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UTILIZATION OF SISAL FIBER AS A SUBGRADE SOIL REINFORCEMENT: A CASE STUDY OF ALEM TENA TOWN ALONG MODJO-MEKI EXPRESSWAY

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ABSTRACT

This research, evaluates the strength properties of subgrade soil in Alem Tena road by reinforcing the sisal fibers randomly sisal fibers in the soil sample. The Sisal fibers were extracted manually and treated with kerosine in order to reduce the capacity of water absorption. Different percentage of sisal fibers 0.5%, 1%, 1.5%, and 2% by weight of dry soil for fiber lengths of 10, 15, and 20 mm were used to study different parameters of compaction, soaked California bearing ratio (CBR) and unconfined compression strength tests (UCS). From the study it is observed, as the fiber content and length increased, the maximum dry density (MDD) of reinforced soil slightly decreased, whereas the optimum moisture content (OMC) increased modestly. The California bearing ratio (CBR) and unconfined compressive strength (UCS) both increased significantly with increasing fiber length and content and this increment is substantial at 15 mm fiber length of 1.5% fiber content. Therefore, it's concluded that 15mm sisal fiber length can be considered as a practical for enhancing the properties of weak subgrade soils.

Keywords: Sisal fiber, subgrade soil, reinforcement, California bearing ratio, Ethiopia.

INTRODUCTION

Strengthening of weak natural soils can be achieved with the aid of different materials and soil reinforcement is one among the techniques. Reinforcing soil mass has three primary purposes: to increase its bearing capacity, to enhance its stability, and to decrease settlements and lateral deformations. The reinforcement inclusion can be in the form of strips, bars, sheets, mats, or nets in a definite pattern (oriented distribution), or the mixing of discrete fibers randomly with the soil [1]. The random inclusion of fibers (natural /polypropylene) in the soil has some advantages over oriented distributed fibers [2] . addition of oriented distributed fibers retains its strength isotropy and it limits the formation of failure planes.

After [3] discovery, in more than 37 countries, nearly 4000 structures have been built using the concept of soil reinforcement. He demonstrated that by adding reinforcing elements to a soil mass, shear resistance can be increased. There has been widespread application of natural materials such as Jute, coir, sisal, and palm as reinforcing materials in the soil for a long time. They are especially important in many countries such as India, the Philippines, Bangladesh, China (the Great Wall of China has long been used as an example of reinforced earth using trees as tensile elements), ziggurats of Babylon, which used woven mats [4] [5] [6] conducted a triaxial experiment to assess the effect of randomly distributed sisal fiber on the mechanical properties of a silty clay soil. Their test results showed that the reinforced soil with 10 mm fiber length using 1% is found to be 20% stronger than unreinforced soil, and reinforced soil has surface shear fracture failure modes as well as crack fracture failure modes. The addition of sisal fiber to black cotton soil was found to increase CBR and UCS by about 1.6 and 3.72 times, respectively, when compared to plain soil, as reported by [7].

In an experimental study, [8] reinforced sandy silt soil with randomly distributed jute fibers. The authors found that increasing the diameter and length of jute fibers leads to an increase in CBR value for fiber with 90 mm length and 2 mm diameter for 1% fiber content. According to [9] random distributions of coconut fiber were able to improve both the UCS and CBR of clay-sand soils. Soil with 1.2 % coir fiber of length varying from 2 cm to 3 cm showed maximum increase in UCS of 43.2 % and 47.4 % respectively, and soaked CBR value was found to increase by four times that of unreinforced soil.

Since natural fibers are readily available and less expensive, soil can be reinforced with them. The inclusion of fibers increases the strength properties of weak subgrade soil, and it is also observed the aspect ratio of the fibers has a great influence on the enhancement of strength in the weaker soil. Currently, there are dearth of knowledge of sisal fibers in the application of weak subgrade soil improvement in Ethiopia. Hence, In this study, the effects of different percentages and lengths of sisal fibers on compaction behaviour of (MDD and OMC), CBR, and UCS of weak subgrade soil by ignoring the aspect ratio of sisal fibers.

I. METHODOLOGY

Disturbed soil samples were collected at Alem Tena near Modjo-Meki road in central Ethiopia for the current study. AASHTO standard were used to determine the engineering and physical properties of the soil. Table 1 outlines the engineering properties of soil. The particle size distribution is found out by wet sieve analysis and hydrometer analysis and shown in Figure 1. Sisal leaves were collected from Wolaita, Diguna Fango woreda which is located in the southern part of Ethiopia. Sisal fibers were extracted manually by using sharp tools and then dried with sun as shown in figure 2. Sisal fiber is immersed in kerosene for 24 hours to protect it from moisture, degradation, and microbial attack. The soaked fiber in kerosene was then removed after 24 hours and dried before being mixed with soil [17]. Physical properties of fibers were studied at the Geosynthetic Industrial Laboratory in Addis Ababa, and mechanical properties are outlined in Table 2.

TABLE- 1: ENGINEERING PROPERTIES OF SOIL

Properties	Values
NMC (%)	12.72
Specific gravity	2.67
Percentage of gravel	0
Percentage of sand	9.6
Percentage of silt	28.5
Percentage of clay	51.5
LL (%)	40
PL (%)	25
PI (%)	15
AASHTO classification	A-6
USCS	CL
MDD (gm/cm3)	1.68
OMC (%)	18.82
CBR (%)	3.1
UCS (kPa)	87.1

TABLE- 2: PROPERTIES OF SISAL FIBER

Properties	Values
Color	White
Diameter (□m)	150
Density (gm/cm^3)	1.35
WAC of uncoated sisal fiber (%)	88.92
WAC of kerosene coated sisal fiber (%)	50.16
Average tensile strength of single sisal fiber (MPa)	420
Young’s modulus (GPa)	9
Elongation at break (%)	5

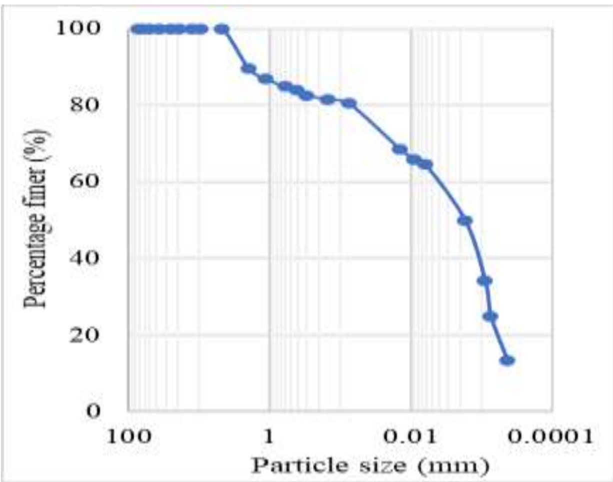

Figure 1: Gradation of Subgrade soil

Figure 2: (a) Sisal plant (b) Extraction of Fiber (c) Untreated sisal fiber (d) kerosene treated sisal fiber

A. **Preparation of samples and testing program**

We have carried out Compaction test (MDD and OMC), one point soaked CBR test and UCS test for both reinforced and plain soil samples. For reinforced soil samples the tests were conducted by mixing the kerosene coated sisal fiber randomly with different length and percentage by weight of dry soil. The first round of the test was related to effect of fiber length, in this test fiber length changed while percentage was constant. The fiber lengths were 10, 15 and 20 mm. The second round was related to effect of fiber percentage, so different percentages i.e., 0.5%, 1%, 1.5% and 2% by weight of dry soil with constant length were evaluated. After 2% fiber content the mixing of soil-fiber was very difficult, there were many lumps caused by fibers adhering together which creates sparse pockets of low density. Therefore, it was stopped at 2% fiber content [17]. This was also experienced by [10] at 1.5% with 25 mm length for untreated sisal fibers.

B. **Preparation of samples and testing program**

We have carried out Compaction test (MDD and OMC), one point soaked CBR test and UCS test for both reinforced and plain soil samples. For reinforced soil samples the tests were conducted by mixing the kerosene coated sisal fiber randomly with different length and percentage by weight of dry soil. The first round of the test was related to effect of fiber length, in this test fiber length changed while percentage was constant. The fiber lengths were 10, 15 and 20 mm. The second round was related to effect of fiber percentage, so different percentages i.e., 0.5%, 1%, 1.5% and 2% by weight of dry soil with constant length were evaluated. After 2% fiber content the mixing of soil-fiber was very difficult, there were many lumps caused by fibers adhering together which creates sparse pockets of low density. Therefore, it was stopped at 2% fiber content. This was also experienced by [10] at 1.5% with 25 mm length for untreated sisal fibers.

Figure 3: Compaction test

C. **California Bearing Ratio (CBR) test**

CBR tests was conducted according to AASHTO T 193-99 on the collected weak subgrade soils for both (with and without sisal fiber) reinforcement. To prepare CBR soil samples, modified compaction efforts were used at their respective OMCs and MDDs determined from compaction tests. For reinforced weak subgrade soil samples extracted treated sisal fibers were mixed randomly with the soil in dry state before the addition of water. then water corresponding to OMC was added and thoroughly mixed, followed by compaction in the mould. Testing was undertaken in a water-soaked condition. The mold, along with compacted soil, was placed in a water-filled tank for four days (96 hours). After four days, the sample was taken out of the tank, the water poured off the top, and the excess water was allowed to drain for 15 minutes before placing the sample in loading frame.

Figure 4: CBR test setup

D. **Unconfined Compression Strength (UCS) test**

Figure 5: UCS test sample

Fibers at various lengths and percentages were randomly mixed with the soil and then water corresponding to OMC of table 3 was added, mixed, and compacted in a sample tube. The inner surface of the sample tube is lubricated with oil to allow for the sample to be extruded from the tube with minimal disturbance and the sample is removed from the tube by the extruder. The remolded samples with a height of 11.4 cm and a diameter of 5.7 cm were placed in a loading frame and subjected to axial load at a strain rate of 1.27 mm/min in accordance with AASHTO T 208-05.

II. RESULTS AND DISCUSSIONS

TABLE 3. RESULTS OF MODIFIED COMPACTION TEST, CBR AND UCS FOR REINFORCED WITH SISAL FIBERS MIX RATIO [17]

Length (mm)	Percentage	MDD (gm/cm^3)	OMC (%)	CBR value (%)	Percent increase in CBR value	UCS value (kPa)	Percentage increase in UCS value
0	0%	1.68	18.82	3.1	-	87.1	-
10	0.50%	1.675	19.22	4.2	35.48%	105.9	21.58
10	1%	1.661	19.26	6	93.55%	138.5	59.01
10	1.50%	1.641	19.47	9.6	209.68%	173.2	98.85
10	2%	1.61	20.31	8.5	174.19%	149.9	72.1
15	0.50%	1.65	19.25	4.5	45.16%	116.4	33.64
15	1%	1.637	19.59	8	158.06%	152.5	75.09
15	1.50%	1.6	20.2	12.1	290.32%	195.5	124.45
15	2%	1.56	20.64	10.1	225.81%	164.4	88.75
20	0.50%	1.628	19.86	5.2	67.74%	129.1	48.22
20	1%	1.595	20.26	9.2	196.77%	168.7	93.69
20	1.50%	1.57	20.6	11.6	274.19%	184.9	112.28
20	2%	1.542	21.64	7.8	151.61%	141.1	62

I. **The effect of random inclusion of sisal fibers on compaction test**

The experimental test results compaction characteristics, CBR and UCS tests of both unreinforced and reinforced soil samples are tabulated in Table 3. The test results demonstrated in figure 6 and 7 shows that the shape of compaction curves is similar to those of unreinforced soils. All samples used for compaction have an increase in dry density as their water content is increased up to the point of optimum water content beyond which an increase in water content reduces the dry density.

A. **Effect of fiber percentage variation on MDD and OMC**

The addition of sisal fiber on MDD and OMC for different percentages with varying length of fiber is shown in figure 6 and 7. It is apparent that MDD slightly decreases as the percentage of fibers by dry weight of soil increases, while OMC slightly increases. This observation is similar to the other natural fibers reinforcement on different type of soils. Similar observations are made by several studies [11] [10],[12]. This decrease in the maximum dry density with increase in percentage of fiber is due to the low specific weight of the sisal fibers in comparison to that of soil. Hence, the average unit weight of the solids in the soil-fiber composite is reduced. At 20mm fiber length of 2% fiber content, maximum dry density is reduced by 8.21% than that of unreinforced soil. The increase in OMC with increasing percentage of fiber is due to water absorption nature of organic natural fibers. Adding 2% fiber at 20 mm fiber length increases OMC by 14.98%.

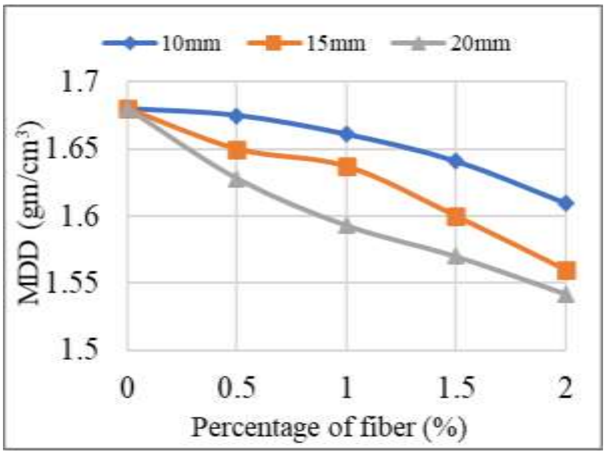

Figure 6. Effect of fiber percentage on MDD for 10mm, 15mm and 20mm fiber length[17]

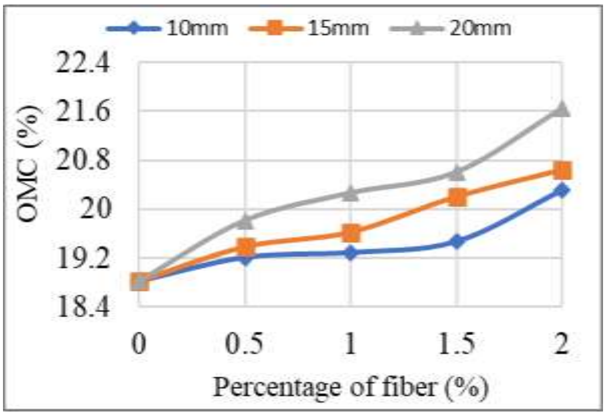

Figure 7. Effect of fiber percentage on OMC for 10mm, 15mm and 20mm fiber length[17]

B. **Effect of fiber length variation on MDD and OMC**

Figures 8 and 9 illustrate the variation of fiber length on both MDD and OMC of soil, from the figure it can be seen that MDD decreases slightly as the fiber length increases, while OMC increases. It is evident from the results that as fiber length increased from 10 mm to 20 mm at 2% fiber content, MDD decreased from 1.61 to 1.542 gm/cm^3 while the OMC increased from 20.31 to 21.6%. This was due to the longer sisal fibers absorbing more water.

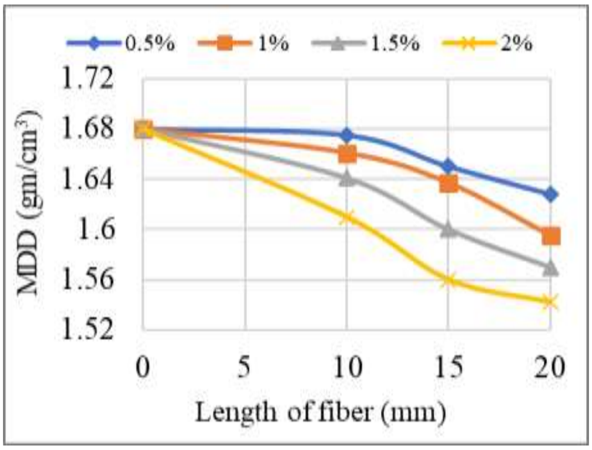

Figure 8: Effect of fiber length on MDD for a particular fiber percentage [17]

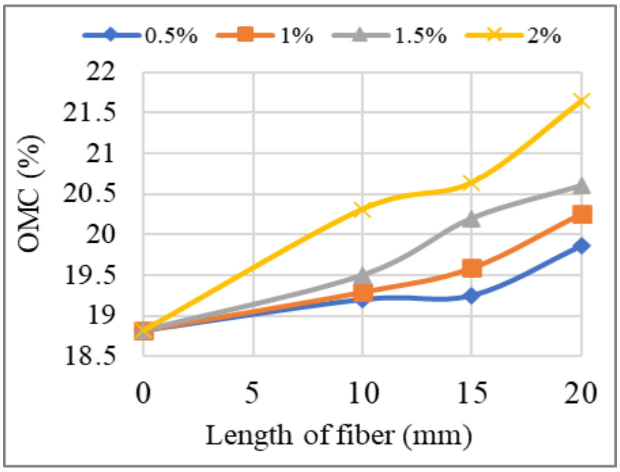

Figure 9: Effect of fiber length on OMC for a particular fiber percentage [17].

II. **The effect of random inclusion of sisal fibers on CBR**

The CBR value of plain and reinforced soil sample is shown in figure 10 and 11. It is observed that for all combinations of length and percentage, the CBR value of reinforced soil is greater than that of plain soil. This pattern of results were observed with, sisal fiber [10], with different natural fibers [12] and also with the addition of bamboo fiber by [13].

A. **Effect of fiber percentage variation on CBR value**

In figure 10, it is seen that the CBR value of soil is enhanced as the fiber content increases up to 1.5% and this aspect is observed for all fiber lengths. The maximum increase in CBR value is 3.9 times (290.3%) over unreinforced soil at a fiber content of 1.5% for 15 mm fiber length. The minimum increase is 1.35 times (35.5%) over unreinforced soil at 0.5% fiber content for 10mm fiber length. Natural and synthetic fibers were used by some researchers and similar trends were observed.

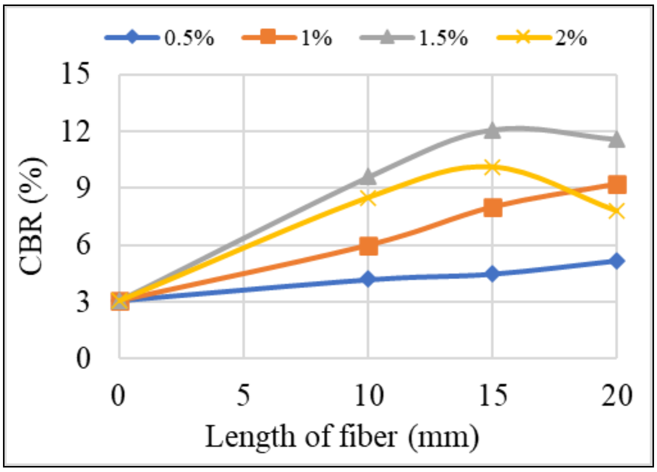

Figure 10: Effect of fiber percentage on CBR for 10mm, 15mm and 20mm fiber length [17].

[14] study of clay soil by mechanical stabilization using jute fibers also observed similar trends but the length of fibers used was 2 mm with random distribution, [15] used coconut coir fiber on clay soil type with 1% fiber content. These trend in the results are similar to findings reported by [16] in his review article. Since fibers are randomly distributed, mechanical interaction between fibers and soil particles occurs through friction and interlocking. This interlocking transmits the stress between the soil and fibers and enhance the better load-deformation behavior (strength property). Therefore, fiber reinforcement performs as both frictional and tension resistance element.

According to the Ethiopian Road Authority specification on Soils for high volume roads, CBR values ranging from 7% up to 20% are specified for subgrades. From the test results, CBR value is improved to a maximum of 12.1% for a 15 mm fiber length at a fiber content of 1.5%. There is a decrease in CBR value after a further increase in the percentage of sisal fiber at 2% fiber for 10 mm, 15 mm, and 20 mm. this is due to the reason that a soil with more fibers than necessary leads to localization of fibers, and this causes poor bonding between the soil and fiber. Beyond 1.5% fiber content, sisal fiber tends to stick together and adhere to one another, making it difficult to distribute the fibers randomly.

B. **Effect of fiber length variation on CBR value**

Figure 11 illustrates the CBR value of soil reinforced with the same fiber content increases as fiber length increases. A similar pattern is observed for 10 mm and 15 mm fibers, but not for 20 mm fibers with 1.5% or 2% fiber content. These findings suggest that fiber length has a relationship with fiber content. At a fiber content of 1.5%, the CBR values of soil reinforced with fibers lengths of 10 mm, 15 mm, and 20 mm are 9.6%, 12.1%, and 11.6%, respectively.

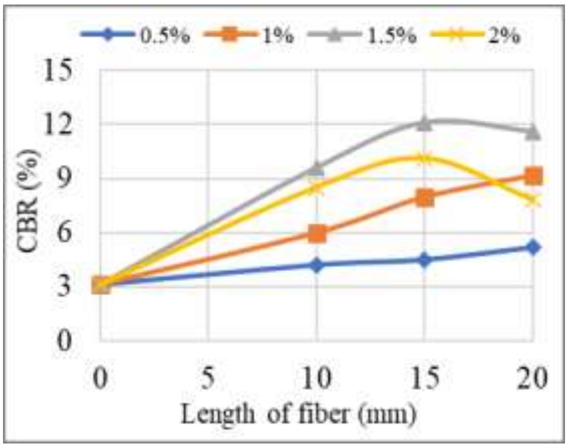

Figure 11: Effect of fiber length on CBR for a particular fiber percentage [17]

This is due to the length of the fiber determining the area in contact with the soil. Shorter fibers have smaller surface areas in contact with soil, so improvement is minimal. However, if the length of fiber exceeds beyond the required, the CBR value will decrease, because as long lengths of fiber remain unattached with soil particles, preventing fibers from interlocking with soil particles.

III. **The effect of random inclusion of sisal fibers on UCS test**

Table 3 depicts the UCS values of sisal fiber-reinforced and unreinforced soil. By adding sisal fiber to the soil, reinforced soil's UCS value improves over unreinforced soil in all combinations of length and percentage. Table 3 shows a maximum UCS value of 195.5 kPa for 1.5% fiber content of 15 mm fiber length, which is 2.24 times greater than that for plain soil (124.45%). 105.9kPa is the lowest value of UCS when 0.5% fiber content at 10 mm fiber length is used, which is 1.2 times (52.95%) higher than plain soil

A. **Effect of fiber percentage variation on UCS value**

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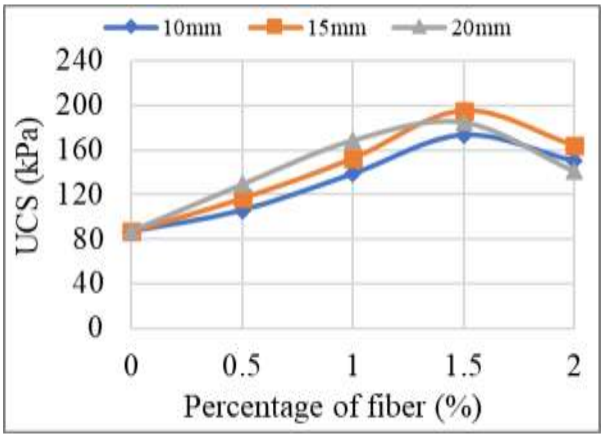

Figure 12: Effect of fiber percentage on UCS value for 10 mm, 15 mm and 20mm fiber length [17]

Increase in fiber content consequently increases the friction between the discrete fiber and soils particles, which contribute to increased resistance to an axial force applied. But with further increase in the percentage of sisal fiber beyond the required, the strength of reinforced soil is reduced. Because the addition of excess fiber leads to the domination of fiber-to-fiber interaction rather than soil-to-fiber interaction. This phenomenon was observed when fiber content exceeds 1.5%, and the UCS value decreased. From figure 15, for the unreinforced soil sample, the failure mainly occurs on the bottom of the specimen showing that two failure modes, one shear failure and the other bulging. When the fiber percentage and length increase the failure mode is mainly bulging in the middle of the sample

C. **Effect of fiber length variation on UCS value of reinforced soil.**

According to figure 14, when sisal fiber is increased from 10mm to 20mm length, the UCS value of reinforced soil with 1.5% fiber content increases from 173.2kPa (for 10mm fiber length) to 195.5kPa (for 15mm fiber length) and then decreases to 184.9kPa (for 20mm fiber length). At 1.5% fiber content, the increase in UCS value of soil reinforced with 10 mm, 15 mm, and 20 mm fiber lengths is 1.98 times (98.85%), 2.24 times (124.45%), and 2.12 times (112.28%) that of unreinforced soil. Therefore, fiber content determines optimum fiber length. The reason for this is that as fiber length increases, the total area of the fiber in contact with the soil increases. In contrast, increasing the length beyond the optimum reduces the UCS because long fibers do not create adequate interlocking between soil particles.

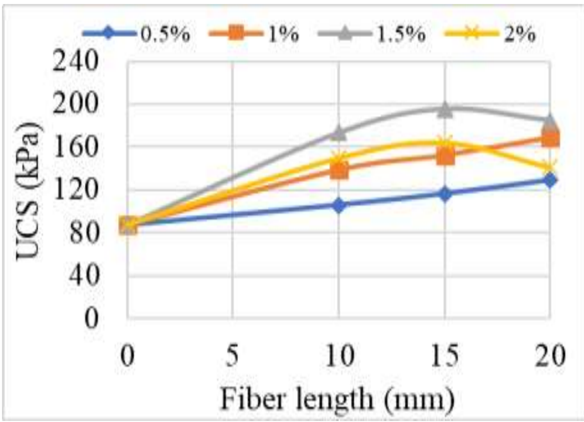

Figure 14: Effect of fiber length on UCS value for a particular fiber percentage [17]

Figure 15: Failure mode of remolded sample a. Unreinforced soil

b. Reinforced sample for 20mm fiber length at 0.5%, 1.5% and 2% content

III. Conclusion

With variations in percentage and length, the effect of random distribution of sisal fiber as reinforcement on CL soil of Alem Tena road in central Ethiopia was studied. Compaction, soaked CBR and UCS tests of both reinforced and plain soil samples were conducted. According to the results, the following are summarized.

Compaction characteristics (MDD and OMC) are slightly altered by the addition of sisal fiber to the soil. MDD is reduced slightly, while OMC increases slightly with an increase of fiber content and length.

The CBR value of the soil is found to increase with the addition of sisal fiber to the soil. When the sisal fiber content is increased, the CBR value of soil further increases and this increase is remarkable at the fiber content of 1.5%, beyond this percentage there is a decrease in CBR value for all fiber lengths. The length of fiber has a significant effect on the CBR value of soil. The CBR value of soil also increases with the increase in the length of sisal fiber. The optimum CBR value of 12.1 % is obtained at 1.5% fiber content for 15 mm fiber length which is 3.9 times (290.32%) over unreinforced soil.

In fiber-reinforced soil, the UCS is improved by incorporating sisal fiber. The UCS of soil increases with percentages of sisal fiber and length. A fiber content of 1.5% will provide stronger performance for the three fiber length, beyond this point an increase in fiber content reduces the UCS value. For 15 mm fiber length and 1.5% fiber content, an optimum UCS of 195.5 kPa is obtained, which is 2.24 times (124.45%) higher than unreinforced soil.

In summary, according to the study, sisal fiber reinforcement can significantly improve the compaction, CBR and UCS of CL soil. The optimum fiber content and length of sisal fiber is 1.5% and 15mm respectively.

IV. Acknowledgement

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V. Conflicts of Interest

The authors declare that they have no conflicts of interest

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