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Stabilisation of Karewa Soil Using Pine Needles and Cement:An Experimental Study with Statistical Regression Analysis

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Abstract

Karewas are unique but problematic soils in the Kashmir Valley, consisting of sand, silt, clay, and loessic sediment, with low shear strength and susceptibility to disturbances. This study investigates stabilising Karewa soils using pine needles and Ordinary Portland Cement (OPC).

Pine needles from Dabjan Shopian, Kashmir, were cut into 1 cm and 2 cm lengths, and OPC was added. Karewa soil samples were analysed for water content, plastic and liquid limits, specific gravity, optimum moisture content, maximum dry density, and soaked CBR.

Laboratory tests involved adding varying proportions of pine needles (0.5%, 1%, 1.5%, and 2%) and a constant cement content (0.5% by dry weight). These tests revealed that pine needles and cement significantly improved the soil's compaction and strength.

Multiple linear regression analysis showed that 56.3% of the variability in CBR could be explained by the predictors, with a significant positive relationship between the percentage of pine needles and CBR.

This study demonstrates that pine needles and cement can enhance Karewa soil's strength and stability, offering a sustainable solution for soil stabilisation in the Kashmir Valley.

Keywords: Karewa Soil; Soil Stabilization; Pine Needles; Regression Analysis

1.Introduction

Karewas are unique soil formations in the Kashmir Valley, appearing as low mounds or elevated plateaus. A variety of elements, such as clay, silt, sand, shale, mud, lignite, crushed stone, and loessic sediment, make up their composition. Nestled inside the Pir Panjal range to the south and an offshoot of the central axis mountains to the north, they cover over half of the valley's area, add to its picturesque attractiveness, and are essential to the ecosystem of the area.[1]

Karewa soils have problematic engineering traits, notably low shear strength when wet and

susceptible to physical disturbance [2]. They display plasticity and compressibility, swelling when moist and shrinking upon drying. Over time, under sustained loads, they may undergo creep, especially when near their shear strength, increasing the risk of sliding [3]. These soils also exert significant lateral pressures and have low values for their resilient modulus. Deformation of these soft sediments is chiefly influenced by their shear strength, which varies with the plastic and liquid limits. These limits are determined by the water content thresholds of fine-grained sediments in a remoulded state [4]. Bhat et al. (2016) investigate seismites in the Karewa basin of Kashmir, identifying various soft sediment deformation structures believed to result from seismic activity. These structures, found in Plio-Pleistocene Karewa Formation deposits, indicate past seismic events through distinctive characteristics and deformation patterns [5]. Because of progressive failure mechanisms, Karewa soils are susceptible to landslides and slope failures, which frequently occur at shear stress levels far lower than peak strength. This phenomenon is linked to uneven distribution of stress throughout the failure surface and the soil's tendency to soften under strain. Over recent years, the incidence of slope failures has notably risen compared to other natural disasters [6]

A terrible landslide in March 2015 killed sixteen people from two families in Laden village, Badgam district, Kashmir Valley, while they were asleep. 44 dwellings in the Budgam neighbourhood of Chare-sharief were destroyed and many more were damaged in similar occurrences. According to a state government investigation, the landslip was caused by the lower Karewa formation's instability, namely the presence of plastic clay. This unconfined layer of clay served as a lubricating surface, allowing slippage and sliding, which resulted in the catastrophic events [7]. Karewas are presently being excavated for construction purposes. Between 1995 and 2005, extensive areas of Karewas in Pulwama, Budgam, and Baramulla districts were cleared to extract clay for the construction of the 125 km long Qazigund-Baramulla rail line. (LotusArise March 2022). Thus, strengthening and stabilising Karewa soils is imperative to mitigate the imminent threat they pose to life and property in their vicinity. By binding soil particles together or changing the moisture content of the soil, soil stabilisation seeks to increase the strength and resistance of the soil to softening [8]. The kind of soil, the planned construction method, and the accessibility of building supplies are the main factors that influence the stabiliser selection for a given site[9]. In construction, improving the geotechnical properties of soil is essential to enhance its stability [10-11].Enhancing the geotechnical properties of soil is crucial for ensuring structural stability and durability[12-13]. Numerous researchers have studied methods to stabilise Karewa soil. The application of tyre shreds to improve the strength characteristics of Karewa soils was studied by Sumira Farooq and Kumar (2022), who found that the number of shredded tyres rose steadily and improved the soil's CBR values [14]. Brooks et al. (2009) demonstrated that increasing rice husk ash content improved soil stabilisation, enhancing CBR, UCS, and reducing swell, while higher fly ash concentrations enhanced restricted compressive strength's stress-strain behaviour[15].By adding natural fibres and chemical binders to soil, there are significant improvements in shear strength and axial strain to failure as well as a change in stress-strain behaviour from strain softening to strain hardening. It was observed that short natural fibre soil composites have gained heightened recognition within geotechnical engineering, marking them as a relatively recent advancement in geotechnical project [16]. By addition of fibres there is enhancement in shear strength, ductility, and failure strain. These improvements were attributed to several factors: enhanced cohesion within the soil-fibre matrix, increased friction between the soil and fibres, the tensile strength of the fibres themselves, and their ability to sustain large strains within cracks, collectively contributing to the observed property enhancements[17].The study investigated the use of HDPE strips to reinforce soil, demonstrating substantial enhancement in soil strength via CBR tests, particularly advantageous for highway infrastructure[18].

It is common practice to use cement for soil stabilisation in order to improve the properties of poor soils and provide a solid base for building projects[19].While a large proportion of cement significantly alters the qualities of poor soils, a low percentage of cement improves the physical properties of soil[20].Cement stabilisation is preferred for granular soils and clay soils with low Plasticity Index, according to several research [21].

Pine needles, abundantly available as scrap material, are utilised due to their cost-effectiveness and easy accessibility. The potential of natural pine needle fibre (PNF) is being explored due to its abundance and associated disposal challenges [22]. Environmental factors are the driving force behind the use of pine needles for soil stabilisation; experiments show decreased OMC, MDD, and soaking CBR values along with increased internal friction angle and cohesiveness, which are especially prominent at higher aspect ratios [23]. Kandel, Ashish, et al. (2020) looked into the effects of adding locally accessible pine needles in various ratios to the dry weight of the clayey, soft soil. The shorter pine needle fibres in the soil matrix were stronger than the longer ones, according to their findings. This study provides important insights for sustainable building practices by highlighting the potential of pine needles as a workable and environmentally friendly soil stabilisation option in areas with soft clayey soil [24].

The effects of adding various amounts of ordinary Portland cement (OPC) and pine needles to Karewa soil are examined in this research. At Optimum Moisture Content (OMC), various combinations of pine needles (both 1 cm and 2 cm lengths) and cement (0.5% by dry weight) are added to the soil samples.

2.Materials Used for Research

The following items were used in this investigation and put through laboratory testing in compliance with accepted codal norms.

i) Pine Needles:

Figure 1: Different sizes of dried pine needles

Pine needles were gathered from Dabjan Shopian Kashmir's nearby forest. After the pine needles were removed, the fibres were cut into 1- to 2-cm lengths. Table 1 lists the attributes of pine needles.

Table 1: Physical Properties of Pine Needles

S.No.	Property	Value
1.	Length	1 cm and 2 cm
2.	Diameter	0.1 to 0.2 cm
3.	Nature	Dried
4.	Colour	Light Brown

ii) Cement:

An ordinary Portland cement, readily available in the market, was employed as an additive in the study. Table 2 lists cement's characteristics

Table 2: Properties of Cement

S.No.	Property	Value
1.	Compressive Strength	43MPa
2.	Standard Consistency	32%

3.	Fineness Value	3%

ii) Karewa Soil

Figure 2: Collected soil sample of Karewa Soil

The Kashmir valley's Shopian Karewas provided the soil samples, which were meticulously collected while being kept as homogeneous as possible. Table 3 provides the Karewa Soil's characteristics.

Table 3: Properties of Karewa Soil

S.No.	Property	Value
1.	Colour	Brown
2.	Natural Moisture Content	21%
3.	Specific Gravity	2.5
4.	Liquid Limit (%)	31
5	Plastic Limit (%)	25
6.	Plasticity Index	6
7	Classification	ML
8.	Optimum Moisture Content (%)	18.7
9	Maximum Dry density (g/cc)	1.83
10.	Soaked CBR	5.17

3.Methodology

3.1 Experimental Part

Soil samples from Karewa soil in Shopian, Kashmir Valley were air-dried, sieved, and mixed uniformly. Tests included gradation analysis, specific gravity determination, and consistency limits evaluation per standard procedures [25, 26]. Locally sourced pine needles (1 cm and 2 cm lengths) and high-quality cement (0.5% by dry weight) were prepared. Different combinations of pine needles (0% to 2%) and constant cement were added to soil samples for stabilisation. After being subjected to Proctor compaction tests to determine their maximum dry density and ideal moisture content, the samples were subjected to California Bearing Ratio (CBR) tests. [27, 28] to assess load-bearing capacity and soil stability. Data analysis of compaction and CBR results evaluated the impact of pine needle proportions on soil properties.

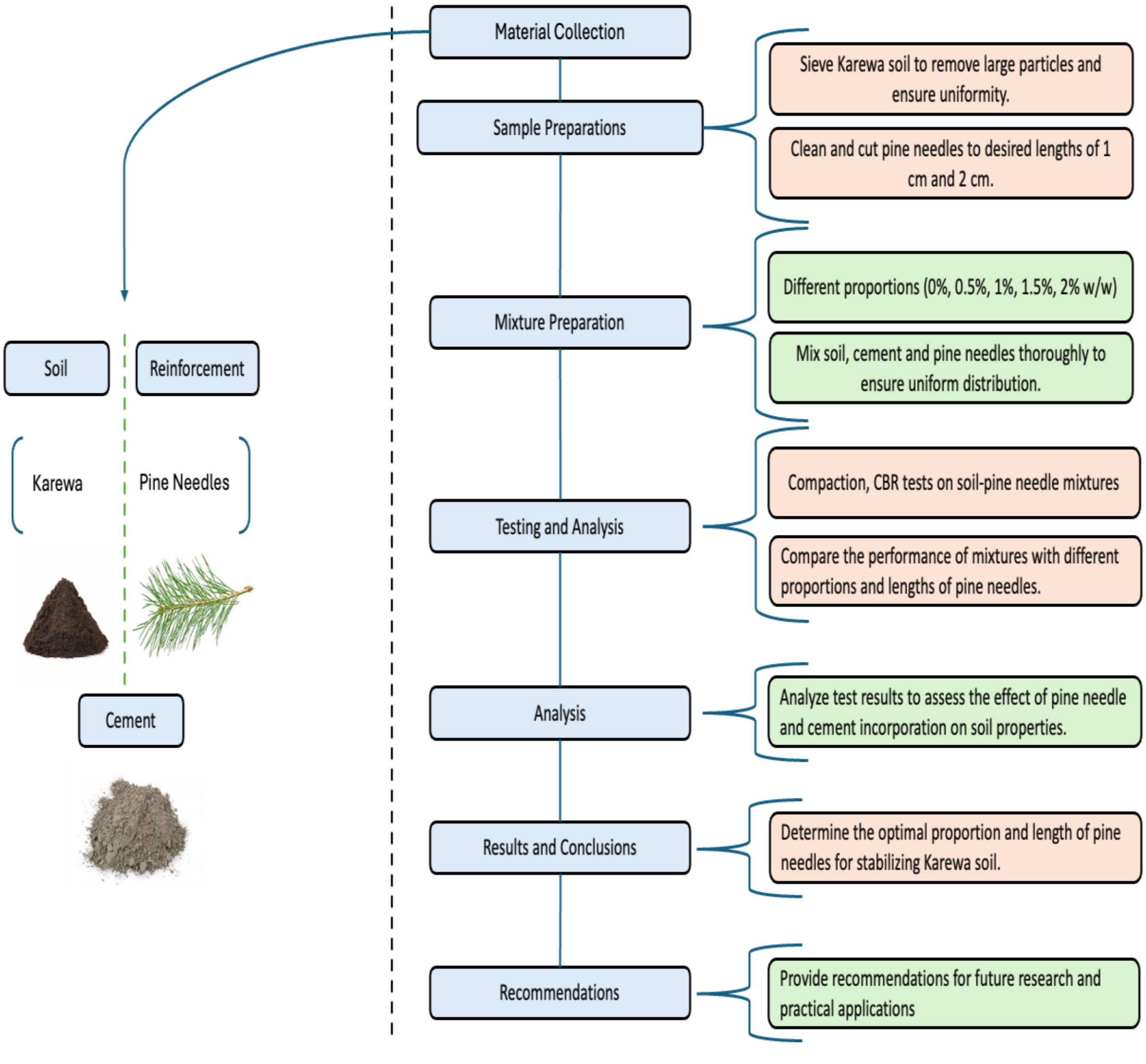

Figure 3 : Methodology for Experimental Part

3.2 Modelling Part

Experimental data collected includes independent variables (e.g., pine needle and cement proportions) and dependent variables (e.g., compaction and CBR results). Multiple linear regression analyses these relationships, estimating how each independent variable affects the dependent ones. Metrics like p-values, adjusted R-squared, and R-squared assess the significance and accuracy of the model. Interpretation of regression coefficients shows the strength and direction of these relationships. This combined experimental and modelling approach enhances understanding of pine needles and cement as stabilisers for Karewa soil, helping to identify optimal proportions and encourage sustainable construction practices.

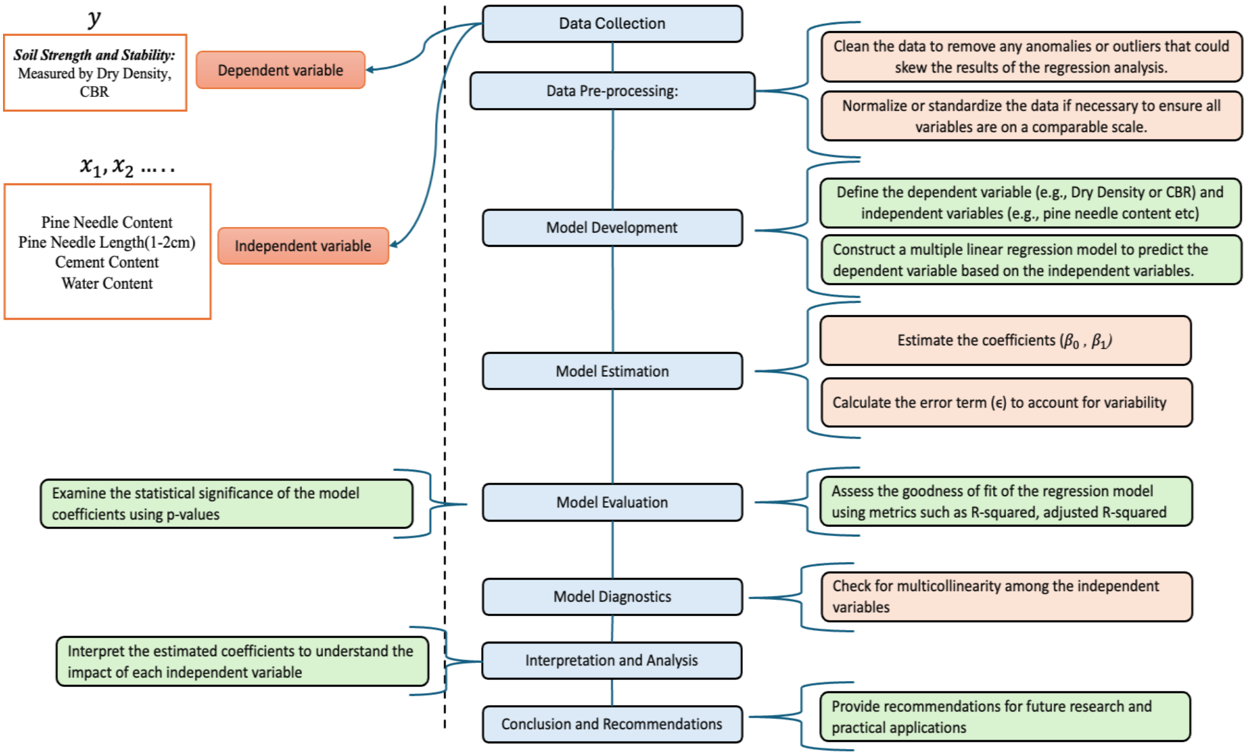

Figure 4: Methodology for Modelling Part

4. Results and Discussions

4.1 Properties of untreated Karewa Soil: Figure 5 displays the particle size distribution curve of untreated Karewa soil. The distribution of different sized particles inside the soil mass is shown by the gradation curve, which clarifies the soil's composition, which is predominantly silt with a small amount of clay. According to conventional testing protocols, Atterberg limit tests were carried out [29], yielding a plastic limit of 25% and a liquid limit of 31%. Karewa soil has been classed as clayey silt with poor flexibility by the Indian System of Soil Classification (ISC)[26].

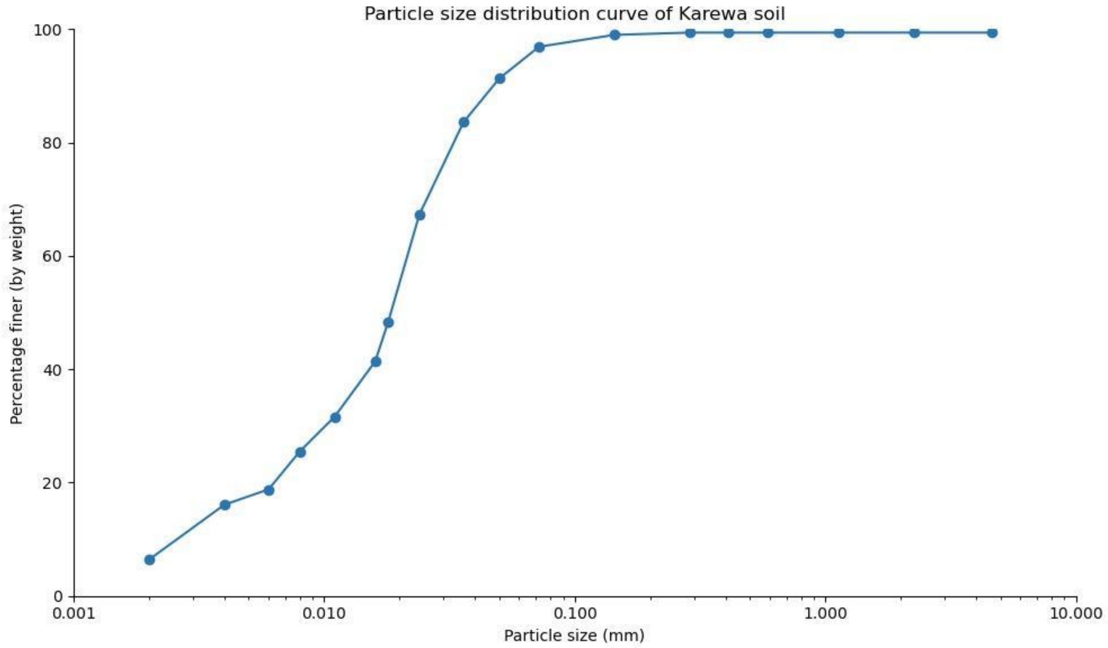

Figure 5: Particle size distribution of untreated Karewa Soil

Figure 6 illustrates how the typical Proctor compaction test method [27] was used to create the compaction curves for Karewa soil. The findings show that an ideal moisture content is 18.7% and a maximum dry unit weight of 1.83 g/cc.

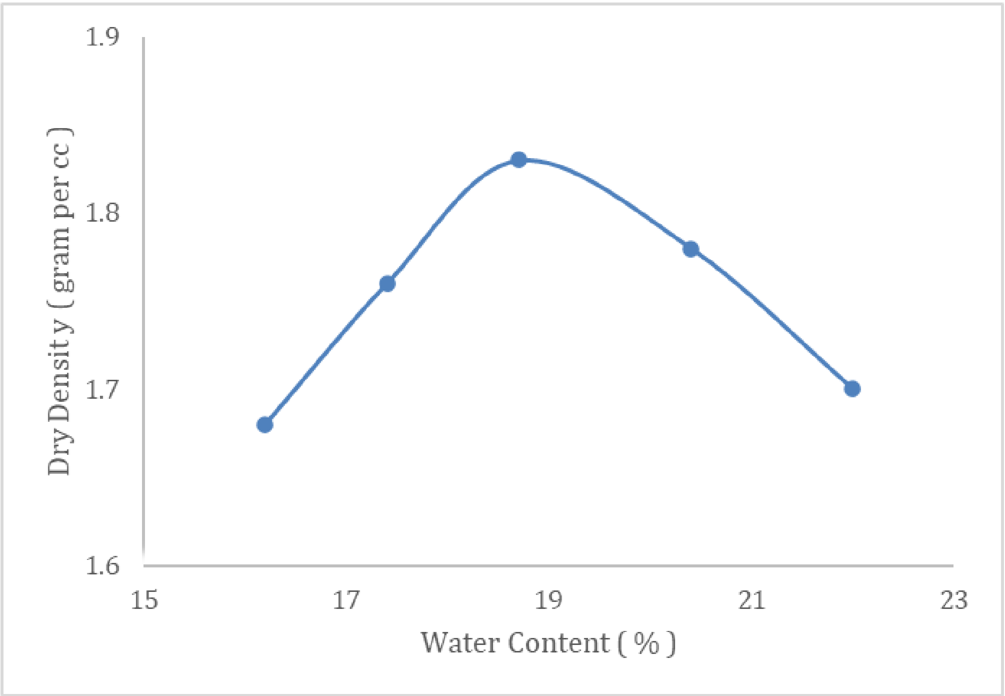

Figure 6: Compaction Curve Of untreated Karewa Soil

Tests for California Bearing Ratios (CBRs) were performed in compliance with established codal protocols. [28]. The soaked CBR of untreated soil was found to be 5.1%. The load penetration curve is shown in figure 7.

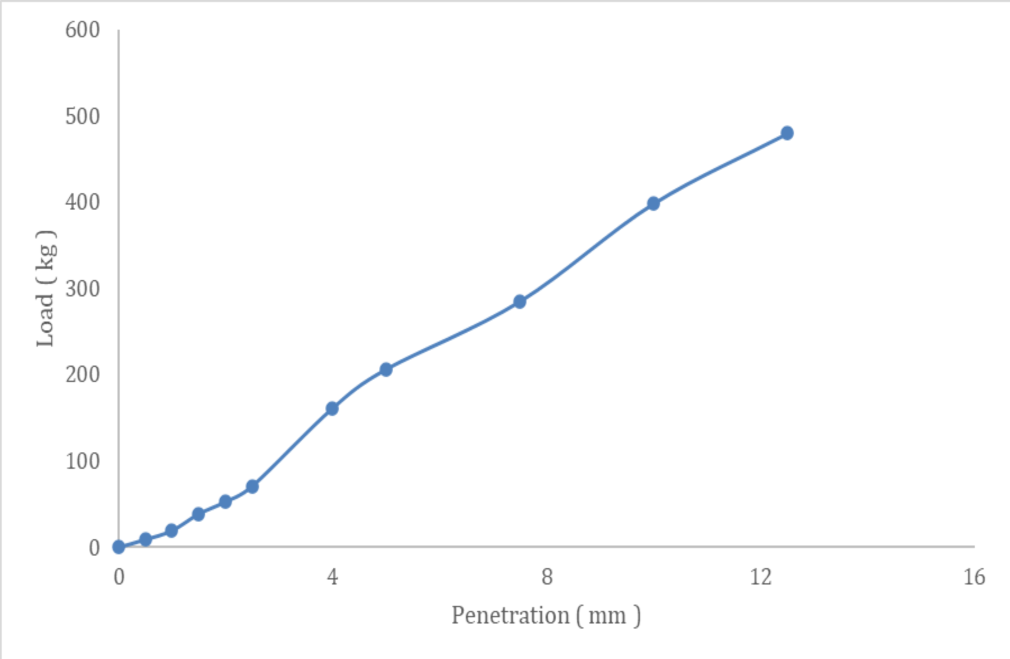

Figure 7: Load Penetration Curve of untreated Karewa Soil

4.2 Properties of Karewa Soil Stabilised by Pine Needles and Cement

4.2.1 Effect of Pine Needles on Compaction Characteristics

By forcing air out of a material's voids, particles are packed closely together during the compaction process. The amount and type of energy used, along with the properties of the material (particle size, distribution, shape, plasticity, and moisture content) all have an impact on the final compacted unit weight[30]. In order to find out how the presence of pine needles and cement affected the soil's maximum dry density (MDD) and optimal moisture content (OMC), we performed a Standard Proctor compaction test in this investigation.Figure 8 displays the compaction curve that was achieved by adding only 1 cm and 2 cm lengths of pine needles at a rate of 0.5% of the dry weight of soil. A decrease in the maximum dry density and a rise in the soil's ideal moisture content are shown by the graph. The impact appears more pronounced when using 2cm needles, indicating a greater variation in results compared to the 1cm needles. Researcher Kandel, Ashish, et al[24] has also found the same trend that the shorter pine needle fibres in the soil matrix were stronger than the longer ones.

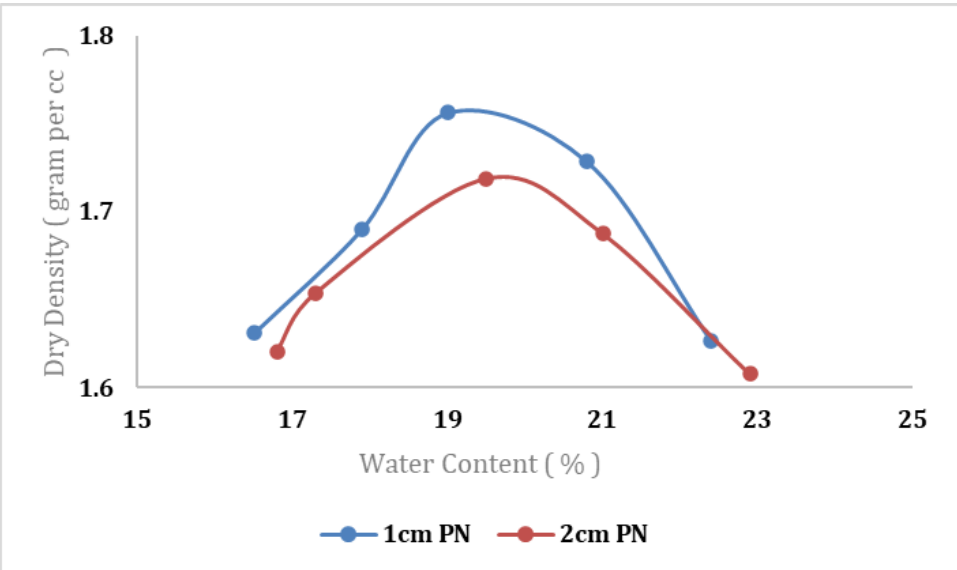

Figure 8: Compaction curves of Karewa Soil treated by Pine Needles

4.2.2 Effect of Pine Needles and cement on Compaction Characteristics

The compaction curve presented in the figure 9 shows the effect of incorporating pine needles, each measuring 1 cm in length, at a rate of 0.5% by weight of dry soil, alongside a consistent cement content (0.5% of dry weight of soil), on Karewa soil. The plot demonstrates a notable enhancement in dry density from 1.83g/cc to 1.89g/cc, accompanied by a reduction in moisture content from 18.7% to 18.2%. When one increases the percentage of pine needles to 1%, 1.5%, and 2% while keeping the cement content constant, a pattern becomes apparent: the soil's ideal moisture content rises, and its dry density consistently decreases. The 2019 study by Obaid Qadir Jan and Sandeep Raj focuses on using Ordinary Portland Cement (OPC) to stabilise Karewa soils, which are noted for having a high compressibility and low shear strength. According to the findings, adding more OPC reduced plasticity, enhanced volume stability, raised maximum dry unit weight, lowered optimal moisture content (OMC), and raised UCS and CBR[31].

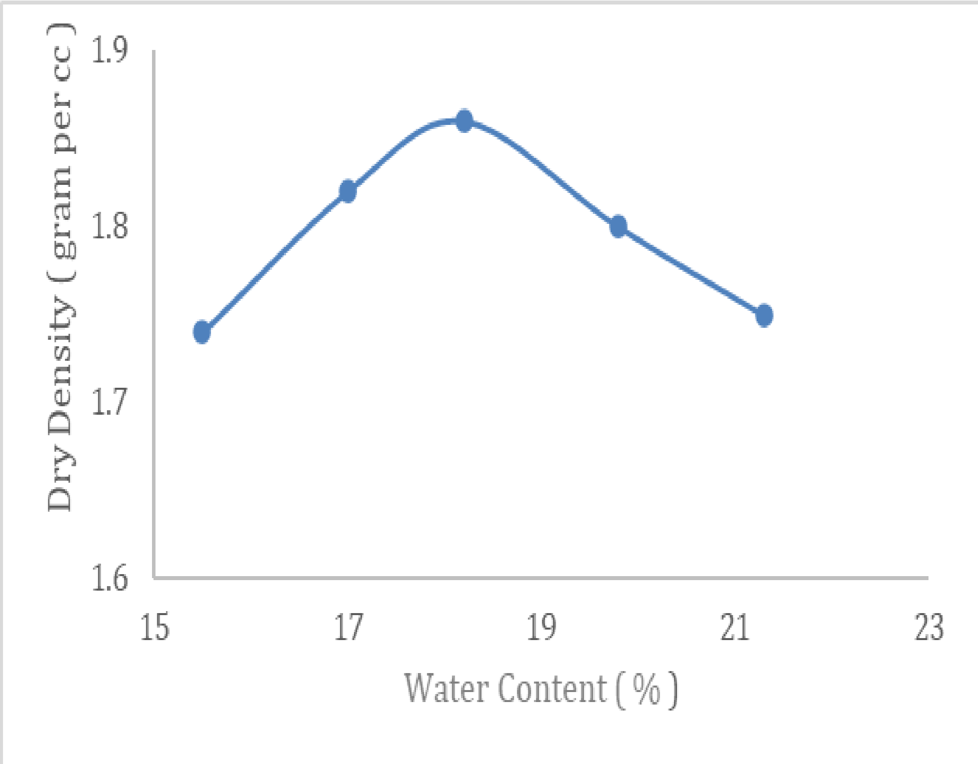

Figure 9: Compaction curve of karewa soil treated by pine needles (0.5%) and cement (0.5%)

4.2.3 Variation of Maximum Dry Density and Optimum Moisture Content with pine needles and cement.

Figure 10 and 11 shows variation of MDD and OPC by increasing the percentage of Pine Needles at constant percentage of cement (0.5%). The decline in dry density due to introduction of pine needles into the karewa soil matrix is because pine needles alter its composition, disrupting the packing of soil particles, being fibrous and relatively bulky compared to soil particles, creating void spaces within the soil structure, reducing its overall density. The moisture-absorbing properties of pine needles influence the soil's moisture characteristics. Pine needles add to the soil mixture's overall moisture content as they take in moisture. Numerous other researchers have noted a similar trend, where an increase in pine needles is associated with a drop in maximum dry unit weight and an increase in OMC. Pine needles were discovered to increase the Optimum Moisture Content (OMC) and decrease the Maximum Dry Density (MDD) by Anshu and Palpi Boruah [32]. The strength of the treated soil did not decrease in comparison to the untreated soil, even though the MDD did.

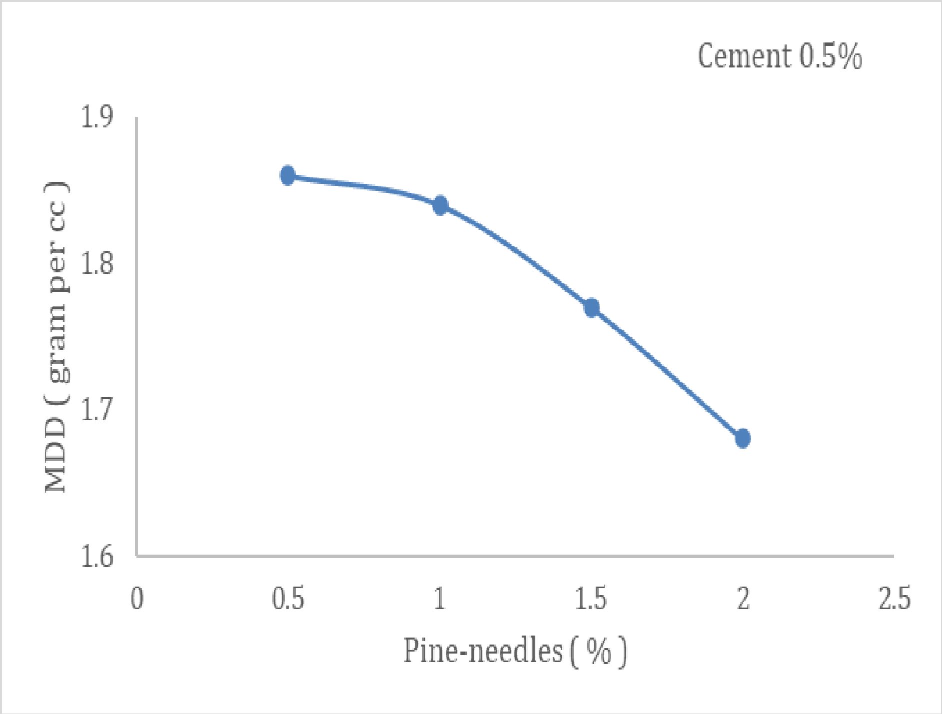

Figure 10: Variation of MDD with %age of Pine Needles

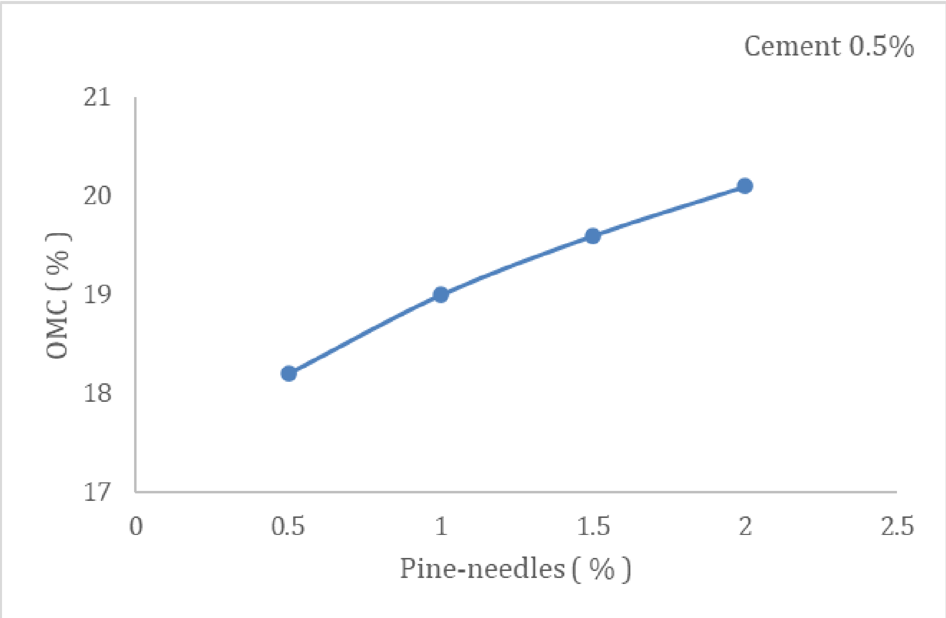

Figure 11: Variation of OMC with %age of Pine Needles

4.2.4 Effect of Pine Needles and Cement on Strength characteristics

Adding pine needles to Karewa soil resulted in a slight increase in the CBR (California Bearing Ratio) value, from 5.17% for the unreinforced soil to 6.49% with the addition of 1.5% pine needles and 0.5% cement. However, further increasing the pine needle content to 2% resulted in a decrease in CBR to 5.93% as shown in figure 12. This suggests that the optimal percentage of pine needles for improving CBR is 1.5% by weight of the soil. Other researchers, such as Ahmed, Parkash, and Vishal Kumar (2017), investigated the stabilisation of clayey soil using pine needles and calcium chloride, resulting in enhanced Maximum Dry Density (MDD) and CBR values that are appropriate for a variety of applications [33]. Research by Carlos, David Miranda, et al. (2024) has investigated the possibility of improving unpaved forest roads by pine needles, to reinforce fine soil. The inclusion of pine needles improved CBR values, according to the results. Specimens reinforced with 1% natural fibres showed the greatest improvement, with a 45% rise [34].

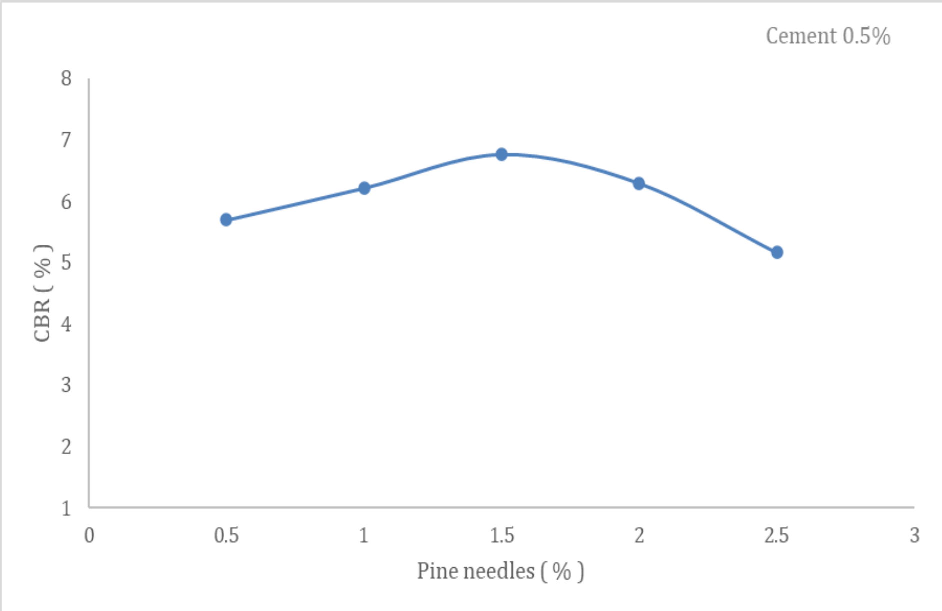

Figure 12: Variation of CBR with %age of pine-needles

4.3 Results of OLS Regression Modelling

4.3.1 Modelling of Dry Density

```
                            OLS Regression Results
==============================================================================
Dep. Variable:            Dry_Density   R-squared:                       0.578
Model:                            OLS   Adj. R-squared:                  0.485
Method:                 Least Squares   F-statistic:                     6.174
Date:                Mon, 27 May 2024   Prob (F-statistic):            0.00261
Time:                        02:22:11   Log-Likelihood:                 37.001
No. Observations:                  23   AIC:                            -64.00
Df Residuals:                      18   BIC:                            -58.32
Df Model:                           4
Covariance Type:            nonrobust
==========================================================================================
                             coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------------
const                      1.7450      0.111     15.687      0.000       1.511       1.979
Water_Content              0.0005      0.006      0.080      0.937      -0.012       0.013
Percentage_Pine_Needles   -0.0652      0.035     -1.880      0.076      -0.138       0.008
Percentage_Cement          0.2452      0.062      3.976      0.001       0.116       0.375
Length_Pine_Needle        -0.0324      0.019     -1.680      0.110      -0.073       0.008
==============================================================================
Omnibus:                        5.493   Durbin-Watson:                   1.624
Prob(Omnibus):                  0.064   Jarque-Bera (JB):                1.687
Skew:                           0.067   Prob(JB):                        0.430
Kurtosis:                       1.680   Cond. No.                         191.
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

The Ordinary Least Squares (OLS) regression analysis was conducted to investigate the factors influencing the dry density of Karewa soil, which was mixed with varying percentages and sizes of pine needles, as well as different proportions of cement and water. The dependent variable in this model is Dry_Density, and the predictors include Water_Content, Percentage_Pine_Needles, Percentage_Cement, and Length_Pine_Needle. The model was fitted using data from 23 observations.

Approximately 57.8% of the variability in dry density can be explained by the predictors included in the model, according to the R-squared value of 0.578. This points to a somewhat strong explanatory capacity. The model's adjusted R-squared value, which takes into consideration the number of predictors, is somewhat lower at 0.485, indicating that some explanatory power is lost when the model's complexity is taken into account.

Percentage_Cement emerges as a significant predictor of dry density with a p-value of 0.001. The positive coefficient (0.2452) suggests that increasing the percentage of cement in the composite material leads to an increase in dry density. This makes intuitive sense as cement is a dense material that contributes to the overall density of the composite.

Percentage_Pine_Needles has a negative coefficient (-0.0652) and a p-value of 0.076, indicating a marginal significance. This implies that a higher percentage of pine needles might decrease the dry density, though this relationship is not statistically significant at the conventional 0.05 level. Because pine needles are fibrous and light, their proportion decreases total density, which is the cause of the negative effect.

Length_Pine_Needle also has a negative coefficient (-0.0324) and a p-value of 0.110. Although not statistically significant, this result suggests that longer pine needles might slightly reduce the dry density. This could be due to the structural characteristics of longer fibres, which may lead to less compact and denser composite structures.

Water_Content has a coefficient close to zero (0.0005) and a high p-value (0.937), indicating that it does not significantly affect dry density. This might be because the water content does not vary enough within the tested range to influence the density noticeably, or its effect is overshadowed by the other more dominant factors in the model.

The diagnostic tests indicate that the model's assumptions are reasonably met, with the Omnibus Test p-value of 0.064 suggesting minor deviations from normality, the Durbin-Watson statistic of 1.624 showing no strong evidence of autocorrelation, and the Jarque-Bera Test p-value of 0.430 further supporting residual normality. These results provide additional insights into the model's validity.

The marginal significance of the percentage of pine needles suggests a potential trade-off between incorporating lightweight natural fibres and achieving higher density. While the data indicates a trend that increasing pine needle content reduces density, further investigation with larger sample sizes or additional variables might be necessary to confirm this relationship.

The length of pine needles, although not statistically significant, shows a tendency towards reducing dry density, hinting at the structural influence of fibre length on material compaction.

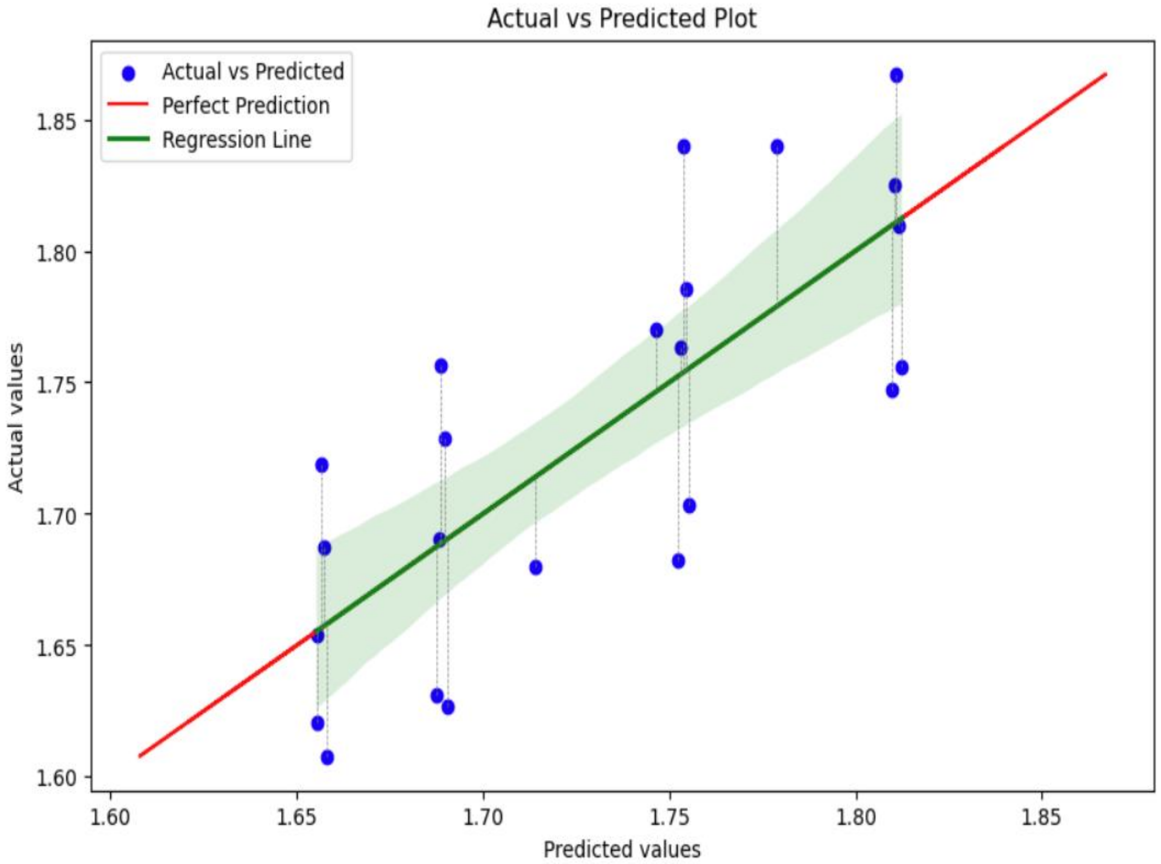

Figure 13: Comparison of Actual vs. Predicted Values from OLS Model of Dry Density

The actual versus predicted plot provides a visual assessment of the regression model's performance in predicting dry density. The green regression line represents the model's best fit through the predicted values, while the red line indicates perfect prediction where the actual values would exactly match the predicted values.

In this plot, the majority of data points are positioned close to the red line, indicating that the model's predictions are generally accurate. However, some deviations from the red line are noticeable, suggesting that there are areas where the model's predictive power could be enhanced. The dispersion of points around the green regression line highlights the inherent variability in the data, underscoring the potential influence of additional factors or interactions not currently accounted for in the model. While the plot reflects a reasonably good fit, it also points to opportunities for model refinement to improve predictive accuracy.

4.3.2 Modelling of CBR

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                            OLS Regression Results
==============================================================================
Dep. Variable:                    CBR   R-squared:                       0.563
Model:                            OLS   Adj. R-squared:                  0.418
Method:                 Least Squares   F-statistic:                     3.872
Date:                Tue, 04 Jun 2024   Prob (F-statistic):             0.0832
Time:                        01:35:41   Log-Likelihood:                -2.2414
No. Observations:                   9   AIC:                             10.48
Df Residuals:                       6   BIC:                             11.07
Df Model:                           2
Covariance Type:            nonrobust
====================================================================================
                       coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------
const                5.4678      0.307     17.810      0.000       4.717       6.219
percentage_of_PN     0.5639      0.213      2.651      0.038       0.043       1.084
length_of_PN        -0.0741      0.210     -0.353      0.736      -0.587       0.439
==============================================================================
Omnibus:                        0.090   Durbin-Watson:                   1.242
Prob(Omnibus):                  0.956   Jarque-Bera (JB):                0.305
Skew:                           0.094   Prob(JB):                        0.859
Kurtosis:                       2.118   Cond. No.                         5.73
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
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The conducted analysis aimed to investigate the relationship between California Bearing Ratio (CBR) and two potential predictors: percentage of pine needles (PN) and length of pine needles. With an R-squared value of 0.563, the model's independent variables can be responsible for roughly 56.3% of the variability in CBR that has been observed. This implies a modest level of explanatory power, meaning that CBR may potentially be influenced by other factors not included in the model. After accounting for sample size and degrees of freedom, the corrected R-squared value was 0.418, indicating a somewhat reduced percentage of variation explained. The model's overall significance was assessed using the F-statistic, which produced a result of 3.872 and a p-value of 0.0832. Although this p-value suggests marginal significance at the conventional threshold of 0.05, it should be interpreted with caution, considering its proximity to the threshold.

Upon examining the coefficients estimated for the independent variables, notable insights emerge. The intercept term (const) exhibited a significant positive relationship with CBR, with an estimated coefficient of 5.4678 ($p < 0.001$). This suggests that even in the absence of the predictor variables, there exists a baseline level of CBR. The coefficient for percentage of pine needles (PN) was also found to be statistically significant, with a value of 0.5639 ($p = 0.038$). This suggests that there is a direct correlation between an increase in CBR and a rise in the percentage of pine needles. The non-significant p-value of 0.736 indicates that the length of pine needles coefficient did not demonstrate statistical significance in predicting CBR. This implies that the length of pine needles alone may not be a significant predictor of CBR. Using multiple linear regression analysis, researchers Sharma and Sharma (2023) investigated adding natural pine needle fibre (PNF) and construction demolition waste as additives to black cotton soil (BCS). They found a strong correlation between the predicted and measured Unconfined Compressive Strength (UCS) values.[21]

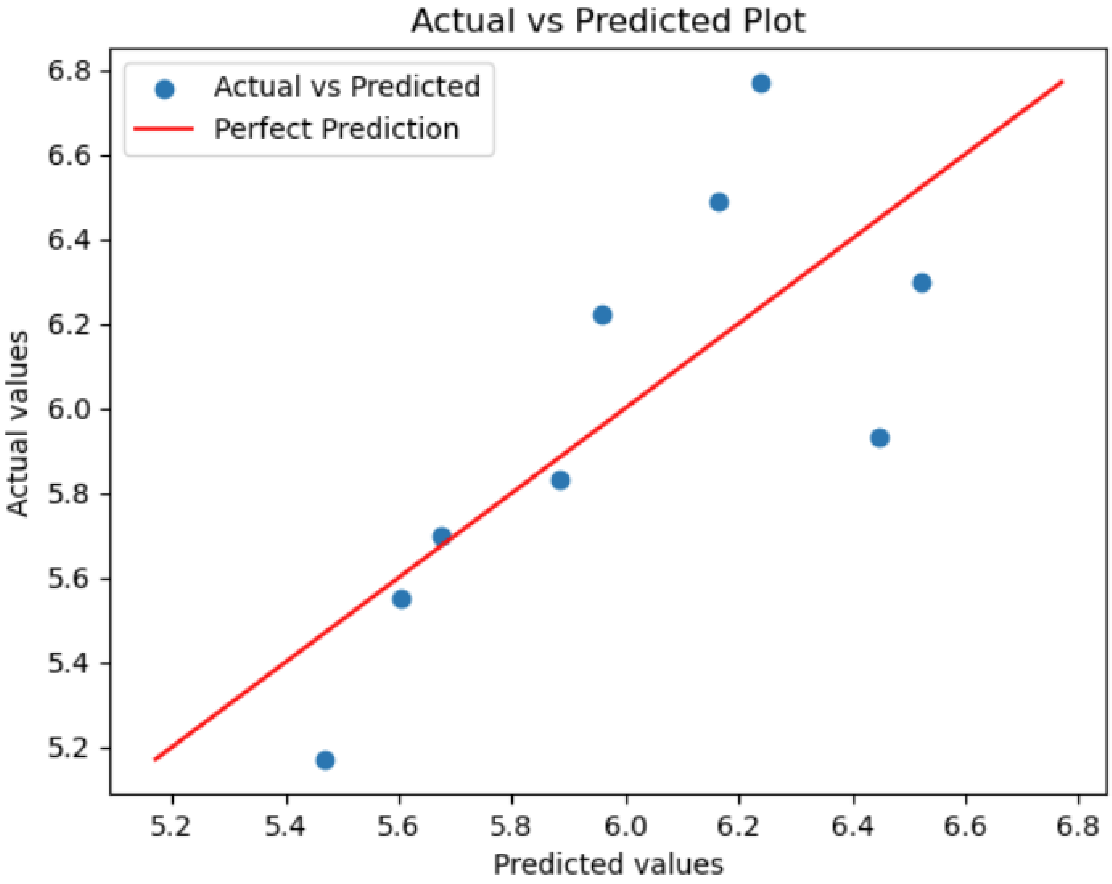

Figure 14: Comparison of Actual vs. Predicted Values from OLS Model of CBR

5. Conclusion

This study explored the stabilisation of Karewa soil using pine needles and cement. At first, the soil's optimum moisture content (OMC) was 18.7% and its maximum dry density was 1.83 g/cc. It was categorised as clayey silt with minimal plasticity. Adding pine needles (1 cm and 2 cm) at various percentages (0.5% to 2%) and 0.5% cement altered the soil's properties, decreasing dry density and increasing OMC, especially with 2 cm needles.

Regression analysis revealed that cement significantly increased dry density, while pine needles had a marginal negative effect. The CBR model indicated that pine needle percentage positively influenced CBR. The study concludes that using pine needles and cement improves Karewa soil's compaction and strength characteristics.

6. Limitations of Study

The study has several limitations. The sample size of 23 observations for the regression analysis may limit the generalizability of the results. Additionally, the research focused on a specific type of soil (Karewa) and may not apply to other soil types. The effects of varying environmental conditions and long-term durability of the treated soil were not considered. Moreover, the marginal significance of some predictors suggests that further investigation with larger sample sizes or additional variables is necessary to fully understand the relationships between the additives and soil properties.

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