academicJournals

Vol. 5(4), pp. 187-193, April, 2013
DOI 10.5897/IJWREE11.060
ISSN 2141-6613 © 2013 Academic Journals
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Study on the effects of vegetation density in reducing bed shear stress on the downstream slope of earthen embankment

H. M. Rasel[1]*, M. R. Hasan[2] and S. C. Das[3]

[1]Department of Civil Engineering, Rajshahi University of Engineering and Technology, Rajshahi, Bangladesh.
[2]Institute of Environmental Science, University of Rajshahi, Bangladesh.
[3]Bangladesh Water Development Board (BWDB), Dhaka, Bangladesh.

Accepted 27 March, 2013

River bank, coastal erosion and embankment failures are endemic and recurrent natural hazards, causing loss of lands and livelihoods along major rivers and coastlines. Overflow is the most damaging factor for earthen embankments on the downstream (d/s) slope due to the erosion of surface material which is caused by the high bed shear stress and supercritical flow over the entire d/s slope. Vegetation planted on d/s slope may have a considerable effect in reducing bed shear stress which makes erosion. However, the influence of vegetation for flow resistance as well as bed shear stress control has been studied a little. Therefore, the aim of this research is to introduce the use of natural resources like vetiver grass for controlling bed shear stress which actually causes embankment erosion starts from the high flow region that is, in supercritical flow state. A small-scale experiment is performed with four different densities of vegetal cover considering different discharges on d/s slope. Vegetative barrier affect the mean flow rate by induced drag force against hydraulic forces. Hydraulic characteristics and mechanism of vegetation in open channel during overflow are studied through flume experiment. Results demonstrated that vegetation markedly reduced the effective bed shear stresses which are the influencing factor for causing erosion on the d/s slope, toe and bed of embankment. Results also revealed a significant reduction of damage due to erosion and risk of failure from overtopping flow can be achieved by providing dense vegetation cover on the d/s slope of earthen embankment.

Key words: Embankment, downstream slope, drag force, bed shear stress, vegetation density.

INTRODUCTION

Bangladesh with its repeated cycle of floods, cyclones, and storm surges, has proved to be one of the most disaster-prone areas of the world. River bank and coastal erosion, and embankment failures happen continuously throughout Bangladesh. These are endemic and recurrent natural hazards, causing loss of lands and livelihoods along major rivers and coastlines. There are several traditional embankment protection works are available such as CC blocks, Geobags etc. From a strictly economic point of view, the cost for mitigating these problems is high. In addition, 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 the river bank or coastline

*Corresponding author. E-mail: hmrruet@yahoo.com.

and embankment, this bandage approach compounds the problem.Not only that, hard engineering structure makes the scenic environment unpleasant and helps only to transfer the problem to another place, to the opposite site or downstream, which aggravates the problem rather than reducing (Grimshaw, 2008). Scientists on river management and restoration claim that the river not only includes nonliving substances (flow, sediment) but also organism, so the vegetation in the watercourse should be included in the river dynamic system, at the same time, the vegetation will cause flow resistance, rise of water level and reduction of discharge capacity (Wu, 2008). Powledge et al. (1989a) observed that the initial erosion process begins anywhere within the supercritical flow region, especially at a point of slope discontinuity that is, from crest and toe of downstream slope of embankment.

Bangladesh Water Development Board (BWDB) has been constructed nearly 13000 km of embankments (over 4000 km of coastal embankments along the coastline 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, hoars and canals). A large number of sea dike or river embankment failures have been initiated from damages induced by wave or flow overtopping (Islam, 2000). For earth coastal dikes or river embankments, overtopping is one of the most damaging factors for the downstream slope. Eventually a failure of the downstream slope may lead a failure of the dike. Water infiltrates into dike crest, downstream slope and reduces the shear resistance of the soil (Hanson and Temple, 2001). Vegetation planted on the downstream slope may have a considerable effect in reducing overtopping erosion. Vegetative barriers increase the surface roughness and slow the flow rate. It dissipates energy and protects the slope from erosion. In a number of tropical countries Vetiver grass (*Vetiveria zizanioides*) is well-known as bioengineering. Recently, Vetiver grass has been planted on downstream slope as sea dike or river embankment protection.

An eco-friendly Vetiver grass (*V. zizanioides*) has been used successfully over 120 countries for more than a century as traditional technology for riverbank stabilization and embankment erosion control (Truong and Loch, 2004). Recent research and case studies have shown that vetiver grass can be used as a cheap method to protect shorelines or embankments. Mature vetiver is extremely resistant to washouts from high velocity flow due to its extraordinary root depth and strength. The stiff shoots and strong roots can keep the plant stand steadily in water with 0.6 to 0.8 m deep and 3.5 m/s velocity of water flow (Ke et al., 2003). On this subject, Bangladesh is in advantageous position as it has been abundant supply of Vetiver grass. But Vetiver grass technology (VGT) is very new in Bangladesh and using Vetiver as a living barrier against erosion remains untouched excepting as few small-scale trials in some foreign aided projects such as earthen embankment project of BWDB supported by World Bank. Moreover, its application has been based on experience rather than hydraulic principles (Das and Tanaka, 2009). Basically, the upstream side of earthen sea dikes or embankments are armored with stones or concrete blocks where there any exist of important infrastructures while the downstream slope often covered with grass. Very little is known about the strength and stability of downstream slope of sea dikes or river embankments covered with grass during overflow. To minimize the impact of natural disasters as well as to achieve the aim of agricultural production, sustainable and cost-effective maintenance of those embankments is a sine qua non for Bangladesh. However, the understanding of the processes and properties between flows and Vetiver grasses and the flow characteristics of d/s slope of sea dikes or river embankments covered with grass during overflow are still limited. Therefore, the main aim of this study is to introduce the use of natural resources like vegetation to protect the downstream slope of embankments or sea dikes during overflow and to diminish the bed shear stress which makes embankment erosion starts from the high flow region that is, anywhere within the supercritical flow state.

MATERIALS AND METHODS

Experimental set up and procedure

A small-scale laboratory flume experiment is performed to investigate the effects of vegetation (commercially available polypropylene Hechimaron vegetation model with 5 and 20% blocking that is, 95 and 80% of water passes through the model respectively which called the porosity of the vegetation model) roughness on the behaviour of d/s bed shear stress. Note that, four different densities of vegetal cover considering different discharges on the d/s slope are used. Firstly, row vegetation (2D type) and then grid type 3D vegetation is used. Afterward the experiments are conducted with staggered type 3D vegetation. All these experiments are conducted with maintaining a ratio of 0.25 (5 cm spacing case) and 0.75 (15 cm spacing case) with 20% uniform blocking, where, ratio = width of spacing within the vegetation rows over width of vegetation rows, here 5 and 15 cm spacing and 20 cm fixed vegetation width is used. Finally, the test is conducted with all over vegetation on d/s slope and bed with 5 and 20% blocking respectively, to evaluate the comparative results with no or WOV case in case of different vegetation effects as well as to investigate the effects of vegetation density for different blocking effect for controlling the bed shear stress on the d/s slope of embankment. A model of wooden embankment was constructed and placed at the middle of the flume which separated the flume along its length, forming main stream on one side (upstream) and the floodplain on the other side (downstream). The size of the embankment is 0.25 m in height, 0.25 m in crest width and 1.5 m in length, with slopes 3H:1V and 2H:1V in the upstream and downstream sides, respectively as shown in Figure 1. The details test program with four different types of vegetation arrangements are shown in the Figure 2.

To understand the processes and properties of hydraulics of

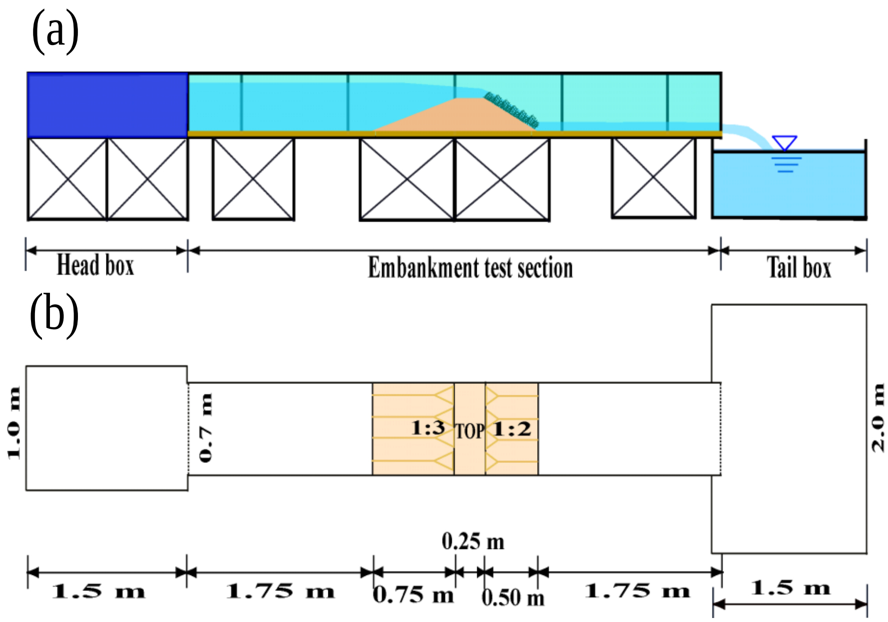


Figure 1. Profile of testing facility (a) front view and (b) top view.

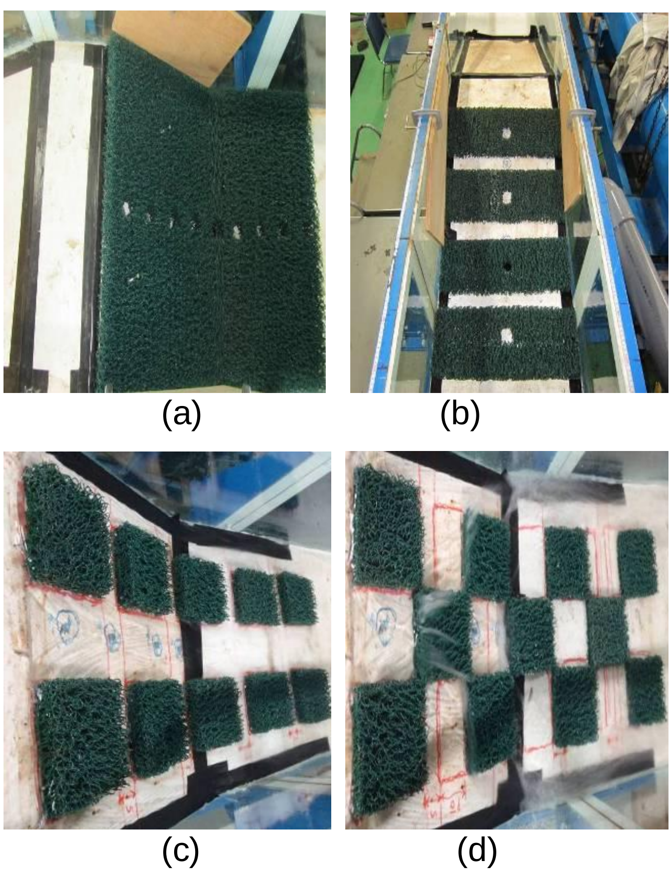


Figure 2. Experimental setup top view- (a) all over vegetation case, (b) row vegetation (2D type), (c) grid type 3D vegetation and, (d) staggered type 3D vegetation placed on the d/s slope and bed in the flume.

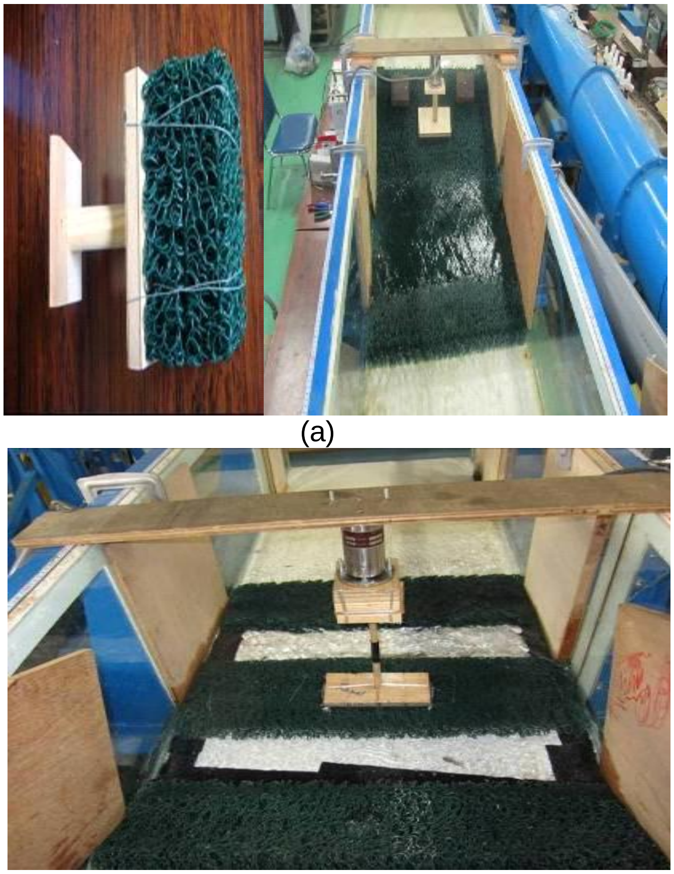
overtopping flow on the downstream slope of the embankment with the vetiver hedges, a small-scale laboratory flume experiments with an embankment using emerged vegetal cover were carried out with three different unit discharges as 0.018, 0.013 and 0.010 m^3/s was taken in our experiments. The longitudinal flow velocities and water depths were measured along the centre line of the flume at 26 points with an interval of 0.10 m up to upstream (u/s) crest of the model and later 0.05 m interval from u/s crest to the d/s end of the flume until steady flow condition was established. A scale factor (ratio of a variable in the model that is, height of embankment model 0.25 m to the corresponding value of its prototype height of 4 m usually used for earthen embankment) 0.0625 was kept constant throughout the tests. Usually earthen embankments are made with 4 m height with slopes 3H:1V and 2H:1V in the upstream and downstream sides, respectively. In the tests the velocities and the water depths were measured for situations with and without vegetation in the flume. The height of the vegetation model was kept constant, 0.05 m and width and length was kept same as the d/s side of the embankment model considering emergent flow conditions.

Data collection

The discharges were measured with an electromagnetic flow meter (model: MK -515/ 8510-XX, paddle flow sensor, Georg Fischer Signet LLC, USA). An electromagnetic velocity meter (type of main amplifier: VM-2000; type of sensor: VMT2-200-04P, Kenek Company, Ltd.) was used to measure the flow velocities at the centerline of the channel and the model. The water surface elevation was measured at the same locations as the velocity profiles by the point gauges (with accuracy up to 0.1 mm), fixed and mounted on a movable sliding carriage.

Drag force measurement

A two-axis load cell (streamwise (X) and transverse (Y) directions,



(a)

(b)

Figure 3. (a) Drag force measurement setup for all over vegetation on d/s slope and bed, and (b) Drag force measurement apparatus and setup for 2D type or row vegetation case.

type LB-60, SSK Co., Ltd.) with a resolution of 1/1000 that can measure a maximum load of 10.0 N was used to measure the drag force on the vegetative roughness model (Figure 3).

Calculation of effective shear stress

During the experiments the steady uniform overflow condition was established at the upstream side of the model and during overtopping flow became unsteady and non-uniform. But for simplicity we consider steady non-uniform flow for calculation of effective shear stress. For a control volume of unit area along the slope the balance of horizontal momentum in this case can be expressed as total shear stress which is equal to the sum of the bed shear stress and the equivalent shear stress due to the vegetation drag:

$$\tau_w = \tau_b + \tau_v \qquad (1)$$

where, τ_b= bed shear stress transfer to the soil; τ_w= stream wise component of the weight of water mass and τ_v=resistance due to the drag around the vegetation. The drag force was measured directly by a two-axis load cell apparatus as mention above.

The streamwise weight component of the weight of water mass per unit bed area is expressed as,

$$\tau_w = \rho g h i_e (1 - \lambda) \qquad (2)$$

where, λ = area concentration due to vegetation. Based on the Equation (2) the effective bed shear stress which directly transfers to the soil was calculated by deducting the drag forces induced by the vegetation for different discharges.

RESULTS AND DISCUSSION

Overtopping flow over earthen embankment in without vegetation (WOV) condition shows that the flow was static at the beginning upstream, accelerating sub-critical flow state over a portion of the embankment crest; through critical flow on the crest and supercritical flow over the remainder of the crest; and supercritical flow on the downstream slope and extend to the further downward same as observed in the previous study (Powledge et al., 1989b). Whereas the flow characteristics with vegetation (WV) condition shows that, the flow was static at the beginning of upstream, accelerating subcritical flow state both on the embankment crest and the downstream slope.

It is clear that the initial erosion process begin anywhere within supercritical flow region due to high bed shear stress, from the point of slope discontinuity that is, from d/s slope to d/s toe region especially for embankment. The effective bed shear stress (EBSS) which actually transfers to the soil surface is well below the shear stress developed in the case of WOV because of the induced drag force due to vegetation.

Figures 4 and 5 illustrate the comparison of bed shear stresses behind vegetation rows (BVR) along d/s slope and bed between row type (2D type) and grid type 3D vegetation on d/s slope and bed of embankment. The flow velocity behind the vegetation rows is much higher in 2D type row vegetation whereas, in grid type 3D roughness flow accelerates between the vegetation rows and therefore velocity is not much significant behind the rows, results the reduction of bed shear stress is attained on just behind the rows due to grid type 3D vegetation. Where, the reduction of bed shear stress from 28 to 40% is attained on the d/s slope. Vegetation also reduced the bed shear stress from 45 to 54% on the d/s bed. In comparison of the BSS behind the vegetation rows (BVR) in between 2D type row vegetation and grid type 3D vegetation, it is seen that the maximum reduction was 40% at d/s slope and 54% on bed, both for the grid type 3D roughness and for 0.25 ratios of rows with 20% blocking.

Herein the following Figures 6 and 7 shows the comparison of bed shear stresses along the d/s slope and bed in between grid type 3D and staggered type 3D vegetation placed both on d/s slope and bed. For grid type 3D roughness, flow accelerates within vegetation rows and increased the flow velocity results in increasing of bed shear stress. The effects of grid type 3D vegetation shows that bed shear stress increased on the

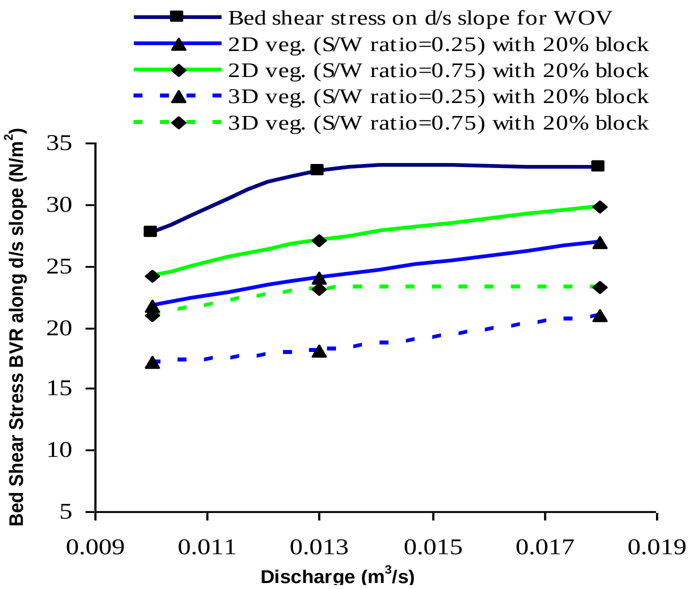


Figure 4. Comparison of effective bed shear stress behind the vegetation rows (BVR) along the d/s slope in between 2D and 3D type vegetation effect.

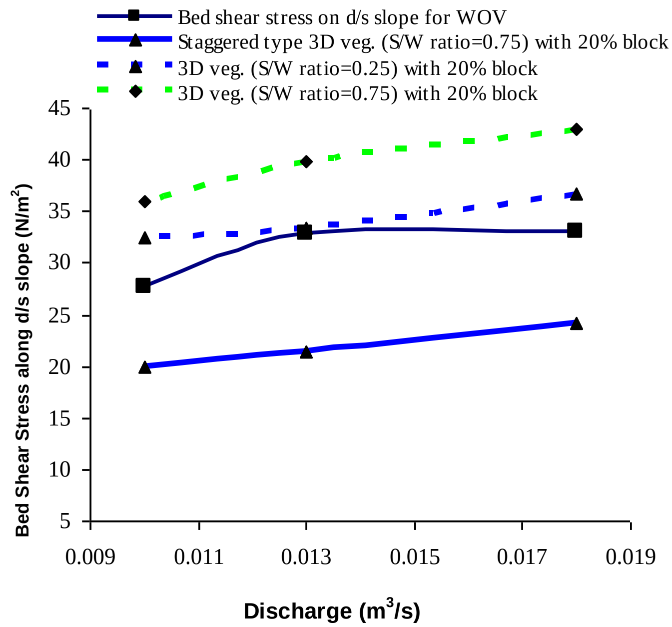


Figure 6. Comparison of effective bed shear stress along d/s slope in between grid-type and staggered type 3D vegetation effect.

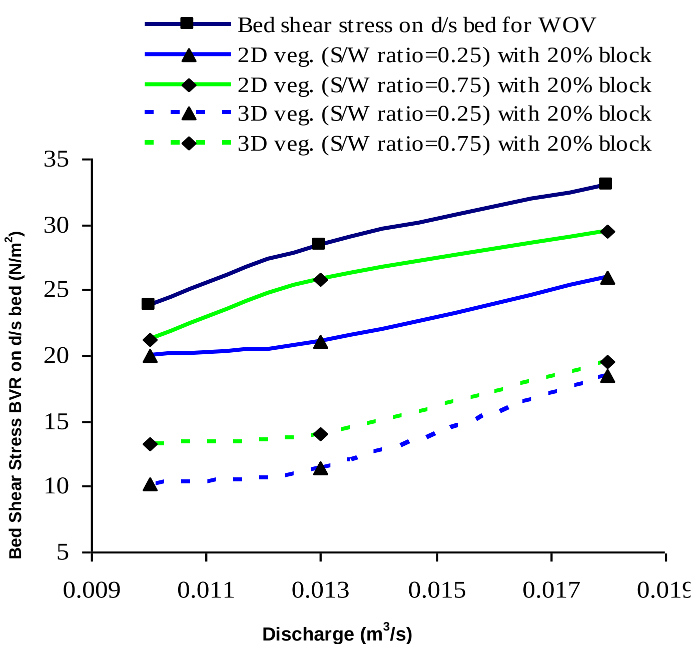


Figure 5. Comparison of effective bed shear stress behind the vegetation rows (BVR) on the d/s bed in between 2D and 3D type vegetation effect.

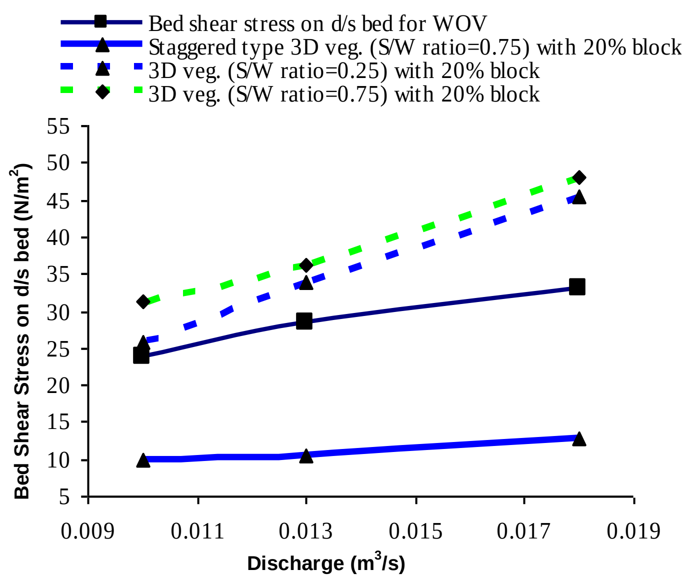


Figure 7. Comparison of effective bed shear stress on the d/s bed in between grid-type and staggered type 3D vegetation effect.

d/s slope as well as bed due to the acceleration of flow in between the vegetation rows. Bed shear stress increased from 10 to 27% on d/s slope and 22 to 35% on bed for 5 and 15 cm spacing rows (0.25 and 0.75 ratios) respectively.

On the other hand, in staggered type 3D roughness the flow could not accelerate directly between the vegetation rows because flow retard by the alternate rows in this type and decreased the flow velocity that results decreased the effective bed shear stress on both d/s slope as well as bed of embankment. The reduction of effective bed shear stress is found out 30 and 61% on the d/s slope and bed respectively for staggered type 3D roughness.

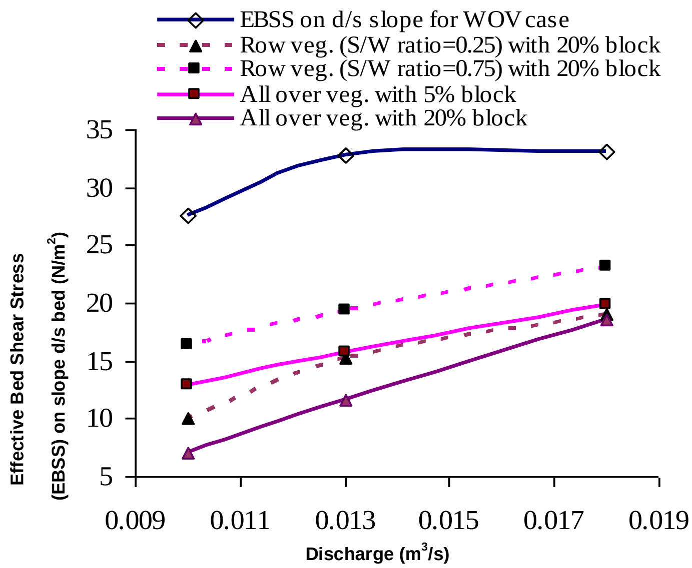


Figure 8. Comparison of effective bed shear stress along the d/s slope in between different row type or 2D veg. and all over vegetation effect on both slope and d/s bed.

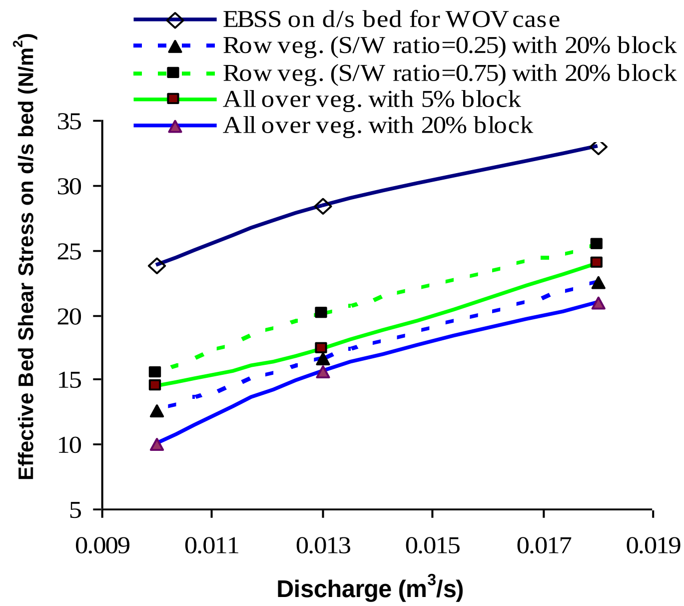


Figure 9. Comparison of effective bed shear stress on the d/s bed in between different row type or 2D vegetation and all over vegetation effect on both slope and d/s bed.

The Figures 8 and 9 illustrate the comparison of effective bed shear stresses for row type 2D vegetation with different spacing and all over vegetation on the d/s slope and bed. It is found that, in row case, maximum reduction of bed shear stress is attained for 5 cm spacing rows (for 0.25 ratio) with 20% blocking, on the other hand, maximum reduction of bed shear stress is achieved due to 20% blocking for all over vegetation case.

Comparative effects of row type 2D and all over vegetation on d/s slope show that, for all over vegetation the maximum reduction of EBSS is established as 61% on d/s slope and 48% on bed, both for 20% blocking case. Similar effects are found on the d/s bed. Vegetation reduced the bed shear stress about 47% for 20% blocking however, the bed shear stress reduction was 35% on the d/s bed due to low blocking case taken as 5% blocking in compared with 2D row type vegetation effect.

Conclusions

A cost effective and eco-friendly solution for stabilization of earthen embankment is presented in this paper. Vegetation markedly reduced the effective bed shear stress on the surface that demonstrated a significant reduction of damage and risk of failure from overtopping flows can be achieved by providing vegetation cover on the d/s slope of the embankment.

Based on the results of this investigation, the following conclusions can be drawn:

1. Bed shear stresses behind the vegetation rows (BVR) are much lower in block type 3D roughness whereas, higher values occurred in 2D type row vegetation.
2. BSS in between grid type 3D vegetation and staggered type 3D vegetation, it is seen that BSS is increased in 3D type vegetation due to the acceleration of flow within the rows whereas, BSS decreased on both d/s slope and bed of embankment as the flow retard directly by the alternative rows in staggered type.
3. It is observed that the maximum reduction of effective bed shear stresses is obtained for 20% blocking all over vegetation on the d/s slope and bed of the embankment compared to all the cases.
4. Spacing of roughness element is also the influencing factor in reducing bed shear stress.
5. It is concluded that vegetation can be the effective and innovative solution for the stabilization of river bank or coastal embankments.

REFERENCES

Das SC, Tanaka N (2009). The effectiveness of vetiver grass in controlling water borne erosion in Bangladesh. Proceedings of the 11th International Summer Symposium, JSCE, 11 September, Tokyo, Japan, pp. 69-72.

Grimshaw D (2008). Vetiver System Applications, Technical Reference Manual (second edition) published by The Vetiver Network International, US, pp. 1-10.

Hanson JG, Temple MD (2001). Evaluation mechanics of embankments erosion during overtopping. Proceedings of the Seven Federal Interagency Sedimentation Conference, March 25 to 29, Reno, Nevada, USA, pp. 24-30.

Islam MN (2000). Embankment erosion control: Towards cheap and simple practical solutions for Bangladesh, Proceedings of the Second

International Conference on Vetiver, Office of the Royal Development Projects Board, Bangkok, pp. 307-321.

Ke CC, Feng ZY, Wu XJ, Tu FG (2003). Design principles and engineering samples of applying Vetiver eco-engineering technology for landslide control and slope stabilization of riverbank. Proceedings of the Third International Conference on Vetiver, Guangzhou, China, October, pp. 349-357.

Powledge GR, Ralston DC, Miller P, Chen YH, Clopper PE, Temple DM (1989a). Mechanics of Overflow Erosion on Embankments, I: Research Activities. J. Hydraul. Eng. ASCE 115(8):1040-1055.

Powledge GR, Ralston DC, Miller P, Chen YH, Clopper PE, Temple DM (1989b). Mechanics of Overflow Erosion on Embankments, II: Hydraulic and Design Considerations. J. Hydraul. Eng. ASCE 115(8):1056-1075.

Truong PNV, Loch R (2004). Vetiver system for erosion and sediment control. In Paper Presented at 13th International Soil Conservation Organization Conference, Brisbane, 4-7 July (Paper No. 247), pp:1-6.

Wu F-S (2008). Characteristics of flow resistance in open channels with non-submerged rigid vegetation. J. Hydrodyn. 20(2): 239-245.