Use of Vegetation and Geo-Jute in Erosion Control of Slopes in a Sub-Tropical Climate

Mohammad Shariful Islam, Shamima Nasrin, Md. Shahidul Islam, and Farzana Rahman Moury

***Abstract*—**Protection of slope and embankment from erosion has become an important issue in Bangladesh. The constructions of strong structures require large capital, integrated designing, high maintenance cost. Strong structure methods have negative impact on the environment and sometimes not function for the design period. Plantation of vetiver system along the slopes is an alternative solution. Vetiver not only serves the purpose of slope protection but also adds green environment reducing pollution. Vetiver is available in almost all the districts of Bangladesh. This paper presents the application of vetiver system with geo-jute, for slope protection and erosion control of embankments and slopes. In-situ shear tests have been conducted on vetiver rooted soil system to find the shear strength. The shear strength and effective soil cohesion of vetiver rooted soil matrix are respectively 2.0 times and 2.1 times higher than that of the bared soil. Similar trends have been found in direct shear tests conducted on laboratory reconstituted samples. Field trials have been conducted in road embankment and slope protection with vetiver at different sites. During the time of vetiver root growth the soil protection has been accomplished by geo-jute. As the geo-jute degrades with time, vetiver roots grow and take over the function of geo-jutes. Slope stability analyses showed that vegetation increase the factor of safety significantly.

***Keywords*—**Erosion, geo-jute, green technology, vegetation.

I. Introduction

THE geographical setting of Bangladesh makes the country vulnerable to natural disasters. The mountains and hills bordering almost three-fourths of the country, along with the funnel shaped Bay of Bengal in the south, have made the country a meeting place of life-giving monsoon rains, but also make it subjected to the catastrophic ravages of natural disasters. Its physiographic and river morphology also contribute to recurring disasters. Abnormal rainfall and earthquakes in the adjacent Himalayan range add to the disaster situation. Different types of common disasters are flood, cyclone, storm surge, flash flood, drought, tornado, hurricane and landslide.

Some of the major dimensions of climate change for Bangladesh include increase in surface temperatures, associated lowering of ground water table for higher evapotranspiration rates, longer spells of droughts in significant parts of the country and so on [1].The perturbation of earth's climate due to the emission of excessive greenhouse gases is now well established. In one model it showed that storm intensity will increase with the CO_2 induced warming [2].The analysis of historical data of cyclones resulted in alarming trends of future cyclones, showing that frequency of cyclones will increase along with their intensity.

During the years from 1779 to 2010, Bangladesh has been hit by more than 60 severe cyclones [3]. These are recurrent natural hazards that cause loss of lands, agriculture and houses. It also destroys embankments, other hydraulic structures and livelihood along coastlines and estuaries. It is very essential that these embankments are protected against flood and cyclonic storm surge to minimize the damages. Since 1960, 13,000 km of embankments have been constructed to safeguard against inundation, intrusion of saline water and devastation. Over 4000 km of coastal embankments along the coastlines surrounding the Bay of Bengal and offshore islands. Nearly 4600 km of embankments along the bank of big rivers and nearly 4500 km of low-lying embankments along the small rivers, and canals has been constructed. 1488 regulators/sluices, 108 bridges and 923 other structures have been constructed in 135 polders over 472 km of embankment to protect 1.09 million ha of land [4].

The general causes of embankment failure are erosion due to rain splash, wave action and overtopping of storm surge, overturning or uprooting of the trees planted along the embankment slope [5]. Inaccurate construction of embankment side slope also enhances embankment failure. Poor maintenance practice is another main reason of embankment failure.

The failure of embankments and riverbank erosion are common problems in Bangladesh. Devastating flood, excessive rainfall and tidal surge accelerates the failure process which results in immense damage to agriculture and infrastructures every year. About 1.7 million hectares of floodplain areas are prone to riverbank erosion [6].

The traditional practice for protection of embankment in Bangladesh is the use of cement concrete blocks, sand bags, stone or wood revetments, geotextile, geobags and tree plantation. Usually, cement concrete blocks are used where storm surge is high; sand bags or wood revetments are used where flow of water is moderately high. Protection of embankment by plantation is another practice, but it is not effective during cyclone and flood because of overturning or uprooting of plants.

An alternative solution for the problems can be plantation

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of vetiver system along the slope of embankments and river banks [7]. Vetiver root system not only serves the purpose of slope protection but also contributes to the green technology of today's world [8, 9]. It adds green environment reducing pollution and as well as prevents soil erosion of embankment and river bank. Thus biotechnology might be a good alternative and effective solution for embankment protection in Bangladesh.

Bio-engineering techniques are being increasingly favored to control soil erosion in general and for slope protection in particular. The technique envisages use of appropriate vegetation, singly or in combination, with minimum artificial intervention resulting in economy and ecological benefits. Jute geotextiles (JGT) fit in with this technique in view of its inherent special features.

JGT has emerged as a strong alternative to synthetic geotextiles for many civil engineering applications. Due to their short life span, JGTs are used as separator, vegetation growing mesh on slopes or as vertical drains. It can have several applications such as: soil erosion control, vegetation consolidation, agro-mulching, reinforcement, and protection of riverbanks & embankments, land reclamation and in road pavement construction.

Engineers can use vetiver for newly constructed roads or dumps for erosion control. The roads and newly raised platforms can be fenced with vetiver for soil conservation. On the riverbanks vetiver grass can be propagated for both erosion control and as housing material. If geo-jute is laid over the exposed surface it will prevent soil erosion primarily performing the function of vetiver roots. As the vetiver roots will take months to grow, during this time, the soil erosion can be protected by use of geo-jutes. As the geo-jute will degrade with time, vetiver roots will grow and take over the function of geo-jutes. Geo-jute prevents the displacement of soil particle and also mulch the soil for better growth of vetiver.

The special attributes of vetiver is that it can grow on sites where annual rainfall ranges from 200 to 5,000 mm [10]. It can survive in temperature ranging from 0˚C to 50˚C. It grows on highly acidic soil types (pH ranges from 3.0 to 10.5). It is also high tolerant to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil [8].Vetiver root can grow up to a depth of 2.5 to 3.0 m [9, 11] and its roots are very strong with high tensile strength of 75 MPa [12].

Thomas et al. [13] conducted a study on the vetiver availability in Bangladesh. They found that vetiver grass is very common in the division of Chittagong, Dhaka and Rajshahi (about 40% of the total land area of Bangladesh) and common in the Khulna, Sylhet division and other parts of Bangladesh (about 45% of the total land area of Bangladesh).

In-situ shear tests have been conducted on vetiver rooted soil system to find the shear strength of the combined system and compared to that of bared soil. It is found that the vetiver root is effective to improve the strength and stability of slopes [5 and 14]. The weather of Bangladesh is sub-tropical. It is well established that vetiver can grow in sub-tropical climate. The main objective of this paper is to evaluate the performance of vetiver and geo-jute in the field for reducing the erosion of embankment slopes. This study also compares the cost of the traditional methods for slope protection with that of the proposed method.

II. Experimental Program

Two sites were selected for this study. The first site was selected in Pubail (a flood plain area) region of Bangladesh where vetiver grows naturally. Another site was selected in Keraniganj to conduct field trial. For the field trial vetiver was collected from the Pubail site.

A. Physical and Index Properties of Soils

A detailed laboratory investigation was carried out to determine the physical and index properties of the soil samples collected from Pubail and Keraniganj sites. The laboratory-testing program consisted of carrying out specific gravity, moisture content and particle size analysis. All the tests were conducted according to ASTM standards [15].

B. In-situ Shear Test

In-situ shear strength test was conducted in the field on block samples under consolidated un-drained condition. Tests were conducted under different normal stresses at different depths. Normal stresses for the in-situ tests were arbitrarily selected in the range between 10.96 kPa and 19.98 kPa. More details about the test are available at Islam et. al., 2013 [14].

1. Preparation of Block Samples

Clump of vetiver grass was cut at the ground level with a sharp knife. Keeping the root position undisturbed, a trench of the size (1 m × 1m) was made up to the desired depth. Initially the rooted area was cut greater, and then made in desired block sample shape by sharp knife. Block sample size was approximately 29×15×19 cm^3.

2. Test Set-up

A device was developed to determine the in-situ shear strength of the vetiver rooted soil and bared soil [5, 14]. Metal box (having bottom face open) was smoothly pushed from the top of the block sample carefully ensuring that the bottom edge of the metal box does not touch the ground level. Then normal load was placed on the metal box. After that the shear force was applied in a particular direction from one side by a hydraulic jack. Calibrated pressure gauge having the capacity of 250 kN was used to measure the shear force. The block sample failed at the bottom. The deformation of the sample was measured by a Linear Variable Displacement Transducer (LVDT) having the capacity of 50 mm. The LVDT was fixed to the ground surface by a metal plate.

C. Direct Shear Test on Reconstituted Samples

Direct shear tests were also conducted in consolidated un-drained (CU) condition on reconstituted soil samples collected from the Pubail site to make the results comparable. Details on these tests are presented in Islam et al., 2013 [14].

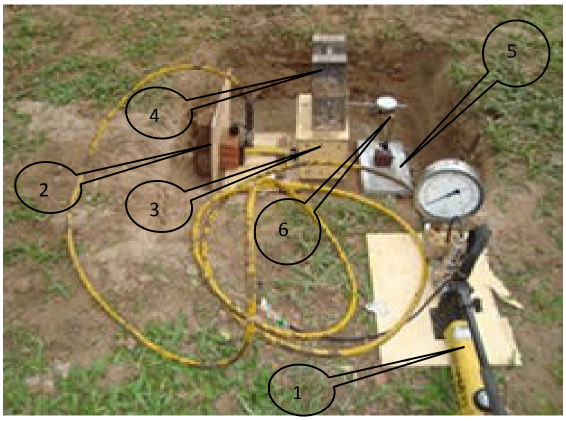


Fig. 1 The test set-up for determination of in-situ shear strength [1) hydraulic jack, 2) wooden plate, 3) metal box (approx. 29 × 15× 19 cm^3), 4) normal load, 5) metal plate, and 6) LVDT]

(a)

(b)

Fig. 2 Preparation of vetiver root mixed soil sample: (a) randomly mixed vetiver roots with wet soil and (b) prepared soil sample inside a probing ring (inner diameter: 63.5 mm; thickness: 25.4 mm)

1. Preparation of Reconstituted Samples

The collected soils were air dried at first and crushed in to powder by a wooden hammer. Water (equal to natural moisture content, 25%) was added to the dry soil and chopped vetiver roots (25mm long) were randomly mixed with the wet soil. Percentage of root content was varied from 0% to 12% of the dry weight of the soil sample. The soil was compacted inside a probing ring (63.5 mm in diameter and 25.4 mm in height) by a wooden rod from a falling height of 100 mm, to attain a density similar to that of field density. The compaction was done in three layers with 25 blows per layer. The wet density of the prepared soil samples varied from 17.45 to 17.50 kN/m^3 which is very close to the field density of the block soil sample (17.48 kN/m^3). The prepared samples were kept in a desiccator to keep the moisture content unchanged. Fig. 2a shows the root mixed soil and Fig. 2b shows a sample prepared inside the ring.

2. Test Set-up

The remolded soil sample was placed carefully in the shear. box from the ring. Then the desired normal load was applied. A dial gauge for getting vertical displacement was attached to record the vertical deformation with respect to time. Enough time (about 2 hours) was allowed for complete dissipation of the pore water pressure before applying the shear force. When the vertical deformation dial reading was substantially ceased, the shear was applied to the soil sample with a constant strain rate of 0.75 to 1.25 mm/min. The lateral deformation was recorded by another dial gauge of 25 mm capacity. The applied shear force was recorded by a load dial gauge of 2.22 kN capacity.

III. Test Result

A. Index Properties of Soils

Fig. 3 shows the typical particle size distribution of the Keraniganj and Pubail soil samples. From Fig. 3, it is seen that clay, silt, and sand fractions of the soil collected from Keraniganj are 10%, 41% and 49%, respectively. The specific gravity and natural moisture content are 2.70 and 15.8%, respectively. The soil collected from Keraniganj site is classified as sandy silt.

From Fig. 3, it is seen that clay, silt, and sand fractions of soils collected from Pubail regions are 26%, 69% and 5%, respectively. The specific gravity (G_s) and natural moisture content of the sample are 2.66 and 25%, respectively. Dry unit weight of the soil samples varies from14.4 to 14.7 kN/m^3. It has been found that the soil samples collected from Pubail is silty clays and the designated group symbol according to ASTM D2487 is CL (inorganic clays of low to medium plasticity or silty clay).

B. Strength Properties of Soils

Fig. 4(a) and 4(b) show the graph of peak shear stress versus normal stress for bared and vetiver rooted soil matrix of in-situ and reconstituted soil samples, respectively. From Fig. 4(a), it is seen that the peak shear stress of vetiver rooted soil matrix is always higher than that of bared soil for any case of normal stress. The strength of vetiver rooted soil is about 2.1 times higher than that of bared soil. Stress-strain relationships showed that rooted soil samples posses high ductility. So, it means that rooted soil can absorb much energy before failure. Fig. 4(b) shows that strength of vetiver rooted soil samples is higer than that of unrooted soil samples as observed in the case of field samples.

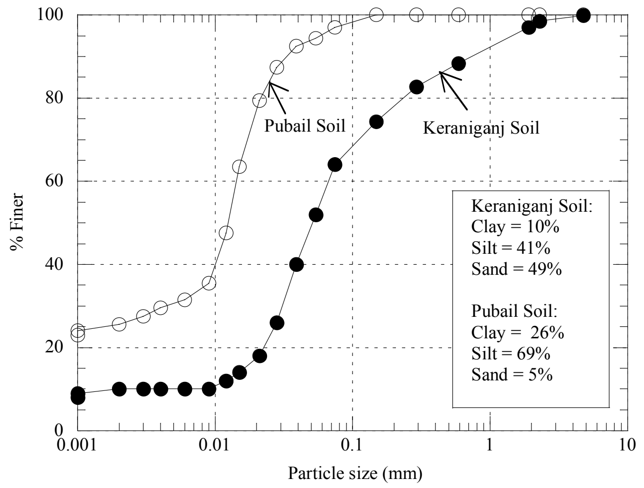


Fig. 3 Typical particle size distribution of Keraniganj and Pubail soil

However, 9% rooted (by weight) soil sample has the maximum strength. It means that there is an optimum root content which will provide maximum strength. Reconstituted soil samples with vetiver roots also showed significant ductility.

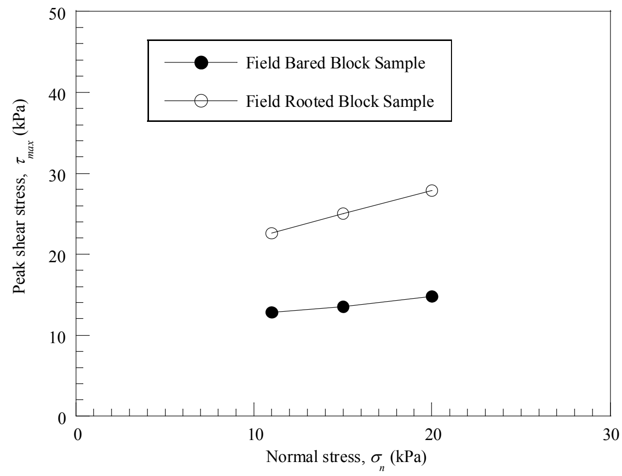
The strength of the rooted soil depends on several factors such as, physical properties of soil, density and moisture content of soil and contribution ofparticular normal stress. However, it is clear that rooted soil will contribute to the stability of the slopes. Detail results on strength properties of rooted soil are discussed in Islam et. al., 2010 [5] and Islam et al., 2013 [14]. Here these results are prsented briefly for using in stability analyses.

C. Properties of Geo-jute (JGT)

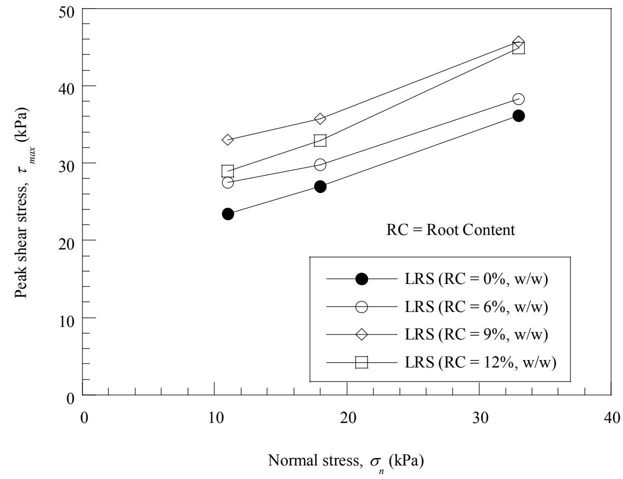
Different types of geo-jute (JGT) based on mesh opening size and unit mass are available. Four types of geo-jute were studied in this study for selecting JGT. Absorption capacity of the selected JGTs was determined using the procedure developed by Khan and Sakib [16]. Absorption capacity and unit mass of the JGTs are presented in Table I. Among these, the geo-jute with unit mass 700 gsm was selected for its dense mesh depending on the rainfall data that will protect erosion effectively for long time before the growth of vegetation. Strength properties of the selected JGT are presented in Table II. The absorption capacity of the selected JGT is 2.75. It remains wet for several days after absorption which creates mulch effectand helps the growth of vegetation even in dry weather condition. The growth rate of root is faster just after the plantation and during the rainy season. But it decreases with the advancement of time after plantation. Fig. 5 shows the JGT used in the field. The opening of the mesh is 31 mm × 33 mm. The weft yarn is 4.0mm in diameter.

IV. Field Trail

The site was selected at the northern approach road of Itavara Bridge of the Konakhola-Kholamura-Hazratpur-Itavara-Hemayetpur Road of Roads and Highways Department for vetiver plantation with and without.



(a)



(b)

Fig. 4 Peak shear stress versus normal stress: (a) field block samples and (b) reconstituted soil samples

TABLE I
Properties of Geo-Jutes

Parameter	Test Standard	Unit	Type of JGT			
Mass per Unit Area	ASTM D3776	gm/m^2	365	500	600	750
Absorption Capacity	Developed at BUET*	(%)	3.50	3.40	2.90	2.75

*[16]

TABLE II
Properties of Geo-Jute used for Field Trail

Unit Mass (gsm)	Opening size (mm^2)	Tensile Strength (N/m)	Absorption Capacity
700	31 × 33	Horizontal: 5886 Longitudinal:21092	2.75

Geo-jute. Annual Average Daily Traffic (AADT) of the road is 71.38 and the road class is Zilla road (District Road).

The road was constructed in the financial year 2005-06. After the construction of the road, the side slope of the road has faced serious erosion problem. Maintenance and protection of the side slope of the road was required using geo-bag, sand bag etc.

A. Geo-jute Placement and Vetiver Plantation

The sloping ground was cleaned and the slope was prepared nearly at 1:1.5. Cow dung was mixed with the top soil of the slope for rapid growth of vetiver grass. Fig. 6 shows the schematic diagram of vetiver plantation and geo-jute application in the field trail. JGT was laid down with 100 mm overlapping. During placement, the weft (4 mm dia) of the mesh was placed along the slope and warp was perpendicular to the slope. JGT was fixed with the ground using 4 mm diameter inverted U-shaped steel clip (10 cm × 24 cm). The clips were fixed at 107 cm intervals along the slope and at 60 cm intervals along the road length. The well rooted clumps of vetiver were planted in 20 cm × 20 cm square grid to ensure a close hedge within 12 months of planting. Total 73370 vetiver grass was needed for this site which was collected from Pubail site.

Fig. 7 shows the photographs of prepared side slope, placement of geo-jute and vetiver after plantation.

B. Field Monitoring

Close monitoring of the planted vetiver and placed geo-jute was conducted after the vetiver plantation. Displacement of JGT was noted and watched without disturbing it initially. Torn portions of JGT were overlapped by fresh JGT-pieces duly stapled on all sides. Watering/maintenance of the plant-saplings were done regularly.

The growth rate of shoots and roots was measured at one week interval from the time of vetiver plantation. Fig. 8 shows some pictures of monitoring of vetiver growth. At a regular interval the root and shoot lengths were measured. For measuring the root length, keeping the root position undisturbed, trench was made up to the root depth. Then the clump of vetiver was taken out with root. After measuring the root length, the vetiver clump was replanted. Special care was taken so that the replanted vetiver can grow properly. Fig. 9 shows the growth rate of both the shoot and root with time. Initial length of shoot and root were 15 cm and 5 cm, respectively. However, both the root and shoot were dried and grown again newly. That's why the initial lengths of root and shoot were not considered in the measurement as presented in Fig. 9. As can be seen from the figure that vetiver was planted in the winter season. For that reason watering was done at the site regularly (alternate day) so that the vetiver plants get enough water for growing. After that the vetiver went through the summer season. Before the summer season root grown up to 30cm and the shoot grown up to 45 cm. After that the vetiver went through the rainy season. During the rainy season the growth of the shoot has been accelerated. After 8 months of vetiver plantation, the root has grown up to 40 cm. It means that the root length will be enough before the next rainy season to protect the slope from erosion.

Fig. 5 Photograph of geo-jute used in the field trail of slope protection

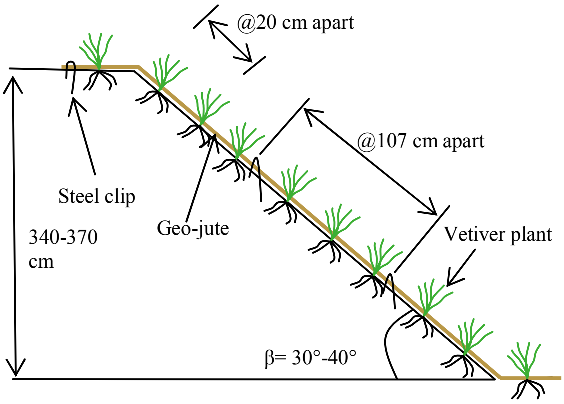


Fig. 6 Schematic diagram showing the placement of geo-jute and vetiver plantation on the embankment slope

V. Analysis

A. Estimation of Slope Stability

1. Bishop Method

Bishop Method [17] as described in (1) is used to determine the factor of safety of bared slope using the laboratory direct shear tests data. Properties of the embankment and foundation soils are taken from the soil test results that were conducted in this study.

Circular slip circle is assumed for the stability analysis. Factor of safety (FS) has been estimated using (1).

$$FS = \frac{\sum \frac{1}{m_\alpha}[c'b + (W - ub)\tan\phi']}{W \sin\alpha} \quad (1)$$

where,

c' = cohesion of soil, b = width of slice, W= weight of slice, u=pore water pressure, ϕ'= angle of internal friction of soil.

(a)

(b)

(c)

Fig. 7 Photographs of: (a) preparation of the slope to lay the geo-jute (JGT), (b) fixing steel clip to keep JGT in the slope and (c) plantation of vetiver on the side slope of the road

(a)

(b)

(c)

Fig. 8 Photographs showing: (a) measurement of growth of shoots after 1 month, (b) measurement of growth of shots after 6 months and (c) measurement of growth of roots after 6 months of plantation

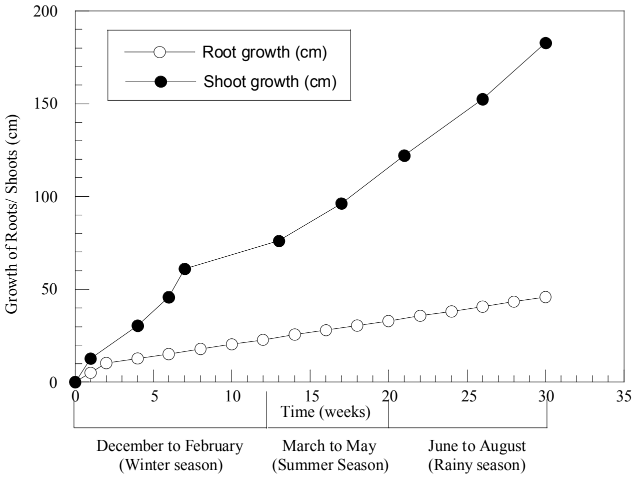


Fig. 9 Growth of shoots and roots with time after plantation

$m_\alpha = (1+\tan\phi' \tan\alpha/F_s)\cos\alpha$

For the analyses, c′= 20 kN/m^2, width of slice = 2 m, and angle of internal friction ϕ′= 23^0 were used.

3. Coppin, and Richards (1990) Method

In-situ test data presented in Islam et. al. [14] was used for determining the factor of safety (FS) using Coppin and Richards method [18].

For Bared soil:

$$FS = \frac{c' + (\gamma z - \gamma_w h_w)\cos^2\beta \, \tan\phi'}{\gamma z \sin\beta \cos\beta} \quad (2)$$

The values used for the analyses are as follows:
Effective soil cohesion, c′ = 10 kN/m^2
Unit weight of soil, γ = 18 kN/m^3
Vertical height of soil above slip plane, z = 1.0 m
Slope angle, β = 35^0
Unit weight of water, γ_w = 9.8 kN/m^3
Vertical height of GWT above slip plane, h_w = 0.5 m
Effective angle of internal friction of the soil, φ′ = 35^0

For Rooted soil the factor of safety (FS):

$$FS = \frac{(c' + c'_R) + [\{(\gamma z - \gamma_w h_v) + W\}\cos^2\beta + T\sin\theta]\tan\phi' + T\cos\theta}{\{(\gamma z + W)\sin\beta + D\}\cos\beta} \quad (3)$$

The values used for the analyses are as follows:
Enhanced effective soil cohesion due to soil reinforcement by roots, c'_R = 9.1 kN/m^3
Surcharge due to weight of vegetation, W = 2.5 kN/m^2
Vertical height of GWT above the slip plane with the vegetation, h_v = 0.4 m
Tensile root force acting at the base of the slip plane, T =5kN/m, Angle between roots and slip plane, θ = 45^0 and
Wind loading force parallel to the slope, D = 0.1 kN/m

TABLE III
ANALYSIS OF FACTOR OF SAFETY

Analysis Condition	Method	Soil Properties			Factor of Safety
		γ (kN/m³)	*c (kPa)*	*φ (°)*	
Bared Slope	Bishop's simplified method	18-19	20	23.0	1.66
Bared Slope	Coppin and Richards (1990) infinite slope method (bared soil)	18	13	8.4	1.66
Rooted Slope	Coppin and Richards (1990) infinite slope method (with vegetation)	18	22	17	2.90

The results of factor of safely analyses are shown in Table III. For factor of safety analyses, it is assumed that the vetiver rooted crosses the slip circle. It is seen that factor of safety for bared slope and rooted slope are 1.66 and 2.90, respectively. So, it is clear that vetiver root is effective for improving the factor of safety significantly.

B. Storage Analysis

The amount of storage of water by the chosen JGT is estimated from the following relation proposed by Sanyal [19].

$$S = N \times d^2 \times (4cot\beta - \pi) \times 103\; mm^2/m^2$$

where, S denotes storage as a result of posing of micro-barriers by Open Weave JGT against the overland flow; β is the angle of inclination of the ground slope= 30; d is the diameter of the weft yarn= 4 mm; N is the number of weft yarn per mete= 86.

It is seen that the estimated storage capacity is 5.37x10^6 mm^3/m^2. It means that on a bared dry slope, 700 gsm open wave JGT can retain 5.37x10^6 mm^3 water m^2. Rainfall data indicates that the maximum rainfall is 340 mm which occurs during July and August. Annual rainfall is 1875 mm. The estimated maximum run off from the rainfall is 3.30x10^8 mm^3/m^2. The excess runoff will not be significant to cause slope erosion as would be in bared slope.

C. Economic Analysis

Table IV shows the cost analysis of slope protection by various methods that are commonly used in Bangladesh. The cost of the materials/items were taken from the rate schedule of LGED and BWDB [20, 21]. Among them, vetiver plantation costs least; 0.79 USD per sq. meter without any geo-jute and 1.45 USD per sq. meter with geo-jute. Cement concrete blocks and clay claddings cost are 18.49 USD and 11.89 USD per sq. meter, respectively. So, it is clear that the cost of vetiver plantation with and without geo-jute is significantly lower than that of the other common practices. Now-a-days, clay is not available and it reduces the top soil of the agricultural land. Cost of cement concrete block is high and production of its materials causes addition of CO_2 to the environment. On the other hand, vetiver plantation will add O_2 to the environment as wells as vetiver can be used for many other purposes such as roofing of the houses.

TABLE IV
COST OF DIFFERENT SLOPE STABILIZATION PRACTICES IN BANGLADESH

Method Name	Description	Cost/sqm (USD)
Cement concrete blocks	Block Size: 20cm× 20cm×15cm Mix Ratio = 1:3:6 Synthetic geotextile Sand and brick aggregate as drainage material	18.49
Clay cladding	Thickness 1.0 m	11.89
Vetiver grass without geo-jute	Spacing: 20cm in square grid 2 slips together	0.79
Vetiver grass with geo-jute	700 gm per m^2 Opening size: 31 mm × 33mm Fixing pin (4mm diameter U-shaped steel pin)	1.45

VI. CONCLUSION

Embankment failure due to erosion is a common problem in Bangladesh. Plantation of vetiver system along the slope of embankments, river banks and hill slope is an alternative green solution to the problem. Vetiver is available in almost all the districts (80-85% of the total land) of Bangladesh. Field and laboratory tests were conducted to determine the strength of vetiver rooted soil [14]. Field trail has been conducted to investigate the suitability of vetiver with geo-jute for slope protection. The main findings of the study are as follows:

(1) In-situ shear tests conducted on vetiver rooted soil system showed that shear strength of vetiver rooted soil matrix is 2.0 times higher than that of the bared soil. Again, the effective cohesion of vetiver rooted soil matrix is 2.1 times higher than that of the bared soil. The vetiver rooted sample showed ductile behavior. Direct shear tests conducted on laboratory reconstituted unreinforced and reinforced samples showed similar trend as observed in in-situ tests. Tests on laboratory reconstituted samples showed that there is an optimum root content.

(2) Field trials have been conducted in road embankment and slope protection with vetiver at different sites. At the initial stage, during the time of vetiver root growth the soil protection has been accomplished by application of geo-jute. Geo-jute laid over the exposed surface prevents soil erosion primarily; it prevents displacement of soil particle and mulch the soil for better growth of vetiver. As the geo-jute degrades with time, vetiver roots grow and take over the function of geo-jutes. It is found that there is no problem of erosion at the side slope protected by vetiver and geo-jute.

(3) Slope stability analyses conducted for both bared and vegetated (with and without geo-jute) slopes. The factor of safety is 1.66 for bared slope and 2.90 for rooted slope, respectively.

(4) Vetiver plantation costs least compared to other common practices such as cement concrete block and clay claddings.

It is found that the sub-tropical climate of Bangladesh is suitable for vetiver plantation. Plantation of vetiver along with the use of geo-jute can be a cost-effective, sustainable, eco-friendly method for the erosion control of slopes in Bangladesh.

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