

Enhancing Subgrade Strength of Rural Roads Constructed on Soft Soils Using Varied Grades of Coir Fiber

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Abstract— With the urbanization in Sri Lanka, shortage of land for pavement construction has become a major issue as Engineers are supposed to resort to constructing pavements in areas with problematic soils. These problematic soils are commonly clays and silts due to their characteristics of high swell-shrinkage and poor load-bearing ability. "Excavation and Replacement" is conventional for subgrade alteration, but is expensive and time-consuming. Currently, subgrade modification includes the application of natural and synthetic reinforcement. Glass fibers, nylon fibers, polyester fibers (PET), polypropylene fibers (PP), and polyethylene fibers (PE) are geosynthetics. Natural fibers like coir, sisal, palm and kenaf are increasingly popular as they are affordable and environmentally beneficial. Two types of coir fiber (Mattress fiber and Bristle fiber) of 0.25% to 0.75% percentages with 0.25% increments and lengths between 1cm and 3 cm was considered in this study. Potential for increasing the soil's load-bearing ability has been evaluated through laboratory analysis, such as Hydrometer analysis, Standard Proctor Compaction (SPC) test, and California Bearing Ratio (CBR) test. The findings demonstrate that weak soils can be stabilized by adding bristle fiber (0.75% of the soil's dry weight) to reach a CBR value of 2.61%, or 2.15 times that of the control sample.

Keywords— Subgrade Modification; Natural Fibers; Expansive Soils; Mattress Fiber; Bristle Fiber

I. INTRODUCTION

The alteration of subgrades by reinforcing them with natural fibers has gained widespread acceptance. A pavement structure's subgrade is just as crucial as a building's foundation. The pavement structure's lifespan is influenced by the subgrade's strength. Pavements are typically constructed on dirt that has been stabilized. Sri Lanka, a developing nation, is rapidly urbanizing the majority of its land. roughly 75% of daily transportation activities in Sri Lanka are supported by the country's well-maintained road network, which spans roughly 116,000 km. While the national highways and expressways of Sri Lanka are being built on well-stabilized soil, most rural areas with low volume traffic do not benefit from these road networks. Hence, most rural roads are to be built on problematic soft soils

Expansive soils, such as silts and clays are tedious to work with due to their high swelling and shrinkage characteristics and low bearing capacity. Currently, the RDA allows the use of geotextiles, lime and cement in the process of stabilizing expansive soils. Sri Lanka is a tropical country with an abundance of coconut trees. Due to the abundance of fiber, geosynthetics and geotextiles can be replaced with natural fiber.

Recently, several studies have examined the usage of natural fibers, including coir, sisal, palm, jute, hemp, bamboo, and kenaf fibers [1], [2], [3], [4]. However, there is no proof that using different grades of coir fiber, specifically, mattress and bristle fiber for subgrade alteration is effective. Being a major exporter of coir fiber, Sri Lanka highlights the two fiber grades' accessibility and environmental friendliness

in comparison to other reinforcing materials like geosynthetics. The purpose of the study is to investigate whether adding the two grades of coir fiber could increase the subgrade's strength.

II. EXISTING LITERATURE

A. Current Issues Faced Due to Expansive Soils

According to [5], the soft soils that are formed as a subgrade for pavements creates bigger problems due to the low-bearing capacity of the ground. The traffic loads that come down on the soft soil causes detrimental pumping action when the subgrade is located in an area with a high-water table. Expansive soils are mostly fine-grained soils such as silts and clays and [6] mentions that structures that are constructed on expansive soils are more prominent in experiencing higher upward pressures due to swelling and shrinking of the expansive soft soil underneath.

B. Use of Geosynthetics for Subgrade Stabilization

Geosynthetics are commonly and widely used in the field of Civil Engineering. American Society for Testing and Materials (ASTM) defines geosynthetics as polymeric planar products that are utilized in construction projects in conjunction with rock, soil, or any other engineering material. Geosynthetics come in a variety of product forms, including geogrids, geotextiles, geomembranes, geonets and coatings made of geosynthetic clay. According to [7], the use of geosynthetics is based on the principles of separation, filtering, drainage, strengthening, protection, and insulation.

According to [8] an alternative to natural fibers, short synthetic fiber soil composites have recently drawn more interest in geotechnical engineering. In geotechnical projects, they are still a relatively new method. There are also synthetic fibers (man-made fibers) which includes polypropylene fibers (PP), Polyester fibers (PET), polythene fibers (PE), glass fibers, steel fibers [9], nylon fibers and polyvinyl alcohol fibers

Studies were done on the effectiveness of PP reinforced stabilized soil specimens were established. After seven and twenty-eight days of curing, tests for unconfined compressive and split tensile strength were performed to show that there is considerable effectiveness in using PP fiber as a geosynthetic [10], [11], [12], [13]. PET fibers, which is one of the most widely used fibers worldwide, has been studied as geosynthetics. Several studies showed that the use of different proportions of PET fibers ranging from 1% to 1.6% improved the shear strength, shear modulus and California Bearing Strength (CBR) of the soil. Furthermore, it was found that this effectiveness can be improved further with the use of lime or cement in the mixture [14], [15]. According to studies conducted by [16], [17], [18], it was found out that glass fiber, also known as fiberglass, can be used to reinforce expansive subgrade to improve unconfined strength (UCS), Indirect Tensile Strength (ITS) and CBR strength in the range of 3% to 5% of fiberglass.

C. Use of Natural Fibers for Subgrade Stabilization

As stated in [19], the improvement of such problematic soils can be done using various treatment and reinforcement methods. By processing the fibers using physical and chemical techniques, natural fibers can be utilized to strengthen. The succulent plant known as *Agave sisalana* yields leaves that are used to make sisal, a natural fabric. When 0.25% to 1.0% of sisal fiber was randomly added to the dry weight of the soil in one study, the target fiber length was found to be at 30 mm [20]. According to a study using fiber with lengths ranging from 30 to 35 mm and percentages of 0.1% to 1.0%, the maximum dry density decreases as the fiber content rises. The fiber's highest soaking CBR value was 14%, and this peak value was discovered at the palm fiber content reached 0.2% [3]. Jute fiber, known by another name, *Corchorus olitorius*, is typically utilized in tropical regions. According to studies conducted on clayey soil, adding fiber in amounts ranging from 0.25% to 1.25% and with length variations of 0.5 and 1.5 cm indicates that adding 1 cm of fiber with a percentage of 0.75% fiber content increased the values of both UCS and CBR [21].

Coir fiber (CF), also referred to as *Cocos nucifera* (L.) (Arecaceae), is the most widely used fiber kind. There are two varieties of mesocarp: brown fiber and white fiber. At the moment, brown fiber is utilized in several industrial and domestic placement materials, including geotextiles. In a study by [22], coir fiber was utilized in discrete arrangements with percentages ranging from 0.25 to 1.0% and a length of 20 mm. The findings demonstrated that as the number of reinforcing layers increased, so did the sample's CBR strength.

There are three further grades of coir fiber, referred to as omatt, mattress, and bristle fibers. These are traditional processing techniques that are unique to Sri Lanka. Bristle fibers, also known as brush fiber, are often considerably stronger and longer fibers that are frequently utilized in the brush and broom manufacturing sector. Compared to bristle fiber, mattress fibers are far longer and less rigid.

Coir fiber of both grades—bristle and mattress—was utilized for this study in lengths ranging from 1 cm to 3 cm as a mixture in a random arrangement, with percentages varying from 0.25% to 0.75% with increments of 0.25%. The coir was infused with a fat clay to study the behavior of the bearing capacity of soil.

III. MATERIALS AND METHODS

A. Expansive Soil

In this study, the expansive soil was obtained from the Biyagama zone - Gampaha district of Sri Lanka. This region falls under the Kelani river basin, which represents the wet – intermediate wet zone of the country. Based on the data which were obtained from the hydrometer analysis, the soil was identified as Fat Clay. The physical and mechanical properties of the soil was found as per the American Society for Testing and Materials, ASTM D4318 -17 for Atterberg Limit Tests, ASTM D698 for the Standard Proctor Compaction Test, ASTM D7928-21 for Hydrometer Analysis and ASTM D1833 for California Bearing Ratio Test (CBR). According to the Unified Soil Classification System (USCS), the soil was categorized as (CH), which is for high plasticity fat clay.

TABLE I. PROPERTIES OF THE EXPANSIVE SOIL

Physical Properties of the Fat Clay	
Properties	Values
Clay content (%)	89
Specific gravity	2.61
Plastic limit (%)	34.6
Liqui limit (%)	76
Plasticity index (%)	41.3
Maximum dry density (g/cm ³)	1.39
Optimum moisture content (%)	27.4
California Bearing Ratio (%)	1.21

B. Coir Fiber

The coir fiber, was the dependent variable in the research. The two grades of fiber were bristle and mattress fiber which were extracted, dried and cut into lengths of 1cm to 3cm to create a mixture of short fibers. The fiber which was cut, was separated into three percentages varying from 0.25% to 0.75% with an increment of 0.25%. The percentages and lengths were adopted to align with the variables that showed positive results in current research under subgrade modification.

C. Sample Preparation

The soil samples were dried under the sun to create a fine dust through a mechanical process from a milling machine. Once the sample was crushed, the bristle and mattress fiber were mixed with the soil at 0.25% of dry weight of the soil, 0.50% of dry weight of the soil and 0.75% of dry weight of the soil. The fiber was cut to create short fibers within the rage 1cm to 3cm. This soil fiber mix was manually mixed to ensure homogeneity of the sample as the fiber was introduced into the soil as randomly distributed.

D. Testing Method

The ASTM standards were adopted throughout the study. to obtain the mechanical and physical properties of the soil, the primary soil tests were conducted. The plastic limit (PL) test was conducted to establish the moisture content at which the fine-grained soil reaches the consistency of liquid. A 20g sample of clay was used, where it was rolled into an ellipsoidal mass and then rolled out to form a thread of clay. The point where the thread crumbles was identified and bits of the sample was oven dried to obtain the water content of the clay sample.

The liquid limit (LL) of the clay was obtained using the Casagrande apparatus. 200g of clay was mixed with water until the consistency of the sample required 25 to 35 blows to close the groove as per the test standards. Once the number of drops were obtained, the sample was removed from the device, weighed and was then dried.

The specific gravity test was done using a pycnometer in accordance with the ASTM D854 standard.

To understand the percentage of sand, silt and clay in the soil sample, a hydrometer test was conducted. The ASTM D7928 standard was followed. A 50g soil sample passing the No.200 sieve was used. 125ml of dispersing agent was then added to the soil.

Compaction test included the ASTM D698 standard proctor mold, where the Optimum Moisture Content (OMC)

and the Maximum Dry Density (MDD) was obtained which was then used for the CBR test. For the proctor test, roughly 2.3kg of the representative sample was obtained and water was introduced to the soil using a spray bottle.

The CBR test was conducted as per the ASTM D1883 guidelines, where the soil was divided into three sections and was compacted in accordance to 56 blows per layer, for three layers, using the 4.5kg rammer. The surcharge weights used were 4.54kg. the sample was then immersed in a pail of water allowing the water to access the top and bottom of the specimen for 96 hours (4 days) before the penetration test. The load was applied on the penetration piston so that the rate of penetration was approximately 1.27mm/min. the load readings were recorded during the penetrations of 0.025 in increments and the load penetration curve was plotted. By accumulating three samples and computing the mean data for each percentage of modified soil sample, the validity of the test results for each combination was confirmed.

IV. RESULTS AND DISCUSSION

A. Atterberg Limits of the Clay Soil

The Fig 1. shows the variation of moisture content with the number of blows. The results indicates that the LL lies at 76%, which is relatively high, that can be seen in most clayey soils. This shows that the soil is able to hold a notable quantity of water before it changes its state from a plastic state to a more liquid state. Thus, requiring a lesser number of blows with increasing water holding capacity. This shows a more expansive nature for this clayey soil

TABLE II. LIQUID LIMIT OF THE CLAY SAMPLE

Can No	Mass of can (g) W_1	Number of blows	Mass of can + wet soil (g) W_2	Mass of can + dry soil (g) W_3	Moisture content (%)
1	18.00	28	36.72	29.00	70.23
2	24.00	23	36.99	31.00	85.71
3	24.00	19	38.88	32.00	86.10
4	18.00	15	35.10	27.00	90.00
5	24.00	12	39.84	32.00	98.12

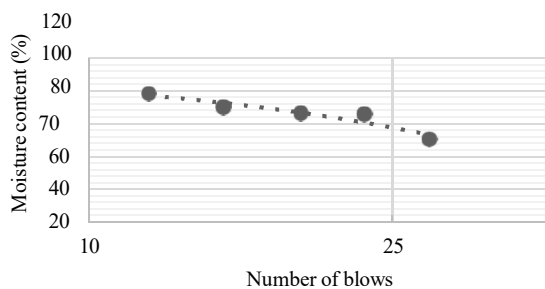


Fig. 1. Liquid Limit Of The Clay Sample

The PL of the soil sample shows a moisture content of average 34.66% which is the plastic limit of the soil sample, as seen in Fig 1. The results show that the soil sample can retain its plastic state (plasticity) till a moisture content of 34.66% has been reached. To further elaborate the plasticity of the soil sample, the plasticity index (PI) should be considered (1).

$$PI = LL - PL \quad (1)$$

TABLE III. PLASTIC LIMIT OF THE CLAY SAMPLE

Can No.	Mass of can (g) W_1	Mass of can + wet soil (g) W_2	Mass of can + dry soil (g) W_3	Moisture content (%)
1	18.08	20.98	20.19	37.17
2	17.65	19.29	18.86	35.23
3	23.72	25.39	24.99	31.60
Average Moisture Content (%)				34.66

The degree of cohesiveness of the soil can be based on the plasticity index of a soil, which in this case is 41.34%, and a plasticity index of above 17% shows a high plastic cohesive soil. According to the Unified Soil Classification System (USCS), the soil was classified as a High Plasticity – Fat Clay (CH). Fat clays are known to be highly cohesive and sensitive to moisture changes.

B. Specific Gravity Test

TABLE IV. LIQUID LIMIT OF THE CLAY SAMPLE

Description	Sample 1	Sample 2
Weight of bottle (g) W_1	18.57	18.50
Weight of bottle + dry soil (g) W_2	28.55	25.53
Weight of bottle + wet soil (g) W_3	90.86	90.32
Weight of bottle + water (g) W_4	84.76	84.11
Specific Gravity	2.57	2.64
Average Specific Gravity	2.61	

C. Hydrometer Test

The calibration formula was used to obtain the Effective Depth value. The values for the corrections and other factors were adopted from the tables provided for the hydrometer apparatus, during the calibration of the apparatus.

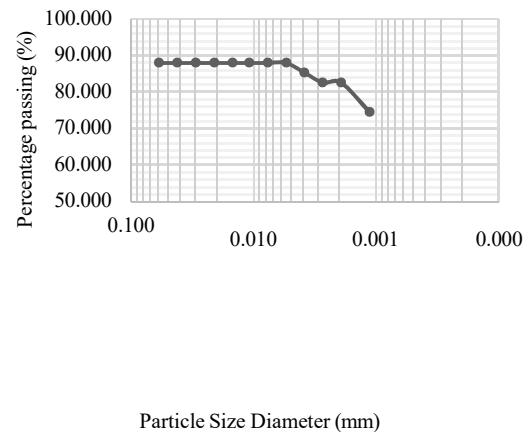


Fig. 2. Hydrometer Analysis Of The Clay Sample

The test showed that the percentage of fine grains in the sample was relatively high consisting of particles of same size. This is seen quite commonly within fines such as silts and clays as their particle size do not change in a significant manner.

D. Standard Proctor Compaction Test

According to the findings of the compaction test, the clay soil's OMC was 27.4%, and its MDD was 1.39g/cm³. It is evident that when water is added, the dry density of the soil gradually rises as the particles reorganize, packing tightly and filling the spaces.

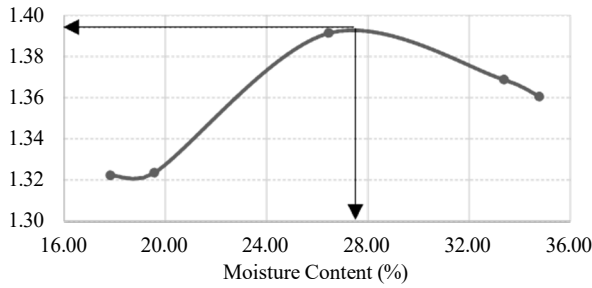


Fig. 3. Optimum Moisture Content Of The Clay Sample

E. California Bearing Ratio Test on Control Sample

The fat clay was undergone a CBR test to understand its load bearing characteristics without any reinforcement. This would then be compared to the reinforced specimen.

The CBR value was calculated by:

$$CBR = \frac{\text{Measured Force at Penetration (kN)}}{\text{Standard Force (kN)}} * 100 \quad (2)$$

The CBR value at 2.5mm penetration should be greater than the penetration of 5.0mm, such it will be accounted as the CBR value of the sample.

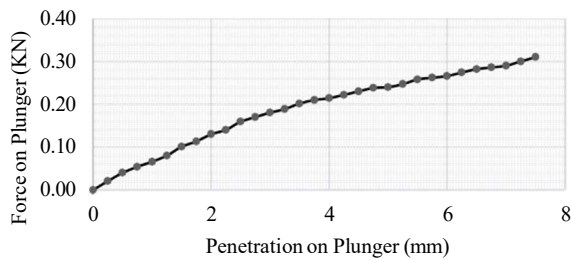


Fig. 4. California Bearing Ratio Graph Of The Clay Sample

In the control sample the CBR value can be obtained as 1.21%. This is quite a low value for a subgrade.

Due to the internal friction between the clay particles, the curve's initial behavior shows a slightly steep slope, indicating that a minimal force is needed to pierce the sample while maintaining some stiffness. When the penetration plunger begins to compress the soil specimen, this demonstrates the early phases of soil deformation. Since there is no soil fiber interlock, the resistance increases very slowly in the graph, indicating that the soil matrix should be able to withstand penetration on its own. Beyond this limit, the curve shows a plateau behavior where the soil cannot distribute the load further due to the fully packed stage.

F. CBR Test on Bristle Fiber Reinforced Sample

This section shows the behavior of clay soil when infused with 0.25%, 0.50% and 0.75% bristle fiber in random arrangement. The fiber was a combination of lengths varying from 1cm to 3cm, portrayed at short fibers.

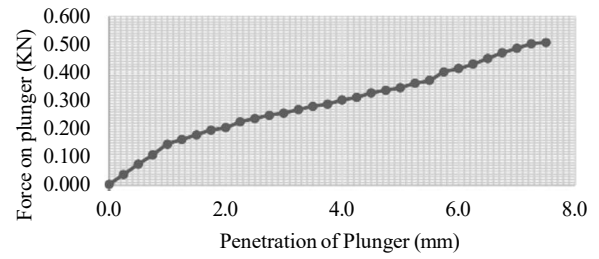


Fig. 5. California Bearing Ratio Graph Of The 0.25% Bristle And Clay

The following results shows the behavior of clay soil when infused with 0.50% bristle fiber in random arrangement.

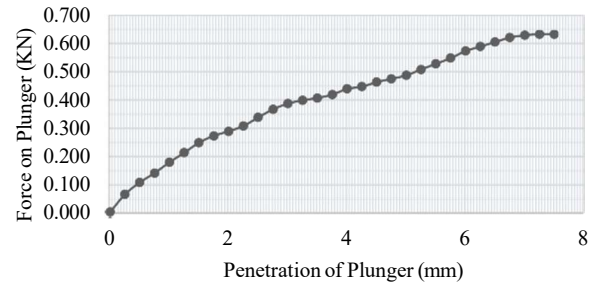


Fig. 6. California Bearing Ratio Graph Of The 0.50% Bristle And Clay

The following results shows the behavior of clay soil when infused with 0.75% bristle fiber in random arrangement.

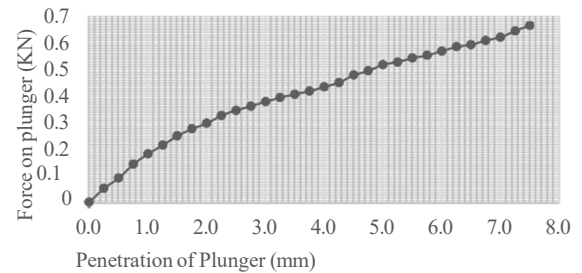


Fig. 7. California Bearing Ratio Graph Of The 0.75% Bristle And Clay

The curve's initial behavior, which displays a steep climb, indicates that the clay containing bristle fiber has a significant degree of resistance. The curve then keeps rising as the plunger penetrates at a steady rate, from 1.0mm to about 5.0mm for all three percentages but is at higher force on 0.75% bristle fiber sample. The load distribution between the clay and fiber matrix is demonstrated by the constant ascent. After

5.0 mm, the curve's slope appears to slightly diminish. This indicates that once the fiber and soil matrix have started to approach their maximum compressibility limit, the plunger penetrates at a significantly slower rate. When the final penetration readings exceed 7.0 mm, plateau behavior occurs, signifying that the maximum resistance has been attained. With the increase of penetration, no further resistance is visible.

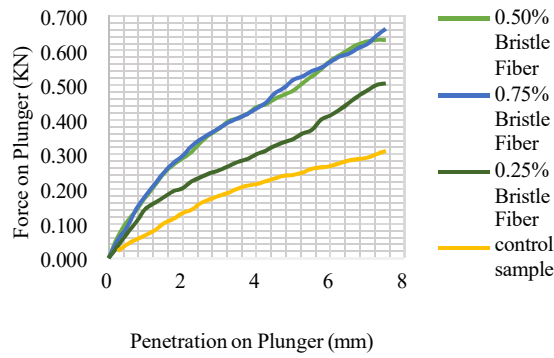


Fig. 8. Comparison Of CBR Values Of Bristle Fiber With The Control Sample

G. CBR Test on Mattress Fiber Reinforced Sample

This section shows the behavior of clay soil when infused with 0.25%, 0.50% and 0.75% mattress fiber in random arrangement. The fiber was a combination of lengths varying from 1cm to 3cm, portrayed at short fibers.

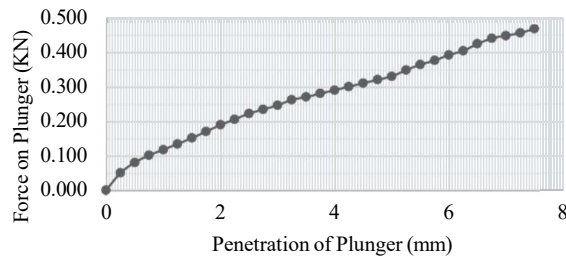


Fig. 9. California Bearing Ratio Graph Of The 0.25% Mattress Fiber And Clay

The following results shows the behavior of clay soil when infused with 0.50% bristle fiber in random arrangement.

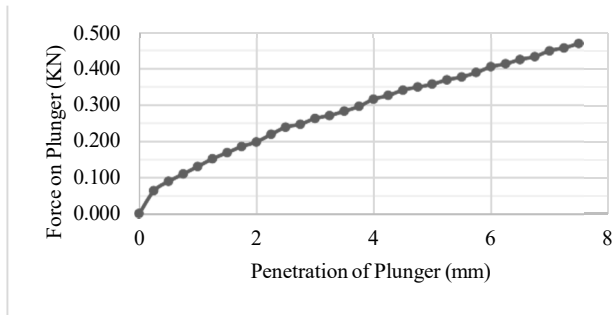


Fig. 10. California Bearing Ratio Graph Of The 0.50% Mattress Fiber And Clay

The following results shows the behavior of clay soil when infused with 0.75% bristle fiber in random arrangement.

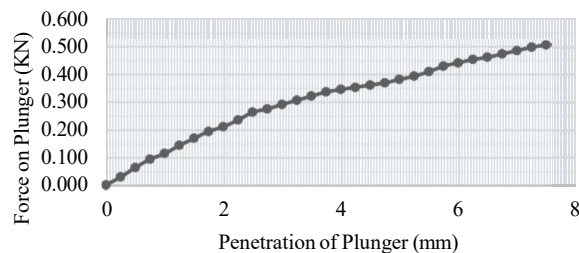


Fig. 11. California Bearing Ratio Graph Of The 0.75% Mattress Fiber And Clay

In comparison to the samples reinforced with bristle fiber, the samples reinforced with the mattress fiber was observed

that the load bearing capacity of the clay sample when combined with mattress fiber in varied percentages show a considerable effectiveness to its CBR value, which ensures that there was some improvement to the soil if used as a subgrade material, yet not upto the standard of the bristle fiber. Although resistive force can be seen from the piston, the fiber-clay matrix had a denser packing in the bristle fiber than the mattress fiber.

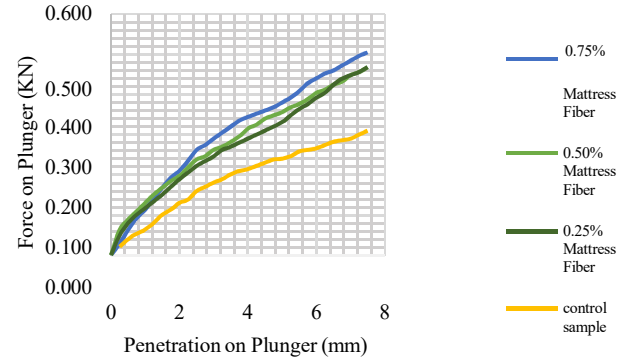


Fig. 12. Comparison of CBR Values Of Mattress Fiber With The Control Sample

V. CONCLUSION

Fiber reinforcement in problematic soils like clay improve the compressive and load bearing characteristics if used as a subgrade material, due to the fiber clay matrix being densely packed. Since coir fiber is readily available and cost effective, the possess of bristle and mattress fiber in varied percentages with clay soil was studied in this work. The following conclusions were drawn from the study as seen in Fig 13.

- The control sample of fat clay possessed a CBR value of 1.21%, which was relatively low for a subgrade material.
- The sample of fat clay reinforced with the 0.25% bristle fiber of random arrangement recorded a CBR value of 1.77%, which was 1.46 times greater than the control sample.
- The sample of fat clay reinforced with the 0.50% bristle fiber of random arrangement recorded a CBR value of 2.54%, which was 2.09 times greater than the control sample.
- The sample of fat clay reinforced with the 0.75% bristle fiber of random arrangement recorded a CBR value of 2.61%, which was 2.15 times greater than the control sample.
- The sample of fat clay reinforced with the 0.25% mattress fiber of random arrangement recorded a CBR value of 1.68%, which was 1.39 times greater than the control sample.
- The sample of fat clay reinforced with the 0.50% mattress fiber of random arrangement recorded a CBR value of 1.80%, which was 1.49 times greater than the control sample.
- The sample of fat clay reinforced with the 0.75% mattress fiber of random arrangement recorded a CBR value of 1.98%, which was 1.64 times greater than the control sample.

- The optimum percentage of fiber was recorded as bristle fiber of 0.75% in random arrangement in improving the load bearing characteristic of the subgrade.

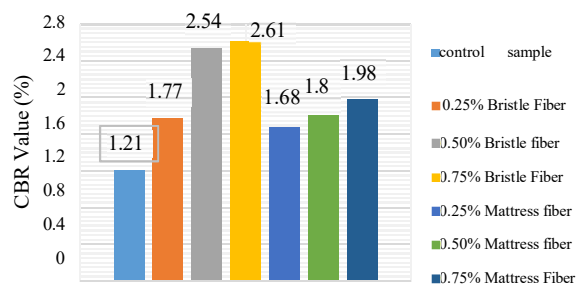


Fig. 13. Comparison Of CBR Values Both Fibers And Optimum Value Of Fiber

According to the results obtained, the inclusion of both bristle fiber and mattress fiber in varied percentages and random arrangement showed promising improvement to the problematic fat clay. The use of bristle fiber was most effective due to its stiff texture and good load distribution characteristics in the matrix, whereas the mattress fiber was effective but in lower quantities when compared to bristle fiber, due to its smooth texture.

It was observed that the inclusion of fiber tends to increase the water retention of the clay soil after soaking. The 96-hour soaking period was a method to replicate the extreme conditions that the subgrade could face. This could increase the swell shrinkage characteristic of the fat clay. Yet the fiber inclusion showed significant improvement in the load bearing characteristic of the fat clay. Coir fiber is cost effective due to its abundance and with a strong history of coir-based products in Sri Lanka, this could be a benefit both economically as well as in terms of sustainability. Additionally, the impact of swell shrinkage characteristic of the fat clay incorporated with both fibers need to be investigated in this study as it is crucial to evaluate the long-term stability of reinforced soil and to ensure that the fibers can be used to improve the swell shrinkage of the clay as well.

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