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Analysis of Vegetation Effects on Slope Stability of Embankment

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Abstract: Embankments play a significant role in protecting cities from many natural disasters. Erosion and landslides of embankments and natural slopes are common phenomena occurring every year in Bangladesh. It has become a great concern of protecting embankments and natural slopes from failure. In many cases, traditional methods for protecting embankments and natural slopes are not effective during their designed lives. In such a condition, bio-engineering has been adopted in many countries as an effective and environment friendly measure for the protection of slopes. The role played by vegetation in improving slope stability is now well recognized. Many research works have been done in many countries on many species of trees that are locally available and suitable for the climatic and soil conditions of that country. In this study, an attempt has been made to evaluate the performance of lebbek tree and royal poincianain protecting the Rajshahi City Protection embankment. In-situ direct shear test was performed on block samples to determine the in-situ shear strength of rooted soil and soil without root. A numerical analysis has been performed to compute the factor of safety and shear strength of slope soil with root and without root. Also the effect of different types of vegetation on slope stability is observed by numerical analysis. It has been found that the values of factor of safety vary between 1.781 and 1.926 in case of slope without root whereas the values of factor of safety vary between 1.997 and 2.173 in case of slope with root. In numerical analysis, the shear strength of soil varies between 40.311 kPa to 41.782kPa in case of slope without root whereas in case of slope with root this value varies between 50.929 kPa to 52.13 kPa. The average percentage of increase in shear strength for lebbek tree root is 14.35% whereas this value for royal poinciana is 24.29%. It has been also found thatthe factor of safety of soil slopes without vegetation, with uniform vegetation, cylindrical vegetation and semi-spherical vegetation are 1.605, 1.653, 1.654 and 1.616 respectively. From the results, it is understood that plants with cylindrical root architecture increase the most significantly slope stability. It also appears that lebbek tree and royal poinciana may be low-cost and environment friendly alternative solution for the protection of embankment in Bangladesh.

Keywords: Protecting Embankments, Bio-engineering, Slope Stability, Factor of Safety, Shear Strength, Numerical Analysis, Lebbek Tree, Royal Poinciana

1. Introduction

1.1. General

Embankment failure and soil erosion has become common worldwide problem including Bangladesh. The major reasons of embankment failure of Bangladesh are breaching of the embankment, cutting by public, overflow, erosion, seepage, sliding and also for poor planning, design and faulty construction. These cause great economic loss every year [7]. Both requirements are necessary to work out correctly. Otherwise this technology will not work effectively. If the roots are strong enough but do not have branches will fail in tension and pull straight out of the ground with only minimal resistance. The root reaches its maximum pullout resistance then rapidly fails at a weak point. The root easily slips out of the soil due to the gradual tapering (progressive decrease in root diameter along its length) which means that as the root is pulled out it is moving through a space that is larger than its diameter which consequently has no further bonds or interaction with the surrounding soil [8]. Another geotechnical expert Gautam. T [6] reported that the planting of broom grass/tiger grass has a direct impact on preventing surface soil erosion on steep hillsides. Tiger grass grows in clumps and has many tangled up roots that grow to about one meter below the ground. This makes it highly effective in preventing soil erosion on hillsides as the grass is less likely to fall compared to other plants and trees that would have been planted there. The roots and leaves of the plant slow down water drops and the flow of water after heavy rain by absorbing the water in the soil. Growing tiger grass on degraded land has been proven to help rehabilitate it as it helps retain ground moisture and promote fertility. Bangladesh is a riverine country and most of the lands are in floodplain zone. There are also some marshy lands (haorarea) in the north-east zone of this country. Because of having low-lands, roads of this country are built on raised embankments. These embankments are mainly constructed with earth. In the past, these earths were mainly clay but now-a-days, due to lack of clay material, embankments are being constructed with dredged fill sand with clay capping. Most of these embankments are kept unprotected and do not maintained well. As a result these earths get erased easily by wind flow and water flow. The arterial road network under the jurisdiction of Roads and Highways department (RHD) in 2011 was about 21,000 km, which includes over 3478 km national highways and 4221 km of regional highways, 83,304 km earthen and 2,13,331 km paved roads [9, 10]. It is not feasible for Bangladesh Govt. to protect all these structures using CC blocks. Sometimes these blocks are proven inefficient for protection and washed away. For all these reasons an alternative and cost-effective measure must be introduced.

Research on the effect of tree roots on slope stability has expanded significantly in the last 30 years. In part this is due to the appreciation of the adverse effects of deforestation on slope stability in the mountainous regions, which is now causing concern in many parts of the world [1].

Mechanical stabilization of soil slopes by tree roots depends largely on the strength of the roots and their growth pattern within the soil. The choice of native tree species based on their root properties is an essential part of biotechnical slope defense, in particular area. The effect of tree roots on a slope's stability can be regarded in terms of its strength and distribution within the soil. Those two factors control the main mechanisms of stabilisation, such as soil strengthening, soil arching and root anchoring [1].

Strong methods of arrangement have an adverse consequence on the environment and sometimes do not work for the duration of development. An alternative solution is to plant the vetiver along the slopes. Vetiver not only serves slope defense purposes, but also adds pollution-reducing green environment. The traditional practice in Bangladesh for the protection of embankments is the use of cement concrete blocks, sandbags, stone or wood walls, geotextiles, geobags and tree plantations. Where storm surge is heavy, cement concrete blocks are typically used; sand bags or wood revetments are used where water flow is reasonably high. Protecting the embankment by planting is another method, but it is not successful during cyclone and flooding due to plant overthrow or eradication [2].

Vegetation application to restore slopes stability is highly requested, particularly in order to solve the problem of shallow slope failure in both genetic and person-made slopes. Variation strengthening trend can be observed with variation in plant species that can be maintained on condition of severe slopes. There have been several key factors that determine the stability of the slope. Although the use of traditional methods to maintain slope stabilization has become a big interest for professionals, the use of engineering in conjunction with bio-engineering has proven to be more price-effective and efficient approach Weather affects the physical advancement of plant species such as the roots that strengthened the soil through technical and geological processes. Root acts by regulating the soil water content from surpassing the ability of the field by means of hydrological system. Root consumes and discharges water into the environment instead of allowing all invasions deep into the land. The infiltration of rainfall water on the slopes causes an increase in the content of soil moisture, especially in the close-surface root forms and characteristics. Various types of plants have different root characteristics and ways of conducting the role. Such features can be identified through the root structure, which can be divided into three key structures: sinkers, core and taproot [3].

Soil erosion is progressively known as an issue that needs an active and cost-effective solution. A number of slope protection methods are currently being used to strengthen slopes. Biotechnological methods are becoming increasingly popular among these methods, particularly for economic and environmental purposes. Environmental vegetation on the slopes can retain, brake and dilute the kinetic energy of the water, as well as provide friction coefficient that slows down the speed of the precipitation. The root system strengthens the soil and also promotes water encroachment by enhancing the soil's permeability. The vegetation's impact is only fully realized once it has developed. The beneficial engineering characteristics of the vegetation may not be visible during the crucial stage of plant establishment, and a site is still highly susceptible to soil degradation. Slopes may suffer from severe soil erosion and instability without effective, adequate and sufficient support, which in turn makes vegetation extremely challenging to create. The erosion of seeds and seedlings from unsecured locations through surface runoff and winds is expensive as all past attempts to maintain vegetation on the slope must be reiterated [4].

Embankment failure is a major blow for Bangladesh's transportation industry. High property costs in this over populated country force the financial prototype of the road embankment that is often failed by the high tidal force wave action. Bio-engineering technique in certain countries is becoming prominent recently. Since Bangladesh could be one of the country’s most influenced by global warming, the ideal choice against global warming would be to enforce biotechnology. It is also cheaper than traditional structural approaches for the safety of the slope [5].

1.2. Practice of Bio-engineering

Soil bioengineering can be an effective means of treating eroding surfaces and unstable surficial soil layers for both natural and man-made slopes. Soil bioengineering is a term that describes the use of living plant materials to build structures that provide slope support. There are a variety of soil bioengineering structures that can be used to rehabilitate unstable and/or erodible sites. These can be used in the treatment of landslide scars, tormented gullies, and both deactivated and active roads, as well as several types of riparian and watercourse sites. Soil bioengineering uses live cuttings to build structures such as low slope support walls, drains and slope breaks. Some structures initially provide physical support against shallow slope movements, while others may act to mitigate the erosion effects of surface runoff. This usually results in a slope that promotes natural or applied re-vegetation processes. Over time, effectiveness of the structure is reinforced as the cuttings sprout and grow. Eventually the vegetation itself takes over the function of supporting the slope by lending mechanical strength (e.g. matting effect, root reinforcement, anchoring, buttressing) as well as providing hydrologic benefits (e.g. interception, protection) that may promote greater slope stability.

In Rajshahi, Lebbek tree (Albizialebbeck) and Royal Poinciana (Delonixregia) are very common and available trees. The roots of these trees are capable of anchoring themselves firmly into soil profiles and the strength properties of root play an important role in terms of erosion control and slope stabilization by means of their influences on the shear strength of slope soil.

1.3. Objectives

1. To evaluate factor of safety for soil slope with different types of vegetation by numerical analysis.
2. To evaluate the increase in shear strength of slope soil of Rajshahi city protection embankment due to penetration of lebbek tree root.
3. To evaluate the increase in shear strength of slope soil of Rajshahi city protection embankment due to penetration of royal poinciana tree root.
4. To evaluate the factor of safety and shear strength of slope soil of Rajshahi city protection embankment with root and without root by LEM and determining the increasing factor of safety and shear strength of soil due to root.
5. To compare between numerical analysis results and field test results.

2. Methodology

2.1. Geometric Model of Slopes

The general geometry of a layered soil slopes with and without roots are given below figure 1:

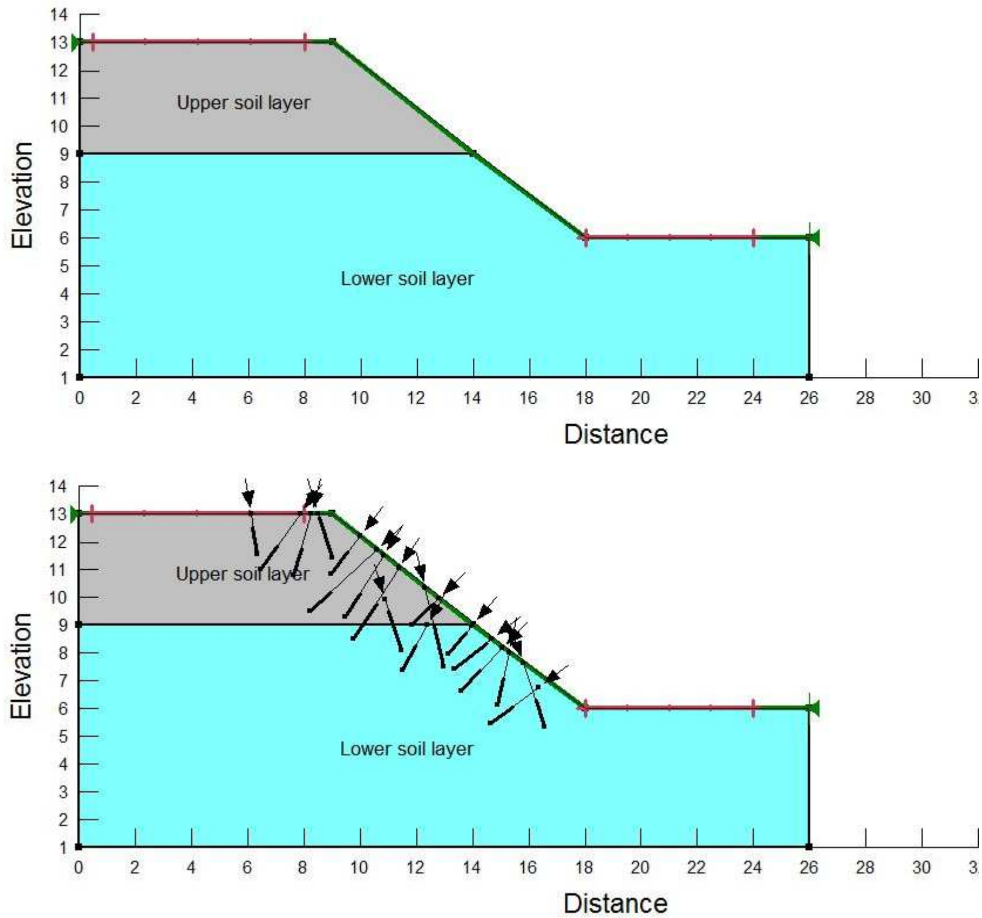
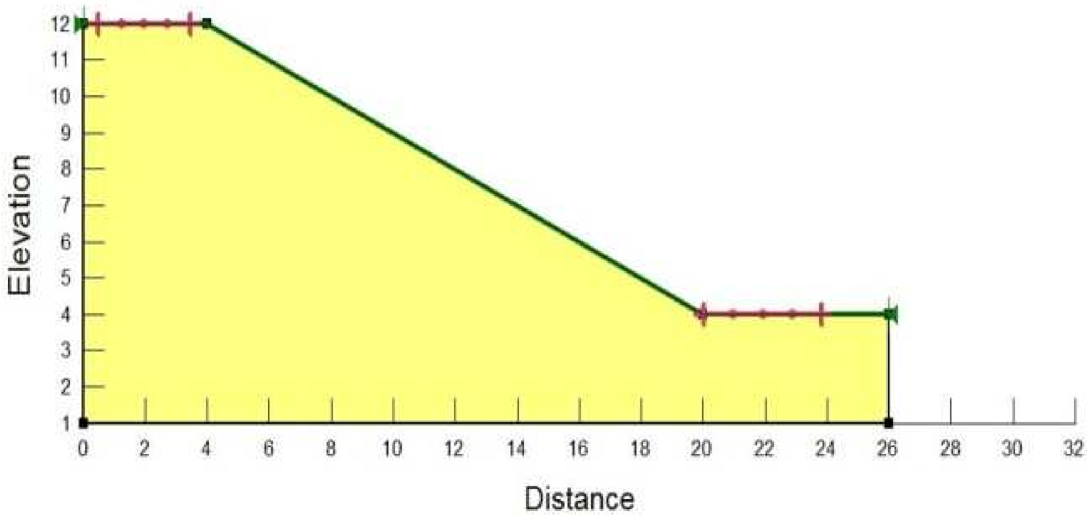
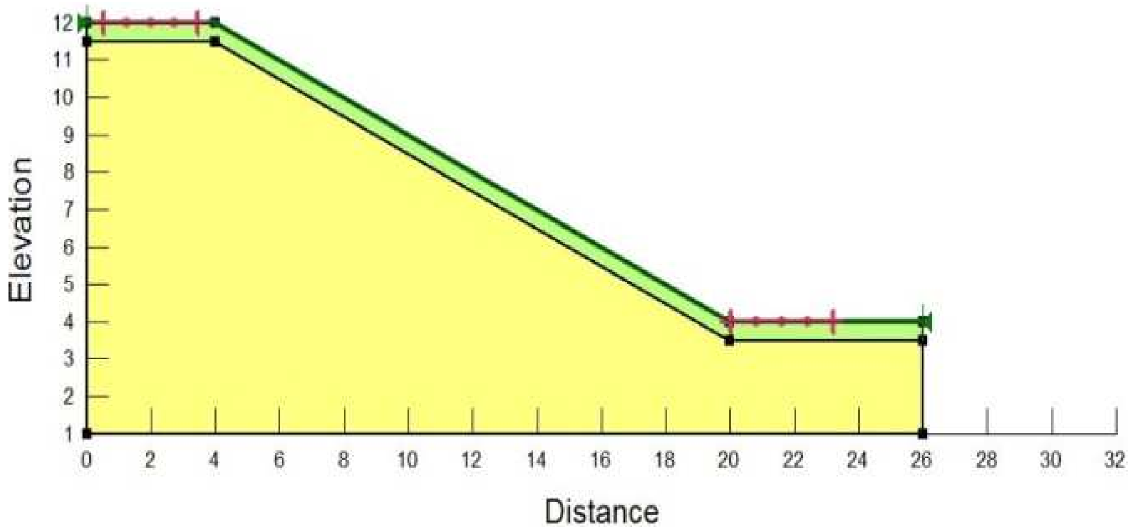


Figure 1. *Slope of layered soil without root and with root. Dimensions are in meters.*

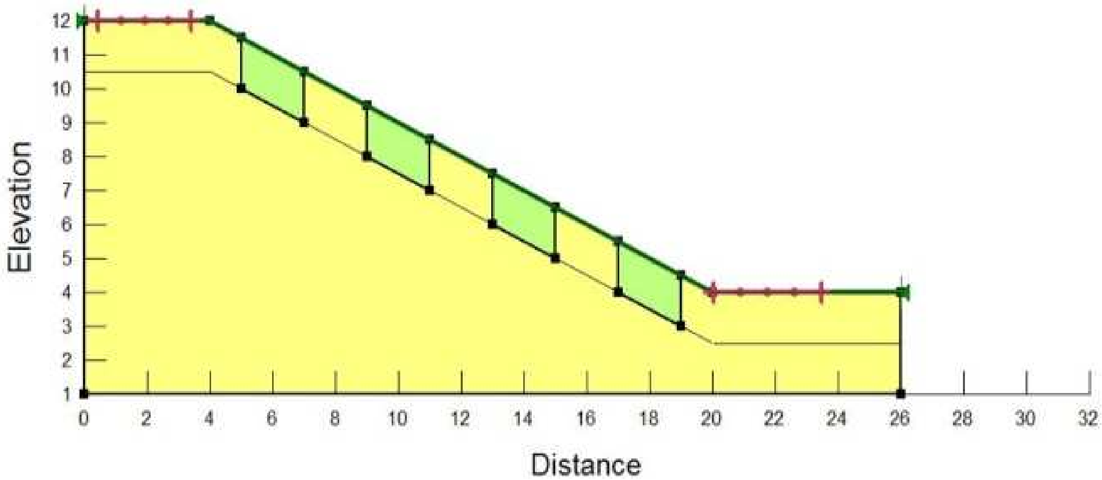
Three types of root morphology are considered: uniform 0.5 m deep plate root system, 2 m diameter and 1.5 m deep cylindrical system, and 1.35 m radius semi-spherical system. In addition to the three types of vegetation, a slope with no vegetation as a reference is also analyzed. The models are shown in the following figure 2:



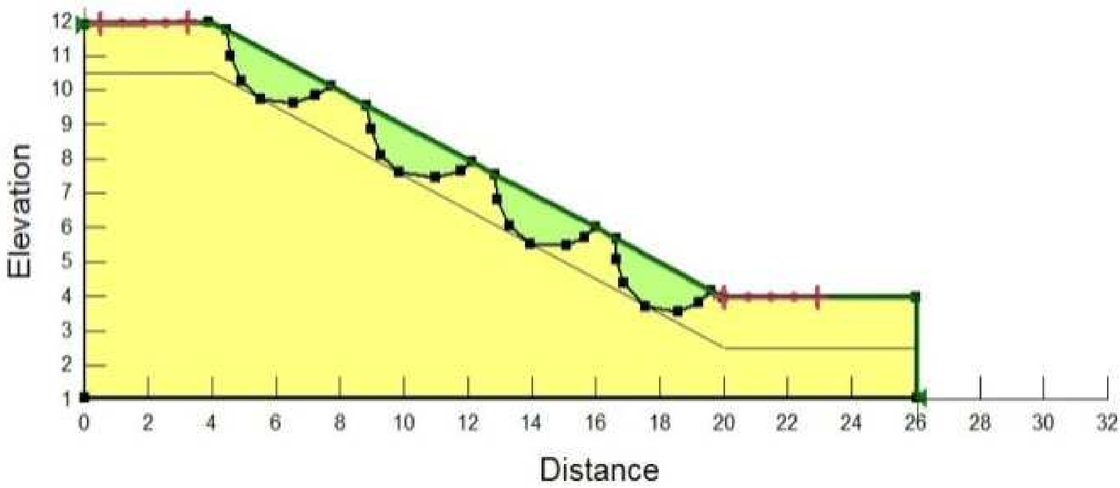
(a)



(b)



(c)



(d)

Figure 2. *Slope models with: a) no vegetation, b) uniform vegetation layer, c) cylindrical vegetation layer and d) semi-spherical vegetation layer. All dimensions are in meters.*

2.2. Input Parameters for Analysis

Table 1. *Input Parameters for Analysis by Anchoring.*

Soil Type	Unit Weight, γ (kN/m³)	Cohesion, c (kPa)	Friction angle, Φ (deg.)
Upper Soil Layer	14.33	7.48	27.34
Lower Soil Layer	16.59	15.08	32.74

For different types of vegetation layers, the following material properties were given table 2:

Table 2. *Input Parameters for Analysis.*

Soil Type	Unit Weight, γ (kN/m³)	Cohesion, c (kPa)	Friction angle, Φ (deg.)
Soil without Root	13	8	20
Soil with Root	13	18	20

2.3. Selected Methods for Analysis

In order to analyses and computation of the factor of safety and shear strength of slope soil, LE based software is selected. The basic theory and different assumption made in the LEM are given in Chapter 4. The selected methods and software are given below:

Limit Equilibrium Methods (LEM):

1. Morgenstern-Price method.
2. Janbu's simplified method.
3. Bishop's simplified method.
4. Ordinary or Fellenius method.

Selected software for the analyses:

1. SLOPE/W (GEO-SLOPE International, Ltd.)

2.4. Field Test

2.4.1. Experimental Setup

An experimental setup was developed in this study to determine the in-situ shear strength of soil profile vegetated with tree root and without root. The shear box was made of 6 mm thick steel plates (0.30 m x 0.30 m x 0.10 m) capable of holding firmly a soil block of 0.30 m x 0.30m x 0.15 m in dimensions. A hydraulic jack with load gauge having capacity of 5 tons was used to apply shear force and a Linear Variable Displacement Transducer (LVDT) was used to determine the horizontal displacement while applying the shear forces. The applied shear forces were read directly from the load gauge that was set with the hydraulic jack. The detail experimental setup has been shown in the figure 3.

Figure 3. *Experimental setup of in-situ direct shear test.*

Figure 4. *Failure plane of soil block without root.*

Figure 5. *Failure plane of soil block with root.*

2.4.2. Test Procedure

A lebbek tree and a royal poinciana were selected for the in-situ direct shear test. In order to perform the test, the lower edges of the steel shear box were made sharp to penetrate the shear box into the soil cutting the roots at ground level. This operation was done such that the soil specimen in the shear box remained undisturbed with roots. A trench was excavated around the soil block, approximately 0.5 m square and 0.15 m deep, sufficiently enough to accommodate the all experimental setup and isolate the soil block from the surrounding soil. The shearing force was applied by hydraulic jack that acted on steel plate of the shear box. The hydraulic force was applied by operating a lever arm and enough space was provided on the opposite side of the hydraulic jack of the shear box for the shear displacement. The shear force was obtained from the load gauge attached to the hydraulic jack and the shear displacement was measured using the dial gauge. Block samples were tested at 0.15m depth under different normal stresses at the field to know the in-situ shear strength of the rooted soil and soil without root following this procedure. The test was performed at 0.15 m depth of each two trenches (i.e., soil block with root and without root) applying the same normal load to determine the increase in shear strength of soil specimen due to penetration of tree root for the same normal load. After shearing the soil block to fail, the shear surface and the orientation of the failed roots were examined carefully to estimate the shear distortion during failure. A total of 9 block samples were tested in the field under different normal stress (i.e., 6.18 kPa, 8.73 kPa and 10.89 kPa) at 0.15 m depth from the existing ground level excavating 9 trenches. Out of 9 samples 6 samples were rooted soil (3 samples for lebbek tree and 3 samples for royal poinciana) and 3 samples were soil without root. Figure 4 and Figure 5 shows the failure plane of soil block without root and with root respectively.

3. Results and Discussions

3.1. Numerical Results of Slope Without Root and With Root by Lem

A clear comparison of various LEM methods of stability analysis of slope in case of slope without root and slope with root has been represented by the below table 3.

Table 3. *Comparison of various methods used in numerical analysis in case of slope without root and with root.*

Method Of Analysis	Factor Of Safety (Without root)	Factor Of Safety (With root)	Max. Shear Strength (kPa) (Without root)	Max. Shear Strength (kPa) (With root)
Morgenstern-Price	1.926	2.173	41.782	51.495
Janbu	1.781	1.997	40.311	51.567
Bishop	1.926	2.173	40.779	52.13
Ordinary or Fellenius	1.842	2.061	40.66	50.929

From the above table 3 it can be concluded that the increasing value of factor of safety due to anchorage of tree root is quite satisfactory. It is shown in figure 6. From table 4, it is found that the increasing value of maximum shear strength of slope soil due to anchorage of tree root is significantly increasing. Graphical representation is shown in figure 7.

Table 4. *Variation of Shear Strength of Soil Profile Due To Anchorage of Root using various numerical methods.*

Method of Analysis	Max. Shear Strength of Soil Without Root (kPa)	Max. Shear Strength of Soil With Root (kPa)	Increase In Max. Shear Strength (kPa)	% Of Increase In Max. Shear Strength
Morgenstern-Price	41.782	51.495	9.713	23.25
Janbu	40.311	51.567	11.256	27.92
Bishop	40.779	52.13	11.351	27.84
Ordinary or Fellenius	40.66	50.929	10.269	25.26

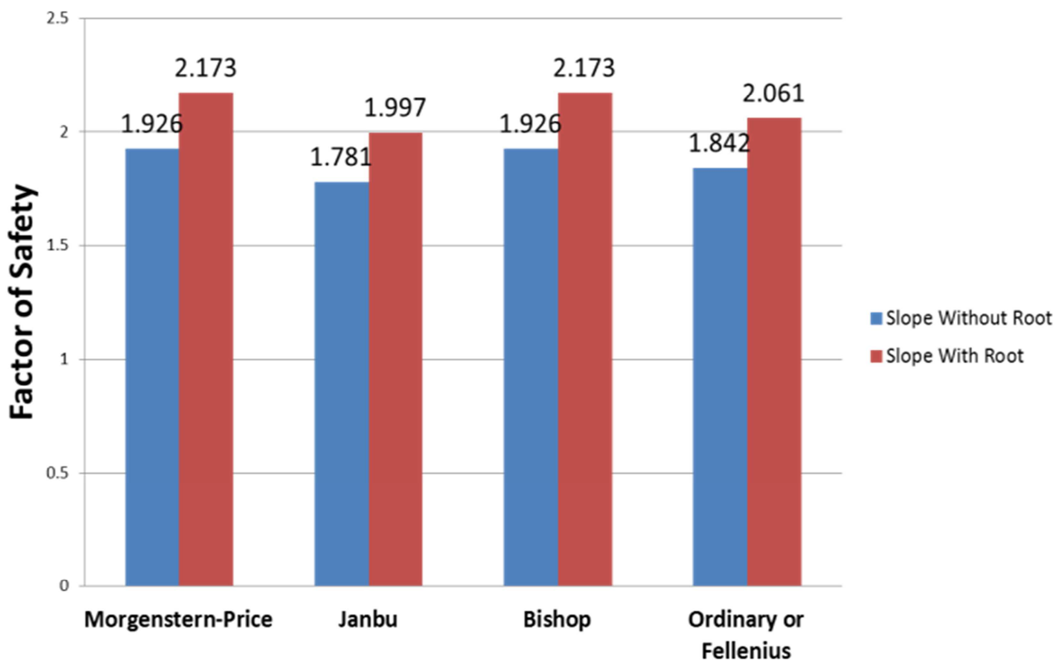


Figure 6. *Comparison of factor of safety of slope without and with root for different methods.*

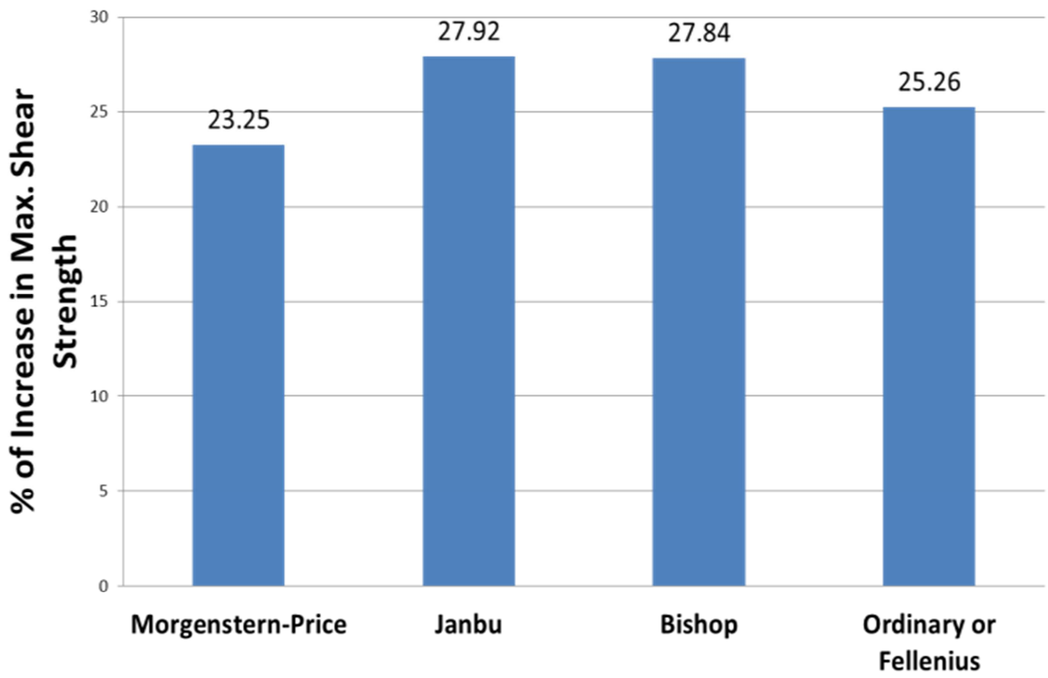


Figure 7. *Comparison of percentage of increase in maximum shear strength of slope without and with root for different methods.*

3.2. Numerical Analysis Results for Different Types of Vegetation

From the numerical analysis results, it is clear that factor of safety increases for the presence of vegetation. The cohesion provides significant strength and consequently requires more mass to create unstable conditions. However slip surfaces are deeper than the root zone, therefore the presence or absence of vegetation has little influence on slope stability. Plants with cylindrical root architecture increase the most significantly slope stability. Uniform root architectures are not deep enough and semi-spherical root architectures have very few deep roots.

The factors of safety calculated for different types of vegetation by software are shown below figure 8:

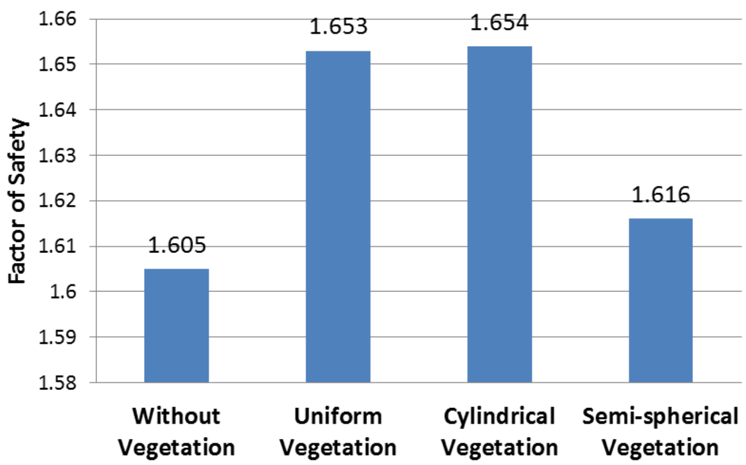


Figure 8. *Factor of safety for different types of vegetation.*

3.3. Field Test Results

The variations of shear stress and horizontal displacement of soil specimens with root and without root at 0.15 m depth from existing ground level are given below:

Table 5. *Variation of Shear Stress & Horizontal Displacement (Specimen without Root 0.15 m below Ground Level).*

Trench 1		Trench 2		Trench 3	
Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)
0.08	0.11	0.06	0.11	0.04	0.11
0.2	0.14	0.12	0.14	0.08	0.17
0.28	0.17	0.2	0.17	0.2	0.19
--	--	0.26	0.2	0.26	0.22
--	--	--	--	0.4	0.25

Table 6. *Variation of Shear Stress & Horizontal Displacement (Specimen with Lebbek Tree Root 0.15 m below Ground Level).*

Trench 4		Trench 5		Trench 6	
Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)
0.1	0.11	0.04	0.11	0.1	0.11
0.2	0.17	0.06	0.14	0.2	0.19
0.3	0.2	0.08	0.17	0.3	0.22
--	--	0.2	0.19	0.4	0.28
--	--	0.5	0.22	--	--

Table 7. *Variation of Shear Stress & Horizontal Displacement (Specimen with Royal Poinciana Root 0.15 m below Ground Level).*

Trench 7		Trench 8		Trench 9	
Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)	Horizontal Displacement (cm)	Shear Stress (kg/cm²)
0.04	0.06	0.04	0.17	0.06	0.11
0.1	0.11	0.1	0.22	0.2	0.17
0.2	0.17	--	--	0.3	0.22
0.3	0.22	--	--	0.6	0.28
0.4	0.28	--	--	1.3	0.33

Table 8. *Variation of shear stress under various normal stresses of soil specimens with root and without root for specific shear strength parameters.*

Criteria	Trench No.	Normal Stress (KN/m²)	Shear Stress (KN/m²)	Shear strength parameters of soil specimen	
				C (KN/ m²)	Φ
Specimen without Root 0.15m below Ground Level	Trench 1	6.18	18.03	13.74	34.77^0
	Trench 2	8.73	19.8		
	Trench 3	10.89	21.3		
Specimen with Lebbek Tree Root 0.15m below Ground Level	Trench 4	6.18	20.88	16.68	34.2^0
	Trench 5	8.73	22.61		
	Trench 6	10.89	24.08		

Criteria	Trench No.	Normal Stress (KN/m²)	Shear Stress (KN/m²)	Shear strength parameters of soil specimen	
				C (KN/ m²)	Φ
Specimen with Royal Poinciana Root 0.15m below Ground Level	Trench 7	6.18	22.94	19.05	32.21^0
	Trench 8	8.73	24.55		
	Trench 9	10.89	25.91		

__Table 9.__ Comparison of Specimen with Root & without Root for Lebbek Tree and royal Poinciana.

Specimen	Normal Stress (KN/m²)	Specimen	Shear Stress (KN/m²)	Increase in Shear Stress, $\Delta\tau_f$(KN/m²)	Percentage Of Increase In Shear Stress,% $\Delta\tau_f$	Average% $\Delta\tau_f$
Lebbek Tree	6.18	With root	20.88	2.85	15.81	14.35
		Without root	18.03			
	8.73	With root	22.61	2.81	14.19	
		Without root	19.8			
	10.89	With root	24.08	2.78	13.05	
		Without root	21.3			
Royal Poinciana	6.18	With root	22.94	4.91	27.23	24.29
		Without root	18.03			
	8.73	With root	24.55	4.75	23.99	
		Without root	19.8			
	10.89	With root	25.91	4.61	21.64	
		Without root	21.3			

Variation of Shear Stress & Normal Stress for three specimens is shown in figures 9, 10, 11 below:

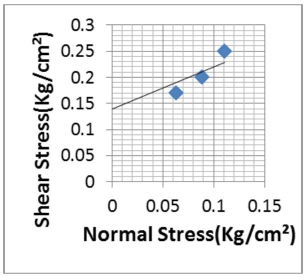


__Figure 9.__ Variation of shear stress and normal stress (specimen without root 0.15 m below ground level).

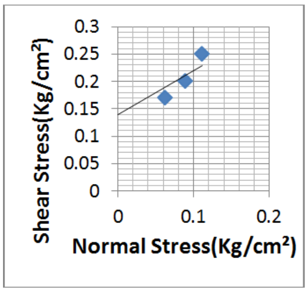


__Figure 10.__ Variation of shear stress and normal stress (specimen with lebbek tree root 0.15 m below ground level).

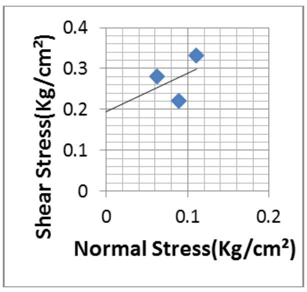


__Figure 11.__ Variation of shear stress and normal stress (specimen with royal Poinciana root 0.15 m below ground level).

From table 9 it is seen that under the same normal stress the shear stress of soil specimen with root is greater than the soil specimen without root. The average percentages of increase in shear stresses of soil specimen are 14.35% and 24.29% of lebbek tree and royal Poinciana respectively. It can be clearly seen that the average percentage of increase in shear strength for royal poinciana is higher than that of lebbek tree. This is because the root density of royal poinciana in soil is higher than that of lebbek tree. This indicates that royal poinciana roots induce higher shear strength to soil than lebbek tree roots. Figure 12 Comparison of average percentage of increase in shear strength between Lebbek Tree & Royal Poinciana

3.4. Comparison Between Field Test Result and Numerical Analysis Result

A comparative study has been made on field test result and numerical analysis result to evaluate the efficiency of the overall work. From the results it is seen in the figure 12 and figure 13 that the average percentage of increase in shear strength for numerical analysis is 26.07% whereas this value for field test is 24.29% for royal poinciana and 14.35% for lebbek tree.

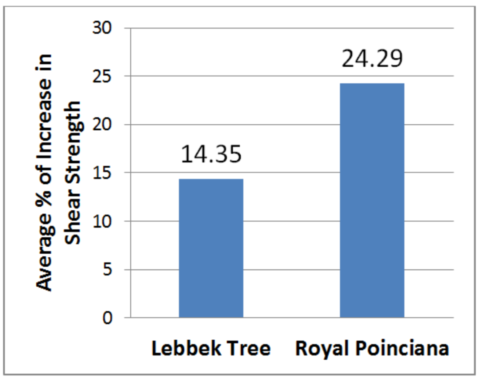


__Figure 12.__ Comparison of average percentage of increase in shear strength between Lebbek Tree & Royal Poinciana.

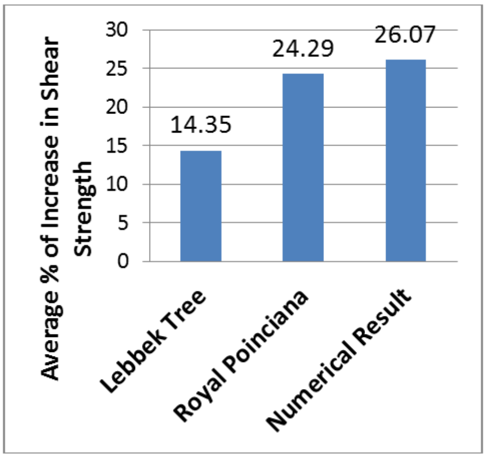


Figure 13. Comparison of average percentage of increase in shear strength between numerical analysis & field test results.

During shearing of root-permeated soil, the tensile strength of each and every root was not mobilized completely as assumed in the model. Some roots were pulled out completely or partly by a rupture at finer point below the shear surface providing a lower resistance to shearing than expected. The penetration of root is assumed to be vertical in the model but some root orientations oblique to the shear surface can give rise to lower shear strength increase in soil. In actual conditions, the root crookedness, jointing and the presence of young roots yield lower shear strength values than those expected from straight, unbranched and mature root which are stronger than the former.

4. Conclusions

The ability of vegetation to stabilize and strengthen soil is now well recognized and this has been applied to the reinforcement of soil on unstable slopes. In-situ direct shear test and numerical investigation is carried out to evaluate the performance of tree root in slope protection. One of the major findings of the study is that the cohesion of soil without root, with lebbek tree root and royal poinciana root are 13.74 kPa, 16.68 kPa and 19.05 kPa respectively. Hence, vegetation increases slope stability significantly by providing additional cohesion in the root zone. The factor of safety of soil slopes without vegetation, with uniform vegetation, cylindrical vegetation and semi-spherical vegetation are 1.605, 1.653, 1.654 and 1.616 respectively. Hence, plants with cylindrical root architecture increase the most significantly slope stability. Uniform rootarchitectures are not deep enough and semi-spherical root architectures have very few deep roots. Root depth, distribution and density representedby generic root architecture models are extremely important in order to quantify correctly the effect of vegetation. In LEM, the values of factor of safety vary between 1.781 and 1.926 in case of slope without root whereas the values of factor of safety vary between 1.997 and 2.173 in case of slope with root. Hence, the factor of safety of slope increases due to the anchorage of tree root. In numerical analysis, the shear strength of soil varies between 40.311 kPa to 41.782kPa in case of slope without root whereas in case of slope with root this value varies between 50.929 kPa to 52.13kPa. The average percentage of increase in shear strength for lebbek tree root is 14.35% whereas this value for royal poinciana is 24.29%. Hence, the shear strength of soil increases due to anchorage of tree root and royal poinciana roots give more stability to soil than lebbek tree roots. The average percentage of increase in shear strength for tree roots found in numerical analysis is 26.07% which is slightly higher than field test value.

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