Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Stabilization of Soft Soil with Pine Needles and Lime

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Abstract
This research studied the effect of addition of locally available pine needles along with a chemical binder as lime, on the compressive strength of a soft clayey soil. The pine needles were added in the parent soil corresponding to proportions of 0, 0.25%, 0.5%, 0.75% and 1% of dry weight of soil with two different lengths (1 cm and 2cm) of needles. Similarly, lime was added as 0, 2.5%, 5% and 7.5% of the dry weight of soil along with water. Altogether 216 samples of cylindrical specimens were tested after 7, 14 and 28 days for Unconfined Compressive Strength (UCS) of the modified soil. The result indicated that addition of pine needles and lime increased the compressive strength of soil by 2.13 times or 113% on average. The proportion for maximum compressive strength was found to be 2.5% of lime and 0.5% of pine needles by dry weight of soil. Also, it was found that shorter fibers in soil matrix gave greater strength than that of longer fibers.

Keywords
Soil stabilization, pine needle, lime

1. Introduction

Soil containing silt and clay particles usually have low bearing capacity, high shrinkage and swell characteristics and high moisture susceptibility. Due to these reasons, these types of soil need treatment before using them as an effective engineering material. This treatment, in one way, can be carried out through the process of soil stabilization.

Soil stabilization is a method or technique of improving the engineering properties of a weak soil like its strength, compressibility, workability, swelling potential and volume change tendencies. Reinforcing soil using randomly distributed fibers along with chemical binder is still a prominent issue nowadays and its application fields are widening. Nepal has most of the hills where pine needles are available in abundance. Pine needles are acidic in nature which makes the soil unfertile and also create the problem of water logging. Dry pine needles are the major cause of forest fires and pine needles in the Nepalese forest have not been put to any use. But the use of pine needles as natural fibers for soil stabilization due to their abundance makes its use cheaper than other fiber reinforcing measures in Nepalese context. Similarly, lime tends to act as an excellent soil stabilizing agent for highly active soils, which undergo through frequent expansion and shrinkage as in our study.

Research carried out by Hejazi, et. Al 2012 [1] found a significant improvement in shear strength, axial strain to failure, changes stress-strain behavior from strain softening to strain hardening by mixing natural fibers and chemical binders in soil. They found that fiber inclusions have economic benefits, easy to work, rapid to perform, feasible in all weather conditions. They also concluded that short natural fiber soil composites have attracted increased attention in geotechnical engineering and is still a relatively new technique in geotechnical projects. A study by Ghavami, Filho and Barbosa 1999 [2] showed that for ordinary soil, the final failure occurs immediately after the ultimate load but in case of fiber reinforced soil, the internal distribution of forces from soil matrix to fibers caused work softening that increased ductility and strength. Research by Li, Li, Wen, Xu, & Amini, 2017 [3] showed the improvement in shear strength, ductility and failure strain achieved with fiber addition. They showed that cohesion, friction between soil and fibers, tension and large strain of fiber in cracks helped to achieve such properties.

A research paper "Reaction products formed in Lime-Stabilized Marine Clay 1996" [4] showed that the strength of soil increased by 5 to 8 times on addition of lime. They concluded that cation exchange, flocculation and aggregation reaction helped to increase the strength of studied soil. Ingles and Metcalf 1972 [5] suggested lime reacted with clay minerals of soil to form a tough water-insoluble gel of calcium silicate, which cemented the soil particles and increased the strength of soil significantly.

Research by Cai, Ng, & Tang, 2006 [6] found that the fiber content, lime content and curing duration significantly increased Unconfined Compressive strength of clayey soil to a certain limit. The increase in lime content initially increased the compressive strength and then a descending trend is seen.

2. Materials and Methods

The soil used in the study resembled to a weak, soft, clayey soil and was collected from UN Park, Located at Jwagal, Lalitpur, Nepal. The index properties as per IS codes were determined as follows: -

Table 1: Index Properties

SN	Properties	Values
1	Natural Water Content	24.528%
2	Specific Gravity	2.492
3	Bulk Density	17.303 KN/m^3
4	Optimum Moisture Content(OMC)	17.6%
5	Maximum Dry Density(MDD)	18.69 KN/m^3
6	Liquid Limit	31.1159
7	Plastic Limit	23.245
8	Plasticity Index	7.8709
9	Soil Classification	CL type

The particle size distribution of the soil is as follows:

Table 2: Sieve Analysis

Gravel	%retained on 4.75mm	1.874
Sand	% between 4.75mm and 75 micron	33.235
Fines	% passing 75 micron	66.765
	% passing 425 micron	73.471

The percentage soil passing through 75 micron sieve is more than 66%, this is fine soil which consists of

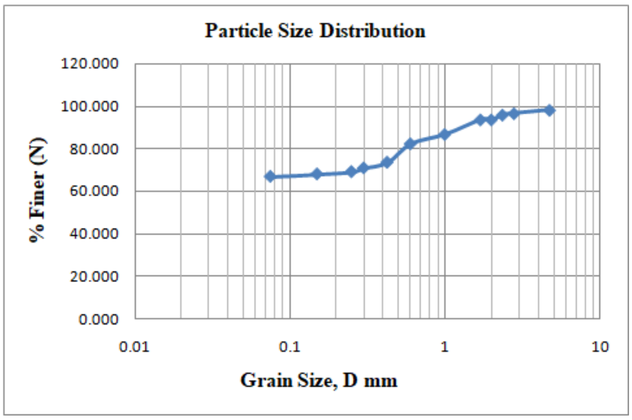

Figure 1: Wet sieve Analysis

silt and clay. Since the soil is mostly fine and the soil of this area has been categorized as soft soil in other paper [7]. We consider it as soft soil.

The reinforcing pine needles were collected from the local forest of Dakshinbarahi, Suryabinayak, Bhaktapur. Pinus Roxburghe or Chir pine (locally known as Khote Salla) was the type of pine tree found there. The leaves are needle-like, in fascicles of three, very slender, 20- 35 cm long, and dark brown when dry. The chemical binder, Lime was collected from local store of the city. The reinforcements consist of length of pine needles with aspect ratio of 20 and 40. Aspect ratio is defined as the ratio of length of fiber to the diameter of the pine needle. The diameter of the pine fibers was 0.5mm, which, with respective aspect ratios of 20 and 40 yielded a length of fiber as 1mm (short fiber) and 2mm (long fiber).

Table 3: Determination of aspect ratio

Length	Diameter	Aspect ratio	Remark
10mm	0.5mm	20	X
20mm	0.5mm	40	Y

Pine needles are cut into pieces of 1cm and 2cm and mixed in percentage of 0%, 0.25%, 0.5%, 0.75%, and 1% by dry weight of soil. Lime is mixed in the percentage of 0%, 2.5%, 5% and 7.5% by dry weight of soil after sieving through IS 425 Micrometer sieves. The parent soil is oven dried and sieved through the IS 425 Micrometer sieve and mixed with pine needles and lime at Optimum Moisture Content (OMC) with mixing of fibers at random orientation. The homogeneous mixture thus prepared is compacted by a constant force of 10kg in the cylindrical mould of Harvard Miniature Compaction Apparatus (HMCA) in three layers by blowing 25 times in each layer of

1/3 height. After the sample is prepared, it is extracted by sample extruder of Compaction Apparatus and thus obtained cylindrical specimen is wrapped in plastic bags to prevent the exposure to the environment. After 3 days, the sample is unwrapped from plastic bags and cured in natural surrounding for the respective days. Thus, prepared sample is then tested in Unconfined Compressive Strength Apparatus on their respective days and results are noted.

Figure 2: Samples kept for curing

Figure 3: A Sample after UCS test

3. Result

Unconfined compressive strength

3.1 UCS test after 7days

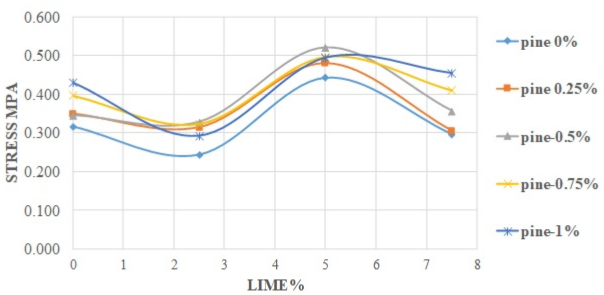

Figure 4: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio X and curing time 7 days

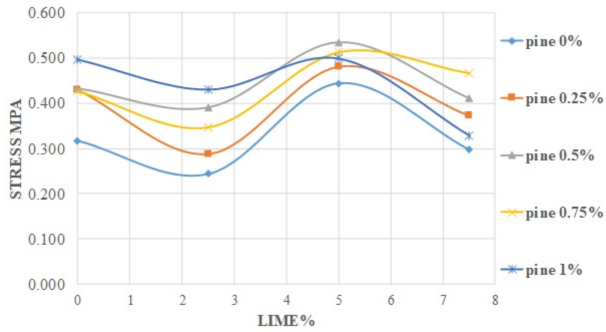

Figure 5: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio Y and curing time 7 days

3.2 UCS test after 14days

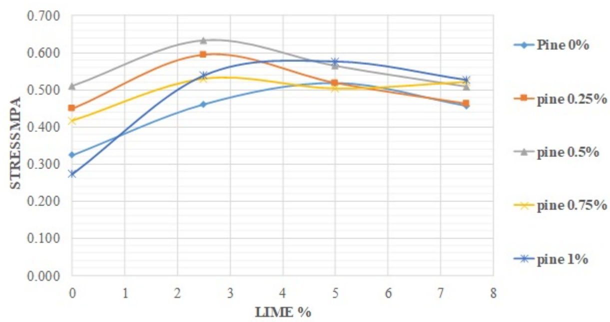

Figure 6: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio X and curing time 14 days

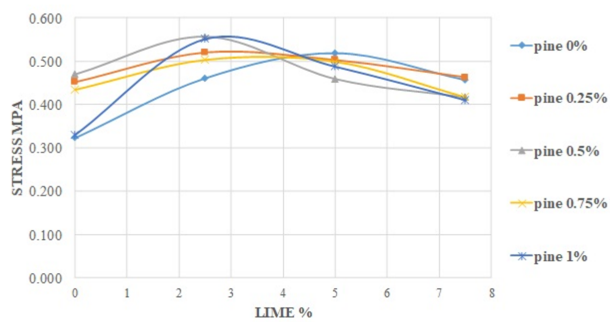

Figure 7: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio Y and curing time 14 days

3.3 UCS test after 28days

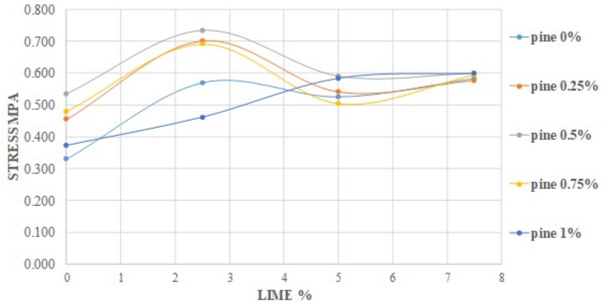

Figure 8: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio X and curing time 28 days

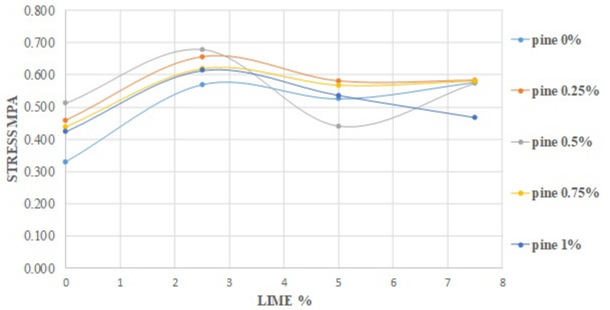

Figure 9: Plot of stress (MPa) and lime percentage in samples containing different proportion of pine with aspect ratio Y and curing time 28 days

The UCS test revealed the nature of strength of 7 days cured sample different to that of 14 and 28 days sample. The 7 day cured samples showed the UCS value at first decreased up to 2.5% lime and started increasing reaching a maximum value of UCS at 5% lime. After 5% lime, the UCS value was found to be on decreasing trend. The pine percentage for maximum UCS value was 0.5%. The peak value of UCS was noted as 0.521MPa and 0.534MPa for smaller aspect ratio X and larger aspect ratio Y respectively.

However, for 14 and 28 days the UCS results seems to differ from 7 days. The peak value of UCS changed from lime percentage of 5 to 2.5. Here the UCS strength gradually increased at 2.5% of lime attaining peak at that value and decreasing afterwards. The pine percentage for maximum strength was found to be 0.5% for both 14 and 28 days. The maximum UCS value for 14 days for aspect ratio X and Y was found to be 0.634MPa and 0.556MPa. Also, the maximum UCS value for 28 days for aspect ratio X and Y was found to be 0.733MPa and 0.678MPa.

The reason for discrepancy in nature of strengths was studied and analyzed. The reason for strength characteristics of 7 days is different as to that of 14 and 28 days due to incomplete reactions between lime and soil.

3.4 Comparison between Aspect Ratio X and Aspect Ratio Y:

For 7 days, the Aspect ratio X(shorter) has a peak strength of 0.521MPa while the Aspect ratio Y(bigger) has a peak strength of 0.534 MPa.

For 14 days, the Aspect ratio X(shorter) has a peak strength of 0.634 MPa while the Aspect ratio Y(bigger) has a peak strength of 0. 567MPa.The UCS value of smaller Aspect ratio is 1.11 times greater than that of larger Aspect ratio in 14 days.

For 28 days, the Aspect ratio X(shorter) has a peak strength of 0.733MPa while the Aspect ratio Y(bigger) has a peak strength of 0.678 MPa. The UCS value of smaller Aspect ratio i.e. X is 1.08 times greater than that of larger aspect ratio i.e. Y in 28 days.

With the increase in curing time, the Unconfined Compressive Strength (UCS) increases. Therefore, the value of UCS at 28 days is greater than UCS value at 14 days and also 7 days. Addition of pine with shorter fiber length (Aspect ratio X) and lime increased the strength than that of parent soil by 2.22 times and addition of pine with longer fiber length (Aspect ratio Y) and lime further increased the strength than that of parent soil by 2.05. In average addition of pine and lime increased the strength by 2.13 times or 113%.

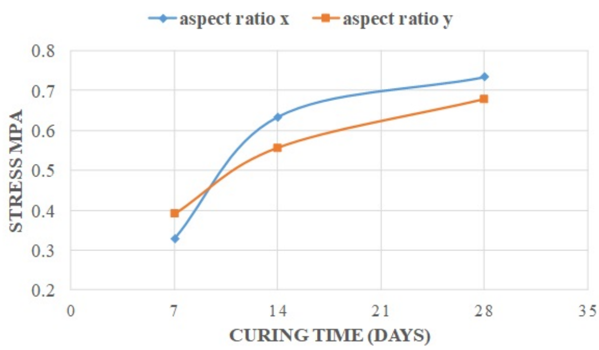

Figure 10: Plot of stress of samples containing 2.5% lime, 0.5%pine with different aspect ratios and curing time in days

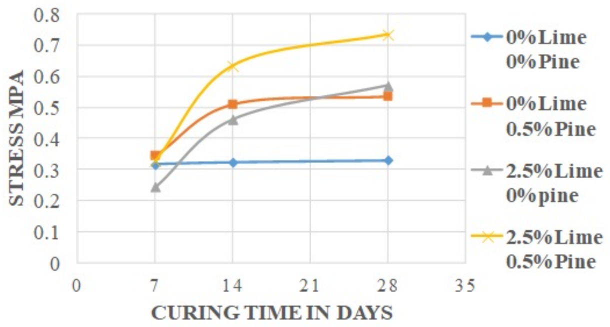

Figure 11: Comparison of strengths of parent soil with optimum proportions of only pine(aspect ratio x), only lime, pine (x) and lime

It is clear from above that the maximum strength is observed with inclusion of both lime and pine needles for all curing days in aspect ratio x. The lime has significant role in strength of the stabilized soil as observed from the above graph. The addition of pine needles increased the strength by 1.61 times than that of natural soil. Similarly, the addition of lime increased the strength by 1.72 times, addition of both lime and pine increased it by 2.22 times for aspect ratio x pine samples.

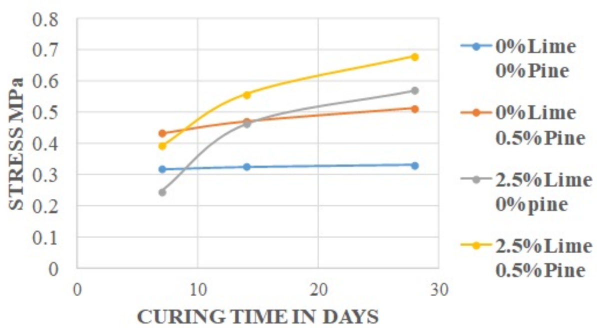

Figure 12: Comparison of strengths of parent soil with optimum proportions of only pine(aspect ratio y), only lime, pine (y) and lime

It is clear from above that the maximum strength is observed with inclusion of both lime and pine needles for all curing days even in aspect ratio y. The lime has significant role in strength of the stabilized soil as observed from the above graph. The addition of pine needles increased the strength by 1.55 times than that of natural soil. Similarly, the addition of lime increased the strength by 1.72 times, addition of both lime and pine increased it by 2.05 times for aspect ratio y pine samples.

4. Discussion

The addition of lime induced strength due to the fact that lime reacted with clay minerals to form tough water insoluble gel of calcium silicate which cemented the soil particles [5]. The amount of lime to be added is related to clay content in soil and normally does not exceed 8% [8] which agrees with optimum lime content obtained in this investigation (here, 2.5%).

Increase in fiber content to a optimum percentage of 0.5% increased the strength due to redistribution of internal forces from the soil matrix to reinforcing fibers. The distribution of stress was dependent upon population and orientation of fibers. At low level of fiber loadings, the orientation of fibers was poor; the fibers were not capable of transferring load to one another and stress accumulated at certain points of composites, which led to lower mechanical properties. At 0.25% of pine, the population of fibers is just right for maximum orientation and fibers actively participate in stress transfer and hence maximum results are obtained up to 0.25% fiber content in case of random orientation. At higher level of fiber loading, the increased population of fibers lead to agglomeration and stress transfer was partially blocked resulting in lowering the mechanical properties after 0.5% loading.

Among Long and Short fibers, the strength of short fibers is found to be greater than of longer fibers. The reason for this is that the longer fibers have local aggregation(clumping) and folding of fibers(balling) problems in soil composites. Because of which fiber lengths beyond certain value do not significantly improve soil properties and proved more difficult to work with in both laboratory and field experiments. [1]

5. Conclusion

In this research, the stabilization of soft soil with locally available pine needles and lime is investigated and the effects of stabilization on the Unconfined Compressive strength (UCS) of a weak and soft clayey soil is studied. It is found that only inclusion of pine fibers does increase the compressive strength of soil but addition of pine fibers with lime further increase the compressive strength of soil. Addition of pine needles of shorter fiber length (1 cm) with lime increased the compressive strength than that of parent soil by 2.22 times or 122%. Similarly, addition of pine needles with longer fiber length (2 cm) along with lime further increased the compressive strength than that of parent soil by 2.05 times or 105%. On average, addition of pine fibers with lime increased the strength of parent soil by 2.13 times or 113%. The optimum proportion for maximum Unconfined Compressive strength (UCS) is found to be 2.5% of lime by dry weight of parent soil and 0.5% of pine fibers by dry weight of parent soil. It is also observed that with the increase in curing time, the UCS increases. Therefore, the value of UCS at 28 days is greater than UCS value at 14 days and 7 days. The UCS value of shorter fiber length (1 cm) is found to be greater than that of longer fiber length (2 cm) which indicates shorter fibers in soil matrix gives greater strength than of larger fibers. These results showed that Lime and pine fibers can be effectively and economically used in many fields including pavement layers (road construction), retaining walls, earthquake engineering, railway embankments, protection of slopes and soil foundation engineering. However, further research on this can be carried out to enhance its development. The analysis for orientation of pine fibers and their strength variation can be studied. The same research can be carried out for different length of fibers, different curing periods and other strength tests than UCS. Different binding materials rather than Lime and other natural and synthetic high tensile strength fibers which are locally available and cheap can also be used as a replacement of pine needles. At all conditions, extensive and very scientific studies using proper technology in the field of soil stabilization using cheap and efficient materials should be encouraged and studied.

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