCTION

Lateritic soils are commonly found in tropical regions and are prone to instability, especially in hilly terrains where rainfall-induced failures are frequent. Soil stabilization using chemical and mechanical additives is one of the effective methods to enhance stability. Among the available additives, silica fume acts as a pozzolanic material improving strength through the formation of calcium silicate hydrate, while polypropylene fibers contribute to tensile reinforcement and ductility. This study emphasizes the combined effect of silica fume and artificial fiber on the strength and slope stability characteristics of lateritic soil, as evaluated through standard laboratory testing and slope stability (Factor of Safety) analysis. The main objective of this research is to determine the optimum combination of silica fume and polypropylene fiber for improving the strength and slope stability of lateritic soil for Sakaleshpura area.

2. MATERIALS AND METHODS

MATERIALS

Lateritic soil

The lateritic soil used in this research work was collected from a landslide site at Donigal village, Sakaleshpura Taluk, Hassan District. This area is prone to landslides, and such events occur regularly in this region.

Photo:1- Soil sample collection site at natural landslide location, Donigal, Sakaleshpura.

Table:1- Basic Properties of Lateritic Soil

PROPERTIES	RESULT
Colour	Reddish brown
Specific gravity As per IS 2386-part-1(1963)	2.66
IS classification 1498:1970	Clayee Silt of Intermediate Compressibility (ML)
Effective particle size, D10(mm)	0.088
D30(mm)	0.54
D60(mm)	1.94
Coefficient of uniformity	22.15
Coefficient of curvature	1.69
Optimum Moisture content (%)	13
Maximum Dry Density (kN/m^3)	17.47
Cohesion (kN/m^2)	28
Angle of internal friction (Φ^o)	42
Liquid Limit(W_L %)	48%
Plastic Limit(P_L%)	38%
Plasticity Index(PI)	10

Silica Fume

Silica fume, also known as microsilica, is a by-product of producing silicon metal or ferrosilicon alloys in electric arc furnaces. It consists primarily of ultrafine spherical particles of amorphous silicon dioxide (SiO2), typically making up (www.mastercivilengineer.com) 85% to 97% of its composition. The particle size of silica fume is about 0.15 micrometers, which is roughly 100 times smaller than average cement particles. Silica fume exhibits strong bonding properties primarily due to its high pozzolanic activity and ultrafine particle size. The key bonding mechanism involves its reaction with calcium hydroxide, which is released during the hydration of cementitious materials in the soil. This reaction produces additional calcium silicate hydrate (C-S-H) gel, a cementitious compound that bonds soil particles together, enhancing cohesion and overall soil strength.

Table:2- Basic Properties of Silica Fume

Properties	Result
Colour	Dark Grey
Specific gravity	2.2-2.3
Surface area	15000-30000m^2/kg
Density	1.3-6kN/m^3

Courtesy:www.mastercivilengineer.com

Photo:2- Photograph of Silica Fume.

Polypropelyne fibre

Locally available ACC Cement old bags which were initially washed with water and air dried and no cement traces were found while using these bag threads as discrect fibers.These fibers were artificial fibers of polypropylene (PP) in nature. These fibers are known for their high tensile strength, excellent resistance to chemical attack including alkalis and acids, and durability against environmental factors. The fibers help improve the mechanical properties of stabilized soil by enhancing tensile strength, crack resistance, and ductility. Using these recycled fibers also contributes towards sustainable construction practices by repurposing waste materials.

Table:3- Basic Properties of Polypropylene fiber

Properties	Result
Colour	Yellow
Density	8.83kN/m^3
Tensile strength	300-700N/mm^2
Elongation at break	10-25%

Courtesy:www.fibercrete.in

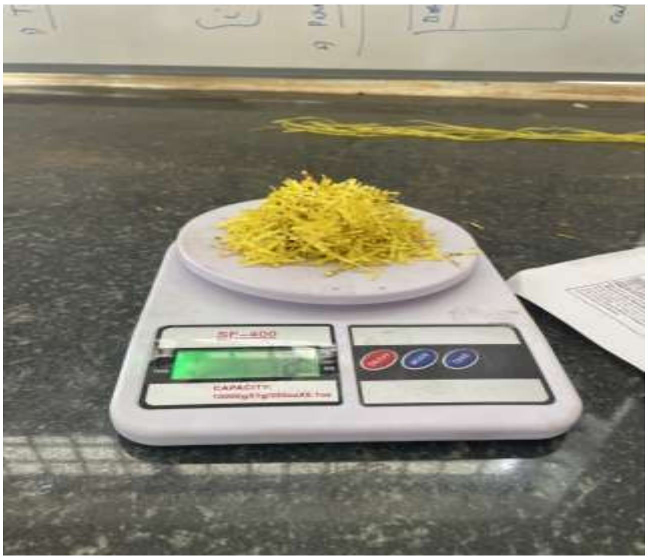

Photo:3- Photograph of Polypropylene fibers.

3. METHODS

The soil was stabilized with 1% to 6% silica fume (by weight of soil) and reinforced with 0.25% to 1% artificial fiber. (by weight of soil). Laboratory tests including compaction and Unconfined Compression Strength (UCS) test were conducted as per BIS 2720 standards. Slope stability was analyzed using the Method of Slices for slope ratios 1:1, 1:1.5, and 1:2. The Factor of Safety (FOS) was determined for various stabilized combinations.

4. RESULTS AND DISCUSSION

Specific Gravity by Density Bottle Method

The specific gravity of the lateritic soil, rich in silt content, was evaluated using the density bottle method in accordance with BIS 2720(Part.4) guidelines. The measured value was 2.66, which falls within the typical range for lateritic soils, indicating the dense mineralogical composition and affecting related parameters such as void ratio and degree of saturation.

Atterberg Limits

The liquid limit determined in accordance with IS 2720(Part.4) guidelines by Casagrande's method was 48%, while the cone penetration method yielded 49%. These results reflect the soil's moderate plasticity, which is crucial in classifying fine-grained soils and predicting their behavior under varying moisture. The plastic limit was found to be 38%, yielding a plasticity index of 10–11%, which indicates moderate workability and resistance to volume change.

Sieve Analysis

Sieve analysis results show that the soil is well graded with a coefficient of uniformity (Cu) of 22.15, a coefficient of curvature (Cc) of 1.69, and significant fines content (D_{10}=0.088 mm, D_{30}=0.54 mm, D_{60}=1.95 mm). The permeability coefficient (K) was 0.774mm/s, classifying the material as sandy silt-silty sand, suitable for stabilization.

Indian Standard Light Compaction Test

The test revealed that the soil's Optimum Moisture Content (OMC) was 13%, with a Maximum Dry Density (MDD) of 17.47 kN/m³ for untreated soil. With increasing silica fume content, OMC increased and MDD first decreased slightly (to 16.57–16.77 kN/m³ at 1–2% silica fume), then improved at 5% (17.45 kN/m³), nearly matching untreated soil. At higher dosages, OMC increased sharply while MDD decreased, as the finer silica fume particles absorbed more water but interfered with particle packing.

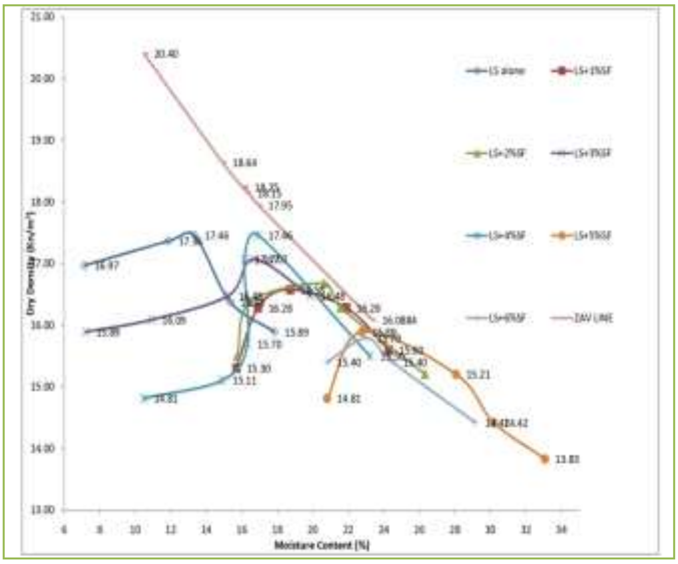

Fig :1- Variation of density-water content for soil with varying percentage of silica fume

Unconfined Compressive Strength (UCS) Analysis

Unconfined Compressive Strength (UCS) tests revealed that compressive strength increased with silica fume content up to 5%, showing peak UCS values of 0.222 N/mm² at 0 days and 0.232 N/mm² at 7 days. Strength gain is attributed to pozzolanic reactions forming additional cementitious compounds, which densify the soil matrix. Beyond 5% silica fume, UCS dropped due to excess unreacted silica interfering with particle bonding. Thus, 5% silica fume was established as the practical optimum for further testing.

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Photo:4- untreated un reinforced soil subjected to UCS Test

Photo:7- Variation of UCS of optimum silica fume stabilized lateritic soil reinforced with artificial fiber

Photo:5- Silica fume treated soil unreinforced with fiber during testing

Photo:8- Optimul combination of silica fume treated soil reinforced with artificial fiber during testing..

Photo:6- LS+5%SF+0.5%RDAPPF UCC specimen samples

Photo:9- Curing of UCC specimens

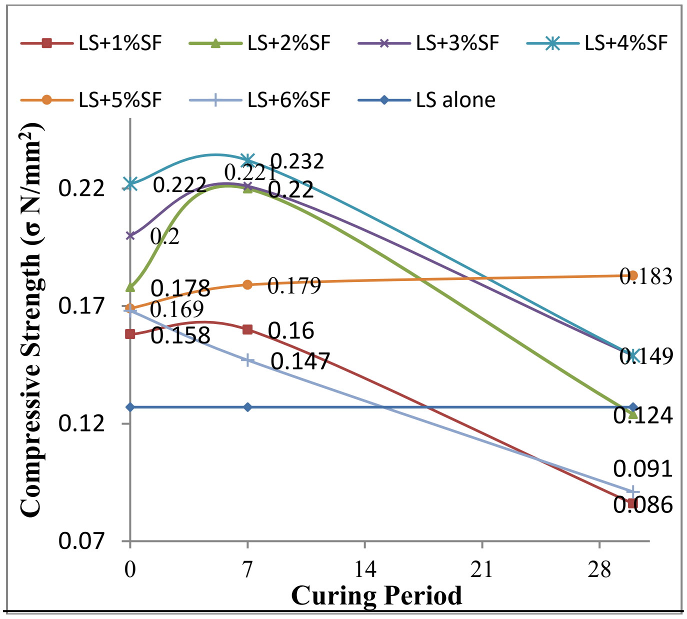

Fig:2- Unconfined Compressive strength of lateritic soil stabilized with varying percentage of silica fume with and without curing.

Inclusion of polypropylene fibers in the lateritic soil stabilized with 5% silica fume yielded the following:

At 0.25% and 0.5% RDAPPF, compressive strength and strain increased significantly after 7 days curing, highlighting improved ductility and stress transfer. And Optimal results appeared at 0.5% RDAPPF, with about 17% strength gain and 15% higher strain compared to unreinforced mixes. Above this fiber content, the strength stopped increasing or slightly reduced, possibly because fibers started to group together, but the soil stayed flexible.

Strength Gain Number (SGN)

Strength Gain Number calculations showed a 44% UCS increase at 30 days for the 5% silica fume combination, compared to the untreated reference value of 0.127 N/mm². This gain is due to the optimal formation of cementitious gels and better particle interlocking, while overdosing causes diminishing returns or negative stabilization.

Comparisons of Factor of Safety (FOS) for Untreated Lateritic Soil with Treated Lateritic Soil Using Method Of slices.

Stability analysis using the method of slices demonstrated:

Untreated soil at slope 1:1, 1:1.5 had FOS around 2.4–3.0.

Addition of 4–5% silica fume improved cohesion and internal friction, raising FOS at all test slopes.

Best results were attained with LS+5%SF+0.5% RDAPPF, average FOS increased by over 20% compared to soil alone.

Steeper slopes could be achieved safely with the optimal stabilized mix.

For long-term (7-day) curing, FOS for fiber-reinforced, Lateritic soil stabilized with silica fume was consistently higher, supporting its use for embankments and cut slopes.

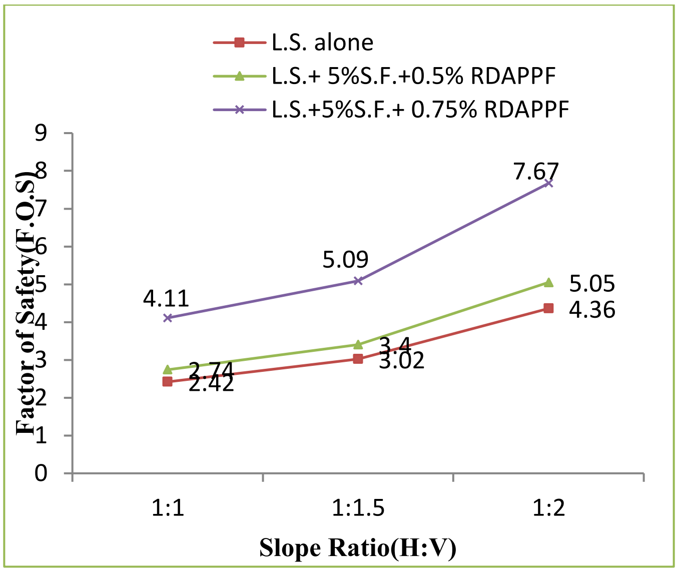

Fig:3- comparative study of soil alone with stabilizing materials and stabilized soil with reinforcing material factor of safety with varying slope for immediate effect.

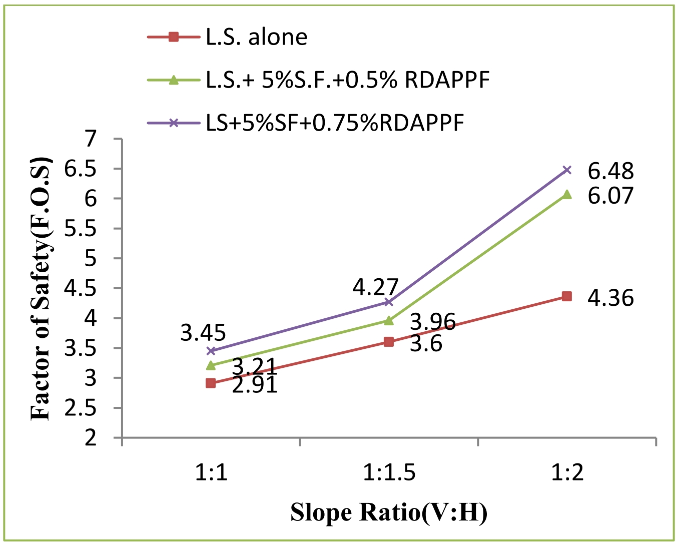

Fig:4-Comparative study of soil alone with stabilizing materials and stabilized soil with reinforcing material factor of safety with varying slope for 7 days curing effect.

Summary of Optimum Mix

The optimum stabilization was achieved at 5% silica fume and 0.5% polypropylene fiber, providing maximum improvement

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in compaction, strength, ductility, and slope stability. Above these mix ratios, further dosage gave diminishing or negative returns due to poor dispersion and excess fine content.

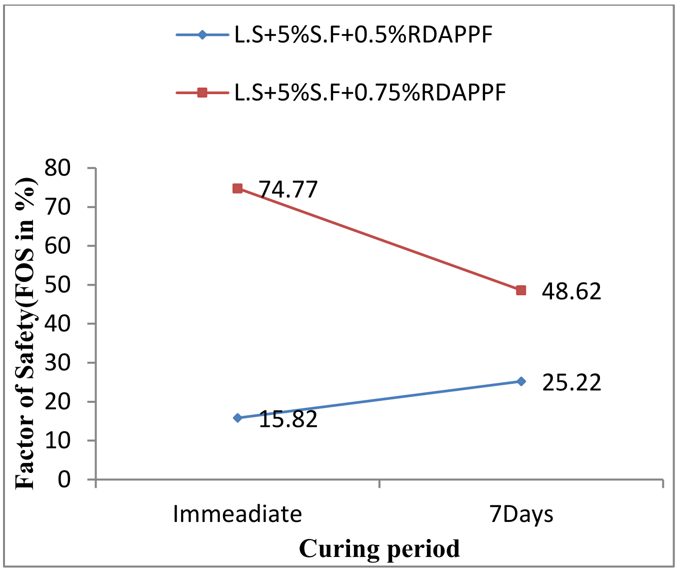

Fig:5- FOS Comparison of LS+5%SF+0.5%RDAPPF edge over LS+5%SF+0.75%RDAPPF

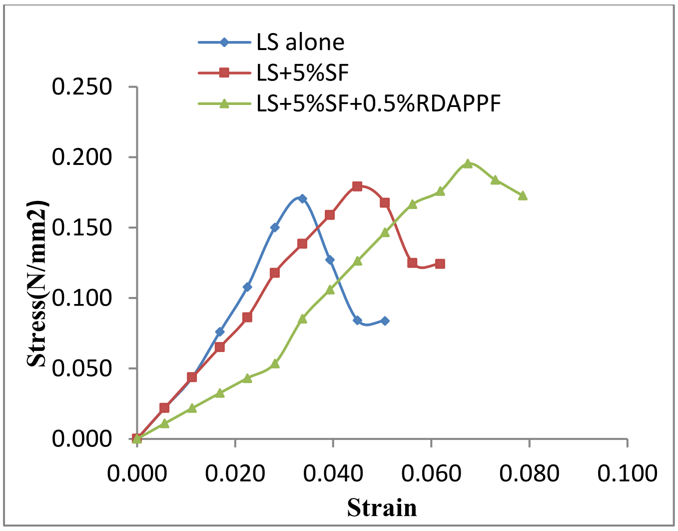

Fig:6- Stress-Strain behavior of Lateritic Soil at 7 days curing

Stress–Strain Behavior

The stress–strain behavior of lateritic soil under different stabilizing conditions is shown in the figure above. From the curve, it is observed that the untreated lateritic soil (LS alone) exhibits a peak stress of about 0.170 N/mm², followed by a sudden drop in stress after failure, indicating brittle behavior. With the addition of 0.5% silica fume (LS + 5% SF), the peak stress increases slightly to about 0.179 N/mm², showing an improvement in strength due to the pozzolanic reaction of silica fume, which enhances particle bonding and reduces voids. When both silica fume and 0.5% randomly distributed artificial polypropylene fiber (RDAPPF) are added together (LS + 5% SF + 0.5% RDAPPF), the stress–strain curve shows a significant improvement in ductility and strain capacity. The sample sustains higher deformation before failure, indicating that the inclusion of fibers improves the energy absorption capacity and post-peak strength retention of the soil. Overall, the combined use of silica fume and RDAPPF leads to a more ductile and stable soil matrix, making it more suitable for slope stability and subgrade applications where deformation control and toughness are essential.

Planned Field Implications

The combined stabilization technique demonstrated substantial potential for improving problematic lateritic soils in tropical, landslide-prone areas. Recommendations for field application include maintaining fiber content at or below 0.75% and regular monitoring of long-term performance.

The compaction test revealed that the addition of silica fume increased the Optimum Moisture Content (OMC) while slightly reducing the Maximum Dry Density (MDD). The UCS results showed that 5% silica fume by weight of the lateritic soil yielded the maximum strength after 7 days of curing. When reinforced with 0.5% RDAPPF, UCS improved further with enhanced ductility. Slope stability analysis indicated that LS+5% SF+0.5% RDAF combination yielded an average 2% higher Factor of Safety compared to chemical stabilization alone, enabling a steeper and more stable slope.

5. CONCLUSIONS

1. The collected lateritic soil is a clayey silt of intermediate compressibility. From sieve analysis clayey silt of intermediate compressibility gradation curve indicates it falls under the uniformly graded category. Hence, silica fume has added because there is a gap has observed in sieve analysis plot.

2. The addition of silica fume has not having beneficial effect in improvement in Maximum Dry Density (MDD). However there is an 60% increase in Optimum Moisture Content (OMC.) Hence, more the Optimum Moisture Content (OMC) internal cohesion effect and frictional values has not shown airmark improvement.

3. Lateritic Soil stabilized with silica fume between 4% to 5% (by weight of the soil) is found to be optimum from Unconfined Compression test.

4. Lateritic soil stabilized with 5% silica fume(by weight of the soil) with either 0.5% or 0.75% RDAF (by weight of the soil) will have marginal improvement in UCS values. However, the addition of RDAPPF resulted in a good improvement in the factor of safety. Therefore, lateritic soil with 5% silica fume + 0.5% RDAPPF showed very good factor of safety for all analyzed slopes and is considered optimum.

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Notations

MDD:Maximum Dry Density

OMC:Optimum Moisture Content

RDAPPF:Randomly Distributed Artificial Polypropylene Fiber.

LS:Lateritic Soil

SF:Silica Fume

FOS:Factor of Safety