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Effect of Slope Gradient on the Application of Vetiver Grass for Slope Stabilization

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ABSTRACT

Slope failure has been a common disaster that occurred all over the world and causes infrastructure damage or/and causalities. The application of vegetation as part of slope stability and to control erosion has proven to be cost-effective for stabilizing the surface of the slope. This research describes the unique characteristics of Vetiver Grass as a bioengineering technique to use for stabilizing slopes. The objectives of this research are to measure the mechanical properties and tensile shear strength of roots in soil with different slope gradients (45°, 50°, and 60°). The methodologies of this study were carried out through physical modeling and lab work to analyze the objective. Shear boxes were applied to measure the mechanical properties and tensile strength of roots in soil with different slope gradients. For 21 days, the greatest soil and root shear stress for 45°, 50°, and 60° slope gradients is 13.73 kN/m^2,13.70 kN/m^2, and 13.25 kN/m^2, respectively. Meanwhile, for 30 days, the greatest shear stress of soil with roots at 45°, 50°, and 60° slope gradients is 32.93 kN/m^2, 27.71 kN/m^2, and 27.22 kN/m^2 respectively. Therefore, the 45° slope gradient has the largest shear stress for a period of 21 days and 30 days. According to this research, among slope gradients of 50° and 45°, the Vetiver root for the 60° slope gradient has the greatest value for tensile strength, which is 0.025 kN for 30 days, while for a period of 21 days it is 0.024 kN. However, to have better approach its appropriate if the Vetiver grass planted with slope gradient 45^0 since obtained great Vetiver root strength compared to others slope gradient. This study can be used as a reference to produce a slope stabilization method by using Vetiver Grass as its medium of bioengineering technique in the future.

1. Introduction

According to Mao [1], Malaysia has experienced several landslides throughout the past. As a consequence of these factors, slope failures often occur gradually. Every year during the monsoon seasons, the occurrence of landslides is common in Malaysia. These landslides either cause the closure of roads, affect buildings, or, worse, sometimes cause casualties. A significant portion of rainfall intensity infiltrates the slope surface, depending on the soil permeability [1].

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According to Mao [1], the Public Works Department (JKR) routinely provides vegetative cover on these cut slopes to decrease erosion and preserve susceptible slopes. Consequently, understanding the soil-root interaction is critical for slope monitoring with vegetative coverings. Both soil and vegetation features and attributes should be thoroughly investigated in order to maximize protection and maintenance efforts. Vegetation in the Malaysian environment has the ability to give immediate mechanical shear strength for slope remediation and long-term advantages [1]. Because of its benefits, the bioengineering approach of plant cover was often used to mitigate slope collapse. The approach is less expensive, grows quickly, and is simple to plant [2].

Even after the slope has been covered with these grasses, slope failures continue to occur. The aim of this study is to better understand the interaction between soil and root when it comes to improving the strength of slopes with different slope gradients. The parametric analysis is used to measure the efficiency of the vegetative cover in protecting the slope. Additionally, the slope geometry (45°, 50°, and 60° slope angles) is analyzed in better detail to provide for the impact of construction. The applicable plant is Vetiver Grass, and its characteristics are underlined. This study emphasizes the need for selecting an appropriate vegetation type and researching its properties for slope preservation and protection.

2. Slope Gradient on the Application of Vetiver Grass for Slope Stabilization

A slope was a section of land that was part of a mountain or hill and had to be angled so that it rose more at one end than the other. According to Graf *et al.,* [3], a structure of soil with definite angles is known as a slope. The factors that make the slope more at risk of landslides or slope failure are that the steep slope as well as abundant and continuous rainfall can cause an increase in surface runoff and groundwater flow. Vegetation as a slope cover has several advantages, including environmental friendliness, ease of maintenance, self-sustainability, and a high degree of biodiversity [4]. According to Chopin and Richards [5], the benefits of plants include self-repair, regenerativeness, and adaptability. This will make it easier to manage the vegetation on the slopes. Because vegetation adapts so well, the root structure will extend to fit in with the ground dirt, which serves as the habitat for the plant. The Vetiver System is a developing soil conservation technique and, more recently, a bioengineering tool. Effective application of the Vetiver System, which has major engineering design and construction requirements, necessitates an understanding of every sector [6].

The tap and fibrous root systems are the two basic types of roots. In plant families, the tap root is the main root that grows from the radicle. The tap root system persists as the primary root (tap root), from which lateral roots emerge. Fibrous root system: This root system has a cluster of short, fiber like roots that sprout from the base of the radicle and plumule. Because these roots are sparingly branched, shallow, and horizontally extending, they are unable to provide significant anchoring. The shear strength of soil with Vetiver roots is 78 percent higher than soil without Vetiver roots [7]. The capacity of vetiver grass to improve the factor of safety of embankment slopes against natural stresses has been demonstrated. According to Hashim *et al.,* [8], the morphological qualities of the root system and the tensile strength of individual roots have the greatest impact on stabilizing sloping terrain via soil reinforcement.

According to Islam *et al.,* [9], slope gradient has a significant impact on the amount of surface water runoff and soil sediment loss. When the slope angle exceeds a critical threshold, the rate of soil erosion increases logarithmically. In different climatic zones, the slope gradient can have a varying effect, primarily dependent on annual rainfall. According to Comino and Druetta [10], several of the studies focus on how soil properties change as a result of the presence of vegetative roots. Direct shear testing, for example, was utilized to investigate and determine additional cohesion caused by vegetation reinforcement, and triaxial tests were performed to evaluate both additional cohesion and increased friction angle caused by root reinforcement [11].

3. Methodology

All the experiments were conducted in the Geotechnical Engineering Laboratory, FKAAB, UTHM, according to the relevant standard. The experiments conducted for physical determination are as follows: shear box and root tensile strength test. The shear box test and root tensile strength test were conducted to identify the mechanical properties and tensile shear strength of the root soil. For the root morphology of Vetiver grass, it was observed by naked eyes. The soil model was designed in a rectangular shape with varied slope gradients. This model of soil dimensions of 50 cm x 50 cm x 80 cm is shown in Figure 1. This soil modelling box is built from plywood and solid wood. Three models are utilized in this work to illustrate the varied slope gradients of 45°, 50°, and 60°. The slope gradient angle is used to place the soil into the soil structure modelling. The soil is put into soil modelling based on the 45°, 50°, and 60° slope gradients that have been specified. The vetiver grass was planted for two phases of time, which are 21 days and 30 days inside the modelling box. The scope of work then proceeded with the determination of the root morphology and mechanical properties of the root using soil with varied slope gradients.

Fig. 1. Physical root-soil modelling with varies of slope gradients

4. Results and Discussion

4.1 Root Morphology

The root morphology was determined by using naked eyes. Figure 2 shows the root morphology of Vetiver grass after extracting it from the soil slope sample. It can be seen that the root morphology can be categorized as a fibrous root system.

Fig. 2. Root morphology of vetiver grass

4.2 Direct Shear Strength Test

An experimental test was done with varied vertical loads, which were 10, 20, and 30 kN/m^2. That load was selected to investigate the association between shear strength and the features of the soil sample. The value of optimal moisture content, maximum dry density, and dry unit weight of the soil sample was employed in the direct shear test based on the outcome of the standard proctor compaction test. Table 1 shows the results of the normal stress and shear stress of the soil for slope gradient 45°.

Table 1
Result of normal stress and shear stress of soil for slope gradient 45°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	7.66
5.56	10.57
8.533	14.95

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 1. The graph has been constructed as shown in Figure 3, and the angle of friction for soil with a slope gradient of 45° was determined.

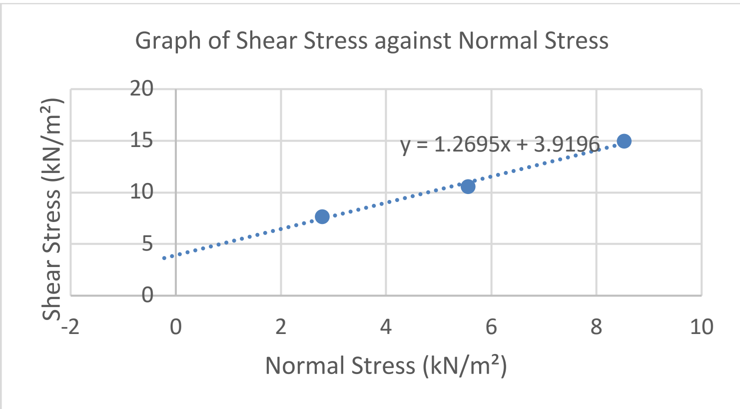

Fig. 3. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion. c =3.92 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 51.77°. Table 2 shows the results of the normal stress and shear stress of the soil for slope gradient 50°.

Table 2
Result of normal stress and shear stress of soil for slope gradient 50°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	6.14
5.56	8.57
8.533	10.21

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table

2. The graph has been constructed as shown in Figure 4, and the angle of friction for soil with a slope gradient of 50° was determined.

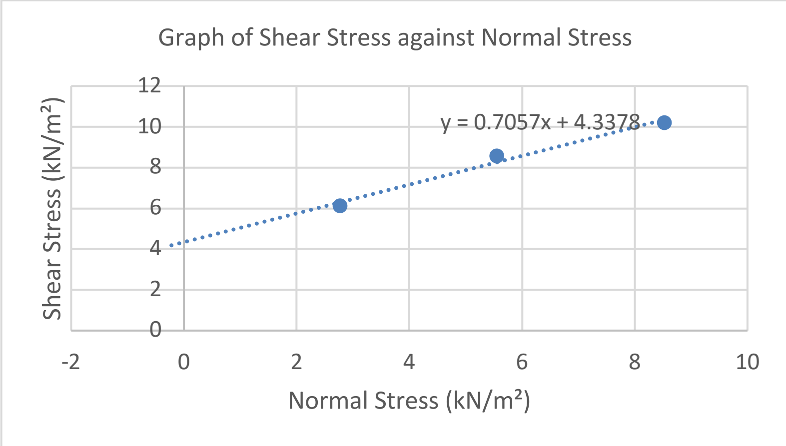

Fig. 4. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 4.34 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 35.22°. Table 3 shows the results of the normal stress and shear stress of the soil for slope gradient 60°.

Table 3
Result of normal stress and shear stress of soil for slope gradient 60°

Normal Stress (kN/m^2)	Shear Stress (kN/m^2)
2.78	7.29
5.56	8.87
8.533	9.48

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 3. The graph has been constructed as shown in Figure 5, and the angle of friction for soil with a slope gradient of 60° was determined.

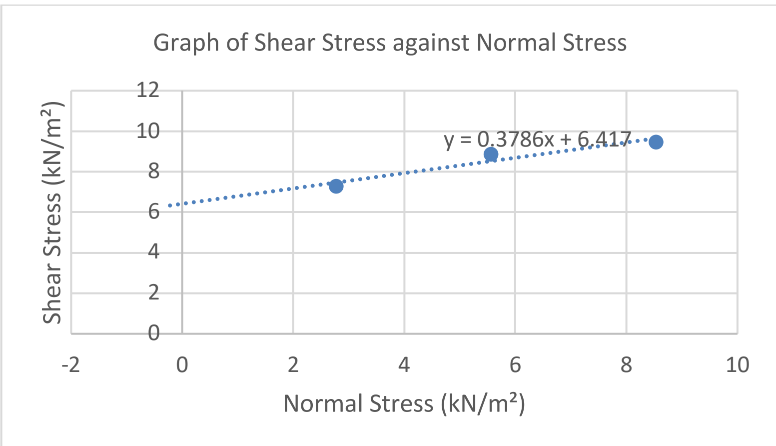

Fig. 5. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 6.42 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 20.74°. Table 4 shows the results of normal stress and shear stress of soil with roots after 21 days for slope gradient 45°.

Table 4
Result of normal stress and shear stress of soil with root after 21 days for slope gradient 45°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	11.67
5.56	12.03
8.533	13.73

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 4. The graph has been constructed as shown in Figure 6, and the angle of friction for soil with roots after 21 days for a slope gradient of 45° was determined.

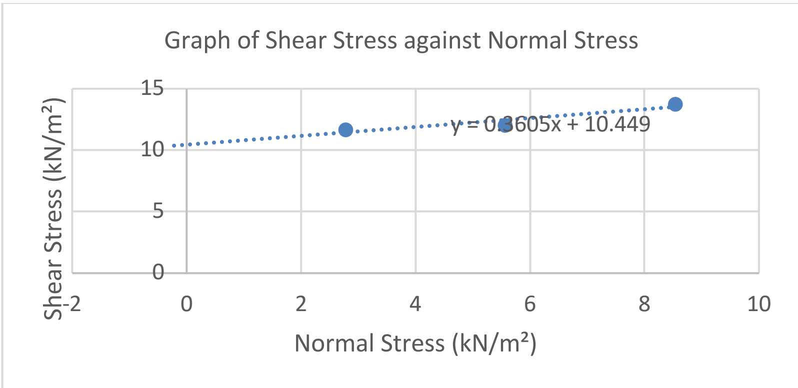

Fig. 6. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 10.45 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 19.82°. Table 5 shows the results of normal stress and shear stress of soil with roots after 21 days for slope gradient 50°.

Table 5
Result of normal stress and shear stress of soil with root after 21 days for slope gradient 50°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	11.55
5.56	11.85
8.533	13.70

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 5. The graph has been constructed as shown in Figure 7, and the angle of friction for soil with roots after 21 days for a slope gradient of 50° was determined.

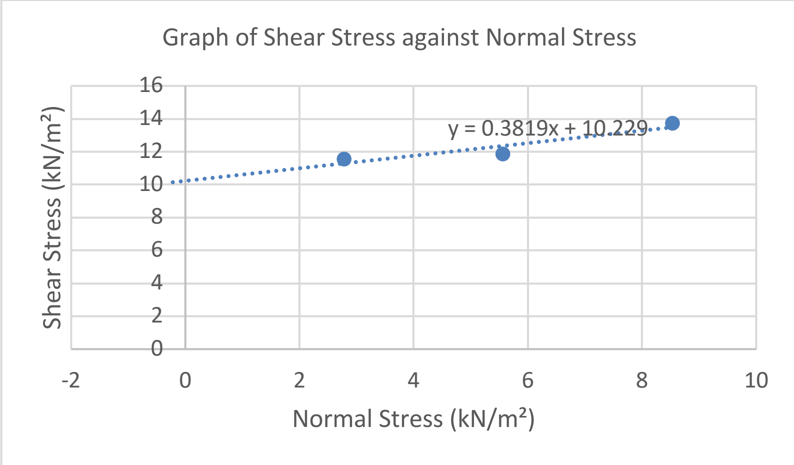

Fig. 7. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 10.23 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 20.90°. Table 6 shows the results of normal stress and shear stress of soil with roots after 21 days for slope gradient 60°.

Table 6
Result of normal stress and shear stress of soil with root after 21 days for slope gradient 60°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	12.52
5.56	12.88
8.533	13.25

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 6. The graph has been constructed as shown in Figure 8, and the angle of friction for soil with roots after 21 days for a slope gradient of 60° was determined.

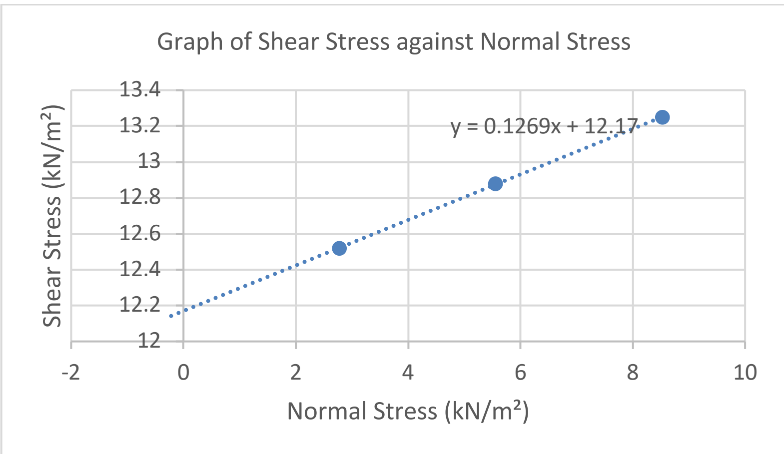

Fig. 8. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 12.17 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 7.23°. Table 7 shows the results of normal stress and shear stress of soil with roots after 30 days for slope gradient 45°.

Table 7
Result of normal stress and shear stress of soil with root after 30 days for slope gradient 45°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	10.82
5.56	28.56
8.533	32.93

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 7. The graph has been constructed as shown in Figure 9, and the angle of friction for soil with roots after 30 days for a slope gradient of 45° was determined.

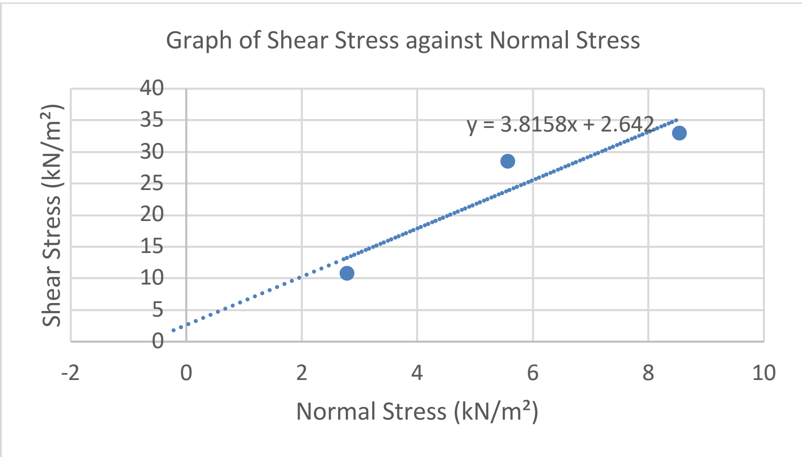

Fig. 9. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 2.64 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 75.31°. Table 8 shows the results of normal stress and shear stress of soil with roots after 30 days for slope gradient 50°.

Table 8
Result of normal stress and shear stress of soil with root after 30 days for slope gradient 50°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	21.27
5.56	23.21
8.533	27.71

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 8. The graph has been constructed as shown in Figure 10, and the angle of friction for soil with roots after 30 days for a slope gradient of 50° was determined.

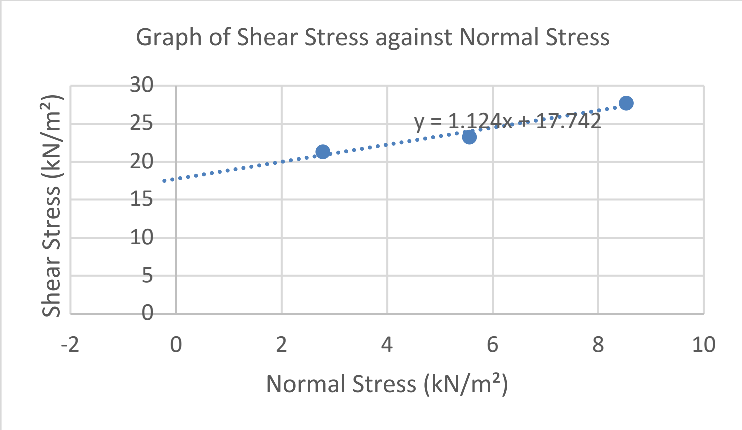

Fig. 10. Graph of shear stress against normal stress

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 17.74 kN/m^2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 48.34°. Table 9 shows the results of normal stress and shear stress of soil with roots after 30 days for slope gradient 60°.

Table 9
Result of normal stress and shear stress of soil with root after 30 days for slope gradient 60°

Normal Stress (kN/m²)	Shear Stress (kN/m²)
2.78	21.27
5.56	24.06
8.533	27.22

In order to obtain the angle of friction, a graph of shear stress against normal stress was plotted. The shear stress was calculated from the results. The data has been recorded and tabulated in Table 9. The graph has been constructed as shown in Figure 11, and the angle of friction for soil with roots after 30 days for a slope gradient of 60° was determined.

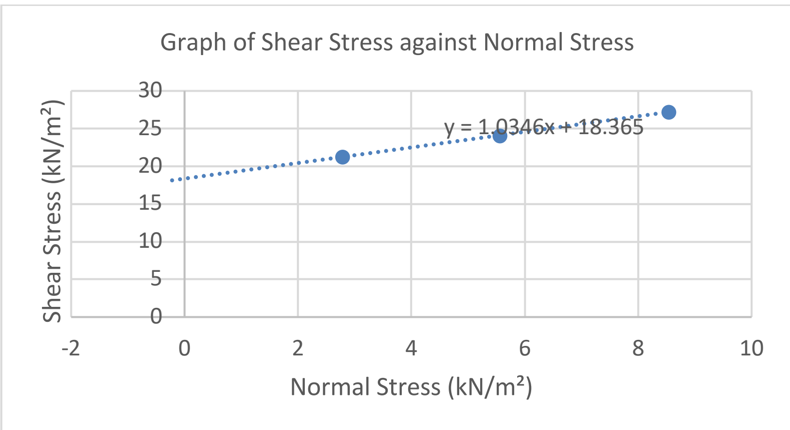

Fig. 11. Graph of shear stress against normal stress.

From the graph, the intersection of the straight line does not pass through zero. Therefore, the cohesion is c = 18.37 kN/m2. Besides, the angle of friction is obtained from the plot. From the calculation, the angle of friction of the soil sample is 45.97°.

Based on the study, it can be summarized that the strength of soil without the presence of the root of Vetiver grass is weaker compared to that of soil with the support of the Vetiver grass root system. Moreover, based on the angles of the slope gradient, which are 45°, 50°, and 60°, it also affects the strength of the soil, either with or without a root. The shear strength of soil without a root, with the highest shear strength for slope gradients of 45°, 50°, and 60°, is 14.95 kN/m^2, 10.21 kN/m^2, and 9.48 kN/m^2. So, a slope gradient of 45° has the highest value of shear strength. For 21 days, the highest shear stress of soil and root for slope gradient 45°, 50° are 13.73 kN/m^2 and 60° is 13.25 kN/m^2. So, the slope gradients of 45° and 50° have the highest shear stress for 21 days. For 30 days, the highest shear stress of soil with roots for slope gradients of 45°, 50°, and 60° is 32.93 kN/m^2, 27.71 kN/m^2, and 27.22 kN/m^2. So, the slope gradient of 45° has the highest shear stress for a 30-day period. Because vetiver grass has strong roots, it can adhere securely to slopes, increasing the slope's shear resistance. This study indicates that the roots of Vetiver grass could function as slope-stabilizing reinforcement.

4.3 Tensile Test

As illustrated in Figure 12, the tensile strength towards the root system was shown using a bar graph. In this tensile test, 10 root samples are evaluated for each gradient of slope. The results were determined using two distinct time periods: 21 days and 30 days. The blue bar corresponded to 21 days, whereas the red bar corresponded to 30 days. According to the results that have been analyzed, the 30-day-old root has high tensile strength. For a 45-degree slope gradient, the tensile strength for 30 days is 0.015 kN, while for 21 days it is 0.011 kN. For a slope gradient of 50 degrees, the tensile strength for 30 days is 0.020 kN, and for 21 days, it is 0.016 kN. For a 60-degree slope gradient, the tensile strength for 30 days is 0.025 kN, and for 21 days it is 0.024 kN. According to this study, the Vetiver root with a 60° slope gradient had the maximum tensile strength compared to slope gradients of 50° and 45°.

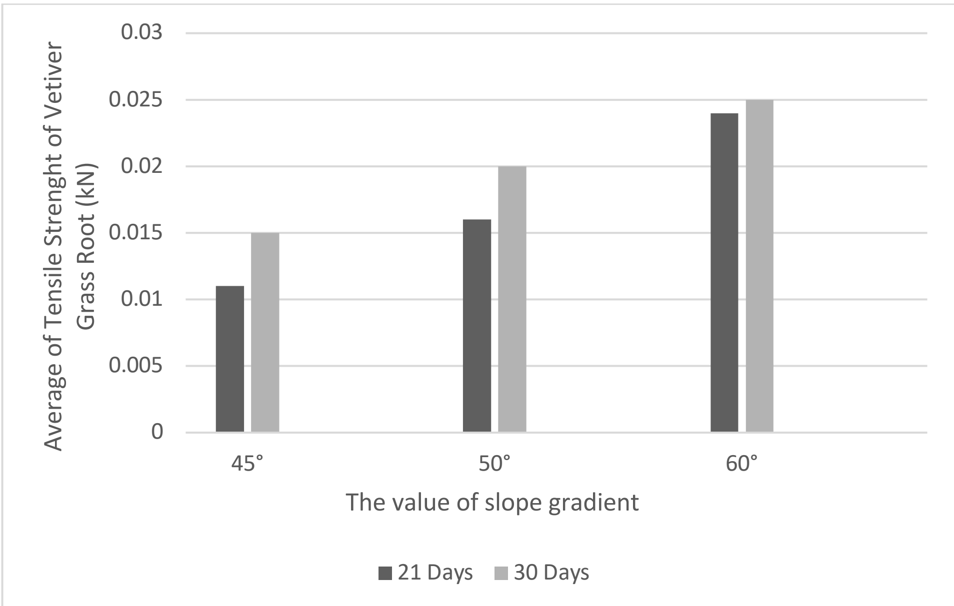

Fig. 12. Result of average of tensile strength of vetiver grass

5. Conclusions

According to the findings of this study, the presence of Vetiver grass roots greatly affected the soil's strength. Due to the presence of highly erodible residual soils and severe wet weather conditions, Malaysia has made significant strides in the use of vetiver grass for erosion control and slope stabilization. For 21 days, the greatest soil and root shear stress for 45°, 50°, and 60° slope gradients is 13.73 kN/m^2,13.70 kN/m^2, and 13.25 kN/m^2, respectively. While for 30 days, the greatest shear stress of soil with roots at 45°, 50°, and 60° slope gradients is 32.93 kN/m^2, 27.71 kN/m^2, and 27.22 kN/m^2 respectively. Therefore, the 45° slope gradient has the largest shear stress for a period of 21 days and 30 days. According to this research, among slope gradients of 50° and 45°, the Vetiver root for the 60° slope gradient has the greatest value for tensile strength, which is 0.025 kN for 30 days, while for a period of 21 days it is 0.024 kN. However, to have better approach its appropriate if the Vetiver grass planted with slope gradient 45° since obtained great Vetiver root strength compared to others slope gradient. As a summary, slope gradient is one of the factors influence the Vetiver root strength.

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