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EFFICACY OF DIFFERENT LAUNCHING MATERIALS IN RIVERBANK PROTECTION: A LABORATORY-SCALE MODEL STUDY

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Abstract

There are many different types of materials that are utilized for slope protection nowadays to save the riverbank against the wave action, current of the river or surface run-off. In general, cement concrete (CC) blocks, stone chips, geo-textile bags (geo-bags) filled with sand are widely used in revetment works in Bangladesh. A study was undertaken to determine the launching behaviour of these bank protection materials to find out the cost-effective and sustainable solution for riverbank protection using scale model. In order to fulfil the objectives, an undistorted model having a scale of 1:30 was designed using Froude's model law. The model consists of two channels namely, the main channel and oblique or shoot channel. Discharges had been fed in the model with the discharge ratio of Q_{shoot}/Q_{main}= 0.8 and 1. The study showed that the scour decreases once the discharge ratio changes from 0.8 to 1.0. However, scour was augmented, under full oblique flow condition (i.e. only shoot channel was opened while the main channel remain closed) than that of under oblique flow condition (when both channels were opened). Moreover, it was observed that the combined apron (geo-bags and CC blocks) works better as compared to single geo-bags or even only CC blocks as launching materials. Finally, the study showed that the cost involved in case of launching apron of composite materials was around 34-35% less than that of the single composition of CC blocks provided.

Keywords: *CC blocks, geo-bags, launching apron, launching material, oblique flow, spur, stone chips*

Introduction

There is active bank erosion cropped up in almost all of the major rivers in Bangladesh causing damage to valuable land, properties and infrastructures from year to year. Because of high density of population along the riverbanks, a great number of people have been displaced due to this continuous bank erosion process. These poor people migrated to nearby towns and cities and live a sub-human life in the slum areas. This has created a great nuisance and social problem in the country. Bank protection work is one of the prime necessities for poverty alleviation and national growth. The issue is the safety of lives, land and sustainability of the infrastructures against the forces acting in the rivers (RRI, 2016).

As Bangladesh is a lower riparian country, the large variation in discharge and the huge amount of sediment load is very difficult to manage. Therefore, major emphasis should be given to the design parameters. Moreover, the design parameters such as design flow velocity, design scour depth can be obtained through the present research work by physical modelling.

A number of studies have been conducted on riverbank management so far. Bhuiyan *et al.* (2002) examined bank erosion processes. Klassen and Masselink (1992) studied bank erosion rates using satellite images. Hasan (2011) has conducted an investigation of river erosion protection by submerged vane in a river bend. Ahmed (1989) carried out an experimental study on dumping of bank protection materials under flowing water to investigate the launching characteristics of C.C. block and geo-bags with different launching configuration. Oberhagemann and Hossain (2011) studied the effectiveness of geo-textile bag revetments for large rivers in Bangladesh. However, a cost-effective and sustainable solution for riverbank protection in Bangladesh still necessitates investigation in a more holistic approach.

Launching Apron (LA) is an important part of river training structures. Without LA of appropriate launching materials, revetment and spurs cannot be stable and may collapse. Therefore, a research work was undertaken to combat riverbank erosion effectively. Through the research work, the performance of

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launching materials for riverbank protection has been assessed to determine their efficacy and to find out the cost-effective material.

Methodology

A closed shed hydraulic laboratory was used for model development. It provides all kinds of facilities related to scale model study. A preliminary layout of the model was given with the reference grid points in the model. Channel planform was given using these grid points and the bed and bank levels were fixed up by levelling instrument as per bathymetry using Rise and Fall method. This requires some cutting and filling of sand from the model.

The model was investigated on a mobile bed and hydraulic similarity was established in the model with an undistorted scale. The scale ratio was selected as 1:30. The model was a Froude model and was studied over a generalized plain bathymetry. The model was carried out to investigate the local scour and velocity field at and around the revetments under different likely approach flow conditions. The model has been designed to fulfil both the flow and sediment transport criterion simultaneously. It means the model velocity would be higher than the critical flow velocity for the initiation of sediment movement. This is because for any velocity higher than the critical, the scour dimensions are the only function of flow direction and structure geometry. The model will, therefore, reproduce the scour holes correctly.

In this physical model, various types of instrument and facilities are needed such as, a sharp-crested weir for measuring flow, point gauge for measuring water level, 3-D current meter for measuring velocity, high resolution camera for taking video and photographic view of model, stopwatch for taking instant time and floats for identifying flow path of flowing water.

The required discharge was estimated using sharp-crested weir in the inflow section using Rebock's formula. Model velocity was measured by a 3D velocity meter. Water slope was calculated by analysing the water level measured at different position using point gauges installed in the model. Flowlines of the stream were identified by dropping floats from the upward calibration section and catching them at the downward ending section of the model. A stopwatch was used to calculate the surface velocity of the flow. Finally, model data was collected, analyzed and each test results was interpreted.

Similarity condition of the Model

The model has been designed such that the scale conditions for the simulation of flow field, sediment transport and local scour are satisfied. The scale conditions (Sharp, 1981) are described below:

i) Geometric condition

The model should be undistorted: $L_r = h_r$

Where, L_r= horizontal scale and h_r = vertical scale

ii) Roughness condition

In the model the following roughness condition should be satisfied in order to reproduce the flow field in principle:

$C_r^2 = L_r/ h_r = 1$ Where, C_r = roughness scale

iii) Froude condition

The Froude condition should be fulfilled which holds when: $V_r = h_r^{0.5}$

iv) Sediment Transport Condition

In the movable bed model following scale condition for sediment transport should be satisfied:

$V_m > V_{cr}$

V_{cr} in the model will be calculated using the following formula:

$$V_{cr} = 0.19(d_{50})^{0.1} \log (12h/3d_{90}) \text{ for } 0.0001m \leq d_{50} \leq 0.0005m \quad \text{Eq. (1)}$$

(van Rijn, 1984)

Where,
d_{50}= median particle diameter (m), d_{90} = 90% particle diameter (m)

The critical velocity for sediment transport can also be calculated from the critical Shields value. The critical velocity in the model has been calculated from the following equations.

$$D_* = d_{50}\{(s-1)\, g/v^2\}^{1/3} \qquad \text{Eq. (2)}$$

$$\theta_{cr} = 0.14D_*^{(-0.64)} \text{ for } 4<D_*<10 \qquad \text{Eq. (3)}$$

(Van Rijn, 1984)

$$\theta_{cr} = 0.24D_*^{(-1)} \text{ for } 1<D_*<4 \qquad \text{Eq.(4)}$$

(Van Rijn, 1984)

$$V_{cr} = \{\theta_{cr}(s-1)d_{50}C^2\}^{1/2} \qquad \text{Eq. (5)}$$

Where, D_* = Particle parameter, d_{50} = Median grain size, s = Relative density of the sediment v = Kinematic viscosity, C = Chezy co-efficient and, θ_{cr} = Critical shields parameters

The critical flow velocity for the median particle diameter of model bed sand (0.085mm) has been determined from the above equations. The investigation is aimed at the equilibrium scour depth with continuous sediment transport. A requirement in this type of model is that in the model, sediment transport has to be occurred at all locations as it occurs in the prototype. In order to fulfil this condition, an increase in the model velocity was considered to ensure the sediment transport in the model.

Model set-up

The hydraulic scale model was set up (Fig. 1) using the existing facilities of RRI. A closed tidal shed of RRI having a dimension of 80m X 25m was used for setting up the model. The area reproduced in the model was about 1.20 km (channel length) and about 0.18 km (channel width). The model set-up includes model bed preparation, water circulation system, construction of stilling pond and instalment of point gauges in the model etc. Two types of design were maintained for the main channel as well as shoot channel. In case of main channel, one end was kept trapezoidal at the left bank while the other end was vertical (Fig. 2). The shoot channel was the rectangular type (Fig. 3).

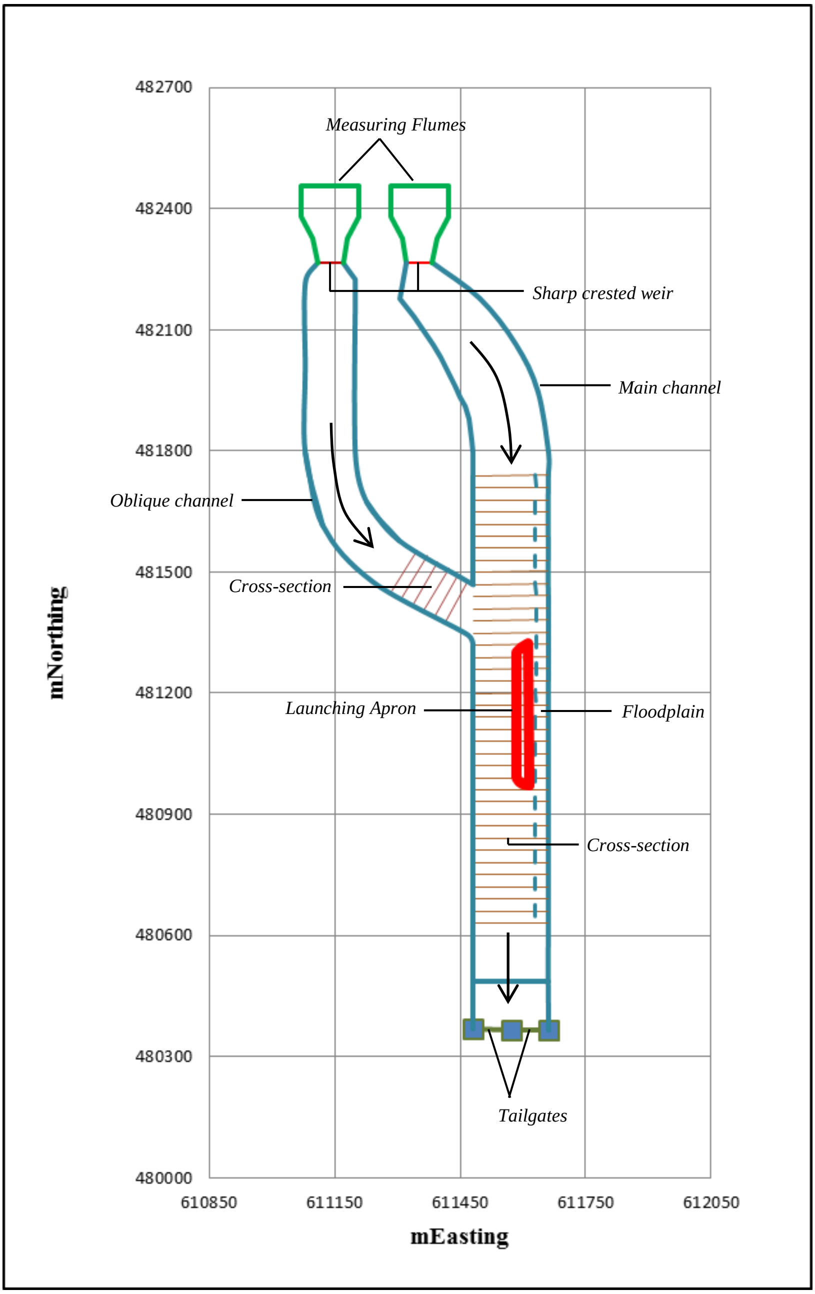

Fig. 1. A layout of the model

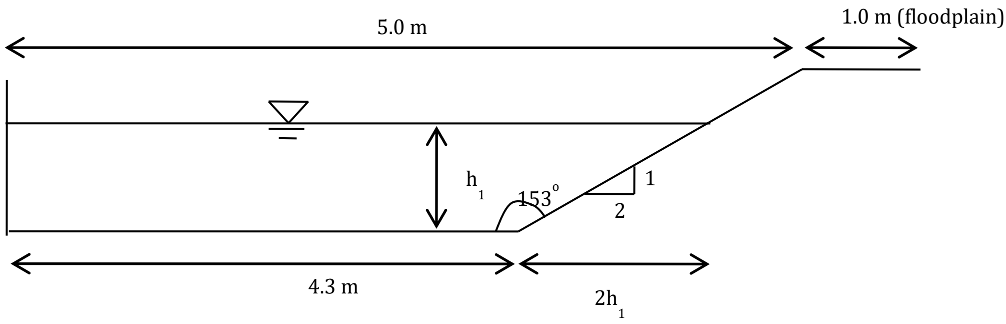

Fig. 2. Section for the main channel

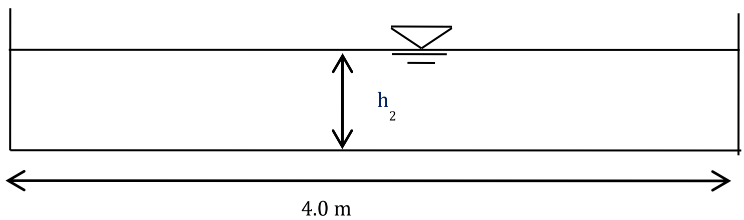

Fig. 3. Section for shoot channel

Test scenarios

The calibration test together with 25 application test runs with various structural intervention along the left bankline was conducted in the model. Test T0 contributed to the calibration of the model. The application tests T1 through T22 are carried out (Table 1) with a view to observing the performance of the bank protection structure (revetment) to prevent riverbank erosion. Each application test was run with both Froude's discharge to determine flow velocity, flow lines etc. and scour discharge to determine the scour depth. Scour discharge was run until equilibrium bed level was reached in the model.

Table 1. Test scenarios and objectives of the model

Test No.	Test ID	Test Scenarios	Angle of flow attack	Discharge Condition
1	T0	Calibration test. Plain bathymetry is used	No oblique flow condition	Discharge in the main channel only. Q_{main}=2025m^{3}s^{-1} (q=450 m^{3}s^{-1})
2	T1	Test with geo-bags as launching materials (LM)		
3	T2	Test with CC blocks as LM		
4	T3	Test with stone chips as LM		
5	T4.1	Test with stone chips as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
6	T4.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
7	T5.1	Test with geo-bags as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
8	T5.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
9	T6.1	Test with CC blocks as LM	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
10	T6.2			Q_{shoot}/Q_{main}= 1.00 Q_{main}=1012.5 m^{3}s^{-1} (q=225 m^{3}s^{-1}) and Q_{shoot}=1012.5 m^{3}s^{-1} (q=253 m^{3}s^{-1})
11	T7	Test with CC blocks as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow
12	T8	Test with stone chips as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow
13	T9	Test with geo-bags as LM. The shoot channel feeds total discharge to the main channel.	60º	Q_{shoot}= 2025 m^{3}s^{-1} = 411 l s^{-1} (model) (q=506 m^{3}s^{-1}) Fully oblique flow
14	T10	Test with 3 spurs: Spur S1 (solid), Spur S2 (CC blocks) and Spur S3 (geo-bags)	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{Shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
15	T11	Test asper design proposed by BWDB (LA consists of 50%CC block and 50%geo-bag and apron length 30m)	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^{3}s^{-1} (q=250 m^{3}s^{-1}) and Q_{Shoot}=900 m^{3}s^{-1} (q=225 m^{3}s^{-1})
16	T12	Same as test T11 but the shoot channel feeds total discharge to the main channel	60º	Q_{shoot}= 2025 m^{3}s^{-1} (q=506 m^{3}s^{-1}) Fully oblique flow

Test No.	Test ID	Test Scenarios	Angle of flow attack	Discharge Condition
17	T13	Same as test T12 but length of LA = 25m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
18	T14	Same as test T13 but length of LA = 35m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
19	T15	Same as test T14 but LA consists of 40%CC block and 60%geo-bag and LA length = 35m	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
20	T16	Same as test T14 but LA is shifted u/s by 60m at CS26-CS14.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
21	T17	Test as per design proposed by BWDB. But CC block portion of LA consists of 45cm cube 50% and 35cm cube 50%. LA placed at CS26-CS14.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
22	T18	Same as test T17 but CC block portion of LA consists of 45cm cube 40% and 35cm cube 60%.	60º	Q_{shoot}=2025 m^3s^{-1} (q=506 m^3s^{-1}) Fully oblique flow
23	T19	Test with 2 spurs S1 and S2 having shank length = 30m and LA length = 30m. The LA of S1 has two layers. Top layer consists of 45cm cube 40% and 35cm cube 60%. Bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%. The LA of spur S2 consists of 125kg geo-bag.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
24	T20	The u/s part of LA of spurs S1 and S2 is same as test T19 (top layer consists of 45cm cube 40% and 35cm cube 60% & bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of stone-chips only.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
25	T21	The u/s part of LA of spurs S1 and S2 is same as test T20 (top layer consists of 45cm cube 40% and 35cm cube 60% and bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of 60cm cube 60% and 45 cm cube 40%.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})
26	T22	The u/s part of LA of spurs S1 and S2 is same as test T21 (top layer consists of 45cm cube 40% and 35cm cube 60% and bottom layer consists of 250kg geo-bag 50% and 175kg geo-bag 50%). The d/s part of LA of spurs S1 and S2 consists of 60cm cube 60% and 45cm cube 40% at the top layer and 500kg geo-bags at the bottom layer.	60º	Q_{shoot}/Q_{main}= 0.80 Q_{main}=1125 m^3s^{-1} (q=250 m^3s^{-1}) and Q_{shoot}=900 m^3s^{-1} (q=225 m^3s^{-1})

Results and Discussions

Comparison of launching

(i) Comparison of launching pattern for different launching materials

A comparison is made among tests T7, T8, T9 and T18 showing the launching behaviour of CC blocks, stone-chips, geo-bags and composite materials (CC blocks + geo-bags) for revetment under oblique flow condition (60-degree) for discharge 2025 m^3 s^{-1}(Fig. 4). From the figures it is evident that stone chips have the best launching pattern as there is no bare space on the launching slope. The composite material, CC blocks and geo-bags stand 2nd, 3rd and 4th position respectively with respect to launching pattern.

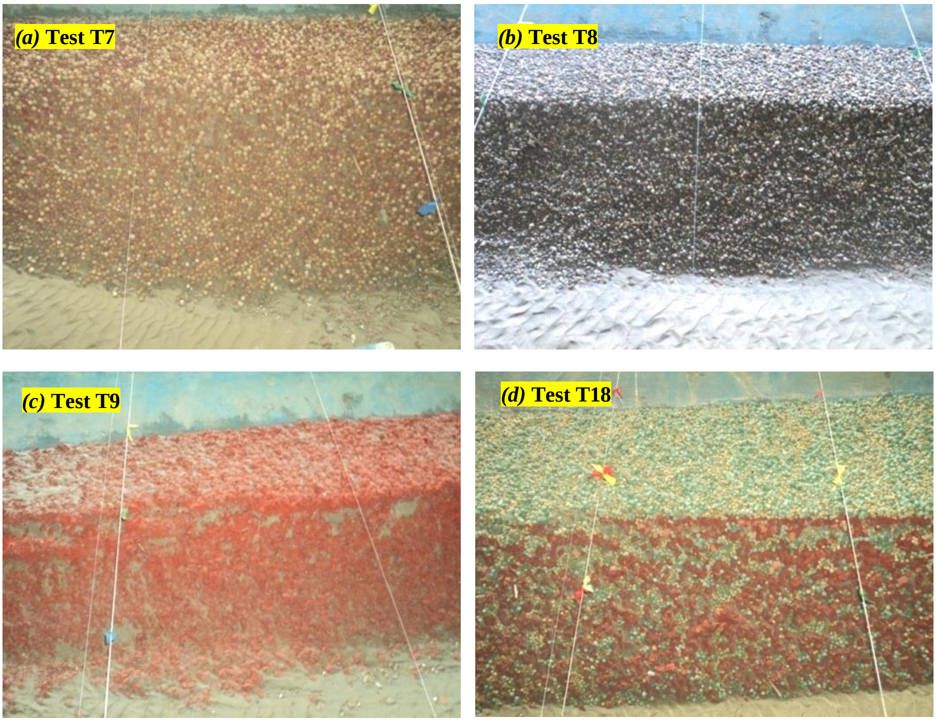

Fig. 4. Launching pattern of different launching materials (a) CC blocks (b) stone-chips (c) geo-Bags (d) CC blocks + geo-bags at various tests

(ii) Comparison of launching behavior for composite materials having different apron length and thickness when CC blocks (top) + 50% geo-bags (bottom) in case of the revetment

Fig. 5 shows the launching behavior of composite materials comprises of CC blocks and geo-bags with the variation of apron length of revetment for tests T12, T13 and T14 (discharge 2025 m^{3}s^{-1}) under fully oblique flow condition (60-degree). It is evident from these figures that test T12 provides better launching pattern in comparison to tests T13 and T14.

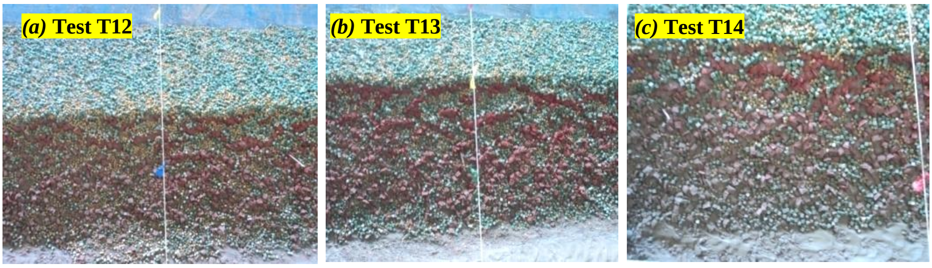

Fig. 5. Launching behavior of composite materials with different apron length and thickness

Note: (a) Apron length 30 m &thickness 2 m; (b) Apron length 25 m &thickness 1.4 m; (c) Apron length 35m &thickness is 1.71 m.

(iii) Comparison of launching behavior for composite materials with different proportion of CC blocks in the launching apron in case of the revetment

A comparison is made among tests T12, T17 and T18 showing the launching behavior of composite materials (CC blocks and geo-bags) with different CC block proportion for revetment under oblique flow condition (60-degree) for discharge 2025 m^3s^{-1} (Fig. 6). It is evident from the figures that test T18 provides the best result as bare space is relatively lower. Channel developed around the LA is well shaped. The numbers of CC blocks rolled in the developed channel are less. More numbers of CC blocks are retained on the developed slope.

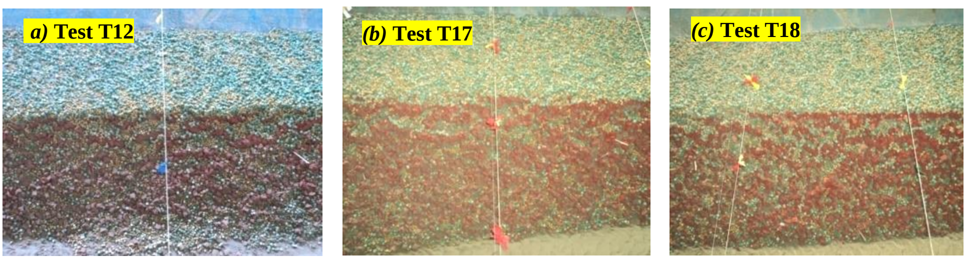

Fig. 6. Launching behavior of composite materials with different CC block proportion

Note: (a) 60% of 45 cm cube & 40% of 35 cm cube; (b) 50% of 45 cm cube & 50% of 35 cm cube; (c) 40% of 45 cm cube & 60% of 35 cm cube.

(iv) Comparison of launching pattern with the variation of the material composition of launching apron in the d/s part of spur S1

Fig. 7 shows the launching pattern with the variation of material composition for d/s part of launching apron of spur S1 (start from spur axis) when the material composition in the u/s part remains the same for tests T19, T20, T21 and T22 under fully oblique flow condition (60-degree) in case of spur.

Test 20 provides best results as the launching characteristics of stones are much better than other materials. Because the scour developed at the toe of the LA of stones is less than that of other materials. Stones are capable to resist scour development but other materials have no such ability. From the d/s part of LA of spur S1, few stone-chips was displaced towards d/s. Bare space is much less than test T19.

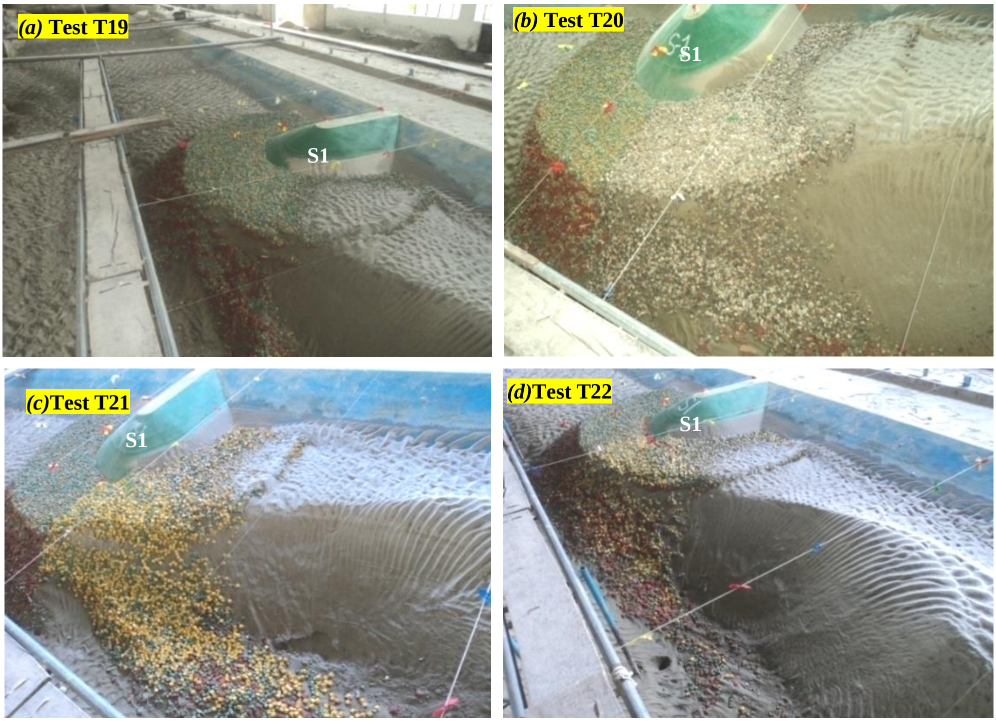

Fig. 7. Launching behaviour of composite materials with different material compositions in the d/s part of spur S1.

Note: (a) U/S part of S1: Top layer constitutes 40% of the 45cm cube and 60% of the 35cm cube, Bottom layer consists of 50% of 250kg geo-bag and 50% of 175 geo-bag (b) U/S part of S1: same as previous. D/S part of S1: Stone-chips (c) U/S part of S1: same as previous. D/S part of S1: 60% of the 60cm cube and 40% of the 45cm cube. (d) U/S part of S1: same as previous. D/S part of S1: 60% of the 60cm cube and 40% of the 45cm cube.

Developed launching slope

i) Launching slope at a section across the revetment after the test run along CS20 (T18) for the low-cost material composition

Fig.8 shows that for the low-cost material composition (T18) for LA of the revetment, the launching slope is 28.15 degree (1:1.87) and launched 27% out of 30m.

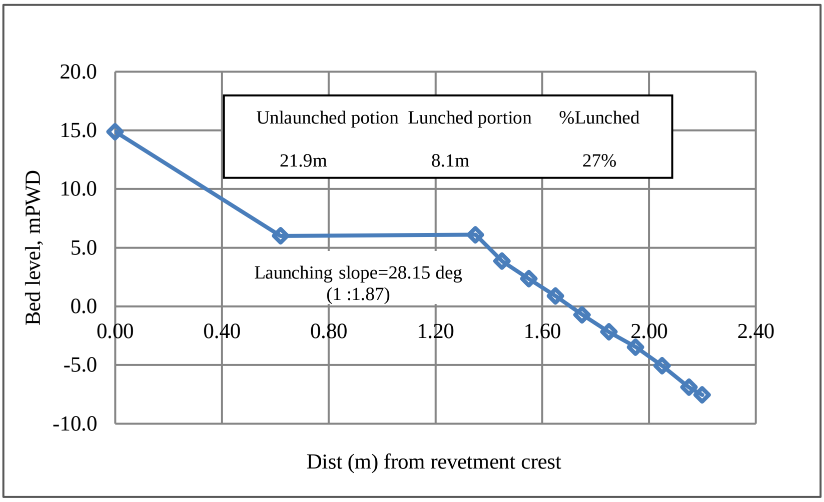

Fig. 8. A section perpendicular to the revetment after test run

ii) Launching slope at a section across the revetment after the test run along the spur S1 axis (CS20) [T22]

Fig.9 shows that for the low-cost material composition (T18) for LA of spur S1, the launching slope is 32.14 degree (1:1.59) and launched 40% out of 30m.

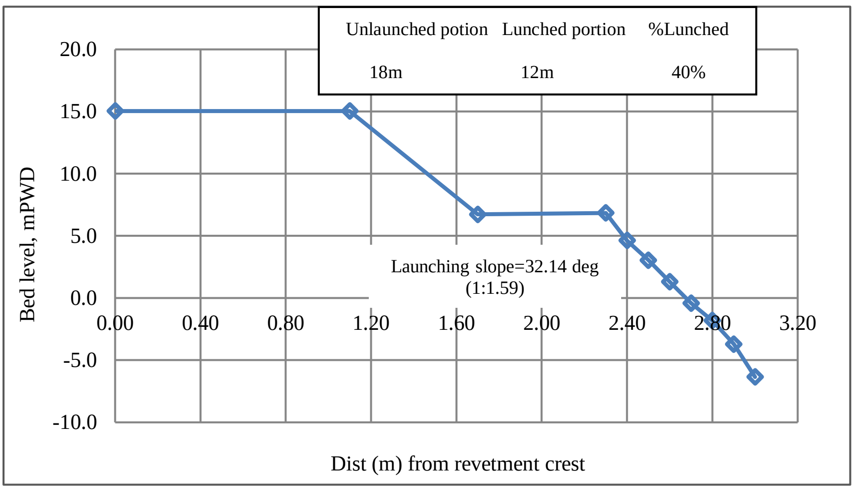

Fig. 9. A section perpendicular to the revetment after the test run along spur S1 axis

Cost analysis

Cost analysis is made based on Standard Schedule of Rates Manual, 2012-13, O & M Circle, BWDB, Faridpur for different material composition (tests T12, T17, T18 and T22) in case of revetment and spur. The cost is around 34-35% is less for LA of composite materials than providing the single composition of CC blocks in case of revetment and spur**.**

Table 2. Cost analysis for revetment and spur

Test No.	LA for Revetment	Costing (Tk.m^{-1})	In case of CC blocks used	% Savings
T12	Top: 45cm cube 60% + 35cm cube 40% + bottom: 250kg geo-bag50% + 175kg geo-bag 50%	378495	573365	33.99%
T17	Top: 45cm cube 50% + 35cm cube 50% + bottom:250kg geo-bag 50% + 175kg geo-bag 50%	375756	567887	33.83%
T18	Top: 45cm cube 40% + 35cm cube 60% + bottom: 250kg geo-bag 50% + 175kg geo-bag 50%	373017	562409	33.68%
T22	LA (u/s part) for Spur			
	Top: 45cm cube 40% + 35cm cube 60% + bottom: 250kg geo-bag 50% + 175kg geo-bag 50%	373017	562409	33.68%
	LA (d/s part) for Spur			
	Top: 60cm cube 60% + 45cm cube 40% + bottom: 500kg geo-bag100%	360376	558099	35.43%

[Note: 1 USD= Tk. 83.05 BDT]

The summary table which shows observational facts and key results is shown in Table 3.

Table 3. Summary table of test results

Sl. No.	Observational facts	Key results	Test No.
1	Launching pattern of different launching materials	The launching materials such as CC blocks, stone-chips, geo-bags and composite materials (CC blocks + geo-bags) tested under fully oblique flow condition (60-degree) shows that stone chips have best launching pattern as there is no bare space on the launching slope. The composite materials, CC blocks and geo-bags possess 2nd, 3rd& 4th position respectively with respect to launching pattern.	T7, T8, T9 & T18
2	Launching behavior of composite materials having different apron length and thickness	The composite materials (CC blocks + geo-bags) tested under fully oblique flow condition (60-degree) shows that the LA having length 30m & thickness 2m shows better launching behavior relative to other options.	T12, T13 & T14
3	Launching behavior of composite materials having different CC block proportion	The composite materials (CC blocks + geo-bags) with different CC block proportion tested under fully oblique flow condition (60-degree)shows that the LA with CC block proportion 40% of 45 cm cube & 60% of 35 cm cube provides the best result as bare space is relatively lower. Channel developed around the apron is well shaped. The numbers of CC blocks rolled in the developed channel are less. More numbers of CC blocks are retained on the developed slope.	T12, T17 & T18
4	Development of launching slope	For the low-cost material composition: In case of LA of revetment, the launching slope 28.15 degrees (1:1.87) having launched 27%. In case of LA of spur S1, the launching slope 32.14 degrees (1:1.59) having launched 40%.	T18 & T22
5	Costing	The cost was found 34-35% less for LA of composite materials (CC blocks + geo-bags) than providing the single composition of CC blocks in case of revetment and spur**.**	T12, T17, T18 & T22

Conclusions and Recommendations

It can be concluded that insignificant scour or launching pattern was observed around the launching apron of different materials particularly in case of parallel flow (*i.e*. no oblique flow). Moreover, it was observed that the scour decreases when the discharge ratio of shoot to main channel changes from 0.8 to 1.0.Scour was augmented under full oblique flow condition than that of under oblique flow condition at discharge ratio either 0.8 or 1.0.The best composition of materials for revetment: LA consists of 45 cm cube 40% and 35 cm cube 60% at the top layer and 250 kg geo-bag 50% and 175 kg geo-bag 50% at the bottom layer. In this case, maximum scour and velocity is found around 12.09 m and 2.46 ms^{-1} respectively under fully oblique flow (60^0).

Maximum absolute (without LA) scour was found 19.62 m around spur (shank length=30 m) under oblique flow condition. The suitable composition of materials for u/s part of LA of spur: LA consists of 45 cm cube 40% and 35 cm cube 60% at the top layer and 250 kg geo-bag 50% and 175 kg geo-bag 50% at the bottom layer. The suitable composition of materials for d/s part of LA of spur: LA consists of 60 cm cube 60% and 45 cm cube 40% at top layer and 500 kg geo-bag at the bottom layer. In this case, maximum scour and velocity was found around 13.56 m and 2.52 ms^{-1} respectively under oblique flow condition (60^0).

Furthermore, it was evident that the combined apron (geo-bags and CC blocks) works better than the simple geo-bag (as per Standard Schedule of Rates Manual, 2012-13, O & M Circle, BWDB, Faridpur) or even only CC blocks as launching materials. Among the 3-LA materials, stone chips are the best as it provides effectual launching pattern. However, it is too much expensive and unavailable in the developing country like Bangladesh. CC blocks have better launching capabilities but it is expensive relative to geo-bags. Geo-bags can be made easily, available and is less costly. Although it (made as per design manual of BWDB) has relatively poor launching compared to CC blocks or composite material (geo-bag and CC bags). The cost is around 34-35% is less for LA of composite materials than providing the single composition of CC blocks in case of revetment and spur.

Performance of composite launching material (geo-bag and CC block) in straight revetment construction in terms of attained areal coverage, developed slope and scour depth is found to be good under generalized bathymetry. Before implementation of the composite launching material, the result may be verified using real bathymetry.

At the d/s part of the spur, the launching material (geo-bag and CC block) used in this study needs more test to get optimum results considering a variation of the size of geo-bag and CC block. In this study, only single-sized geo-bag and CC block have been tested. The composite launching material may be tested at u/s termination of the revetment by simulating the flow condition.

References

Ahmed, N. A. (1989). *A study of some bank protection works in Bangladesh*, M.Sc. thesis, Department of Water Resources Engineering, Bangladesh University of Engineering & Technology, Dhaka, 1000.

Bhuiyan, A. F., Hossain, M. M. and Hey, R. (2002). Bank erosion and protection on the Brahmaputra (Jamuna) River. *WIT Trans. on Ecol. and the Env. 52*.

BUET and IWM (2008). Manual on Hydrologic and Hydraulic Design of Bridges, Bangladesh University of Engineering & Technology, Dhaka 1000 and Institute of Water Modeling, Mohakhali, Dhaka 1206

BWDB (2010). Guidelines for Riverbank Protection. Jamuna-Meghna River Erosion Mitigation Project (JMREMP), Bangladesh Water Development Board, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

BWDB (1995). Standard Design Criteria, Design Circle, Bangladesh Water Development Board, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

BWDB (1993). Guide to planning and design of river training and bank protection works, design manual. Bangladesh Water Development Board, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

BWDB (1993). Standard design procedure, Volume-1, Standard Design Criteria. Bangladesh Water Development Board, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

BWDB (2012-13). Standard Schedule of Rates Manual, O & M Circle, Faridpur, Bangladesh Water Development Board, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

Das, P. (2014). *An experimental study of bank protection work and launching behaviour for oblique flow on a straight riverbank*. Unpublished M.Engg. Dissertation, Bangladesh University of Engineering & Technology (BUET), Dhaka 1000

FAP 21 (2001). Guidelines and Design Manual for Standardized Bank Protection Structure, Bank Protection Pilot Project. Flood Action Plan, Water Resources Planning Organization, Banani, Dhaka 1213, Bangladesh.

Hasan, M. Z. (2011). *A study on riverbank protection works and flooding of Sirajganj,* B. Sc. thesis, Department of Water Resources Engineering, Bangladesh University of Engineering & Technology, Dhaka, 1000.

Klaassen, G. J. and Masselink, G. (1992). Planform changes of a braided River with fine sand as bed and bank material. *Proc. of the Fifth Int.Symposium on River Sedimentation*, Karlsruhe, Germany.

Oberhagemann, K. and Hossain, M. M. (2011). Geotextile bag revetments for large rivers in Bangladesh. *Geotex. and Geomem. 29*(4): 402-414.

RRI (2016). Investigation on launching characteristics of different materials to find out the cost-effective and sustainable solution for riverbank protection. Study report, River Research Institute, Faridpur Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, Dhaka.

Sharp, J. J. (1981). *Hydraulic Modelling*. Butterworths P. 242.

van Rijn, L. C. (1984). Sediment Transport, Part-III, Bed Forms and Alluvial Roughness, *ASCE J. Hydr. Engg*. 110 (12): 1733-1754.

WRE, BUET and RRI (2011). A study on the effect of oblique flow and char movement in riverbank and bank protection.