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Laboratory and Numerical Analysis on The Effect of Using Coconut Fibre as Additive Towards Residual Shear Strength of Soil for Slope Construction

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ABSTRACT

Rapid development of Malaysia has caused population growth in urban areas. This includes new development near slope areas. Utilization of waste material such as coconut fiber could help to increase the slope stability. There is a limited study on the effects of coconut fibre as an additive for slope construction. This study aims to compare the shear strength between treated and untreated residual soil and to assess the Factor of Safety (FOS) with coconut fibre addition using Slope/W. A total of 15 shear box samples were set at the same percentage of coconut fibre (1% by weight of soil). Coconut fibre with different length of 15mm, 25mm, 35mm and 45mm was used in the study. It was found that coconut fibre could increase the shear strength. The optimum length of coconut fibre to achieve the maximum friction angle is 35mm, with soil internal friction angle of 52.15°. Moreover, the Slope/w analysis is conducted to analyse the slope's safety factor. The slope's safety factor increased significantly with the addition of coconut fibre. Based on the findings, this research could shed some light on the effect of coconut fibre incorporated in soil as an additive to improve the shear strength. Using coconut fibre in slope stabilisation could reduce slope failure and at the same time could save the environment by utilizing this waste material.

Keywords: *coconut fibre, shear strength, slope stability, residual soil, Slope/W*

1. INTRODUCTION

Soil problems often arise in engineering construction, whether during or after construction. This problem occurs when the soil does not meet the required specifications, such as the carrying capacity of the soil being insufficient in terms of bearing capacity to support the superstructure above it [1]. Hence, many problems will occur after construction if the design is constructed on poor soil. For example, the structure will crack or collapse because of the settlement of the soil. The coastal regions of tropical nations are rich in coconut, and the world produces at least a million tonnes of it annually. Coconut fibre exhibits good rigidity; as a result, it is used to make rope, matting, mats, and geotextiles [2]. On engineered slopes such as highway and railway embankments, coconut matting provides an efficient and long-term solution to soil erosion and landslides.

Coconuts are formed of water and copra that are sealed in a tough shell and shielded from harm by a fibrous husk. The fibre from the coconut husk is mechanically extracted and utilised to

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make a number of goods with a range of uses. Coconut fibre has a high lignin content, making it difficult, durable, and long-lasting. There are two different kinds of it: "bristle" fibre (combed, 20–40 cm long), and "mattress" fibre (random fibers, 210 cm long). The fibre stabilises the soil and boosts its shear strength [3]. For instance, the yarn can be used in packaging, agriculture, construction, and geotextiles to stop soil erosion on embankments [4].

Coconut fibre is effective in stabilizing the lateritic soils. The maximum dry density (MDD) of the soil decreases with the addition of coir and the value of optimum moisture content (OMC) of the soil increases with an increase in the percentage of coir. The compressive strength of the composite soil rises to 1% of coir content, and a further rise in coir quantity results in the reduction of the values. The percentage of water absorption increases with an increase in the rate of coir. Tensile strength of coir-reinforced soil (dry oven samples) increases with an increase in the percentage of coir [5].

There is a limited study on the effects of coconut fibre used in lengths on the shear strength of residual soil for slope construction. Certain adjustments to the coconut fibre soil reinforcement might be beneficial despite the various benefits such as the changes in size and the proportion of coconut fibre used in the soil help strengthen it. Data on the shear strength of untreated and treated samples were analysed using commercial FEM software (Slope/W) to justify the benefit of using coconut fibre as a soil stabilization agent for slope construction. This study aims to compare the shear strength and safety factors between treated and untreated residual soil.

2. MATERIALS AND METHOD

This section consists of experimental works to categorise the characteristic of residual soil, shear strength of treated and untreated residual soil, and analysis of slope's safety factor.

2.1 Basic properties tests

The residual soil was collected from Bukit Mengkuang, Penang, as depicted in Figure 1. It was collected from a depth of 3 metres below the natural ground level. The soil was oven-dried for 24 hours before being used. Different tests were conducted on the soil sample, such as particle density, plastic limit and liquid limit in order to get the physical properties of the soil.

Figure 1: The residual soil collected from Bukit Mengkuang, Penang

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This study employed coconut fibre as an additive to treat the soil. Coconut fibre is included in the group of hard structural fibers. It is an important commercial product obtained from the husk of the coconut. Coconut fibre is removed from the outer husk of the coconut. The fibers are extracted from the shell by combing and crushing, similar to how jute fibre is removed and the coconut fibre is let to dry by itself under the sun. In this study, all samples were treated with the same percentage (1%) but different lengths of coconut fibre. The portion chosen was based on the optimum ratio between soil and coconut fibers by weight of soil and reinforcement material for the shear strength test. The length of the coconut fibre used during this study was 15 mm, 25 mm, 35 mm and 45 mm. Figure 2 shows the coconut fibre used in this study.

Figure 2: Cone Penetration Test result

Specific gravity is the ratio of an object's density to that of a reference substance. This test used a volumetric flask with a stopper and stored in an insulated container for temperature balance. An amount of 20 g dry sand that passed the 200 mm sieve was used to conduct this experiment. The distilled water was poured into the bottle until 3/4 full and shaken for 5 minutes. The density bottle was placed in a partial vacuum for 24 hours to remove the entrapped air. Three samples were prepared for specific gravity to minimize errors and ensure accuracy.

Atterberg limit tests consisted of soils that passed through a test sieve size of 0.425 mm which were prepared for each test according to standard wet or dry techniques according to [6]. The cone penetrometer test was used to obtain the value of the liquid limit. An amount of 150 g soil samples passed through a test sieve 425 μm, and distilled water was used during this testing. To complete a plastic limit analysis, the cone was released for 5s+1s and the difference in dial gauge reading between the beginning and after the cone penetration was recorded. The liquid limit (w_L) was then calculated as the average of the moisture contents. The plastic limit (w_p) is the water content in which the soil begins to show plastic behaviour. The plastic limit test can be done with leftover soil from the thoroughly mixed section of the soil that has been prepared for the liquid limit test. The soil was rolled between the palm on a glass plate to make a thread off to a diameter of 3 mm or (it will?) begin to crumble. The rolling pace should be between 80 and 90 strokes per minute, with a stroke being defined as one complete forward and backward motion of the hand. The plasticity index (I_p) was then calculated as the difference between liquid limit (w_L) and plastic limit (w_p) [7].

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2.2 Water

Water is one of the essential materials included in soil mixing. During this study, distilled water was performed as the binder for the soil mix.

2.3 Direct Shear Box Test

Direct Shear Box Test has been conducted following [8] to determine the shear strength of the soil. Shear strength is the maximum resistance that a material can withstand when subjected to shearing. The shear box is 60 mm x 60 mm in the plan, and the thickness of the box is about 50 mm. A total of 15 samples were prepared during this test.

2.4 Slope/W Analysis

The slope's factor of safety (FOS) was analysed using the Limit Equilibrium Method (LEM). The procedure for the Morgenstern-Price analysis and half-sine function was used. The study of slope stability problems using the computer-based geotechnical software Slope/w provides more understanding of the detailed forces on the distribution of various parameters along the slip surface for the safety factor.

3. RESULTS AND DISCUSSION

3.1 Basic properties of residual soil

According to [6], specific gravity, Gs, is the proportion of the mass in air of a particular volume of soil particles to the mass in air of a similar volume of distilled water. It is a ratio, and therefore, it has no unit, although it is crucial in the determination of the weight-volume relationship of the soil. The soil sample's specific gravity was determined to be 2.68.

The soil sample from the Cone Penetration Test recorded 64.69% moisture content. When the cone penetrometer's dial gauge reading is 20, the moisture content at 64.69% represents the liquid limit value. Based on the oven-dried soil sample, the plastic limit (w_p) was calculated to be 41.54 %. Figure 3 shows the cone penetration graph obtained from Atterberg limit test.

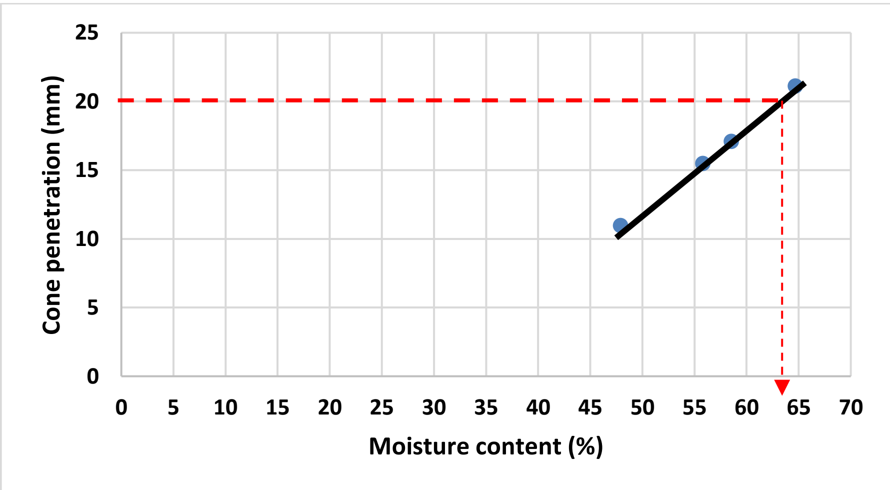

Figure 3: Cone Penetration Test result

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The Plasticity Index is the difference between liquid and plastic limits. From Figure 4 of the plasticity chart, the soil sample was in the group of MH. This is because the liquid limit was 64.69 % which is between 50 %-70 %. Therefore, the soil sample is suitable to be stabilized with coconut fibre since its plasticity index (I_p) is between 15 % and 30 %, which was 23.15 %. According to the British Standard (BS) classification of the soil sample, it can be classified as silt of high plasticity (MH).

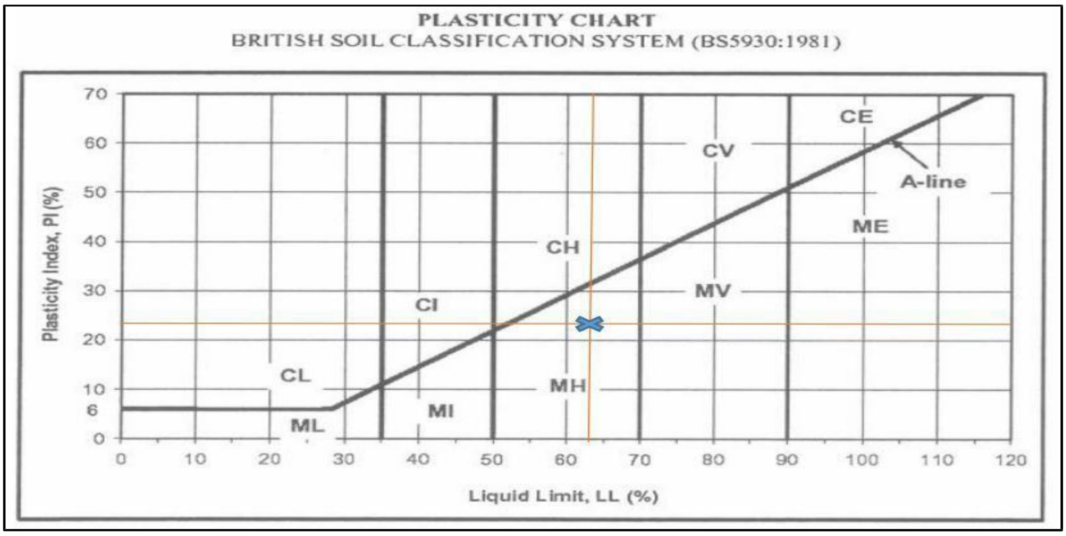

Figure 4: Plasticity Chart

3.2 *Shear strength of the soil*

Direct Shear Box Test was used to determine the shear strength of the treated and untreated soil. Soil reinforced with coconut fibre at different length was found to show the increasing trend of the shear stress but it showed some reduction with 45 mm of coconut fibre, thus it is considered as a failure. The relationship between shear stress and normal stress obtained from various length of coconut fibre is given in Figure 5.

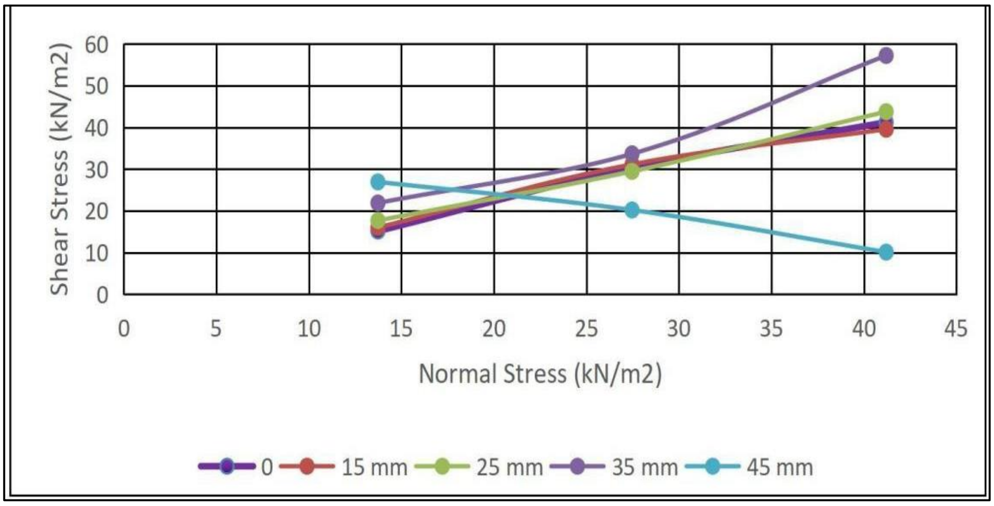

Figure 5: The relationship between shear stress and normal stress for soil reinforced with different length of coconut fibre

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Applying coconut fibers on soil has been found to improve the shear strength parameter which is the internal friction angle. The main factor for this increment is that soil shows brittle failure without coconut fibre. However, the soil is provided with ductility when coconut fibers are used. As previously mentioned, the most crucial idea that underlies this process is the development of friction between the reinforcement and the soil. The shear strength parameter has been observed to increase to a specified reinforcement length limit and then undergo a reduction with an additional fibre length increase. The ideal length of coconut fibre to achieve the maximum friction angle is 35 mm, where the friction angle is 52.15°.

3.3 Slope/W analysis

After learning how coconut fibre improves the shear strength of residual soil through shear box test, it is crucial to comprehend how coconut fibre pre-mixed with residual soil may avoid a global slope failure. There has been a lack of research on the usage of coconut fibre in slope construction, particularly when it has been pre-mixed with residual soil, which is the rationale for why it is significant to the study of coconut fibre. Increased internal friction will result in a corresponding rise in FOS. Nonetheless, a FEM model is still necessary to comprehend the global slope failure mechanism.

From the FEM model, the factor of safety of the slope increases with an increase in internal friction angle. This is due to the larger angle of internal friction values of the admixture with soil. If the FOS if greater than 1.5, the design can be considered as safe. FOS greater than 1.5 is recorded for all the cases. The result from the Slope/W analysis is shown below:

Figure 6 shows the comparison factor of safety result and critical slip surface without pore water pressure and groundwater table. From the figure, the factor of safety (FOS) value obtained for untreated soil was 2.315 while treated soil with 35 mm coconut fibre was 2.981.

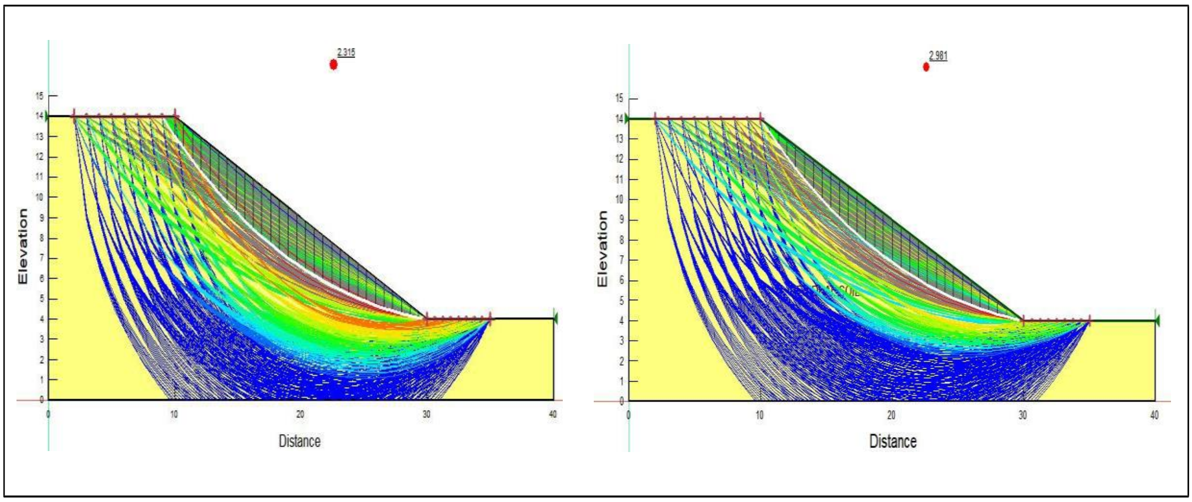

Figure 6: Comparison factor of safety result for untreated soil and treated soil with 35mm of coconut fibre for the condition without pore water pressure and groundwater tab le

Figure 7 shows the comparison factor of safety result and critical slip surface with groundwater table only. From the figure, FOS value obtained for untreated soil was 2.136 while treated soil with 35 mm coconut fibre was 2.782.

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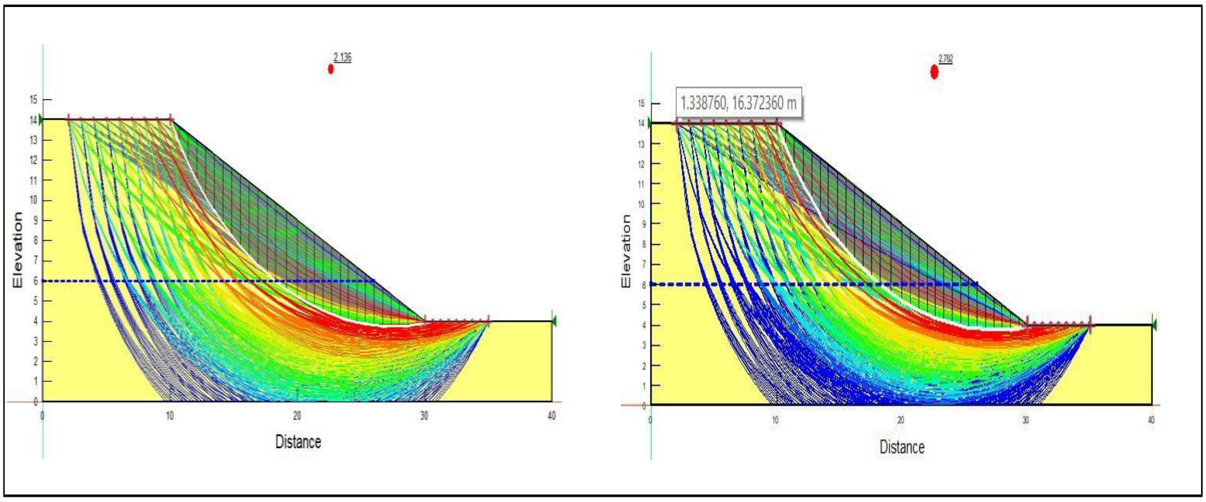

Figure 7: Comparison result for untreated soil and treated soil with 35mm of coconut fibre for the condition groundwater table only

Figure 8 shows the comparison factor of safety result and critical slip surface with pore water pressure only. From the figure, the factor of safety (FOS) value obtained for untreated soil was 1.931 while treated soil with 35 mm coconut fibre was 2.489.

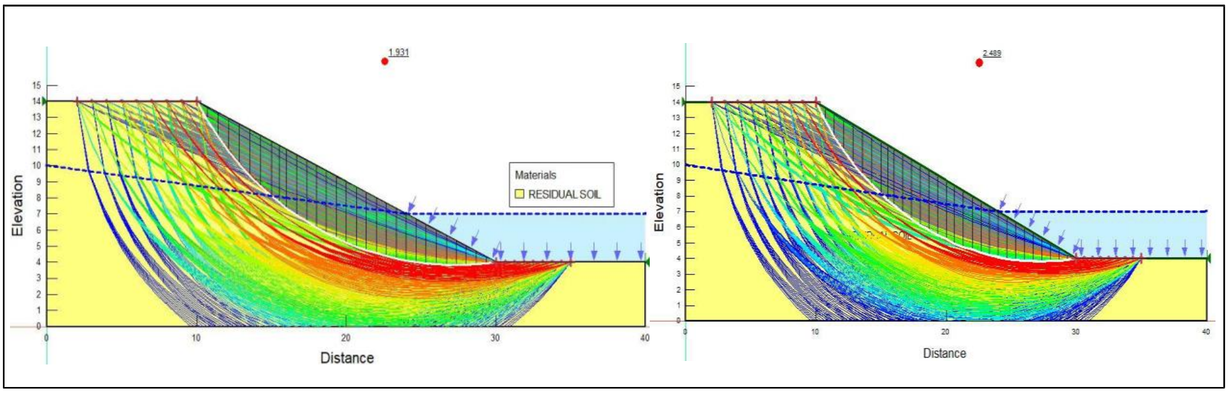

Figure 8: Comparison result for untreated soil and treated soil with 35mm of coconut fibre for the condition pore water pressure only

Table 2 shows the summary of Slope/W result. Due to the greater angle of internal friction values of the admixture with soil, the factor of safety of the slope increased with an increase in internal friction angle. With the use of admixtures, the safety factor dramatically rose. To be deemed safe, all untreated slope construction must have a factor of safety greater than 1.3; however, treated slope construction requires a factor of safety larger than 1.5 [9]. Jabatan Kerja Raya (JKR) mandates a 1.3 minimum factor of safety before permitting the construction of a slope. All slope designs can be regarded as safe because they achieve the minimal value desired by JKR, which is at a FOS value of greater than 1.3. According to prior studies in Semenyih, Selangor, untreated slope FOS was 1.375 [10]. Due to the different conditions imposed on the slope, the FOS is smaller when compared to this study. According to the outcome calculated in the table above, the safety factor will decline as groundwater tables and pore water pressure increase. This is due to the fact that the existence of pore water pressure will weaken the soil and produce stress [11]. Therefore, it can be claimed that increasing FOS by adding coconut fibre results in a significantly safer slope. They can therefore be used on modest slopes like river banks and railroad embankments. Since the untreated slope FOS is more than 1.5, it can

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be used to build slopes. The surcharge is not included in the outcomes, though. So, when the loading is applied to the slope, the safety factor may change. Thus, utilising coconut fibre as a supplement to strengthen the shear strength of soil is the suggested course of action to stabilise the soil. Bear in mind, although the FOS for untreated slope is already considered as safe, there are a lot of uncertainties in slope construction such as overloading and excess rainfall which will result in a greater pore pressure built up behind the slope and the presence of tension crack that may destabilise the slope. This study considers all possible uncertainties that may arise so that a safe slope can be built.

Table 2 : Summary results of Slope/W

Length of coconut fibre	0 mm	35 mm
Angle of friction	43.528	52.152
Cohesion	2.805	2.244
Factor of safety (FOS)		
WITHOUT pore water pressure and groundwater table	2.315	2.981
WITH Groundwater table **ONLY**	2.136	2.782
WITH Pore water Pressure **ONLY**	1.931	2.489

4. CONCLUSIONS

This study aims to compare the shear strength between treated and untreated residual soil and to assess the FOS with coconut fibre addition using Slope/W. Tests on the Direct Shear box showed a slight change in shear strength. It was discovered that the maximum friction angle is 52.15^{o}. The maximum value of shear stress is 57.23 kN/m^2. This maximum shear strength value corresponds to an optimum coconut fibre length of 35mm. From the research, it can be concluded that the maximum shear stress value increased until additional coconut fibre reached 35mm in length but decreased when it reached 45mm in length of coconut fibre, which indicates that the condition was considered as a failure. So, the recommended optimum length of coconut fibre added for the soil sample is 35 mm. Next, this study found that the FOS of the untreated soil is already suitable for slope construction since the FOS is more significant than 1.3; however, the results from Slope/W analysis did not include the surcharge and any other condition. So the FOS may change when the loading is applied on the slope. Therefore, the recommended action to stabilize the soil is by using coconut fibre as an additive to increase the shear strength of the soil.

5. RECOMMENDATIONS

From this study, there are some recommendations listed as below:

- In order to achieve more reliable findings on slope structural behaviour, the test can be conducted on different conditions of soil.
- A physical model test can be conducted on the treated and untreated slope in order to obtain a clearer picture of the shear strength behaviour of the slope.

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- The Slope/W analysis should be done on different condition in order to obtain more accurate FOS results.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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