Selection Of Wild Plant Species As Soil Bioengineering For Soil Slope Stability In South Kalimantan Indonesia To Overcome Shallow Landslides

Selección De Especies De Plantas Silvestres Como Bioingeniería Del Suelo Para La Estabilidad De La Pendiente Del Suelo En Kalimantan Del Sur, Indonesia, Para Superar Deslizamientos De Tierra Poco Profundos

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ABSTRACT

Soil Biotechnology is a cost-effective and environmentally friendly alternative method to improve soil slope stability, as well as to control slope surface erosion. Vegetation, which is part of soil bioengineering, can indirectly affect slope stability through its influence on fluctuations in soil water content. Furthermore, it has the ability to control the adverse effects of rainfall on the slope surface and can draw water from the soil through evapotranspiration. These conditions can reduce soil moisture and pore pressure, increase soil shear strength, and increase resilience. Vegetation roots tend to increase soil permeability, infiltration, and moisture content. In this research, vegetation was used for soil bioengineering in the form of plants that grow wild and are easily found in the mainland of South Kalimantan Province, in Indonesia. These plants include Teki, Paitan, Elephant, Setaria, and Alang-alang grasses. This research aims to determine the effects of different plants and their root types on the surface of the soil slope, especially to determine changes in the value of the soil shear strength, the resisting moment of slope failure, and the safety factor of the slope's stability. Accordingly, soil testing and the analysis of slope stability were carried out using the direct shear test and the Bishop methods respectively with the help of the 2022 version of the Geo5 computer application program. The results showed that the use of Elephant grass vegetation on the slope surface was able to increase the shear strength of the soil, the landslide resisting moment, and the safety factor for slope stability which was better than other types of vegetation.

***Keywords**: Soil Bioengineering, soil shear strength, resisting moment, safety factor of slope stability*

RESUMEN

La biotecnología del suelo es un método alternativo rentable y respetuoso con el medio ambiente para mejorar la estabilidad de los taludes del suelo, así como para controlar la erosión de la superficie de los taludes. La vegetación, que forma parte de la bioingeniería del suelo, puede afectar indirectamente la estabilidad de las pendientes a través de su influencia en las fluctuaciones del contenido de agua del suelo. Además, tiene la capacidad de controlar los efectos adversos de la lluvia en la superficie de la pendiente y puede extraer agua del suelo a través de la evapotranspiración. Estas condiciones pueden reducir la humedad del suelo y la presión de los poros, aumentar la resistencia al corte del suelo y aumentar la resiliencia. Las raíces de la vegetación tienden a aumentar la permeabilidad del suelo, la infiltración y el contenido de humedad. En esta investigación, la vegetación se utilizó para la bioingeniería del suelo en forma de plantas que crecen de forma silvestre y se encuentran fácilmente en el continente de la provincia de Kalimantan del Sur, en Indonesia. Estas plantas incluyen pastos Teki, Paitan, Elephant, Setaria y Alang-alang. Esta investigación tiene como objetivo determinar los efectos de diferentes plantas y sus tipos de raíces en la superficie del talud del suelo, especialmente para determinar los cambios en el valor de la resistencia al corte del suelo, el momento resistente de falla del talud y el factor de seguridad de la estabilidad del talud. . En consecuencia, el ensayo de suelos y el análisis de estabilidad de taludes se realizaron mediante el ensayo de corte directo y los métodos de Bishop respectivamente con la ayuda de la versión 2022 del programa de aplicación informática Geo5. Los resultados mostraron que el uso de vegetación de pasto elefante en la superficie de la pendiente pudo aumentar la resistencia al corte del suelo, el momento de resistencia al deslizamiento y el factor de seguridad para la estabilidad de la pendiente, que fue mejor que otros tipos de vegetación.

Palabras clave: Bioingeniería de suelos, resistencia al corte del suelo, momento resistente, factor de seguridad de estabilidad de taludes

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1. INTRODUCTION

Soil change is a dynamic system that occurs when large amounts of soil, rock or a combination of the two transform into a new state. An example of such change is the landline, which usually occurs when there is a disturbance that affects the shear strength and shear stress of the soil. One of the factors that often affect soils is high and intense rainfall over a long period. Indonesia is a country with areas where landslides are relatively frequent, and this was caused by the country's climate change. Therefore, it is necessary to handle and overcome climate change in order to reduce the occurrence of landslides.

The factor of safety of the slopes is a very important issue in geotechnical engineering [1]. The stability of a soil slope is determined by the nature and magnitude of the load, which is the driving force of landslides, and the resistance, which depicts the strength of the vegetation root system when soil biotechnological methods are used. Vegetation, as a part of soil bioengineering, can indirectly affect a variety of soil components including slope stability, through its influence on fluctuations in soil water content. Furthermore, it can control the influence of rainfall on the slope surface and it is also able to draw water from the soil through evapotranspiration. These conditions can increase the soil's moisture, pore pressure, shear strength, resistance permeability, and infiltration. Vegetation can also improve slope stability by influencing hydrological processes that determine stability conditions and directly modifying the soil's mechanical properties [2]. In many cases, vegetation makes a significant contribution to slope stability and promises an economical solution [3].

A research on the behavior of vegetation root reinforcement due to the presence of water is consequently needed to support the modeling of slope failure caused by rainfall. Subsequently, the presence of vegetation root reinforcement had been modeled as an additional soil cohesion component in slope stability analysis [4-7]. Punetha et al stated that soil bioengineering is a cost-effective and environmentally friendly alternative method to improve soil slope stability and surface erosion [8]. In this research, it was proven that there are at least 3 phenomena of failure of the soil root system on the slope surface, adhesion, tensile, and progressive failures in slope stability systems utilizing soil bioengineering.

According to Azis, the vetiver root vegetation type is better than other types of vegetation roots in terms of the ability to increase the safety factor of slope surface stability [9]. Furthermore, poorly graded sand and sandy silt soil were used to develop a medium for growing vetiver grass.

Various methods of soil bioengineering have been carried out by researchers. Some of these methods include layering shrubs on the surface of the slopes, using stone gabions combined with vegetation, and so on. Furthermore, efforts to obtain vegetation types that can grow in various weather conditions and various soil types, as well as contribute greatly to increasing slope stability are indispensable in the soil bioengineering method. One of the efforts presently gaining popularity is the conservation of sloped soil by utilizing body parts from vegetation. In this research, however, a type of vegetation that grows wild, has the capability of surviving in various weather conditions and soil types, as well as having a complex physical root system was used.

In the research used vegetation as soil bioengineering, specifically Teki, Paitan, Elephant, Setaria, and Alang-Alang grasses, which are easy to find and grow in the wild of South Kalimantan Province, in Indonesia. This study aims to determine the effects of various plant roots on the soil surface of the slope, especially to determine changes in the value of soil shear strength, slope failure resisting moment, and the safety factor of slope stability. Accordingly, soil testing and analysis of slope stability were carried out using the direct shear test and the Bishop methods respectively with the help of the Geo5 version 2022 computer application program [10].

This research was conducted after reviewing several results that are in line with the results obtained from previous works [11] regarding the role of vegetation on slope stability. Several research have been conducted with the to determine the effects of vegetation roots from various types of plants on soil parameters, especially its shear strength. Additionally, landslide events is evidence that a soil's structure has changed shape hence it is no longer able to withstand the load and water pressure [12]. Based on the sliding depth, landslide events can be distinguished as follows.

The collapse that occurs during the deformation indicates that the shear resistance applied to the soil has reached its critical value, therefore the soil pores are easily destroyed and soil aggregation is very weak. This theory is known as the Mohr Columb theory [13-14], stating that the shear stress in the soil has a functional relationship with the cohesion and friction between soil particles, hence:

$$\tau = c + \sigma \tan\phi \quad (1)$$

Description:
τ = soil shear stress
c = cohesion
σ = normal voltage
ϕ = inner shear angle

Table 1. *Landslide Depth Classification (after USSR State Committee on Construction, 1981)*

NO	Landslide Type	Depth (m)
1.	Surface Slide	<1,5
2.	Shallow Slides	1,5-5,0
3.	Deep Slides	5,0-20
4.	Very Deep Slides	>20

The soil bioengineering method involves the utilization of living plant materials. In handling slope failure or landslides, this method is a conservation measure that is carried out by covering the slope surface with plants, to reduce infiltration that occurs in the soil [15-16]. The influence given by plants consists of a hydrological mechanism in the form of evaporation and absorption by leaves and roots, hence the transpiration process occurs which can reduce positive pore water tension. It also consists of a mechanical mechanism by which the plants add strength to the soil by utilizing their ability to grip/anchor their roots into the soil layer, and the ability of roots to bind soil particles together, thereby reducing erosion as illustrated in Figure 1. Other things that affect the strength of the plant used was the size of its roots, as well as the root content at a location, and the plant's ability to grow in the soil.

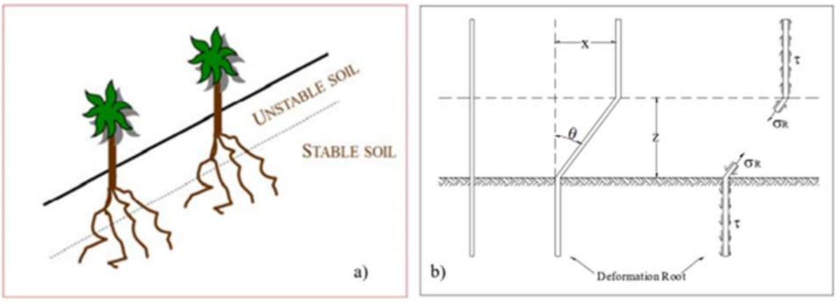

Figure 1 *Schematic of the Effect of Plant Roots on Soil Slope [2].*

2. RESEARCH METHODS

2.1. MATERIAL

In this research, 5 types of vegetation were used, namely: Paitan grass (*Axonopus compressus*), Teki grass (*Cyperus rotundus L.*), Elephant grass (*Pennisetum purpureum*), Setaria grass (*Setaria sphacelata*), and Alang-alang grass (*Imperata cylinder*). The visualization of each type of vegetation is shown in Figures 2.a to 2.e. All these types of vegetation grow wild, can survive under various weather and environmental conditions, and can grow on various types of soil. different plants used in this research were taken from South Kalimantan Province and Central Kalimantan Province, Indonesia.

The results of testing the physical properties of the soil with the type of vegetation are shown sequentially and graphically, with a gradation curve of the grain size of the soil as a vegetation growth medium, in Table 2 and Figure 3 respectively.

Based on the results obtained from these tests, the highest water content value was found in the soil overgrown with Elephant grassroots, which was 32.68%, while the lowest was found in the soil with Alang-alang grassroots at 10.08%.

Figure 2a *Visualization of Paitan Grass (Axonopus compressus), has a root type W, and has a root length of up to 1m*

Figure 2.b *Visualization of Teki Grass (Cyperus rotundus L.), has a root type W, and has a root length of up to 4m*

Figure 2.c *Visualization of Elephant Grass (Pennisetum purpureum), has root type R, and has a root length of up to 4.5m*

Figure 2.d *Visualization of Setaria Grass (Setaria sphacelata), has root type M, and has a compound root length of 40-60 cm*

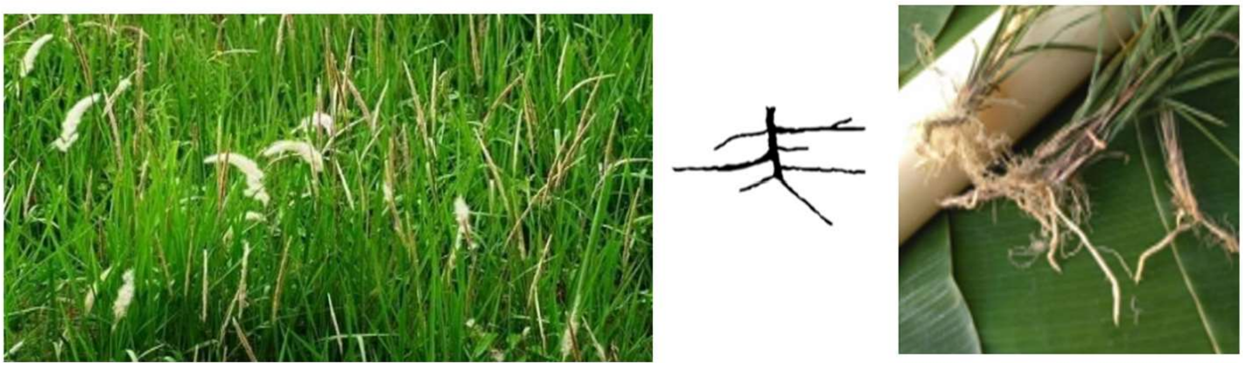

Figure 2.e *Visualization of Alang-alang Grass (Imperata cylindrical), has root type H, Fiber, and has a compound root length of 40cm*

Furthermore, the results of the Atterberg limit test showed that the soil overgrown with Paitan grassroots had a liquid and plasticity limit value of 66.11% and 38.64% respectively, and was classified as Organic clay (OH) based on the USCS classification system.

The soil with Teki grassroots had a liquid limit value of 81.82% and a plasticity limit of 64.58% and was included in the Inorganic Silt (MH) soil type based on the USCS classification system. Following this, soil overgrown with Setaria grass had a liquid and plasticity limit of 27.38% and 21.51% respectively, and was classified as Silty or clayey fine sand (ML) while soils overgrown with Elephant grass had a liquid and plasticity limit of 40.93% and 23.98% and was classified as Inorganic clay low (CL) soil. Lastly, the soil overgrown with Alang-alang grass's roots had a liquid limit of 34.2% and a plasticity limit of 20.43% and belongs to the Inorganic clay low (CL) soil.

2.2. TESTING PROCEDURE

The testing procedure was divided into 2 stages. Phase 1 involves testing the soil's physical properties to determine its suitability for growing all the types of vegetation observed. In Phase 2, the soil's mechanical properties were tested in the form of direct shear tests in the laboratory for each variation of soil and vegetation. During this test, the parameters of cohesion and the angle of friction on the soil and its vegetation were obtained. Figure 4 shows the schematic of the direct shear test equipment used in this research. The shear test method refers to So and Okada [16].

Table 2: *Test Results of Soil Physical Properties and Vegetation*

Parameter / Jenis Vegetasi		Paitan Grass	Teki Grass	Setaria Grass	Gajah Grass	Alang-Alang Grass
Root of Diameter (mm)		0.700	0.470	0,800	1,400	0,960
Ratio of Root Content (%)		14.000	12.000	38.000	24.000	16.000
Specific Gravity (Gs)		2.371	2.428	2.545	2.577	2.580
Water Content (W)	%	65.690	54.500	20.690	32.680	10.080
Volume Weight (g)	gr/cm³	1.570	1.589	1.857	1.836	2.079
Gravel (>2mm)	%	0.71	0.25	2.47	0.47	13.05
Coarse Sand (0.6-2.00mm)	%	0.03	0.09	5.68	4.30	5.50
Medium Sand (0.2-0.6mm)	%	0.01	0.10	18.45	11.97	4.36
Fine Sand (0.05-0.2mm)	%	1.39	1.60	22.34	20.57	12.49
Silt and Clay (0.002-0.05mm)	%	78.47	49.21	40.90	50.67	52.35
Clay (<0.002mm)		19.39	48.75	10.16	12.03	12.25
No. 10 (2.00mm)	%	99.29	99.75	97.53	97.73	86.95
No. 40 (0.425mm)	%	99.25	99.63	88.53	92.73	80.25
No. 200 (0.0075mm)	%	99.21	99.37	55.23	67.13	65.51
Liquid Limits (LL)	%	66.11	81.82	27.38	40.93	34.21
Plastic Limit (PL)	%	38.64	64.58	21.51	23.98	20.43
Plasticity Index (PI)	%	27.48	17.23	5.88	16.95	13.78
USCS Classification	USCS	OH	MH	ML	CL	CL

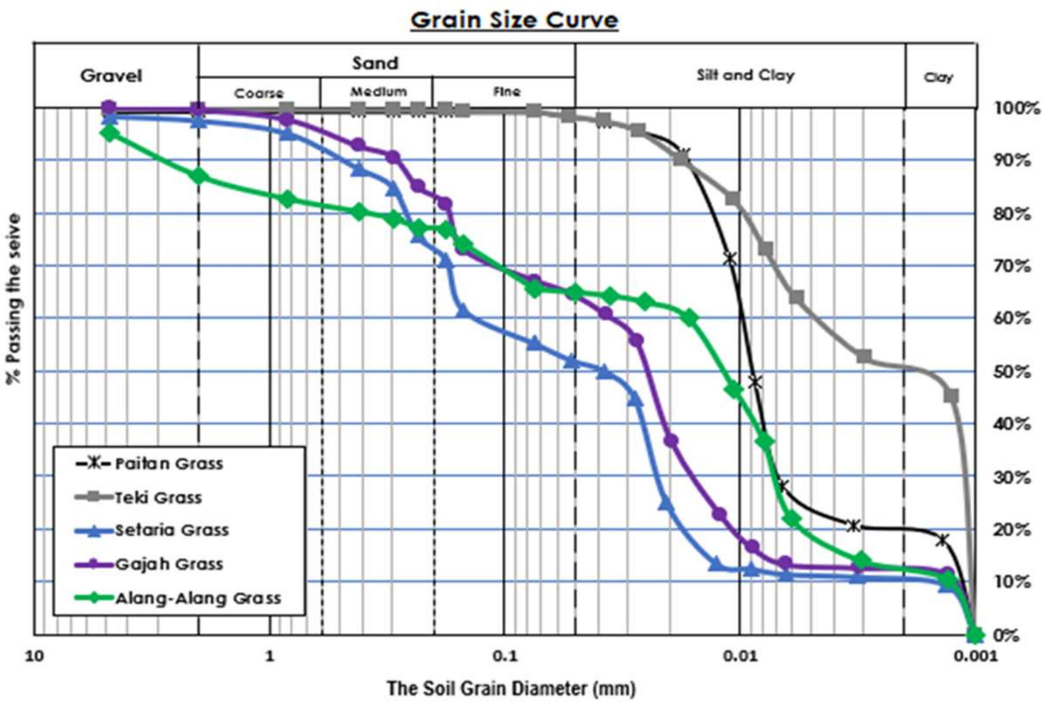

Figure 3: *Graph of Soil Grain Distribution with 5 Types of Plant Roots*

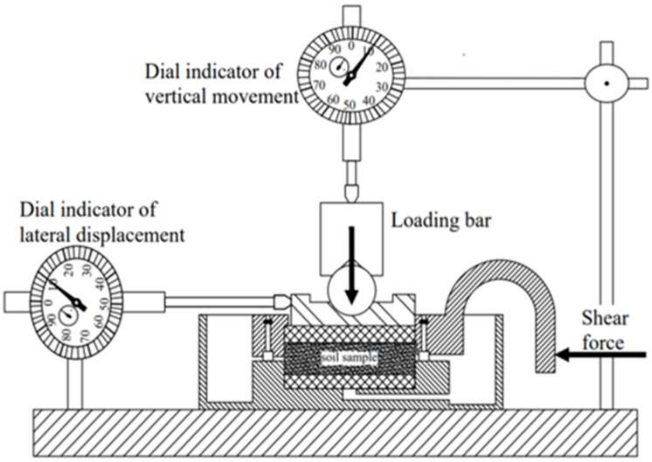

***Fig. 4**: Scheme for the Direct Shear Test Tool*

All parameters of the soil and vegetation's physical and mechanical properties were obtained from the results of direct shear testing and index properties testing, then these quantities were used as input values in the slope modeling with vegetation using the Geo5 version 2022 computer software application. Especially the soil shear parameters such as cohesion and internal friction angle, which is an added value from the previous parameter. This is the research of the behavior of vegetation roots that is strengthened when water is present, and this is necessary to assist the modeling of slope failure due to rainfall.

The results of this modeling analysis produce a slope safety factor in conditions before and after the presence of vegetation on the slope's surface. Furthermore, the value of the retaining moment of slope stability was also obtained from various variations of vegetation. An analytical investigation was conducted to determine how each variation's physical and mechanical parameters relates to each other as well as how plant type and slope resisting moments relate to one another.

3. RESULTS AND DISCUSSION

Relationship between Vegetation Type to Cohesion Parameters and Friction Angle in Soil

The relationship between the vegetation type and the cohesion parameters as well as the angle of friction in the soil is shown in Figures 5 and 6, and the value of the friction angle in the soil was the largest compared to the roots of other grass vegetation. The smallest value of cohesion and internal friction angle was found in the roots of the Setaria grass vegetation. This was due to the differences in the diameter and length of the grass's roots. However, the Elephant grass had a larger diameter and length of grass stems as well as a higher root density compared to other types of grasses observed in this research.

This shows that the dimensions and density of vegetation roots embedded in the soil can play an important role in increasing the cohesion parameters and internal friction angles through the interaction of soil and vegetation roots. This is in line with the results of Tengbeh's research [17], where it was stated that the cohesion value increases with increasing root density. Vergani et al and Gray et al also stated that the strengthening of vegetation roots in the soil can increase the soil's shear strength as long as the root and soil networks are fused in one bond, and this is often referred to as "root cohesion" which is an important factor that is relevant to the mechanism of the bonding process [18-19].

Relationship of Vegetation Type to Soil Shear Strength

The soil's shear strength parameters overgrown with various vegetation produced different values. As shown in Figure 7 below, the value of the soil's shear strength varied for each soil with the type of vegetation. Based on the graphical image, soils with vegetation roots of the Elephant grass type produce the highest shear strength value compared to the roots of other vegetation types.

Furthermore, based on the results of mechanical properties testing, the soil with Elephant grass's roots had the highest friction angle and cohesion value of 0.788 kg/cm^2 and 27.19° respectively, hence it had the highest shear strength of 141.863 kg/cm^2. The increase in the shear strength of the soil is mainly through an increased cohesion which was caused by the presence of vegetation whose roots performs the binding action or the composite pattern and the adhesion of soil particles to the root medium [20].

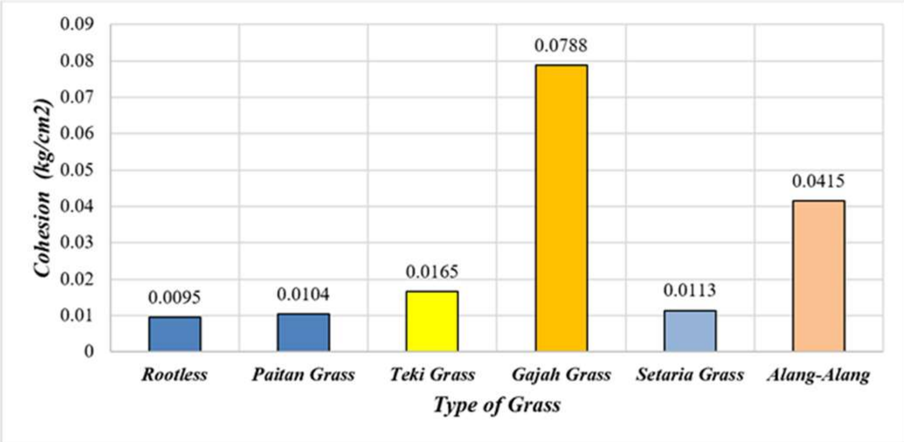

***Figure 5**: Graph of the Relationship between Soil Cohesion and Plant Root Types*

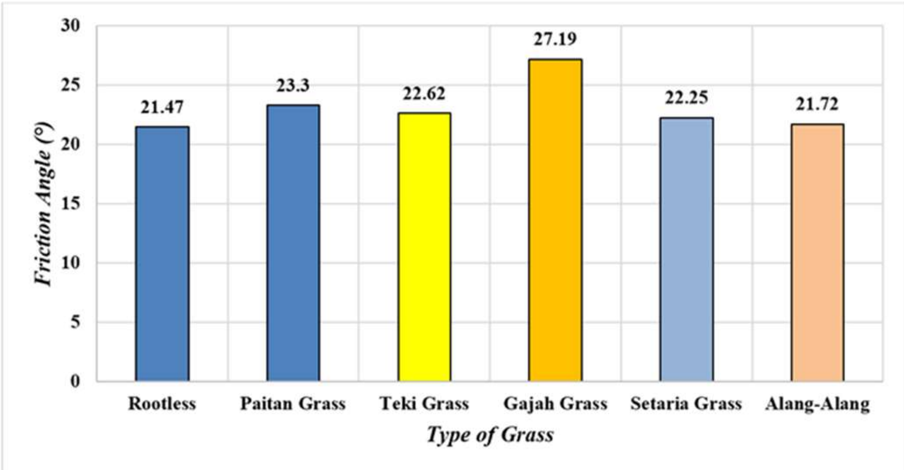

***Figure 6:** Graph of Inner Friction Angle Relationship and Type of Plant Root*

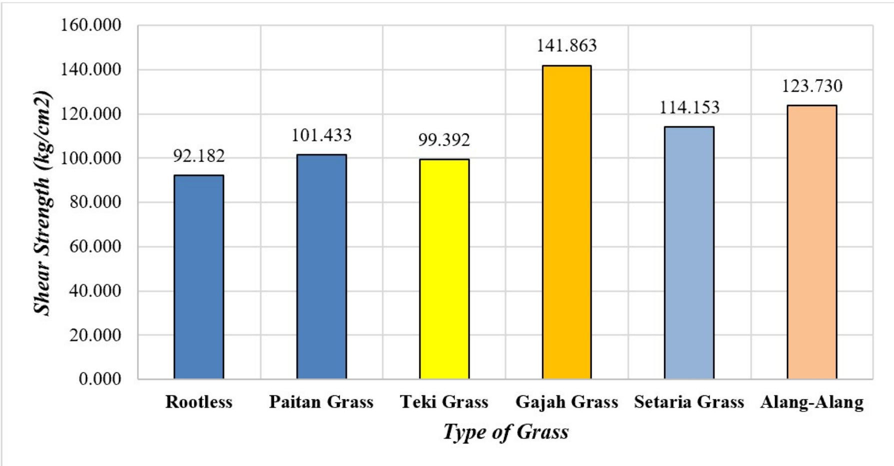

***Figure 7:** Graph of Soil Shear Strength Relationship with Plant Root Types*

Effect of Vegetated Soil Moisture on Shear Strength

Figure 8 is a graphical representation of the relationship between the water content of each soil overgrown with different vegetation and the shear strength of the soil. Based on the figure, it can be seen that the greater the value of the soil water content, the higher the shear strength of the resulting soil.

When viewed from the point of the water content of each soil having different vegetation types, the value of the shear strength of vegetated soil was not dominantly influenced by the value of the water content. However, the Elephant grass vegetation produced higher soil shear strength than other types of vegetation, although the value of the soil moisture content was not minimum. This condition indicates that the physical factor of grass vegetation, especially the diameter and length of the root stem, has a more significant effect on the shear strength of the resulting soil compared to the factor of soil water content.

Based on the research conducted by [21], it was stated that the optimum water content value that can increase the shear strength of the soil is about 32%. This is in line with the results of this research where the soil with Elephant grass has a water content of 32.68%, hence it had the highest shear strength value of 141.863 kg/cm2. Furthermore, Brenner [22] also stated that soil moisture decreases due to the presence of vegetation in the soil which can reduce pore water pressure on the soil slope and then increase slope stability. According to Wang et al [23], the effects of water content on soil reinforcement with plant roots resulted in changes in the interfacial friction between the soil and the grasses used during precipitation. It was also found that grass can delay the initiation of landslides, but the effect diminishes with increasing soil moisture content.

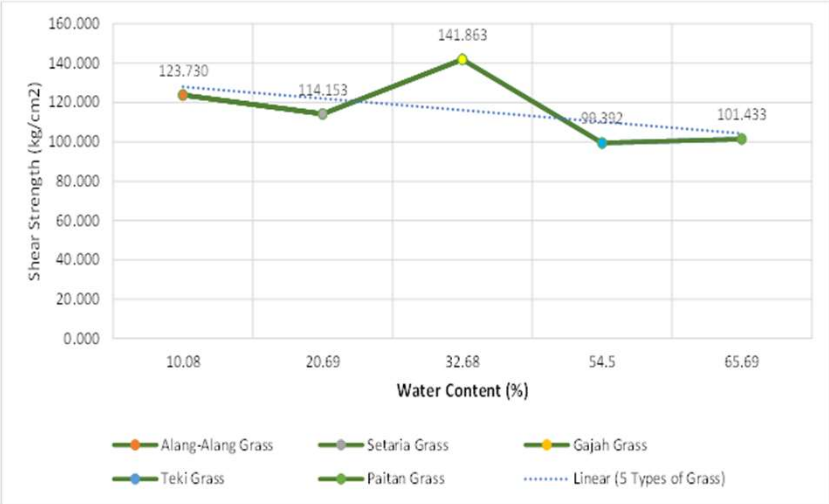

Figure 8: *Relationship between Moisture Content and Shear Strength for 5 Types of Vegetation*

Effect of Vegetated Soil Root Diameter on Shear Strength

The diameter of the vegetation roots also contributed to the soil's shear strength value. It is depicted on the curve pattern shown in Figure 9 below. Based on the graphical image, it can be seen that the Elephant grass's root resulted in the highest soil shear strength value compared to other types of vegetation roots. This is in accordance with the aforementioned explanation where the roots of the Elephant grass vegetation had a larger root diameter than the others.

Effect of Vegetation Root Type on Safety Factor and Slope Stability Retaining Moment

In this research, the slope modeling was conducted using subgrade soil, which is a type of laterite soil commonly used for road construction in South Kalimantan, then simulations were carried out on the slope surface with the different vegetation types. They include Paitan, Teki, Setaria, Elephant, and Alang-alang grasses. Furthermore, the Slope Stability Safety Factor and Retaining Moment values were obtained with the help of the 2022 version of the Geo5 computer software application. Figure 10 shows some result examples of running the 2022 version of the Geo5 computer software application on the soil slopes overgrown with one type of vegetation on the slope surface.

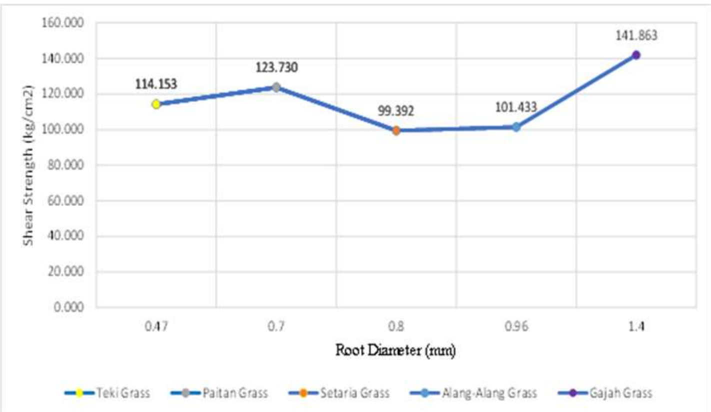

Figure 9: *Relationship of Root Diameter and Shear Strength for 5 Types of Vegetation*

In Figure 11, it can be seen that the slope stability safety factor increased after the vegetation was planted on the slope surface. The graph shows that the safety factor (FS) of the slope increased to 25.51 after the presence of Elephant grass vegetation on the slope surface compared to when the vegetation was absent, in which case FS was 19.29. Hence, the slope's stability safety factor increased by 24.4% after the slope surface was overgrown with Elephant grass. The increase in FS value obtained with the vegetation of other grass types was insignificant compared to their absence on the slope surface. This is in line with the results of the research conducted by [24-27], where it was stated that the higher the concentration of fibrous roots, the stronger the plant holds the soil.

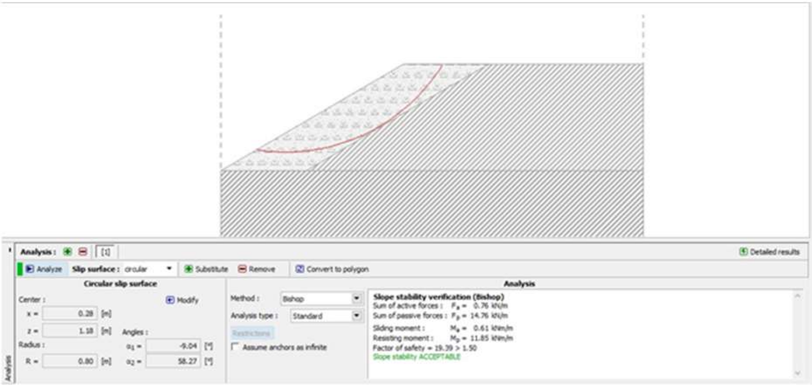

Figure 10: *Example of the 2022 version of the Geo5 software running computer application on one type of vegetation*

Finally, Figure 12 shows the relationship between the retaining moment of slope stability and the type of vegetation on the slope surface. According to what was depicted in the figure, when viewed from the value of the slope stability resisting moment resulting from various types of vegetation on the slope surface, the soil overgrown with Elephant grass species produced a greater slope stability barrier moment compared to the other types of vegetation. This was because the physical roots, which are larger in diameter and longer, can produce higher shear strength. As observed, vegetation roots can increase the soil shear strength by the root's tensile strength and provide slope shear resistance during or after heavy rains in shallow landslides [28]. Suman et al stated that the physical factor of vegetation roots, especially their level of density, can significantly increase the soil's shear strength parameters and increase the safety factor (FS) of slope stability [29].

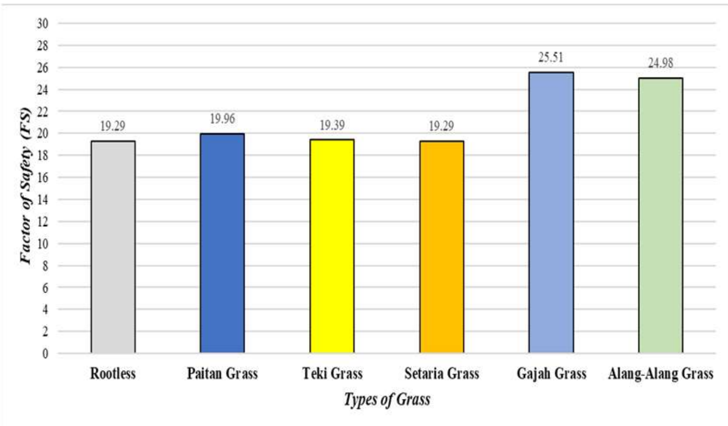

***Figure 11**: Graph of the Safety Factor for 5 Types of Vegetation*

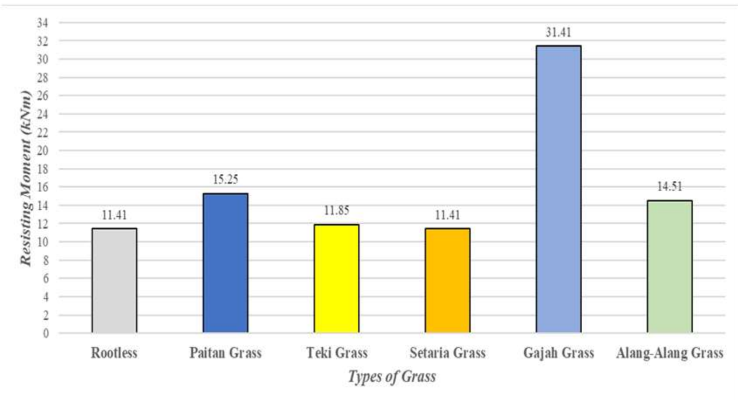

***Figure 12:** Graph of Retaining Moment for 5 Types of Vegetation*

4. CONCLUSIONS

1) This research shows that the effect of vegetation roots can make a significant contribution to increasing the shear strength of the soil. Its contribution mainly depends on the physical composition of the plant's roots, mainly related to the length, diameter, and density of the roots.
2) The use of vegetation in maintaining the stability of shallow soil slopes has potential value in an effective, economical, and environmentally friendly way.
3) The smallest value of cohesion and internal friction angle was found in the roots of the Setaria grass vegetation. This was due to the differences in the diameter and length of the grass's roots.
4) The diameter of the vegetation roots contributed to the soil's shear strength value. The Elephant grass's root resulted in the highest soil shear strength value compared to other types of vegetation roots. This was due the roots of the Elephant grass vegetation had a larger root diameter than the others.
5) The use of Elephant grass vegetation on the slope surface was able to increase the shear strength of the soil, and the landslide resisting moment. It also aided in the enhancement of the safety factor of slope stability more than the other vegetations.

5. ACKNOWLEDGMENT

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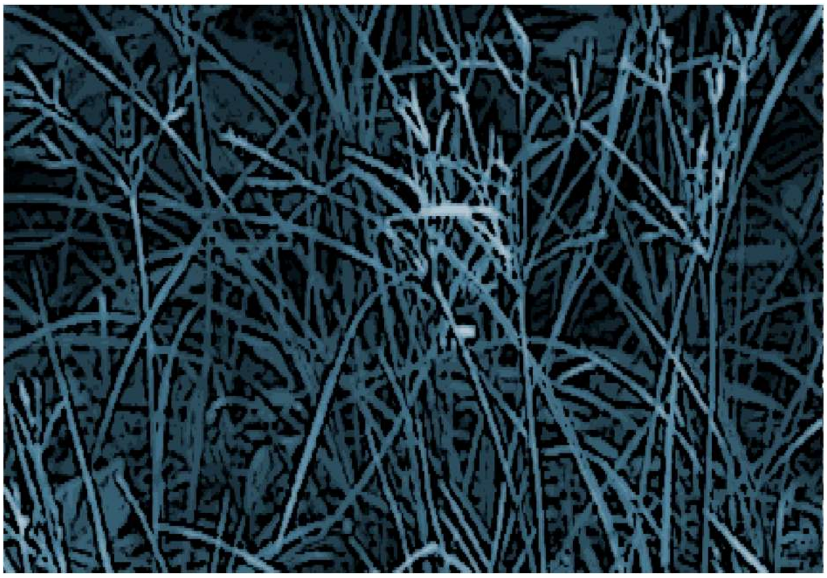

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