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Abstract. Coconut fibre or more commonly known as coir fibre is obtained from the outer shell of coconut. The production of coconut in Malaysia is the fourth important industrial crop after oil palm, rubber and paddy field. However, wastes generated by the coconut are almost fully utilised as by-products and reinforcing material for soil. In fact, the availability of the coconut waste in Malaysia makes it suitable for soil reinforcing material purposes. Problem that sometimes occurs is to dispose this big, heavy and hard coconut at landfill area. It may require more space to go through landfill method. Disposal of this waste material is vital as it can affect the environment. Therefore, by using part of the coconut component can help to overcome this problem. In this research, white coir fibre was utilized as the reinforcing material to sandy soil to suit the backfill material for earth retaining structure that is related to road infrastructure. The lengths of the white coir fibre were fixed at some length according to its orientation such as random, vertical and horizontal. Shear strength parameter were tested using Direct Shear Test. In this research, inclusion of white coir fibre in sandy soil shows enhancement of the shear strength parameter such as internal friction regardless of its orientation. However, there is no clear relationship between the effect of white coir fibres orientations to the shear strength of sandy soil.

1. Introduction

The concept of reinforcing soil with natural fibre materials originated in ancient times [1]. Nowadays, soil reinforcement or soil stabilisation is no longer odd in the research field. Soil reinforcement is defined as a technique adopted to improve the engineering characteristics of soil in order to improve the soil properties such as shear strength, compressibility, density; and hydraulic conductivity [2,3]. Many cases develop due to unsuitable backfill material of retaining earth structure. Nevertheless, sandy soil is usually used to suit the backfill material. Hence, to increase the shear strength of this soil, suitable materials should be utilised. Other soil reinforcing technique such as the commonly used soil nailing is expensive. In order to substitute this method, utilisation of soil reinforcement using waste materials are utilized. The most important concept of reinforcement is the development of friction between the soil and the reinforcement leading to the transfer of the built-up loads of the soil to the reinforcement [4,5].

There are two types of materials that can be utilized for the purpose of soil reinforcing which are manmade and natural materials. Manmade materials examples are Polypropylene (PP) fibres, glass
fibres, steel fibres and others. Meanwhile, natural fibres that are widely used by the researchers are coconut fibre, palm fibre, jute, bamboo, cane and sisal.

Inclusion of coir fibre into the soil as soil reinforcement is highly efficient. There are two types of coir fibre which is brown coir fibre and white coir fibre. Mature coconuts produced brown coir fibres while immature coconuts produced white coir fibres. This research focused on the use of white coir fibre as reinforcing material as it is easy handling. With the high degree of cultivation of coconut in Malaysia, the coir fibre can be put to use for reinforcing material. This shall prove to be a highly economic measure of strengthening of soil and with high degree of efficiency [6]. The previous study that has been carried out by previous researchers is using brown coir fibre as soil reinforcing material. Brown coir fibre is used because these are thick, coarse, strong, durable and have high abrasion resistance. Due to its high lignin content, coir degradation takes place much more slowly than in other natural fibres. So, the fibre is also very long lasting with infield service life of 4-10 years [7]. Fibres were placed at different specific orientations with respect to the shear plane. The fibre content, orientation of fibres, and modulus of fibres were found to influence the contribution of fibres to the shear strength development [8].

The main objective of this research was to determine the shear strength of sand reinforced with white coir fibre. Furthermore, the effect of white coir fibre orientation in reinforced sand was investigated. From this research, the performance of white coir fibre will be evaluated and compared with the brown fibre.

2. Materials and Methods
In this research, two types of sands were used i.e. fine sand (0.2mm to 0.063mm in diameter) and coarse sand (2.0mm to 0.6mm in diameter). Coconut wastes were collected from a commercial centre at Jalan Permatang Pauh, Penang (Figure 1). The coconut wastes were kept in a tight container to preserve the moisture content and natural properties before the coir were extracted.

![Figure 1](image-url) 

**FIGURE 1.** Coconut waste and the extracted coir

A series of direct shear test according to BS 1377: Part 7: 1990 were conducted to determine the shear strength of sand reinforced with coir fibre. Shear box of 60 mm x 60 mm dimension was used, and the rate of displacement was kept at 0.5 mm/min. In order to ensure uniform specimen density, dry pluviation method was implemented whereby sand was dropped at the height of 30 cm from the shear box plate using suitable funnel. The coir fibres were placed in three different orientations; vertical, horizontal and random, as shown in Figure 2.
Summary of test parameters for the direct shear test is shown in Table 1 below.

| Factors                  | Orientation   |
|--------------------------|---------------|
|                          | Horizontal    | Vertical | Random |
| Length of coir fibres(mm)| 50            | 25       | 50     |
| Gap between coir fibres(mm)| 5           | 10       | -      |
| Number of coir fibres(mm) | 11            | 25       | 11     |

3. Results and Discussions
This research investigates the effect of coir fibre orientations to the shear strength behaviour of sand. The results of direct shear tests for both fine and coarse sand without coir fibres are compared with sand with coir fibres. The results of the direct shear test are shown in Table 2.

| Specimen                | Coir Orientation | Maximum stress (kPa) | Normal stress (kPa) |
|-------------------------|------------------|----------------------|---------------------|
|                         |                  | 100 (Diff)%          | 200 (Diff)%         | 300 (Diff)%         |
| Unreinforced Fine Sand  | -                | 117.833              | 214.625             | 345.083             |
| Fine Sand with Coir Fibres | Vertical   | 155.708 (+32)        | 290.375 (+35)       | 366.125 (+6)        |
|                         | Horizontal      | 143.083 (+21)        | 223.042 (+4)        | 357.708 (+3)        |
|                         | Random           | 138.875 (+17)        | 265.125 (+23)       | 391.375 (+14)       |
| Unreinforced Coarse Sand | -                | 122.042              | 189.375             | 328.250             |
| Coarse Sand with Coir Fibres | Vertical | 198.583 (+62)        | 273.542 (+44)       | 328.250 0           |
|                         | Horizontal      | 185.167 (+51)        | 366.125 (+93)       | 446.083 (+35)       |
|                         | Random           | 227.250 (+86)        | 336.667 (+77)       | 483.950 (+47)       |

Specimens reinforced with coir fibres for all orientations are found to show higher maximum stress values compared to specimens without coir fibres. This indicates improvement to the reinforced
specimens. The highest improvement is found to be in coarse sand with random orientation of coir fibres which shows 86% improvement. However, there is no clear relationship between the effect of coir fibres orientation to the amount of enhancement.

**FIGURE 3.** Mohr-Coulomb envelope for coarse sand

**FIGURE 4.** Mohr-Coulomb envelope for fine sand

**TABLE 3.** Summary of direct shear test results

|                      | Coarse Sand | Fine Sand |
|----------------------|-------------|-----------|
|                      | Without Coir| Vertical  | Horizontal | Random | Without Coir | Vertical | Horizontal | Random |
| Angle of friction (°)| 46.45       | 42.27     | 56.64      | 57.36   | 48.54       | 50.96    | 49.07       | 52.44  |
| (Diff.) (%)          | -           | (-9)      | (+22)      | (+23)   | -           | (+5)     | (+1)        | (+8)   |
4. Conclusions
This study aims to determine the performance of sandy soil reinforced with white coir fibres. The effect of coir fibres orientation to the soil shear strength is also investigated. Based on the study, the additional of coir fibres is found to improve the shear strength of sandy soil. The followings are the conclusions of the study:

- Sand reinforced with white coir fibres show improvement compared to sand without coir fibres.
- There is no clear relationship between the effect of white coir fibres orientations to the shear strength of sandy soil.
- Based on the study, there is a good potential for white coir fibres to be used as soil reinforcement material especially as backfilling material for retaining walls.

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