International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 05 | May 2026 www.irjet.net p-ISSN: 2395-0072

ENHANCING NEAR-SURFACE SOIL SHEAR STRENGTH BY USING PINE NEEDLES

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Abstract - *This paper explores how pine needles can be used as a natural and environmentally friendly resource to increase shear strength of near-surface soils in hilly areas like Himachal Pradesh. Pine needle, which is in plenty and, in most cases, contributes to the environmental problem such as forest fire and pollution, is investigated as a sustainable geotextile solution. The study aims to determine the physical and mechanical characteristics of soil and pine needles using different laboratory tests, such as grain size analysis, specific gravity, liquid limit, standard Proctor test, and direct shear test. Four different lengths of pine needles (1 cm, 1.5 cm, 2 cm and full length) were added to the plain soil and compared. The findings reveal that the presence of soil alone is more shear strength, but when pine needles are added, ductility and brittleness are enhanced. It was noted that the longer the pine needles the better the shear strength and the best the fibres used in the tests were the 2 cm ones. The paper ends with the conclusion that pine needles would be an effective reinforcing fibre when added to soil and can be used to offer the sustainable approach to soil stabilization, as well as to overcome the environmental issues associated with pine litter deposits.*

Key Words: **Pine needles , OMC , MDD , Direct shear test, Standard Proctor.**

1. INTRODUCTION

In hilly regions, where soil erosion, landslides and slope instability is prevalent, soil stability is crucial. In places such as Himachal Pradesh, we need stable soil for safe construction, agriculture and ecosystem preservation[1]. Typically, engineers strengthen soil by using synthetic materials, but these materials are expensive and not environmentally friendly. So, there is a need for natural and bio-friendly alternatives. These days natural fibres like coir, jute, and hemp are used to improve soil strength as they are inexpensive, widely available and eco-friendly. Pine needles are also a natural resource and are readily available and found in abundance in hilly regions due to the presence of chirr (Pinus roxburghii) pine trees. But they are not commonly used and cause issues such as forest fires and low rate of decomposition. Pine needles are fibrous and their surface is not smooth, so they can help in cohesion of soil particles and improving its strength. Pine needles used in soil can not only increase the stability of soil but also help in preventing environmental issues arising from their disposal. The study will evaluate methods to improve the shear strength of shallow soil using pine needles. Various tests are performed to assess the characteristics of soil and pine needles and test their combined behavior[2]. The objective is to develop a cost-effective, easy and environmentally sustainable technique for soil stabilization in hills.

1.1 SCOPE OF THE PROJECT

The research will cover the scope of the study as follows: The current research aims at assessing the possibility of pine needles as a reinforcing substance in enhancing the shear strength of near-surface soil. The research is narrowed down to lab-based research through the standard geotechnical tests. Basic tests like grain size analysis, specific gravity and moisture content are used to characterize soil samples used in this research and aid in understanding their physical properties before reinforcement. The influence of pine needles on soil behavior has been investigated by carrying out direct shear tests under varying normal stresses which enabled comparison of reinforced and unreinforced soil conditions. The length of pine needles has been varied to see the variation in interlocking behavior and shear strength with special consideration to short and relatively long fibres. The research is limited to controlled laboratory settings; hence, the aspects of field level performance and long-term stability are not discussed in the research. This study applies mainly the geological aspect to the hilly state as Himachal Pradesh where the pine needles are in abundance and the geotechnical issues of soil stability exist. The treatment or alteration of pine needles by chemicals or other methods is not part of this study and only untreated fibres are examined.

1.2 EXPERIMENTAL STUDY

The experimental study was conducted to investigate the effect of pine needle reinforcement on the shear strength behavior of near-surface sandy silt soil. The study mainly

focused on comparing the engineering performance of unreinforced soil with soil reinforced using pine needles of different lengths. Laboratory investigations were performed according to ASTM and IS standard procedures to ensure accuracy and reliability of the results. The materials used in the study included sandy silt soil collected near National Institute of Technology Hamirpur, pine needles obtained from Chirr Pine (*Pinus roxburghii*) trees, water for moisture conditioning, and standard geotechnical laboratory equipment. The soil sample was oven dried, pulverized, and passed through a 4.75 mm sieve before testing. Pine needles were cleaned, dried, and cut into different lengths of 1 cm, 1.5 cm, 2 cm, and full length to study the effect of fibre length on soil behavior.

1.3 Experimental Investigation

A set of laboratory tests such as grain size analysis, specific gravity test, liquid limit test, Standard Proctor Test, and direct shear test were carried out following ASTM standards. The behaviour of unreinforced soil and its reinforced counterpart has been compared under different normal stresses by applying the direct shear test. The results showed that pine needles caused a significant increase in the shear strength, ductility and interlocking behaviour of the soil. It was found that the shear strength was higher as the length of the fibre increased and hence, the pine needles of 2 cm length and the full length resulted in the higher shear strength. The study results indicate that pine needles are suitable as a low cost, biodegradable and sustainable reinforcement material for soil stabilization.

2. METHODOLOGY

2.1 Soil Sample

The soil sample was collected near NIT Hamirpur, Himachal Pradesh. Soil was oven dried, ground and passed through a 4.75 mm sieve prior to testing.

Fig: 1 collected soil sample.

Table -1: Physical properties of soil

SOIL PROPERTIES	Value
Specific gravity	2.60
Sand %	34
Silt%	59
Clay%	6
Liquid Limit	30%
Plastic Limit	NP
OMC %	12.1%
MDD (g/cc)	1.79 g/cc
Angle of internal friction (ϕ)	39
Cohesion(kPa)	0

2.2 Pine needles (Reinforcement material)

Pine needles were cleaned, dried and cut to a desired length of 1 cm, 1.5 cm, 2 cm and full length (~ 4 cm) for experimentation.

Fig: 2 Pine needles.

Table-2 Mechanical properties of pine needles

PROPERTIES	PINE NEEDLES
Length(mm)	15 mm
Avg Diameter (mm)	0.1 mm
Specific Gravity	1
Color	Brown

2.3 Laboratory test conducted

Test/ Procedure	Standard / Method	Purpose / Use in Study
Sieve Analysis Set	(ASTM D1140, D7928)	To determine particle size distribution.
Density Bottle	IS:2720 (Part 3/Sec 1)	To determine specific gravity.
Standard Proctor Compaction	(ASTM D(698)	To determine OMC and MDD.
Casagrande Apparatus	(ASTM D4318)	To determine liquid limit.
Oven and Weighing Balance	(ASTM D2216).	For moisture content determination.
Direct Shear Apparatus	(ASTM D3080)	To measure shear strength parameters (C and ∠ ϕ)

(1.) Standard proctor test for determination of OMC and MDD

Standard proctor test is a laboratory compaction test to measure Optimum moisture content (OMC), Maximum dry density (MDD) of soil.

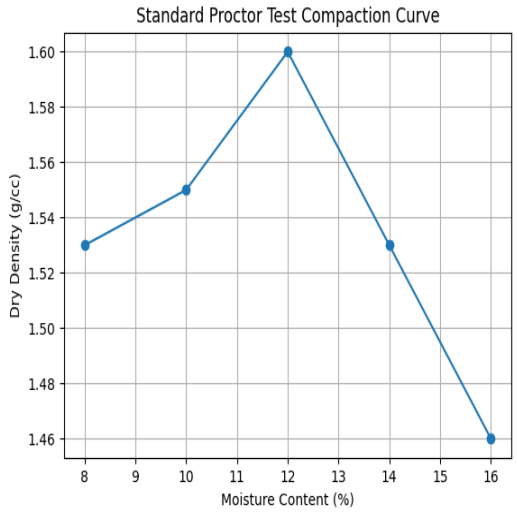

Fig: 3 OMC and MDD of soil sample.

Compaction curve data: From the compaction data, the inter-relationship between the moisture content and dry density of soils can be ascertained. With increase in moisture content of 8 to 12 the dry density also rises, by 1.53 to 1.60 g/cc. This is because with a little water, the soil particles are closer together and thus denser. The highest value of dry density is 1.60 g/cc and this is called as Optimum Moisture Content (OMC). Beyond this, that is at moisture content of 14 percent and 16 percent, the dry density decreases. This is because excess water is present in the space between particles that reduces compaction. So, the best moisture content for soil to be compacted is 12%.

Table- 3 Data of OMC and MDD

Moisture Content(%)	Dry Density(g/cc)
8	1.53
10	1.55
12	1.60 (Peak)
14	1.53
16	1.46

Result-

- Optimum Moisture Content (OMC) = **12%**.
- Maximum Dry Density (MDD) = **1.60 g/cc.**

2.4 Direct Shear Test (Main experimental)

The main experimental test used in this study was the direct shear test, which was used to examine the characteristics of shear strength of reinforced and unreinforced soil.

The test was performed under different normal stresses:

- 0.5 kg/cm^2
- 1.0 kg/cm^2
- 1.5 kg/cm^2

Pine needles of varying lengths were mixed with soil samples, and shear strength parameters were evaluated.

Fig: 4 Direct shear apparatus

2.5 Shear Strength Results:

(1) Unreinforced Soil

Normal stress (kg/cm2)	Peak Shear Stress (kg/cm2)
0.5	0.38
1.0	0.69
1.5	1.19

(2) Soil Reinforced with 1 cm Pine Needles

Normal Stress	Shear Stress
0.5	0.46
1.0	0.77
1.5	1.28

(3) Soil Reinforced with 1.5 cm Pine Needles

Normal stress	Shear stress
0.5	0.52
1.0	0.83
1.5	1.35

(4) Soil Reinforced with 2 cm Pine Needles

Normal stress	Shear stress
0.5	0.58
1.0	0.90
1.5	1.42

(5) Soil Reinforced with Full Length Pine Needles

Normal stress	Shear stress
0.5	0.85
1.0	1.70
1.5	2.60

2.5 Comparison of Shear Strength Values:

Table 4 shows the differences in shear strength for different normal stresses and displacement (1 cm, 1.5 cm, 2 cm). In all the cases, the value of shear strength also increases with the variation of normal stress from 0.5 to 1.5. This means that the soil becomes strongest as the load is increased. As for the shear strength, it is also greater with every normal stress applied at both 1 cm and 1.5 cm and 2 cm. As an illustration, the value at 0.5 normal stress increases by 0.38 to 0.58 and at 1.5 normal stress, it increases by 1.19 to 1.42. This illustrates that the higher the amount of soil movement before failure, the higher the resistance of the soil. From the overall information in the table, it can be seen that when the load is increased and the soil is displaced, the shear strength of the soil increases; this indicates the steady behaviour of the soil.

Table- 4

Normal Stress	Soil	1 cm	1.5 cm	2 cm
0.5	0.38	0.46	0.52	0.58
1.0	0.69	0.77	0.83	0.90
1.5	1.19	1.28	1.35	1.42

It is seen that the shear strength is enhanced due to addition of pine needles. The shear strength is greater for all levels of normal stress for reinforced samples. The enhancement is higher for longer fibres.

3. COMPARISON AND RESULTS OF SHEAR STRENGTH:

3.1 Comparison of Material Behaviour:

Material	Strength Level	Behavior
Soil (Sand)	High	Dense, Frictional
Pine Needle 1 cm	Very Low	Poor interlocking
Pine needle 1.5 cm	Low- Medium	Moderate interlocking
Pine needle 2 cm	Medium	Better fiber interaction
Full Length	Very high	Max. reinforcement

3.2 Graphical Comparison

Test data is used to get graphical comparison to show the relation between normal stress and shear stress in a visual way. The normal stress is plotted in the X-axis and the peak shear stress on the Y-axis in this study. The points plotted follow a straight line trend that is increasing, suggesting that the shear strength also increases with an increase in the normal stress. This is a straight line that signifies the behaviour of shear strength of the soil and which is based on Mohr-Coulomb Failure Criterion.

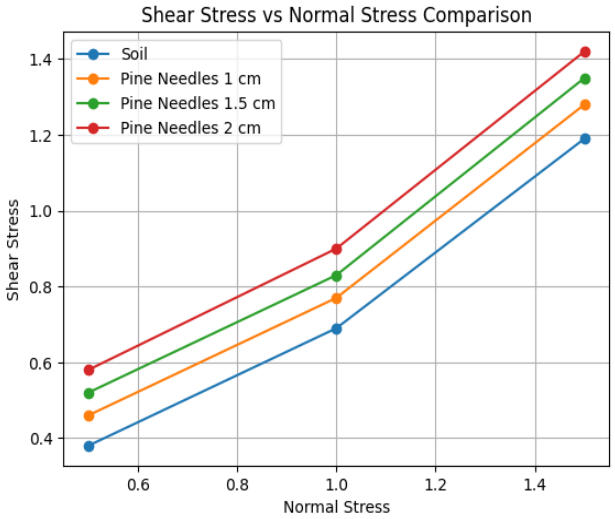

Fig:5 Shear of Unreinforced soil and reinforced soil with 1, 1.5 and 2cm pine needles.

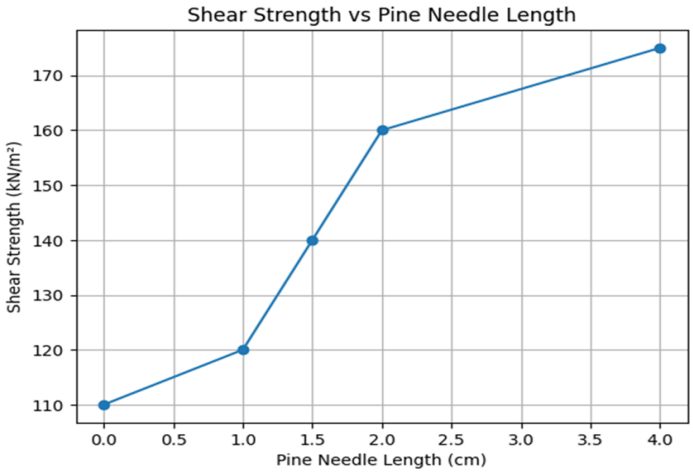

Fig: 6 Shear strength of all pine needles.

1. Increase in length of pine needle leads to increase in shear strength.
2. The increase is not linear (at first it increases slowly, then fast).
3. Optimum strength is at full-length (~4 cm).

This confirms:

- Better interlocking.
- Higher frictional resistance.
- Enhanced soil reinforcing action.

Shear stress versus normal stress plot for reinforced and unreinforced samples shows a linear relationship. But the slope is greater for the reinforced samples, showing that the shear strength parameters have been improved.

4. CONCLUSION

The present research was undertaken to investigate the performance of pine needles as a reinforcement material to enhance the shear strength of shallow soil. From the experimental studies, such as direct shear testing, index property testing and comparative analysis, the following conclusions are made:

1. Soil Characteristics:
The main experimental test used in this study was the direct shear test, which was used to examine the characteristics of shear strength of reinforced and unreinforced soil.

2. Influence of Pine Needles:
Shear strength of soil was affected by the addition of pine needles. Following observations were made:

• Shear strength is observed to increase as the normal stress increases.
• It was found that shear strength of the reinforced samples was higher than that of the unreinforced soil sample.

3. Effect of Fibre length: Pine needle length is an important factor in the reinforcement of soil:

• 1 cm: Limited improvement due to poor interlocking.
• 1.5 cm length: Average improvement with improved interaction.
• 2 cm length: Better improvement due to better interlocking and friction.
• Full-length (~4 cm): Optimum shear strength and mixed properly.

4. Shear Strength Improvement: The research suggests a gradual improvement in shear strength with increasing fibre length. The improvement in shear strength with full-length pine needles was in the range of 65-80% when compared with the soil alone, which shows the effectiveness of pine needles as reinforcing material.

5. Soil vs Pine Needles:

• Soil alone has greater strength due to high packing.
• Pine needles alone are weak due to high compressibility.
• But soil + pine needles exhibits highest strength.

6. Environmental Significance: The use of pine needles helps in:

• Reducing forest waste.
• Minimizing fire hazards.
• Encouraging green building.

5. REFERENCES

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