Behaviour of the Undrained Shear Strength of Soft Clay Reinforced with Natural Fibre

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Abstract. The term soil reinforcement is conventional since decades ago for the stabilization of soft ground such as of clay and peat. Numerous research has arisen in the utilization of natural fibres as the reinforcement materials. Cost reduction, increment of sustainability awareness and eco-friendly environment are some of the advantages when using natural fibres to stabilize soft ground. A research study was carried out to evaluate the strength of the soft soil when unreinforced and reinforced using natural fibres. The findings on the experimental investigation of the study will be presented in this paper. Crushed coir fibres were used to reinforce an intermediate plasticity soft clay where both materials were collected locally in Brunei Darussalam. The crushed coir fibres were added at 0.5%, 1.0%, 1.5% and 2.0% to the dry weight of the sample. A series of an unconsolidated undrained Tri-axial test was conducted on the unreinforced and reinforced samples where the behaviour of the samples were observed and compared. The results indicated that inclusion of fibres affects the soil’s undrained shear strength. It was observed that increasing the percentage inclusion increases the undrained shear strength of the soil, up to a certain amount. Further increment of fibres, however, does not show further improvement in the undrained shear strength.

1. Introduction

One of the challenges in construction on soft ground is that problems such as insufficient bearing capacity and soil settlement may arise. These complications are generated by the low shear strength and low permeability of the soil. The strength of the soil is a crucial factor in any construction fields in order to resist the high tension stresses imposed by the structures. A shear failure may occur along the internal surface of the soil, if its condition is not being enhanced, due to excessive compression.

Ground improvement technique, particularly soil reinforcement has been introduced to overcome these problems by improving the engineering properties of the soft ground to enhance the performance of the soil [1]. Reinforcement materials are added into the soil matrix to enhance the strength and decrease the soil’s deformation [2]. This paper will present the study on soil reinforcement by randomly distributing the fibres. A random distribution of fibres also helps to develop the shear strength of the soil without having to present the weakness plane in the soil composite which eventually will help to reduce settlement [3]. Fibres that are naturally available from plants such as coir fibres, hemp, wheat and bamboo have gained attractions among researchers over the past few years due to the rise in sustainability awareness [2, 4–5]. Other reinforcement materials are of synthetic or manufactured fibres such as polyester, scrap rubber tire and polypropylene fibres but the production of these materials contribute to the emission of greenhouse gases. Hence, the option of using natural fibres is favoured [6].
Previous laboratory investigations have proven that the strength and stiffness of soft soil increased significantly with the addition of coir fibres [2, 7-8]. The use of hemp fibres added ductility to compacted soft clay by replacing the strain softening with strain hardening behaviour in the reinforced clay. The presence of hemp fibres improves the soil by increasing its fibres content from 0.5% to 1.25% but reduced at 1.5% showing the presence of threshold fibres content [9]. Another research was studied using sawdust as the fibres material where the unconfined compressive strength increases by 41.436%, from 0% to 3% addition of sawdust fibres into the clayey silt soil but when 5% of the fibres was added, the unconfined compressive strength decreased. A similar pattern was observed for the unconsolidated undrained shear strength but the percentage improvement from 0% to 3% was found to be 39.535% [10]. When the normal effective stress is higher, the effect of adding homopolymer polypropylene fibres becomes insignificant regardless the amount of added fibres. Based on the results from direct shear test, 0.25% addition of fibres is more effective than the 0.5% fibres [11]. Reinforcement using crushed coir fibres have been done on the assessment on the soft soil’s consolidation behaviour where 2.0% inclusion of fibres gives the most significant effect [12]. This paper attempts to use a similar type of fibre reinforcement but on the investigation of the strength of soft clay using the unconsolidated undrained Tri-axial test.

2. Experimental programme

2.1. Materials used

Reinforcement fibres: Brown fibres from coconut husks or known as coir fibres were used in this study. The fibres were extracted from the outer shell of matured coconuts as they have stronger properties and high resilient. Since coconuts are in abundance in Brunei Darussalam, some of the unwanted husks were disposed by burning which pollutes the air, hence utilizing them as reinforcement materials helps to protect the environment and reduce cost as they are naturally available. However, the length-to-diameter ratio of the fibres vary as the thickness are not consistent. This gives problems to the observation of the experiment if the fibres were to be used in strands of different lengths. Hence, the coir fibres used for this study were crushed into tiny grains.

Soft soil: The testing sample for this experiment was natural clay which is slightly dark brown in color, obtained locally at the site of the Raja Isteri Pengiran Anak Saleha (RIPAS) Bridge at Sungai Kebun. The sample was first studied according to BS 1377: Part 2 to determine its basic properties as tabulated in Table 1.

| Properties                   | Values |
|------------------------------|--------|
| Liquid limit, LL             | 38.4%  |
| Plastic limit, PL            | 22.5%  |
| Plasticity index, PI         | 15.9%  |
| Optimum moisture content, W_{opt} | 20.0% |
| Specific gravity, G_s        | 2.7    |
| BSCS Classification          | Intermediate plasticity |

2.2. Materials preparation

Reinforcement fibres: Strands of coir fibres were extracted from matured coconut husks that have been washed, dried and decorticated. The fibres strands were further crushed and passed through a 600 μm sieve size to eliminate the remaining strands of fibres.

Soft soil: The wet soft clay was brought into the laboratory and oven-dried for 24 hours prior to crushing and sieving using the 63 μm mechanical sieve shaker. In accordance to BS 1377: Part 4, the clay sample was compacted using the standard Proctor test where the optimum moisture content was
obtained. The dry clay sample was then mixed with water at its optimum amount and kept in a sealed bag for 24 hours to retain its moisture before preparing the testing sample.

2.3. Specimens preparation
Crushed coir fibres were randomly mixed with the wet soil sample after 24 hours. This is to imitate the in-situ state where the fibres can only be added into the ground in its wet condition. The mixing of the fibres with the soil was done thoroughly in portions to ensure that all of the fibres required were fully used in the required amount of soil sample in the Tri-axial mould having a diameter of 50 mm and 100 mm height. The samples were compacted in layers of 3 following the standard Proctor test and the testing specimens were extruded using the Tri-axial mould that has been greased.

2.4. Testing programme
The undrained shear strength of the unreinforced and reinforced specimens was investigated by conducting an unconsolidated undrained test using the Tri-axial equipment in accordance to BS EN ISO 17892 (Part 8) at a strain rate of 0.5mm/min. The crushed coir fibres were added at 0.5% increment to a maximum percentage inclusion of the fibres at 2.0% considering the previous work done on the consolidation behaviour of the unreinforced and reinforced specimens [12, 13]. A repeat test with 0.5% inclusion of fibres was also conducted in order to check for the results' consistency.

3. Test results
The results of the fibre-reinforced Sungai Kebun Clay specimens are presented in Table 2 where $q_u$ is taken at 20% axial strain. From this table, the unconfined compressive strength is influenced by the amount of fibre content in the sample.

| Test Number | Inclusion of fibres to dry weight of soil (%) | $q_u$ (kPa) Taken at 20% axial strain |
|-------------|---------------------------------------------|--------------------------------------|
| 1           | 0.0                                         | 40.0                                 |
| 2           | 0.5                                         | 56.9                                 |
| 3           | 1.0                                         | 57.0                                 |
| 4           | 1.5                                         | 89.4                                 |
| 5           | 2.0                                         | 117.7                                |

The typical stress-strain relationship of the fibre-reinforced specimens is shown in Fig.1. As seen in the figure, the amount of fibres included in the specimens significantly contribute to the increase in stress for all various percentage of fibre inclusions. The strength increases from 40.0 kPa when unreinforced to 56.9 kPa when 0.5% of crushed coir fibres was added, and increases further to 89.4 kPa at 1.5% and 117.7 kPa at 2% of crushed coir fibres inclusion. Thus, the stress-strain behavior of the fibre-reinforced specimens depends on the content of fibres. This result correlates well with [14] where their compressive strength increases for 0.4% to 1.6% inclusion. The compressive strength increases by 2 times for the inclusion of dry coir fibres and NaOH-treated coir fibres, and 3 times improvement for CCl$_4$-treated coir fibres indicating that the fibre inclusion influences the behaviour.

Fig. 2 shows the degree of improvement by inclusions of coir fibres. It can be represented by taking $q_u/q_{uo}$, where $q_u$ is taken as the maximum compressive strength at 20% axial strain and $q_{uo}$ is the maximum unconfined compressive strength with no fibre inclusions. As can be seen in the figure, the inclusion of fibre has an effect on the strength of the soil where increasing the fibre content improves its strength. The latter could be due to the effect of fibre strains has on the friction between the fibres and soil grains. The soil and fibres are bound closely together, minimizing the void content which makes shearing of soil difficult. The fibres are high in tensile strength such that when the specimen is sheared the fibres are able to withstand the tension and thus, improve the shearing strength of the
specimen. Previous research [10], however, indicated that compressive strength would increase as amount of fibre inclusion increases up to a certain percentage, beyond this percentage there will not be any significant improvement. The amount of inclusions analyzed in this study is up to 2% only. As suggested, there is a limiting fibre content where beyond that value there will not be any improvement in strength and this limiting value is affected by the type of fibres being used. In order to understand the behavior further, the amount of inclusion in this study need to be further increased.

![Stress-strain relationship](image1.png)

**Figure 1.** The stress-strain relationship of the unreinforced and fibre-reinforced specimens.

![Inclusion vs Degree of Improvement](image2.png)

**Figure 2.** The relationship between percentage inclusion of fibres and the degree of improvement.

### 4. Conclusion

From the results that have been discussed, the following conclusions can be drawn:

- The utilization of crushed coir fibres gives effect on the behaviour of the unconsolidated undrained Tri-axial test where the addition of crushed coir fibres as the soil reinforcement shows a significant improvement on the strength behaviour when compared to being unreinforced.
- The unconfined compressive strength of the unreinforced specimen improved significantly when 0.5% of crushed coir fibres was added up to 2.0% and the axial strains increase with the increase in stresses for all percentage increments of crushed coir fibres inclusions.
5. Limitations and recommendations

- The existing displacement transducer limits the movement to take further readings of the tests conducted where the tests had to stop before reaching the actual failure stage yet. It is recommended to take into account that the existing transducer needs to be modified or replaced.
- Since the tests were conducted at 100 kPa chamber pressure for all testing specimens where only the percentages inclusion of fibres act as the variation, to obtain the cohesion additional chamber pressure should be applied at 200 kPa and 300 kPa. This enables further investigations on the behaviour samples.

6. References

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