In-situ Shear Strength of Vetiver Grass Rooted Soil

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ABSTRACT

River bank erosion and embankment failures happen continuously throughout Bangladesh. From a strictly economic point of view, the cost of remediating these problems is high, and the State budget for such works is never sufficient which confines rigid structural protection measures to the most acute sections, never to the full length of coastline and embankment. From field survey, it is observed that the general reasons of embankment failure are erosion due to rain splash, wave action and overtopping of storm surge. Poor maintenance practice, overturning or uprooting of trees are also other reasons of embankment failure. It was found that the traditional practice for protection of embankment is to use cement concrete blocks, stone or wood revetments, geobags, geotextile and plantation etc. These are expensive and not so effective to protect the embankments and river bank for the designed life. On the other hand, protection of embankment slopes using vegetation is being used in many countries efficiently. The special attributes of vetiver grass (*Vetiveria zizanioides*) is its longer life, strong and long finely structured root system and high tolerance of extreme climatic change. This paper also presents the soil characteristics of coastal regions of Bangladesh and the effectiveness of vetiver grass in protecting the embankment slopes against erosion, flood and cyclonic tidal surge. From the laboratory investigation, it is found that the soils used in the coast for embankment construction are generally silty sand. A device was developed to determine the in-situ shear strength of the vetiver rooted soil matrix. Block samples (approx. $29\times15\times19$ cm^3) was tested at different depths under different normal loads at the field to know the in-situ shear strength. It is found that the shear strength of vetiver rooted soil is 78% higher than that of soil without root. Again, the failure strain is 515% higher than that of soil without root. This means that vetiver grass is able to increase the factor of safety of embankment slopes against natural forces.

Keywords : coastal embankment, vegetation, vetiver grass (*Vetiveria zizanioides)*, rooted soil, in-situ shear strength

1. INTRODUCTION

Coastal regions of Bangladesh are most vulnerable for cyclone, flood and tsunami etc. About 28% of the population lives in the coastal regions. The great majority of this people directly or indirectly depend on agriculture for earning their living. The annual growth rate of GDP is greatly dependent on agricultural produce. With the aim of increasing agricultural production, safeguard against inundation, intrusion of saline water and devastation construction of earth embankments and dykes, their repairing and rebuilding have been the history of Bangladesh since time immemorial. During the years from 1797 to 1998, Bangladesh has been hit by more than 60 severe cyclones. As the embankments, river bank and other hydraulic structures are the first defense against the storm surge, they received the most severe injury. So, it is clear that embankments should be protected against flood and cyclonic storm surge to minimize the losses that occur due to their damages. As for example, cyclone SIDR destroyed fully 362 km and partially 1927 km of coastal embankment, whose damage value is 32 million US$ (DMB, 2008).

Unfortunately, our State budget is never sufficient which confines rigid structural protection measures to the most acute sections, never to the full length of the river bank or coastline and embankment. This bandage approach compounds the problem. On the other hand, hard engineering structure makes the scenic environment unpleasant and helps only to transfer the problem from one place to another place, to the opposite site or downstream, which aggravates the problem rather than reducing. Establishment of vegetation as a soft bioengineering technique to rigid or hard structures accepted all over the world due to its low cost, longevity and environment friendliness.

The general reasons of embankment and river bank failure is erosion due to rain splash, wave action and overtopping of storm surge. Poor maintenance practice, overturning or uprooting of trees, inaccuracy in construction of embankment slopes are also enhance embankment failure (Islam and Arifuzzaman, 2010).

Many researches have been conducted in abroad to know the performance of vetiver grass against climatic change, slope protection, coastal embankment protection and so on. Hengchaovanich (1998) analyzed slope stability based on vetiver root strength. Ke et al. (2003) tested vetiver as a bank protection measure on several test sites (in Australia, China, Philippines and Vietnam). Their tests showed promising results for the use of vetiver grass as a bank protection measure. Verhagen et al. (2008) conducted different laboratory and model tests on vetiver grass to realize the use of it in coastal engineering and showed that vetiver grass is able to establish a full-stop of bank erosion caused by rapid draw down. However, a very few researches have conducted in Bangladesh for the protection of embankment against natural disasters using vetiver grass.

Islam (2003) studied the performance of vetiver grass on eighteen coastal polders over eighty-seven kilometers of earthen coastal embankment of Bangladesh. He observed that the main problem in maintaining those earthen embankments is water borne erosion either through surface run-off or from wave action or both. He provided some guide lines on vetiver application which is helpful for better performance. He achieved successful cases where initial protection and watering could be ensured. Moula et al. (2008) studied on the nursery performance of vetiver grass with different number of tillers. He investigated the optimum number of tillers per clump for the proper propagation of vetiver grass. According to his observation, it is revealed that propagation of vetiver clump with double tillers is better than single or triple tillers.

The lessons learnt from cyclone that afforestation on the embankment slope (allowable species), river bank and in the foreshore decrease the cyclone havoc and protect the wave action to a certain extent. However, the tree on the embankment slope may cause many problems. Cyclone may damage trees making hole on the embankments, it may also create local scour around the tree. It will increase disaster during the storm surge event. An eco-friendly vetiver grass (*Vetiveria zizanioides*) has been used successfully over 100 countries for more than a century as traditional bioengineering technology in stabilizing inner slopes, reducing run-off and controlling soil loss. On this subject, Bangladesh is in advantageous position as it has abundant supply of vetiver grass.

Although a few researches have been conducted to know the strength of vetiver roots, performance of vetiver grass and tillers effects but in-situ shear strength of the vetiver grass rooted soil matrix was not investigated. For proper stability analysis of embankments, river banks and hilly slopes it is essential to know the strength of the rooted soil matrix. In the absence of such data stability of a slope can not be estimated properly. This paper presents the soil characteristics of coastal regions, in-situ strength of vetiver rooted soil matrix and soil without root. Finally, the effectiveness of vetiver grass in protecting the embankments against erosion, flood and tidal surge has also been presented.

2. FIELD SURVEY

Field survey was carried out to know the available grass or vegetation types at the coast of Bangladesh. The suitability/sustainability of the vetiver grass at the coastal regions of Bangladesh was also investigated.

2.1. Selection of Study Area

Man has little control over natural disaster. We cannot resist cyclone and flood but we can try to minimize the loss due to natural hazards. Because of the funnel shaped coast of the Bay of Bengal, Bangladesh very often becomes the landing ground of cyclones formed in the Bay of Bengal. The Bay cyclones also move towards the eastern coast of India, Myanmar and occasionally into Sri Lanka. But they cause the maximum damage when they come into Bangladesh, west Bengal and Orissa of India. This is because of the low flat terrain, high density of population and poorly constructed houses, embankments, hydraulic structures etc. In Bangladesh, most of the damage occurs in the coastal regions of Khulna, Patuakhali, Barisal, Noakhali and Chittagong and the offshore islands of Bhola, Hatiya, Sandwip, Manpura, Kutubdia, Maheshkhali, Nijhum Dwip, Urir Char and other newly formed islands. The cyclonic vulnerable area can be seen from Fig. 1. As the coastal zone is the most vulnerable to natural hazards, the study area has been selected in the coastal zone of Bangladesh. Kuakata region of Bangladesh coast has been selected for this study because of its importance due to its high potential as a tourism area.

2.2. Selection of Vegetation

Field survey was carried out to find out the grass available in the coast, which are helpful for erosion control. It was found that shrub species of local named Durba (*Cynodon dectylon*), Chalia, Aralie, Jhora, Dol ghas (*Hydrilla verticillata*), Shon ghas, Binna (*Vetiveria zizanioides*), Chesr, Tihera, Agali, Banna lata (*Mikania cordata*), Bazra, Gini, Tara, Cowpee and Ipil-ipil (*Leucaena leucochephala*) etc. are found in the study area.

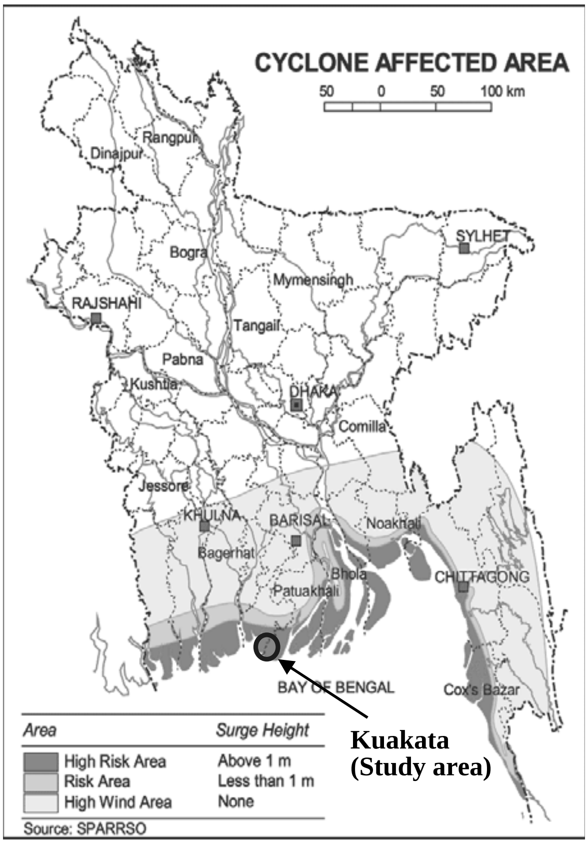
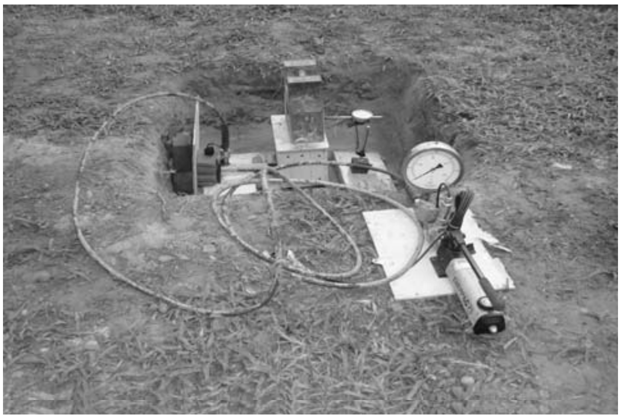


Figure 1: Map showing the cyclone affected regions of Bangladesh and study area

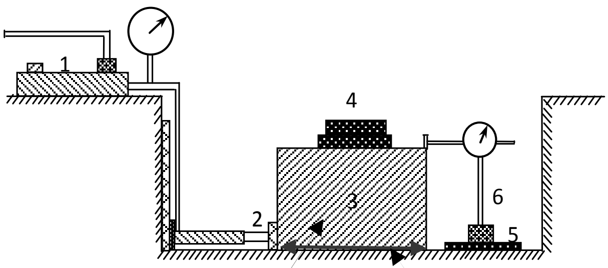
Binna or vetiver grass (*Vetiveria zizanioides*) is used in more than 100 countries of the world (Truong, 2000). Most developed and developing countries like Australia, China, India, Malaysia, Spain, Thailand and Zimbabwe use vetiver for different erosion protection works. It creates a simple vegetative barrier of rigid, dense and deeply rooted clump grass, which slows runoff and retains sediment on site. The special attributes of vetiver is that it can grow on sites where annual rainfall ranges from 200 mm to 5,000 mm (Rahman et al., 1996). 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 (Truong and Baker, 1998). Even in the soil with ECse values 7.8 dSm^{-1}, the relative yield of vetiver grass is found to be 100%. But in soil with ECse values of 10 and 20 dSm^{-1} yield of vetiver is reduced by 10% and 50%, respectively (Truong et al., 2002). Its roots are very strong with high tensile strength of 75 MPa (Hengchaovanich, 1998). Vetiver hedges can survive even for more than 100 years (Verhagen et al., 2008).

Mean annual rainfall varies from about 1500 mm in the southwest (Khulna district) to over 3750 mm in the southeast (Cox's Bazar) and about 2506 mm in Patuakhali district. The heaviest rainfall occurs in July and ranges from 350~875 mm (Islam, 2003). Soil Resources Development Institute assessed soil salinity status of Patuakhali and Barguna districts. The soil salinity varies from 2.0~10.0 dSm^{-1} for most of the area where our study area is also exists. Therefore, it is clear that the local climatic and soil condition is suitable for vetiver grass to grow at the coast of Bangladesh. Hence, vetiver is considered in this research as a potential vegetation in protecting the coastal embankments against cyclonic tidal surge. Figure 2 shows a naturally grown clump of vetiver grass found at the study area, Kuakata. This means that it can be easily grown at the coast of Bangladesh.

Figure 2: Naturally grown clump of vetiver grass at the study area Kuakata, Bangladesh



(a)



(b)

Sample is inside the box

Failure line

Legend:

1) Hydraulic jack
2) Wooden plate
3) Metal box (approx. 29 × 15× 19 cm^3)
4) Normal load
5) Metal plate
6) LVDT

Figure 3: Apparatus for in-situ shear strength test: (a) field test set-up and (b) schematic diagram of test set-up

3. EXPERIMENTAL PROGRAM

Field tests were conducted to determine the in-situ shear strength and failure strain of vetiver rooted soil matrix and soil without root at Kuakata. A special device has been developedfor conducting the field tests. Disturbed soil samples were also collected in polythene bag during the field test for laboratory investigations.

3.1 Laboratory Tests

A detailed laboratory investigation was carried out on 24 soil samples collected from Kuakata region. The laboratory-testing program consisted of carrying out specific gravity, moisture content, particle size analysis and direct shear tests. Tests were conducted according to ASTM standards (ASTM, 1989). Besides, 39 laboratory tests data of particle size analysis and specific gravity of the coastal soils (Khulna, Bagerhat and Patuakhali district) was collected from BRTC, BUET.

3.2 In-situ Shear Test for Block Samples

In-situ shear strength test was conducted in the field on sixteen block samples. Tests were conducted under different normal stresses at different depths. Normal stresses were arbitrarily selected in the range between 10.96 kPa and 19.98 kPa.

3.2.1 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 upto the desired depth. Initially the rooted area was greater than desired block sample size. After that the rooted area was made in desired block sample shape by sharp knife. Then the metal box (having bottom face open) was smoothly pushed from the top of the block sample. Then normal load was placed on the metal box. It was carefully ensured that, the bottom edge of the metal box can not touch the ground level. Then horizontal force was applied to the box from one side by hydraulic jack. Calibrated pressure gauge was used to measure the horizontal force. The block sample was failed at the bottom and the deflection of sample was measured by Linear Variable Displacement Transducer (LVDT) which was fixed to the ground surface by metal plate.

3.2.2 *Test Set-up*

A device was developed in this study to determine the in-situ shear strength of the vetiver rooted soil and soil without root. Block samples (approx. 29×15×19 cm^3) were tested at different depths under different normal stresses at the field to know the in-situ strength of the rooted soil and soil without root. For this purpose, Linear Variable Displacement Transducer (LVDT) having capacity of 50 mm was used to determine the horizontal deformation. Hydraulic jack was used to apply horizontal force. Pressure gauge having capacity of 800 psi was used to measure the in-situ soil strength. Both pressure gauge and deformation gauges were calibrated before using them in the test. Figure 3a and 3b show the photograph of the apparatus and the schematic diagram of the test set-up for in-situ shear test, respectively.

4. RESULTS AND DISCUSSIONS

4.1 Laboratory Tests

4.1.1 Physical and Index Properties

The physical and index properties as well as grain size of the 63 samples are presented in Table 1. Specific gravity (G_s) of the samples varies between 2.66 and 2.72. Natural moisture content ranges from 11 to 25 %. Dry unit weight of the soil samples varies from 14.4 to14.7 kN/m^3. According to ASTM D 422, clay, silt and sand fractions vary from 0 to 5%, 13 to 28% and 70 to 86%, respectively. Using the results of grain size analysis, soil samples have been classified according to the ASTM D2487 (ASTM, 1989). It has been found that all the samples are silty sand and the designated group symbol is SM.

Table 1: Physical properties of the coastal soil

G_s	w_n (%)	γ_d (kN/m)	Clay %	Silt %	Sand %
2.66~2.72	11~25	14.4~14.7	0~5	13~28	70~86

Note: G_s = specific gravity; γ_d = dry unit weight; w_n = natural moisture content

4.1.2 Shear Strength Properties

Consolidated drained (CD) direct shear tests were carried out on two samples according to ASTM D 3080. Figure 4a shows the particle size distribution of the tested samples. Figure 4b shows failure envelope of the samples in CD test. The cohesion of the soil samples varies between 4.0 kPa and 5.0 kPa. Angle of internal friction is in the range of 36˚ to 38˚. Here, cohesion is very low and it is reasonable, because the tested soil samples were silty sand and the maximum percentage of clay was 3%.

4.2 In-situ Shear Strength of Block Samples

It was found that the root of the vertiver grass was up to about 500 mm from the Existing ground Level (EGL). Tests were conducted at 200 mm and 400 mm depths from EGL for both rooted soil and soil without root. For each depth, tests were conducted for arbitrarily selected three different normal stresses (i.e., 10.96 kPa, 15.47 kPa and 19.98 kPa). For each case, two tests were conducted to check the repeatability of the test results. That means a total of twenty four block samples were tested in the field under different normal stresses at different depths. Out of twenty four samples, 12 samples were vetiver rooted and other 12 samples were soil without root.

Figure 5a and 5b show the typical shear stress and shear strain graph of block samples at 200 mm and 400 mm depths at 19.98 kPa normal stress. The test results of the samples at depth 200 mm and at 400 mm are presented in Table 2 and Table 3, respectively.

From Table 2, it is seen that the average strength of vetiver rooted soil matrix at 200 mm depth is 87% higher than that of soil without root for the particular normal stress range (i.e., 10.96 to 19.98 kPa). The average failure strain is about 770% higher than that of soil without root for the particular normal stress range (i.e., 10.96 to 19.98 kPa).

From Table 3, it is seen that the average strength of vetiver rooted soil matrix at 400 mm depth is 69% higher than that of soil without root. The average failure strain is about 259% higher than that of soil without root for the particular stress range.

From these results, it is found that the average strength of rooted soil matrix over the depth (i.e., up to 400 mm) is 78%

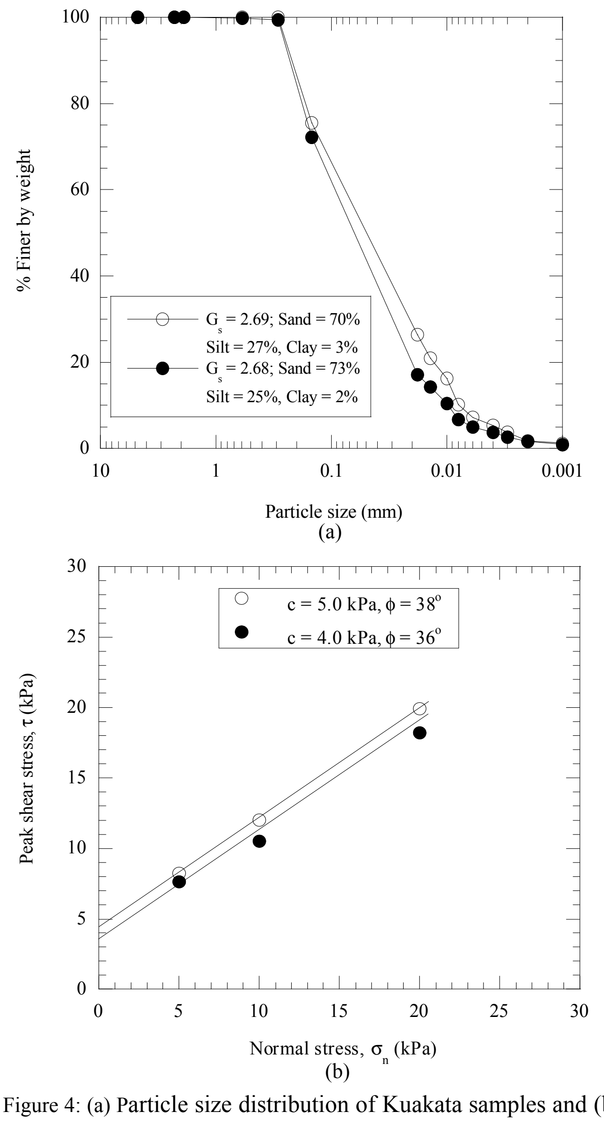


Figure 4: (a) Particle size distribution of Kuakata samples and (b) failure envelope of the soils in consolidated drained direct shear test

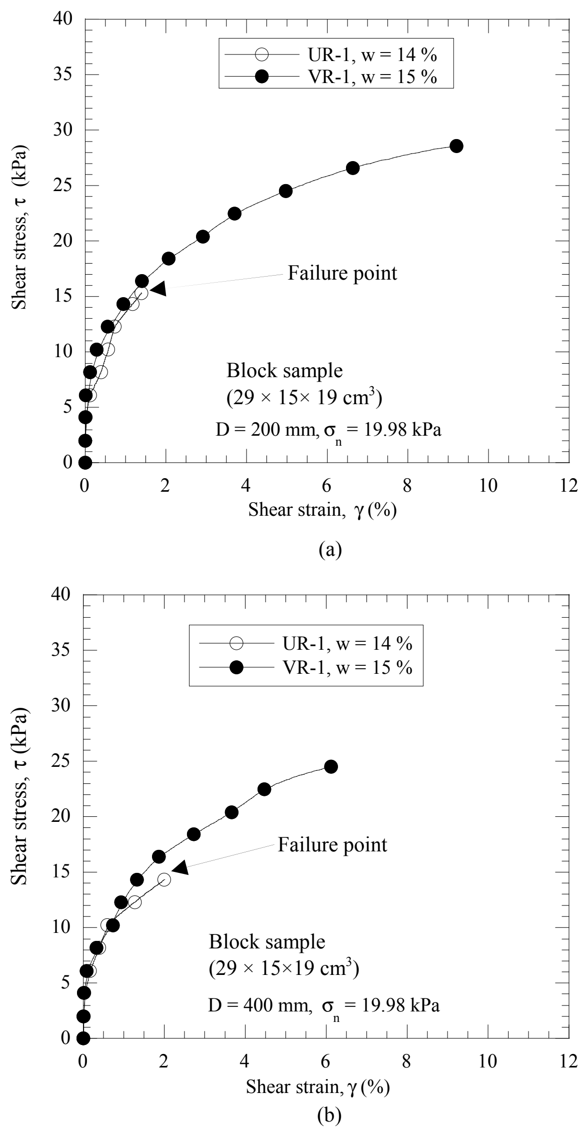


Figure 5: Shear stress versus shear strain: (a) at 200 mm depth and (b) at 400 mm depth (UR = soil without root; VR= vetiver rooted soil matrix; D = depth from existing ground level; σ_n = normal stress)

Table 2: Comparison of shear strength and failure strain of rooted soil matrix and soil without root at 200 mm depth

Normal stress (kPa)	Peak shear stress τ_{max} (kPa)		Failure shear strain γ_f (%)	
	Rooted Soil	Soil without root	Rooted Soil	Soil without root
10.96	22.5	12.3	6.93	0.63
15.47	25.5	13.3	9.13	1.07
19.98	28.6	15.3	9.20	1.40

Table 3: Comparison of shear strength and failure strain of rooted soil matrix and soil without root at 400 mm depth

Normal stress (kPa)	Peak shear stress τ_{max} (kPa)		Failure shear strain γ_f (%)	
	Rooted Soil	Soil without root	Rooted Soil	Soil without root
10.96	20.4	12.3	4.67	1.20
15.47	22.5	13.3	6.00	1.57
19.98	24.5	14.3	6.13	2.00

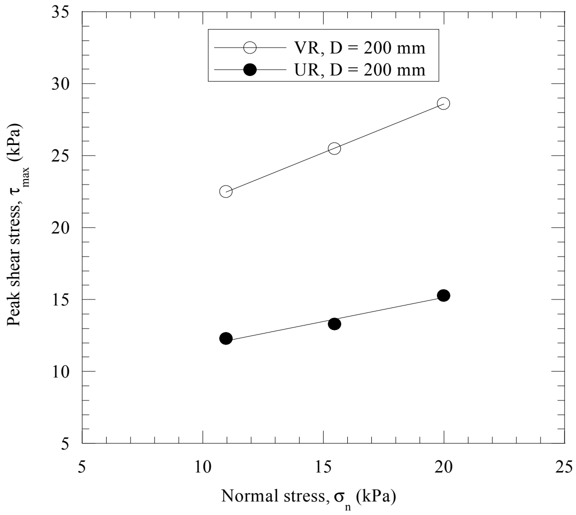


Figure 6: Peak shear stress versus normal stress at 200 mm depth (UR = soil without root sample; R = vetiver rooted soil matrix; D = depth)

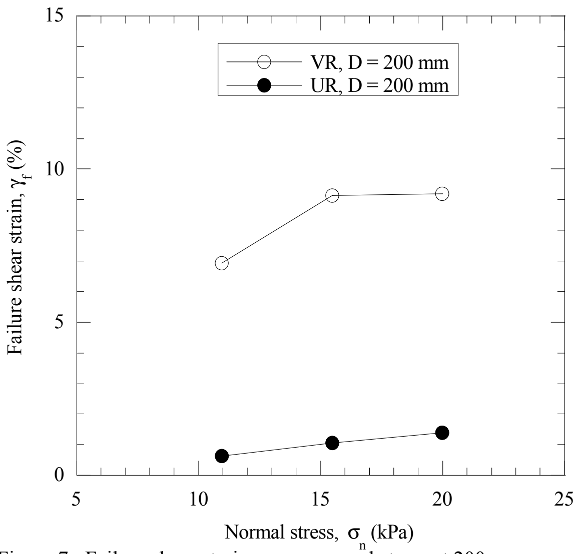
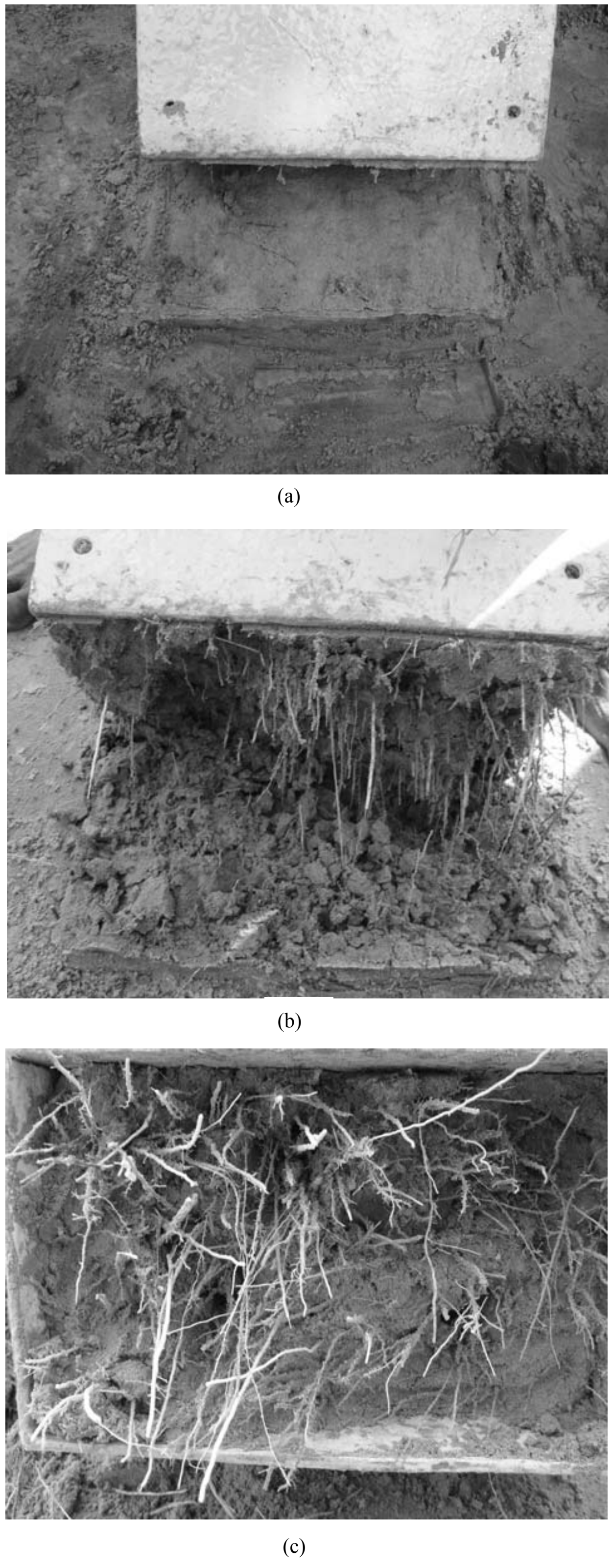


Figure 7: Failure shear strain versus normal stress at 200 mm depth (UR = soil without root sample; R = vetiver rooted soil matrix; D = depth)



(a)

(b)

(c)

Figure 8: Failure pattern of samples: (a) soil sample without root; (b) vetiver rooted soil matrix and (c) massive root system of vetiver grass in soil matrix

higher than that of soil without root. Again, the failure strain of the rooted soil over the depth is 515% higher than that of the soil without root.

It is found that the strength and failure strain of vetiver rooted soil at 400 mm depth is significantly lower than that of those at 200 mm depth. This is due to the low density of roots at the bottom of the block samples. Since the root was up to about 500 mm depth the intensity of roots were maximum at the centre i.e., about 250 mm depth from the EGL.

Figure 6 shows peak shear stress versus normal stress of vetiver rooted soil matrix and soil without root at 200 mm depth. Figure 7 shows failure shear strain versus normal stress of vetiver rooted soil matrix and soil without root of the same samples. Peak shear stress increases with the increase of normal stress in both cases. However, the increase in strength of rooted soil is stiffer (34˚) than that of soil without root (18˚). Again the peak shear strain is also increases with the increase of normal stress in both cases.

This means that vetiver rooted soil matrix can able to absorb high disturbing force and deformation than soil without root.

Photographs of Figures 8a and 8b show failure pattern of the block sample without root and the vetiver rooted block sample. It is seen that the failure plane of soil without root sample is very smooth. There is no anchorage between the top and bottom part of the failure block sample. Therefore, it seems that it will be easily dislodged even under low velocity flows. On the other hand, in vetiver rooted soil matrix, the root system makes an anchor with the soil particles. This anchor bonding increases the shear strength of rooted soil matrix. Therefore, it is expected that it will be very difficult to dislodge the rooted soil matrix even under high velocity flows. Photograph of Figure 8c shows clearly the massive root system and anchor system between vetiver grass and soil sample.

5. CONCLUSIONS

River bank and embankment failures happen continuously throughout Bangladesh. From the field survey, it is found that the general reasons of embankment failures are erosion due to rain splash, wave action and overtopping of storm surge. Poor maintenance practice, overturning or uprooting of trees are also enhance embankment failure.

The traditional practice for protection of embankment is to use cement concrete blocks, stone or wood revetments, geotextile and plantation etc. These are expensive and not so effective to protect the embankments for the designed life.

Protection of embankments by bioengineering process (e.g., using vetiver grass) is being used in many countries efficiently. The special attributes of vetiver grass is its longer life, strong and long finely structured root system and high tolerance of extreme climatic change.

From the laboratory investigations on the soils of coastal regions, it is found that the soils are generally silty sand (SM). It is also found that the shear strength of such soil is very low. So it seems that embankment slope made from such soil will be dislodged easily due to storm surge.

A study of twenty four block samples revealed the relative strength of vetiver rooted soil matrix and soil without root.

From these results, it is found that the average strength of rooted soil matrix is 78% higher than that of soil without root. Again, the failure strain of the rooted soil is 515% higher than that of the soil without root. The increase in strength of rooted soil with the increase of normal stress is stiffer than that of soil without root Therefore, it is expected that it will be very difficult to dislodge the rooted soil matrix even under high velocity flows.

Vetiver grass has strong and long finely structured root system which makes a heavy anchor with the soil particles. This anchor increases the shear strength and shear strain of rooted soil matrix.

Finally, it can be said that the vetiver will be effective to protect the coastal embankment against erosion, runoff, wave action, flood and cyclonic tidal surge etc.

Further studies are being conducted to study the performance of vetiver rooted soil in laboratory model at Bangladesh University of Engineering and Technology (BUET). Pilot projects are also undertaken to study the performance of vetiver rooted soil in coastal embankment and river bank protection.

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