Influence of Random Inclusion of Coconut Fibres on the Short term Strength of Highly Compressible Clay

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Abstract. The choice of natural fibres for soil stabilization provides an economic, safe and eco-friendly alternative to improve the properties of soil. They are an important step forward toward sustainable development. An attempt was made to study the influence of the random addition of untreated coconut fibres on the short term strength of soil, its stress-strain behavior, compaction characteristics and index properties. The soil selected for the study is a highly compressible clay sample with a liquid limit of 52.5 % and plasticity index of 38 %. The soil has no organic content. The study reveals that the compaction curves tend to shift to the right side, indicating more plastic behavior with the addition of fibres. The addition of fibres also re-orient the soil structure to a more dispersed fashion. A significant increase in the unconfined compressive strength is also observed. An increase of nearly 51 % in the unconfined compressive strength is observed at 0.75 % coir inclusion. The stress-strain behavior of the soil shows a shift toward more plastic behavior. The mode of failure of the soil specimen is by cracking and with fibre inclusion, length of the failure cracks is restrained as the fibre tends to hold the cracks together, resulting in shorter cracks, with significant bulging of the specimen at failure.

1. Introduction
Reinforcing soil with tensile elements is a widely used successful ground improvement technique. Traditional soil reinforcements include rods, strips, sheets, membranes, etc. The use of natural fibres like jute, bamboo, coir, etc. is also widely prevalent in countries like Sri Lanka, Philippines and India, where these fibres are abundantly available. The use of these fibres as reinforcement does not only provide an economic option but is also a major step forward in the direction of sustainable development [1]. It does not cause environmental degradation and also provides opportunities of employment in the local community. Studies show that the strength of fiber reinforced soil increases with increase in aspect ratio, fiber content, fiber modulus; and soil fiber surface friction. The reason for the increase in compressive strength of specimens reinforced with different proportions of fibers as compared with compressive strength of specimens of unreinforced soil is attributed to better adhesion of soil matrix with fibers [1-4].

Of all the natural fibres available, coir is abundantly available and has a high tearing strength[2]. Rao and Balan [5] report that coir contains 54 % cellulose and 40 % lignin. The high lignin content makes it a useful reinforcement in geotechnical applications like enhancing stability of embankment and erosion control. It is very effective in improving the short-term stability and
deformation behaviour [2, 5] and has greater applicability in temporary structures. Phenol and bitumen coating can improve the durability of these fibre [2].

Case studies on the use of coir to reinforce bunds [6] demonstrate that it is cost effective than stone pitching, strengthen pavements [7] and other ground improvement techniques. Strength behaviour of coir reinforced was studied by authors like Babu and Vasudevan [2], Chauhan et al. [8], and Arif and Singh [4] but a comprehensive study on its compressibility, post peak behaviour and failure pattern has not been reported in detail. This paper reports the experimental results of coir reinforced soil, elaborating of the effects of coir on the compressibility, strength and failure. A number of tests on consistency limits, standard compaction tests and unconfined compression tests were performed with different percentages of coir (0.25, 0.5, 0.75, 1.0 and 1.25) to study the effect of coir reinforcement on improving the geotechnical properties of the soil.

2. Materials
2.1. Soil
The soil used for the study was extracted from Angarai village in Thiruchirapalli District, India. Sample was retrieved at a depth of 2 m below the ground level from trenches made for this purpose. The soil is dark brown in colour with a characteristic pungent odour. The soil has no organic content. The specific gravity of the soil is 2.00. The geotechnical properties of the soil are listed in Table 1. The toughness index of the soil (Table 1) indicates that the soil does not have adequate resistance to deformation.

| Table 1. Geotechnical Properties of the Soil |
|---------------------------------------------|
| DESCRIPTION                     | VALUE   |
|---------------------------------|---------|
| Specific gravity, Gs            | 2.00    |
| Effective size, D₁₀ (mm)        | 0.0012  |
| Uniformity Co-efficient, Cᵤ     | 11.67   |
| Co-efficient of curvature, C_c  | 0.134   |
| Liquid limit, w_l               | 43      |
| Plastic limit, w_p              | 26.83   |
| Flow Index, I_f                 | 50.8    |
| Toughness Index, I_t            | 0.32    |
| Maximum Dry density, γ_d (kN/m³)| 19.12   |
| Optimum Moisture Content        | 22%     |
| Compression Index, C_c          | 0.295   |

The particle size distribution curve of the soil is shown in figure 1. The soil falls under inorganic clay (CI) according to Indian Standard Soil Classification systems and low compressible clay according to USCS. The unconfined compressive strength of the soil indicates that it is a stiff clay.
2.2 Coir
Coconut coir was obtained from Thiruchirapalli, Tamilnadu. It was cleaned and cut to length of 15 mm. The coir fibres are elastic with high initial strength and durability. The average diameter of the coir fibres used is 0.01 mm. The percentage of water absorption of the coir fibres was 54%.

3. Sample preparation and testing
Soil from the borrow area was air-dried, pulverized, sieved and mixed thoroughly with coir at the required water content. Percentage of coir used for the study are 0.25 %, 0.5 %, 0.75 % and 1 %. The soil-coir fibre mix was kept in a container for the mix to reach equilibrium moisture content. This soil was used for determining the consistency limit, optimum moisture content, maximum dry density and unconfined compressive strength. The tests on unreinforced and reinforced soil was carried out in accordance to IS: 2720-2006 [9]. The unconfined compressive strength was tested at optimum moisture content.

4. Results and Discussions
Results of the experimental investigations carried out to study the effects of coir reinforcement on compaction characteristics, unconfined compressive strength and stress-strain behaviour is presented.

4.1 Compaction Characteristics
Light compaction tests were carried out to on unreinforced and reinforced soil (at selected fibre percentages) to determine the maximum dry density (MDD) and optimum water content (OMC). On fibre inclusion, compaction curves tend to shift right at all percentages of fibres tested. Random inclusion of coir fibres cause an increase in OMC and decrease in MDD. Fibres have a tendency to absorb moisture and this can be attributed to the increase in OMC on random fibre inclusion [10-12]. Fibres have less unit weight. Replacing fibres in the soil matrix because a decrease in weight occupied in the standard volume, causing a decrease in the maximum dry density [12-13]. The change in OMC and MDD is not very appreciable (Fig. 2) for all percentages of fibre studies.
4.2 Stress Strain Behaviour

Figure 3 depicts the stress-strain behaviour of unreinforced and coconut coir reinforced soil at various percentages of fibre inclusion. It can be observed that fibre reinforcement increases the plastic nature of the soil. Inspite of the increase in shear strength of the reinforced soil, the stress-strain behaviour remains the same. A decrease in the rate of loss shear strength post failure is observed (Fig. 3). This behaviour can be noted for all percentages of fibre inclusion. Figure 3 also shows that the decrease in the rate of loss of shear strength increases with fibre content (i.e) higher the fibre content, more plastic the fibre-soil matrix is. At lower strain rates, the behaviour of the unreinforced and reinforced soil is markedly similar. The study also shows that fibre reinforced soil takes longer to fail. Energy absorption capacity, which reveals the toughness of the reinforced soil matrix, also increase with the increase in fibre content (Fig. 3). The strain at failure also increases with the increase in fibre content. Again, this is an indicator of increase in plastic behaviour of the fibre reinforced soil.

4.3 Unconfined Compressive Strength

The unconfined compressive strength of the soil reinforced with coconut coir shows a marked change. The unconfined compressive strength is defined as the maximum load per unit area or the load per unit area at 10 % axial strain, whichever occurs first during the performance of a test [13]. Random inclusion of coconut coir results in the increase of the unconfined compressive strength of the soil upto 0.75 %. At 0.75 % of fibre inclusion, there is an increase of nearly 60 % in the unconfined compressive strength. The presence of fibres in the soil matrix increase the interaction between the soil and the fibre, thereby increasing the strength. But, this is true only upto a certain percentage of fibre inclusion (in this case, 0.75 %). Beyond this fibre content, fibre clumping takes place and this results in the decrease of shear strength. The improvement of the unconfined compressive strength of the soil is depicted as a shear strength improvement index (SII) in Figure 4. It can be observed that fibre inclusion is effective at percentages of 0.25, 0.50 and 0.75 and 0.75 % is the optimum.

![Figure 2. Effect of Coconut Coir Inclusion on the OMC and MDD](image-url)
5. Conclusion
Results of the experimental investigation illustrate that random inclusion of coconut coir improves the unconfined compressive strength and stiffness of the soil. The optimum dosage of coconut coir inclusion is 0.75 %. Random inclusion of fibres improve the energy absorption capacity, inhibit formation of long and wide cracks and considerably improve the geotechnical performance of the soil. Though coir is biodegradable, it has high durability and is resistant to deterioration. Hence, coir reinforcement can be suitably used for improving the strength of temporary structures.
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