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BIOGEOTECHNICAL – ENVIRONMENT AL REMEDIATION USING NATURAL GROWN PHILIPPINE BAMBOO SPECIES FOR SLOPE STABILIZATION

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Abstract

This paper presents the importance of plant root systems to the stability of slopes, particularly on engineered cut slopes. The locally grown plant of study is the selected common Philippine bamboo species such as Kawayan Tinik ***(Bambusa Blumeana Schultes),*** Bayog ***(Dendrocalamus Merrillianus Elmer),*** Kawayan Kiling ***(Bambusa Vulgaris Schrader)*** and Patong ***(Dendrocalamus Asper Schultes)***. It grows widely, abundantly in the moist areas, riverbanks, and sloppy areas in the Philippines. The study determined the effects of roots strength of the Philippine bamboo species on soil properties and soil slope stability. The results revealed that roots of Philippine Bamboo species make the soil stable and developed high internal friction, cohesion, develops high strength preventing immediate erosion and landslide. The void spaces between the soil particles filled up by bamboo roots systems and the result arguably, implies that the higher the plant age, the higher the plant diameter and height, thus the higher pull-out resistance. The use of Philippine Bamboo species such as Kawayan Tinik ***(Bambusa Blumeana Schultes)***, Bayog ***(Dendrocalamus Merrillianus Elmer)***, Kawayan Killing ***(Bambusa Vulgaris Schrader)*** and Patong ***(Dendrocalamus Asper Schultes)*** as vegetation in cut slope, hillslope, and riverbanks can minimize and prevent erosion and shallow landslides.

Keywords: Bioengineering, Biotechnical, Geotechnical- Environmental Remediation, Slope Stabilization

1. INTRODUCTION

Plants are vital in naturally built environments that will be used in slope stabilization. Forest vegetation, especially tree roots, helps stabilize the slope by reinforcing soil shear strength. The importance of plant root systems [1] to the stability of slopes [2] has received considerable attention in recent years, particularly on engineered cut slopes [3]; this is bioengineering for slope stabilization [4]. Roots can influence slope Stability through hydrological and mechanical factors [5]. Soil-bioengineering has been primarily used in controlling erosion [6], [7], but it has also been shown to be successful in the stabilization of slopes against shallow failures [8]. [2]

The root systems can contribute an additional component to the shearing resistance [9]. Roots help stabilize hill slopes by reinforcing soil shear strength [10],[11]. To evaluate the effect of roots on slope stability, information about the number of roots and their strength should be known to be affected in a significant way [12],[13]. The positive effect of roots on soil stability depends on the tensile strength of the individual roots [14]. On the spatial distribution of the root, as in the soil roots, the origins increase soil shear strength [15] by transmitting developed shear stress to tension strength [16]. The additional strength created by roots is the growing cohesion [17], which increases with vertical stress and the area occupied by the roots [18].

Roots can influence slope stability through hydrological and mechanical factors [19]. Information about the number of roots and their strength should be known to evaluate the effect of tree roots on slope stability [20], and Tree roots help stabilize hill slopes

by reinforcing soil shear strength [21]. To assess the impact of tree roots on slope stability [22], information about the number of roots and their strength should be known to be affected in a significant way. Vegetation may be used in slope protection to prevent or reduce erosion from precipitation, surface runoff, and internal seepage or piping [23]. In this instance, the vegetation using various types of bamboo may replace [24] one or more layers of granular filter materials placed on the slope in conventional application [25]**.**

Bamboo is one of the most common plants that grow widely and abundantly throughout the tropics [26], especially in moist areas, and can be found in the Palawan Ocean Islands. Bamboo is found in abundance and has been used thoroughly to its extent, although it is considered a natural engineering material [27]. Bamboo is grown on various continents in the world [28].

The Asia–Pacific bamboo region is the largest bamboo growing area in the world [29],[30]. Asia has a large area of bamboo occupied by six countries, viz. India, China, Indonesia, Philippines, Myanmar, Vietnam, and others. Globally, among the sympodial and monopodial bamboo, the sympodial type dominates the major part [31].

Table 1: Bamboo regions along with countries [31].

Bamboo region	**Countries**
1. Asia–Pacific	China, India, Burma, Thailand, Bangladesh, Cambodia, Vietnam, Japan, Indonesia, Malaysia, Philippines, Korea, and Sri Lanka
2. American bamboo	Mexico, Guatemala, Costa Rica, Nicaragua, Honduras,
Region (Latin America, South America and North America)	Columbia, Venezuela, and Brazil
3. African bamboo region	Mozambique, Eastern Sudan
4. European countries	England, France, Germany, Italy, Belgium, Holland. United States
	Canada has introduced many bamboo species from Asian and Latin American bamboo-producing countries.

In the Philippines and the rest of South and Southeast Asia, the versatility of bamboo is apparent from its many uses as containers, ornaments, toys, food supplements, musical instruments, structural components, and various industrial items**.** Other uses **include** soil stabilization, construction**,** ethnobotanical uses, and many more [32].

Of the 62 bamboo species, 21 are endemic or native Philippine bamboo. Thirteen are climbers, and eight are erect. The rest are introduced, and some were raised in prehistoric times [33], [34]. The bamboo is usually used in construction, furniture, basketry, and decorative articles.

The current commercial bamboo can be increased to 15 species, especially those with thick culm walls and big-diameter culms, including four common bamboo species in the Philippines, were presented below where in bamboo used for erosion control and slope stability [35].

Fig 1: *Dendrocalamus Asper Schultes*

Fig 2: *Dendrocalamus Merrillianus Elmer*

Fig 3: *Bambusa Blumeana Schultes*

Fig 4: *Bambusa Vulgaris Schrader*

The main objective of this study is to describe the bamboo root strength capacity, root tensile strength, and root Shear strength and their effects on slope soil Moisture content, Liquid limit, Plastic limit, Cohesion, angle of internal friction, and Factor of safety of the slope areas. Thus, these four common bamboo species in the Philippines were utilized.

2. METHODOLOGY

This study used the single group design of experimental research, which attempts to establish a cause-and-effect relationship with the alleged cause manipulated. The material used in the study was composed of plant root samples from the slope areas. Likewise, the study used standard tools and equipment to determine soil properties and soil with roots. The material selection and preparation were in accordance with the standard requirements of the American Society of Testing Materials (ASTM) and the Bureau of Research and Standards (BRS). The materials used were stratified and taken from slope areas. Nine (9) samples were in each stratified area using quadrant methods. This study used the standard procedure of materials selection and testing of the three (3) sets of samples in each stratified site. The laboratory procedure was derived from the materials testing and laboratory engineering manual. The following were the detailed research procedures: (1) Site visit and exploration, (2) Collection of Sample, (3) Plant Physical properties analysis, (4). Root strength test, (5) Analyses the result of the laboratory test and see how effective the sample is used for slope protection, and (7) Comparison of the strength of vetiver grass and another plant's

tensile strength to bamboo roots' tensile strength. Root tensile strength was a factor in considering tree and plant anchorage and resistance of the roots to failure.

3. RESULTS AND DISCUSSION

The bamboo-based ecoengineering design for slope stability takes advantage of successful eco-engineering experiences and incorporates nature. The ecoengineering work applies the approach to an instability-prone slope where bamboo is abundant. incorporate and the evolving utilized bamboo vegetation. The bamboo root strength analysis determines the bamboo root systems' capacity to hold soil.

3.1 Bamboo roots strength.

Tensile strength is the resistance of a material to breaking under tension. The resistance of a material to breaking under tension. The root strength of ***Dendrocalamus Merrillianos E.*** roots ranges from 9988.948 kPa to 3745.856 kPa, and the load (g) ranges from 3000g to 1200g. The root strength of ***Bambusa vulgaris S.*** roots ranges from 12763.656 kPa to 4682.320 kPa, and the load (g) ranges from 2300g to 1500g. The root strength of Dendrocalamus asper S. roots varies from 13873.539 kPa to 6555.247 kPa, and the load (g) ranges from 2500g to 1800g.The results reveal the root test of ***Dendrocalamus Merrillianos E., Dendrocalamus asper S., and Bambusa vulgaris S.*** has a tensile strength of 9988.948 kPa, 12763.656 kPa, and 13873.539 kPa. This implies the root test to hold soil and rock and prevent immediate erosion. The roots that penetrate the soil and slope materials are one solution to minimize and avoid erosion [37]. The Bamboo *root* strength and the root effect hold soil and rocks and prevent immediate erosion. The Shear strength of the obtained soil without roots ranged from 0.34 kPa to 0.97 kPa; its mean shear strength was 0.58 kPa, while soil with bamboo roots shear strength ranged from 4.2 to 14.4 kPa, its mean shear strength was 8.2 kPa. The pull-out strength of Bamboo roots averaged from 1376.67 KN to 1814.97 KN. The pull-out strength means the force that must be applied to the root's anchorage and holding capacity.

Table 2: Plants' root Tensile strength [38] compared to Bamboo root tensile strength.

Botanical name	Common Name	Tensile Strength (MPa)	Average (MPa)
Salix spp	Willow	9-36	22.5
Populus spp	Poplars	5-38	21.5
Alnus spp	Alders	4-74	39
Pseudotsuga spp	Douglas fir	19-61	38.5
Acer sacharium	Silver maple	15-30	22.5
Tsuga heterophylia	Western Hemlock	27	27
Vaccinum spp	Huckleberry	16	16
Hordeum vulgare	Barley Grass	15-31	23
Vetiveria Zizaniodes	Vetiver Grass	40-120	80
Melastoma Clavarei H. Vaniot	Malatungaw		81.53
Melastoma Malabathricum sp.	Amomocil	130.71	81.48
***Dendrocalamus Asper Schultes.**	**Patong**	**56.18 – 138.73**	**97.45**
***Dendrocalamus Merrillianos Elmer.**	**Bayog**	**37.48 – 99.88**	**66.68**
***Bambusa Blumeana Schultes.**	**Kawayan Tinik**	**49.33 – 128.34**	**93.44**
***Bambusa Vulgaris Schrad.**	**Kawayan Tiring**	**46.82 – 127.43**	**87.55**

*** Newly added plant**

Table 1 shows the common plants used as slope stabilizers. The most popular vetiver grass has an average tensile strength of 80 MPa [39,[40],[41]. The melastoma malabathricum [42], [43], [44],[45]and malabathricum Clavarie H.Vaniot [46] having root average tensile strength of 81 MPa shows that bamboo root tensile strength [47] such as Dendrocalamus Aser Schultes, Bambusa Blumeana Schultes and Bambusa vulgaris Schrader of the four common species shows higher tensile strength of 87.55 MPa to 97.45 MPa. The bamboo root tensile strength was compared to other plants and was higher than all other plants [48],[49] except the bamboo species Dendrocalamus Merrillianos Elmer. This shows bamboos were suitable soil stabilizers to prevent slope [36] and river erosion [50].

3.3 Soil properties with Bamboo roots

The root system bamboos are considered suitable for improving soil properties within a short period, and different species did not reveal any significant changes [51]. A significant positive correlation was observed between root distribution in the soil properties for rehabilitating degraded lands prone to soil erosion.

The Soil moisture content is the quantity of water contained in soil with bamboo roots, ranging from 22.22% to 23.21%, and its mean moisture content was 22.55%, while the soil without roots ranges from 20% to 27.77%. These plants absorb water to lessen the saturation that causes Landslide and slope failures [51].

The Liquid Limit is the moisture content at which soil begins to behave as a liquid material and begins to flow. The obtained results show that the soil with Bamboo roots ranges from 90.81% to 32.87%, and its mean liquid limit was 23.2%, while the sample without roots *bamboo roots* ranges from 11.46% to 22.97%, it has a low potential for swelling that usually causes slope failures. The Plastic limit obtained from soil Bamboo roots ranges from 28.57% to 50%, while the sample without bamboo roots ranges from 33.33% to 40%. It means plastic limit changes from medium to high soil transitions between brittle and malleable behavior. Bamboo roots affect soil indices by changing the soil properties to a different kind of soil[52].

The cohesion of the obtained soil without bamboo roots ranges from 0.462771 kPa to 1.567453 kPa, while with Bamboo roots, the soil sample ranges from 1.340594 kPa to 5.512018 kPa; this shows that roots make the soil more cohesive [53]. The soil angle of internal friction is improved when there is an interaction between the soil and the bamboo roots [54]. Thus, bamboo roots improve the soil properties.

3.4 Soil Slope Factor of Stability and Safety.

The estimation of the factor of safety of the soil slope [56] is vital in geotechnical analysis, landslide analysis, and slope erosion, for which the hill should be designed with a predefined probability of failure. Table 3 below shows that the stability factor without Bamboo roots is 0.15, which means the slope areas are highly susceptible, and the safety factor with bamboo roots is 1.03. Thus, the slope areas are marginally stable. Therefore, Bamboo stabilizes the soil slope when bamboo root systems are considered [35]. This means soil-root systems help prevent soil erosion and shallow landslides [57]. Due to its external root system, bamboo contributed little to slope stability [58] for deep-seated landslides. However, this prevents shallow landslides and erosions of not deeper than 1m. FOS increased at the bottom of the slope. Different species along the hill influenced FOS [59]. Differences in root tensile strength

between species played a role in FOS calculations, and soil root-system interactions were the most critical factors affecting slope stability.

Table 3: Soil Slope Factor of Stability Analysis Stability with and without bamboo roots

Factor of Stability	Bottom of the Slope	Middle of the slope	Top of the Slope	Mean	Factor of Stability
The factor of safety with Bamboo roots	1.02	1.08	0.98	1.03	Marginally stable
The factor of safety without Bamboo roots	0.05	0.13	0.18	0.15	Highly susceptible

The influence of plant diversity on slope stability is significant. Root tensile strength at different depths was determined for each species [60]. The factor of safety (FOS) was calculated for slopes with and without vegetation or roots. The FOS was determined for different species performed at the slope's top, middle, or toe.

Table 4: Comparison of slope Factor of stability with and with Bamboo roots.

Source of variation	SS	df	MS	F - Value	F critical (0.05)	Remarks
Bamboo species	899608.1	5	179922	4.4314	2.60299	Significant
Bamboo roots' tensile strength	585624.5	5	117125	2.8848	2.60289	significant
Error	1015025	25	40601			
Total	2500258	35				

Table 4 shows the value of F-value within bamboo species of 4.4314 is greater than the F critical of 2.60299, and the value F-value between bamboo roots tensile strength of 2.8848 is greater than the F-critical of 2.60289 tested at 0.05 level of significance; then the null hypothesis is rejected. The study revealed a significant difference between the slope stability factors of bamboo and soil without bamboo roots [61]. The root distribution of four bamboo species' root strength impact on soil properties and stability factors showed significant improvement under different species [62]. It showed substantial improvement and found that better species are better for soil slope stability, resisting soil erosion, and maintaining soil stability [63]. Thus, the bamboo species significantly differ in root strength when used as slope stabilizers. Also, the bamboo roots' tensile strength significantly differs in stability when used as slope stabilizers. This implies that bamboo root systems are suitable soil slope stabilizers.

4. CONCLUSIONS

Bamboo is native to plants of most common weeds that grow widely and abundantly throughout Palawan and are abundantly found in the hill slopes and cut slopes. Based on the data gathered, Bamboo has a high tensile strength [36], and the shear strength is effective and capable of holding soil and rocks penetrated to the soil at a certain depth to prevent slope failure and erosion [65].

The soil sample with bamboo roots has a small amount of water present compared to the soil sample without roots. This indicates that the roots of bamboo increased water content of the soil sample decreased, the soil can change its shapes without altering its volume, the soil plastic limit changed, the soil type changed, and its properties changed [51].

The soil indices were changed when considering the root systems. Thus, it increases the plastic limits, liquid limits, plasticity index, and liquidity index, improving the soil properties and indices when bamboo root systems are considered [52].

The soil with bamboo roots has a high cohesion and, thus, is difficult to break apart. However, the cohesion of soil changes significantly depending on the presence of water [53],[54]. The stability and bearing capacity of soil with bamboo roots relies primarily on the interactions between particles and the bamboo roots, which improve soil cohesion. Bamboo roots enhance the stability of soil slopes [35] and are suitable stabilizers of soil slopes [57] or cut slope areas [58-64]. The bamboo was an effective slope stabilizer that could prevent shallow landslides when soil slope stability was analyzed with bamboo roots.

Recommendations

After a careful study and analysis of the findings of this study, the following suggestions and recommendations were drawn up for consideration. In reducing landslide risk, several factors should be considered.

1) Study further higher plant diversity generally associated with natural regeneration, which may increase slope stability above that of monospecific and single-age plantings.
2) Bamboo is used as vegetation on cut and hill slopes to minimize and prevent erosion.
3) Further study is recommended on Bamboo as slope and road cut slope stabilizers and other parameters not cited in this study.

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