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PHYSICAL MODELLING FOR THE IMPROVEMENT OF BARISAL HARBOR AREA

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Abstract

A physical fixed bed model for the improvement of Barisal harbor area was carried out jointly WRE, BUET with RRI at RRI to investigate the flow pattern and velocity distribution at different depths and locations at the study reach of Kirtonkhola river under low, medium and high flow conditions. The objective of the study was to find out probable solution of erosion and siltation problem in the study area. Five test runs were conducted under these three flow conditions. The model was distorted and scaled on the basis of Froude's model law with horizontal scale ratio L_r = 1:200, vertical scale ratio H_r = 1:50, time scale ratio T_r = 1:28.28, velocity scale ratio V_r = 1:7.07 and discharge scale ratio Q_r = 1:70711.The model investigation showed that the velocities at medium flow condition were higher than low and high flow condition. Therefore the severity is governed mainly by the medium flow condition. The bank erosion limit was assumed to be 15 m and the velocity was at 0.8d depth for vulnerable to erosion. The bank materials were silt (compact), the critical velocity (non-scouring) at bed is 1.0 m/s for straight channel. For bank slope and flow curvature 20% reduction of critical velocity had been assumed. Siltation study was carried out indirectly from the velocity records and sediment size. Permissible velocity was determined from particle size, cohesiveness and depth of flow. The average velocities from model tests were much higher than the permissible velocity. It showed that there is least probability of siltation at Central Storage Depots (CSD) food jetty and Bangladesh Inland Water Transport Authority (BIWTA) workshop jetty location under the existing situation.

Introduction

Barisal is located along the right bank of Kirtankhola river at downstream of the junction with Bukainagar Nala. At Bhasan Char of Barisal district, the Kritankholariver branches off from the right bank of Arial Khan river. Further downstream, it leaves a branch from its left bank called Khairabad River. The Kirtonkhola river is tidal but its water is sweet round the year. Tides of the Kirtankhola river is semi-diurnal. Its period is 12 hours 25 minutes. At upstream of this junction, the river is strongly meandering, while from Barisal towards downstream the river is noticeably straight. A natural loop cut near the confluence of the Barisal river and the Arial khan during the sixties and subsequent river adjustment is an indication of the fact that the river was still in active process of development. The width of the river between the banks varies from a maximum of 800 m (approx.) near Char Upen to a minimum of 300 m (approx.) near the Launch Ghat location (shown in the Figure 1). Depth variation in the reach was also substantial being nearly 26 m to 9 m in the thalweg. The tidal variation was from about 1.5 m in the dry season to 0.5 m in

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the wet season. The maximum velocity was approximately 2 m/s. The discharge variation was from 3000 m^3/s during low water flow to about 4000 m^3/s for high water flow. Heavy erosion on the right bank of the Barisal river has occurred for a number of years in the area of the BIWTA workshop jetty.

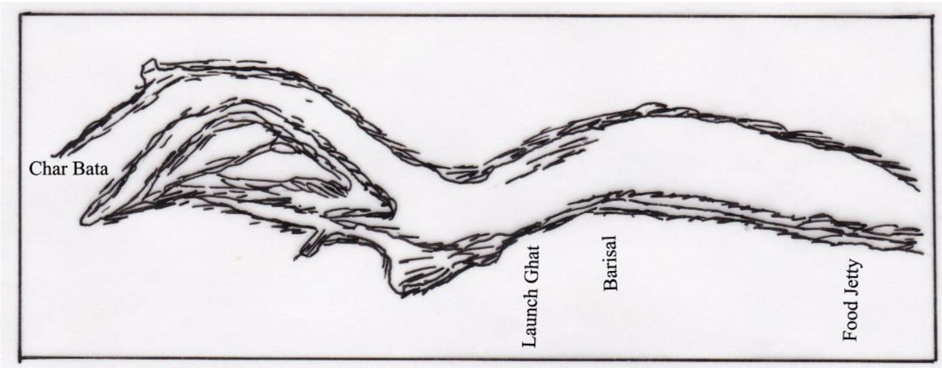

Figure 1. Location sketch of study area

For designing of maritime structures and dredged levels, it is necessary to know the highest and lowest astronomical tides. In terms of amplitudes of tidal constituents, are given by:

Mean sea level ± 1.2 (M_2+ S_2+K_1+O_1)
Where M_2 and $S_2$are semi-diurnal components, $K_{1,}$ O_1 are diurnal components and syndical or semi-diurnal tides prevail.

Mean sea level ± 1.2 (M_2+ S_2+ K_2)
Where M_2, S_2, K_2 are semi-diurnal components and diurnal tide is small.
Sir George Darwin suggested Indian Spring Low Water as chart datum for Indian Waters. It is given by the formula.

Indian Spring Low Water = Mean Sea level- (M_2+ S_2+K_1+O_1)
(Training Programme 1989)

The controlling parameter is a Froude number based upon the speed at which the projection of the moon on the earth moves over the earth's surface and $\sqrt{\square d}$, where d is the water depth. If the Froude number were less than unity, a dispersive wave would result; If the Froude number were unity, a build–up of the wave to a large amplitude would result; If the Froude number were greater than unity, a much smaller wave would result. Inui (1936) has shown for Froude number greater than unity that not only does a phase shift occur, but that negative force (or negative pressure area, which is large with respect to the water depth) generates a decrease in the water level first, followed by an increase in the water level, rather than just an increase in the water level. Tides have recorded in many areas for a great number of years and they have been analyzed to obtain the amplitude and phase of the tidal components. The ocean's tides have been classified as semidiurnal, mixed, and diurnal. The type that occurs at a particular place depends upon the ratio diurnal/semidiurnal $(K_1+O_1)/\ (M_2+\ S_2)$. When the ratio is of the order of 0.1 the tides are semi-diurnal, when it is about unity they are mixed, but predominantly semidiurnal; when it is about 2, they are mixed but predominantly diurnal; when it is 15 or so, they are diurnal (Defant 1958).

Literature review

Taming tidal rivers is always a strenuous work particularly to engineers. Tidal modeling plays a vital role in the field of river training and related works. Lakhya/Dhaleswari Confluence model study was an example of tidal model study. It was a complicated one because it involved two rivers that interact. The purpose of the model was to give the most favorable route for a channel. The complicated tidal river modeling can be performed by two methods, one control method and more than one control method. To avoid modeling of the whole river with all branches, equivalent basin can be made at the upstream end of the reach of the model. One control means control by downstream water level calibration by velocities at upstream and downstream end of modal area. Tidal models by more than one control are more accurate method. The principle of this model is calibration by water levels adjustment/correction by velocities. In 1972, The Tromsoe model study was performed and it was the first model with more than one tidal control (Kamphuis 1975). This method was used in Calabar River Model in Nigeria, Tromsoe Model in San Francisco, Lakhya/Dhaleswari Confluence model in Bangladesh. In Calabar River Model, the model was calibrated on tidal levels velocities, tidal phase difference was known for longer reach than covered by the model, model phase difference was computed & used, and only small corrections were needed to obtain correct velocities. The Lakhya/Dhaleswari Confluence model was very challenging study because it had three tidal controls, very small slopes, interference between rivers and both reversing flow conditions (dry season) and one–directional flow (floods). It soon became apparent that the correct slope in the model was too small to give stable run conditions. Instability was caused by hydraulic coupling between the control system. To avoid the instability two methods were taken into account, (1) Increase slope/ velocity to alter system response (2) Introduce singular head loss between water level followers and main model. The regulation system consisted of two water level controlling systems. One system controlled the downstream water level and other controlled the upstream water level. The two systems were independent of each other except that Time reference is common and there is a hydraulic connection between the two regulation systems (Einar1986). River Research Institute (RRI) of Bangladesh studied some models by more than one control systems, among them The Doarika tidal model study (Einar1986), Bhola Town Protection model study and 3rdKarnafuly bridge models are significant. In 1986, The Doarika tidal model had been studied by more than one control system with the help of tide generator, Water level followers and water supply control systems (Einar 1986). Another model named as Bhola Town Protection work was studied by RRI in 1995 with more than one control system and in 2005, 3rdKarnafuly bridge model was studied with the help of more than one control systems with manually tide generating system.

Methodology

Study Area

The study area for model study was selected based on heavy erosion on the right bank of the Barisal River. This heavy erosion was occurred for number of years in the area of BIWTA workshop jetty. As a result, one half of the jetty was collapsed and also rendered the other half structurally unsound for useful purposes. A physical (tidal) model of the Barisal River was constructed to include the area of existing erosion and siltation and also to include the probable erosion and siltation area near the food jetty.

Data collection

Water levels and cross-sections were collected by depth soundings. Stage hydrograph was made to get a detailed picture of the tidal influence in the river. These measurements were taken by self-recording instruments (Aanderaa WLR5) at char Bata and food Jetty location but only during certain periods to cover low, medium and high stages. The Prototype discharge information was quite useful for model study. In order to obtain a correct picture of the flow pattern, velocity measurements were recorded throughout the study area. Comparing the trend of river shifting from the available hydrographic charts of 1968, 1970, 1975 and 1982, the 1992 situation had been extrapolated.

Data preparation

Topographical information of river bottom elevations at 19 numbers of sections distributed nearly uniformly throughout the length of the reach had been considered to reproduce the topographical features of the river bottom. Subsequently few more sections at some critical positions were used to reproduce the bed profile more accurately. In this case, the scale of sounding information was 1:10,000. In order to get a detailed picture of the tidal influence in the river (e.g. celerity of the tidal wave, time lag between high and low water etc.) high precision, time synchronized water level measurements were performed by Norwegian Hydrodynamic laboratories (NHL). Analysis of these short-term stage recordings enabled the selection of the pilot signals to be used in model simulation. Pilot signals are representative tidal waves of the prototype used for model simulation. The pilot signals for low water and medium and high water conditions are shown in Figure 2 and Figure 3.

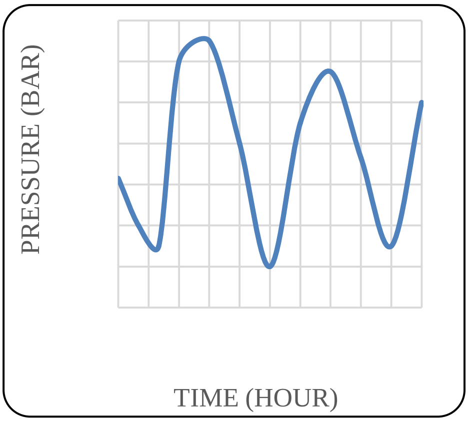

Figure 2. Pilot signal for low water condition

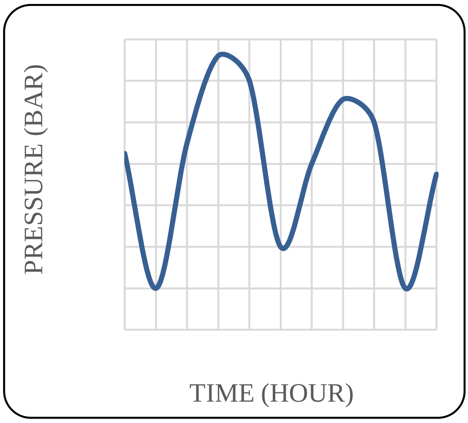

Figure 3. Pilot signal for medium and high water condition

The computation of discharge was made by BIWTA at char Bata and Food Jetty location both in the high and low water seasons. After analysis of the discharge data the following flow conditions had been adopted for the purpose of model run: Low water flow equals to 3000 m^3/s and High water equals to 4000 m^3/s. Velocity measurements were taken at Floating Dock, Char Bata and Food Jetty during the high, medium and low water seasons. Comparing the trend of river shifting from the available hydrographic charts of 1968, 1970, 1975 and 1982, the 1992 situation had been extrapolated. The model study was made to forecast the behavior of the River for this extrapolated situation if no protection works were taken.

Model setup and instrumentation

The model had been constructed to a horizontal scale of 1: 200 and a vertical scale of 1:50 in a 9m X 36m space to accommodate the main river reach including the sumps. Water level followers, that constantly monitor the model water level, were installed at each end of the model.

Layout and instrumentation setup of the model are shown in Figure 4 and Figure 5.

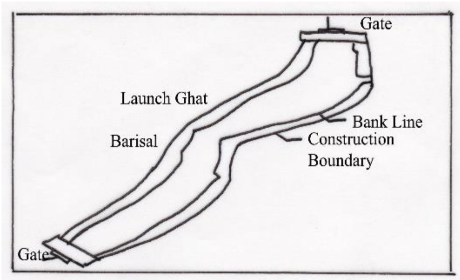

Figure 4. Layout plan of model

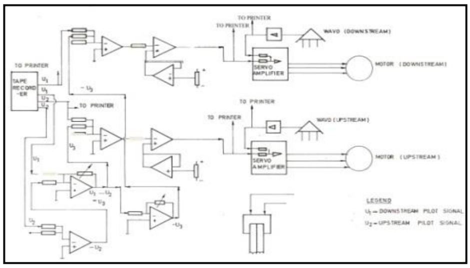

Figure 5. Schematic diagram for operation of instruments

Each end of the model was fitted with adjustment gate connected electromechanically for automatic operation. Hysteresis for the gate operation is shown in Figure 6.

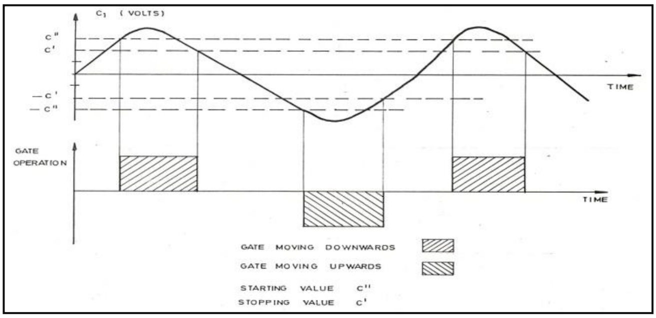

Figure 6. Hysteresis for the gate operation

To reproduce the time dependent water surface slope, it was necessary to control the water levels at each end of the model. For this reason the regulation system consisted of two mutually independent sub systems, each controlling upstream and downstream water levels.

Model design

In the design of the model scale conditions related to the governing process have to be fulfilled in order to obtain complete similitude between model and prototype. The process is flow. For scaling and design of the model Froude's model law $F_r = \frac{v}{\sqrt{gd}}$ and $n_{F_r} = 1$ were considered. The design of the model had been made after analyzing the field data. Low, medium and high discharge had been considered for the design, as these discharges were representative of the morphological development.

Model calibration

The calibration of the model was based on the field measurement of water level and current velocities. These current velocities were achieved in the model by introducing a certain mean slope between the upstream and downstream ends of the model. The mean slope was composed of the variable slope from tidal waves superimposed on the constant longitudinal slope due to upland discharge. Calibration of the model had been conducted in existing condition of the river (without any proposed intervention in low, medium and high water). The main focus of the model calibration had been concentrated on the process of flow and sediment transport. The measurement during the calibration includes water levels, bed levels, point velocities, float tracks and discharges. The model was calibrated for three flow conditions viz. low water, medium water and high water. Two pilot signals, one representative of low water flow and while the other for medium and high water flow were used. Since the transformation due to tide propagation from downstream to upstream is negligibly small, the same pilot signal was used for both upstream and downstream with appropriate time lag.

For stabilizing the regulation system and to prevent unwanted disturbance to enter into the model, filters had to be placed at both ends of the model. Pilot signals had to be transformed accordingly to compensate for the head loss through the filters.

Test procedures

Five application tests had been conducted in the model that included present situation (T_1) for low, medium and high discharges. These tests aimed at assessment and recording of velocities and flow pattern. Test (T_2) was conducted present situation with erosion protection works. Test (T_3) had been introduced present situation with dredge cut at Launch Ghat including erosion protection works. Test (T_4) had been conducted present situation with adjusted channel in front of groins. Test (T_5) had been conducted with future situation without protection water levels had been measured. The measurement made in the model included water level, velocities and flow fields, reduction of the critical velocity (erosive) as well as changes of the flow pattern at the erosive zone by some protective measures and simultaneous increase of the critical velocity (silting) at accretion zone. An A-OTT current meter was used to measure the flow velocity. The instruments were used in the model for tide generating system given below

- Tape recorder
- Weir motor (Gate controlling)
- Servo Amplifier

- Water level follower
- Printer

The model tests were carried out for three flow conditions, low, medium and high. The model was run with rather large amplitudes (especially for low and medium flow conditions) in order to generate high velocities, as one of the main purposes of the investigation was to study the erosion. A summary of the prototype measurements for the model calibration and characterizing the three flow conditions are given below:

<u>Low flow condition</u>

Mean water level	: +0.30 mPWD (+1 ftPWD)
Max. tidal amplitude	: ± 0.63 m
Max. velocities	: 1.40 m/s downstream and 1.60 m/s upstream
Max. discharge	: Approx. 2800 m^3/s (downstream) and approx. 3000 m^3/s (upstream)

This corresponds to the flow conditions on January 26-27, 1983.

<u>Medium flow condition</u>

Mean water level	: +1.35 m PWD (+4.50 ftPWD)
Max. tidal amplitude	: ±0.50 m
Max. velocities	: 2.10 m/s downstream and 1.40 m/s upstream
Max. discharge	: Approx. 4000 m^3/s (downstream) and approx. 3000 m^3/s (upstream)

This corresponds to the flow conditions on June, 14-15, 1983.

<u>Highflow condition</u>

Mean water level	: +1.80 mPWD (+4.50 ftPWD)
Max. tidal amplitude	: ±0.32 m
Max. velocities	: 2.10 m/s downstream and 1.40 m/s upstream
Max. drop in water surface elevation	: 0.05 m downstream and 0.00 m slack water

This corresponds to the flow conditions on September 23-24, 1983

Results and discussion

Study of present situation (T_1)

Study of erosion

Evaluation of present erosion is based on the results obtained from the model reproduction of the present situation, study of erosion consisted of two items:

- Identifying the zones of erosion
- Classifying these zones according to severity

Both velocity and flow pattern were used for the above purpose. Identification of the zones of erosion has been primarily based on the study of flow patterns and severity of the erosion has been determined on the basis of velocity records and visual observations. Some of the areas were not apparently recognizable as having severe erosion problem from the surface flow pattern records. However, visual observation indicated the presence of strong transverse and spiral flow at those zones, where the occurrence of severe erosion is also supported by high velocity records.

Flow patterns for the low flow condition are shown by Figure 7a and Figure 7b.

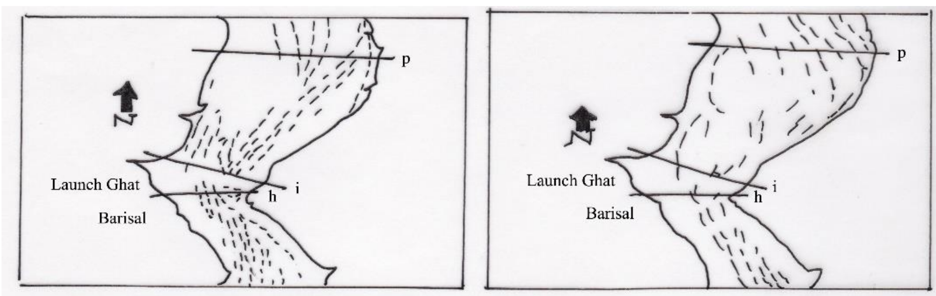

Figure7a. Flow pattern for low flow condition (flood tide)

Figure7b. Flow pattern for low flow condition (ebb tide)

Examination of the figures indicates that the left bank of the river between sections '*p*' to '*i*' is under attack by the current during the ebb tide. The flow lines are almost parallel to the bank lines during the flood tide throughout the reach except between the sections '*i*' and '*h*' where vortices are developed close to the left bank during both tides. The vortex for the ebb tide condition is relatively stronger.

Figure 8a and Figure 8b shows the flow patterns for the medium flow condition.

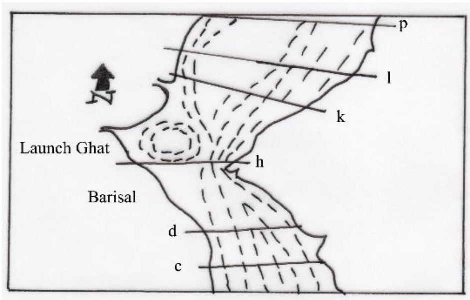

Figure 8a. Flow pattern for medium flow condition (flood tide)

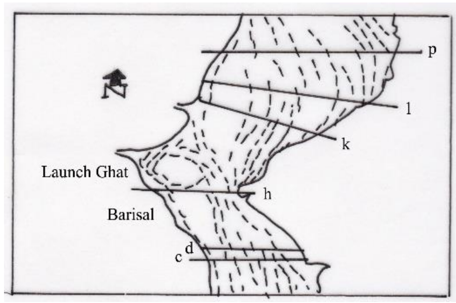

Figure 8b. Flow pattern for medium flow condition (ebb tide)

Here also the left bank is under attack during the ebb tide mild attack on the left bank is noticeable between sections *'k'* and *'c'*.

Strong flow concentration develops near the left bank around section '*h'* along with vortex formation close to the right bank between section '*i'* and '*h'* for both flood and ebb tides. Flow concentration is also noticeable at the right bank between sections '*k'* and '*l'* and a mild attack on the left bank between sections '*o'* and '*p'* during flood tide.

During high flow condition near stagnancy develops during flood tide and as such no photographs for flow pattern were taken. The attack by the flow in that case was shifted downwards and nearly same results were found as of medium flow condition.

From the study of the flow pattern as discussed above and also from visual observation the stretch of the riverbanks vulnerable to erosion is identified and shown in Figure 9.

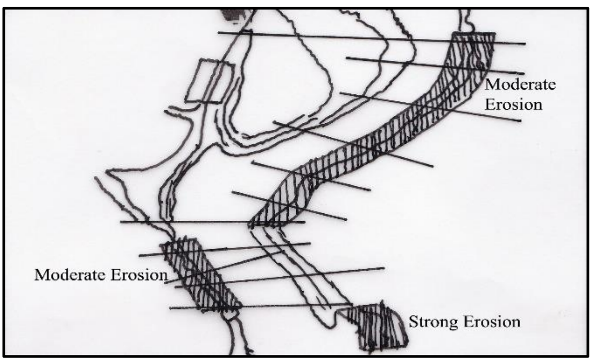

Figure 9. Bank erosion areas

Observation and comparison of velocity plotting for low, medium and high flows show that in general the velocity for the medium flow condition is higher than any of the other two situations. Therefore, the severity of erosion is governed mainly by the medium flow condition. To classify severity of bank erosion the bank limit was assumed 15 m and velocity was assumed at 0.8 depths.

Study of siltation

The problem of siltation had been studied near the BIWTA workshop jetty, CSD food jetty and Launch Ghat. Siltation study in this fixed bed model had been made indirectly from the velocity records and sediment size. Under the present data availability identification of siltation zones can only be made from consideration of permissible velocity. Since the reach is under tidal influence, siltation may occur during the slack current period at those sections where the permissible velocity is not exceeded at any time. Since the average velocities as obtained from model test were much higher than the permissible velocities, it is inferred that there is least probability of siltation at CSD Food jetty and BIWTA Workshop jetty location under the present situation.

Study of present situation with erosion protection works (T_2)

Four numbers of groins of appropriate size and shapes were placed at suitable locations after several trials, in the left bank of the river between sections '*q'* and '*k',* which is shown in Figure 10.

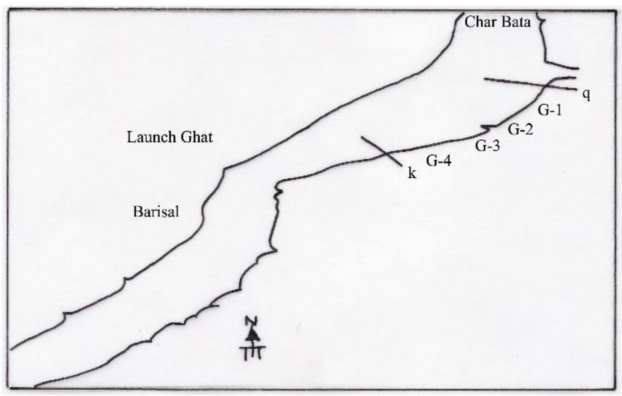

Figure 10. Location of groynes

From comparison of the flow patterns for situations before and after the placement of groins, it was seen that a favorable flow pattern had been achieved; the flow lines were more parallel to the banks.

Figure 11 shows the velocity distributions at 0.6 depths for situation before and after the placement of groins in the reach. From the figure it was observed the velocity had been considerably decreased near the bank reflecting a reduction of the erosive forces on the banks. Another important investigation area near BIWTA workshop jetty and CSD Food jetty are also influenced by the placement of groin. Here also the velocity and flow pattern are favorable.

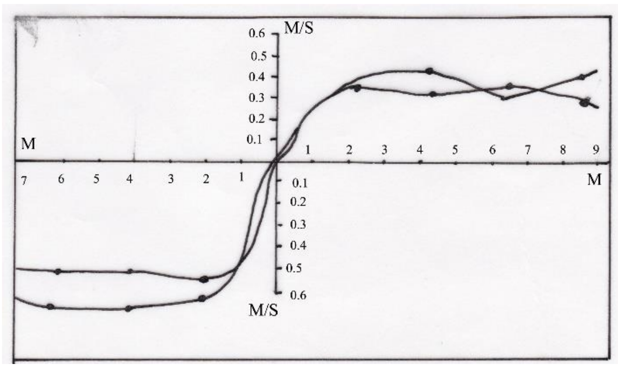

Figure 11. Record of velocity for test runs 1 and 2

Present status with dredging operation at Launch Ghat (T_3)

Under the present condition the dredged channel at Launch Ghat was an upstream blocked dead channel. During both flood and ebb tide the water within the channel remains almost stagnant, enhancing the siltation process compared to other adjacent areas. The test run had been designed to open up the upstream end of the channel by a dredge cut to give it a flushing effect during all flow conditions. The flushing effect is quite noticeable through the new dredge cut channel, with the flow going downstream through the channel during the flood tide and in a reverse direction during the ebb tide. In addition flow pattern also indicate a change in the characteristics of the vortex formed in that area.

Figure 12 shows the velocity distribution in the cut channel. The velocity records show clearly the generation of considerable velocities through the channel indicating a good flushing effect.

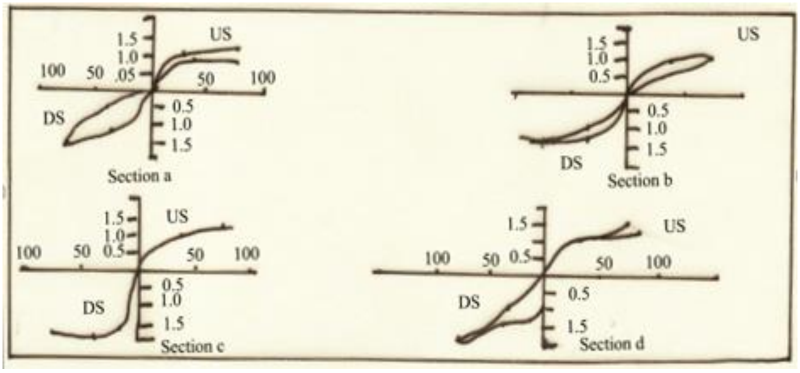

Figure 12. Velocity distribution in the cut channel

Present situation with adjusted channel in front of groynes (T_4)

Placing of groyne had restricted the effective width of the present channel. Consequently the char land in front of groins would be eroded to adjust the flow. The test run had been designed keeping in mind that the adjusted channel flow would have quite significant influence on the characteristic of the flow in general and in front of the dredge cut channel in particular. A comparison of the flood and ebb tide flow for this situation with corresponding flow before any channel adjustment in front of groynes had been made, it was clearly seen that an improvement on the flow pattern had occurred. It was therefore expected that in the actual situation placement of groins would have a better flushing effect through the dredge cut channel than as was indicated by the flow pattern shown in Test run No. 3.

Figure 13 shows the velocity distribution in the dredge cut channel for medium flow situation. This velocity distribution when compared with the corresponding velocity distribution for the Test run No. 3 situation indicates that there had been an overall increase in the velocity in the dredge cut channel showing a better flushing effect.

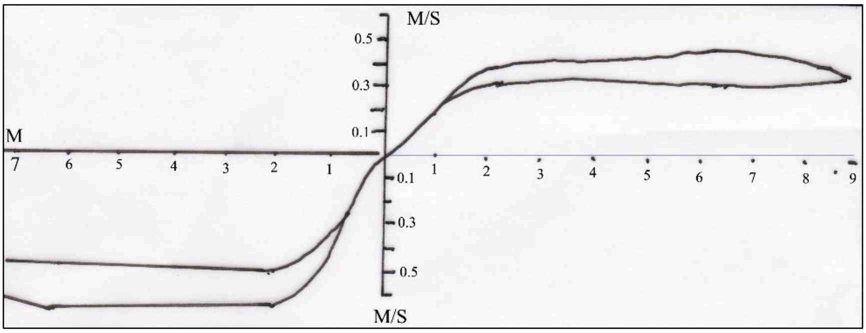

Figure 13. Velocity distribution in the cut channel in front of groynes

Future situation without protection works (T_5)

Study of future situation without protection works was needed to have a picture of erosion and siltation for the extrapolated condition in the year of 1992. Figure 14 indicates a considerable change of the flow pattern compared to the corresponding 1982 situation (Figure 8). The comparison of flow pattern shows that the existing (1982) siltation zone between sections '*q'* to *'j'* close to the right bank (near Char Upen) was likely to be extended downstream up to the section m in 1992 situation. This fact was also supported by the velocity records shown in Figure 15.

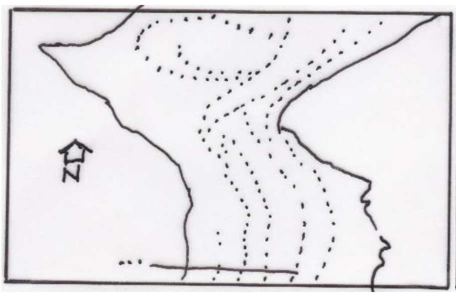

Figure 14. Flow pattern for test run 5 (ebb tide)

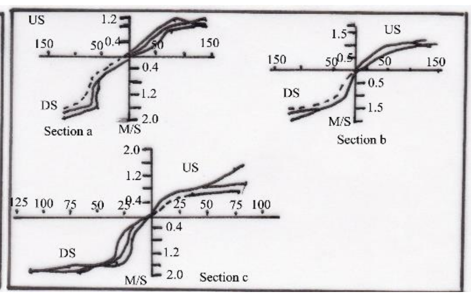

Figure 15. Velocity record for test run 5

Conclusions and recommendations

The model study carried out for Barisal Harbour area gave considerable support to the following recommendations:

a) Erosion protection works were necessary for zones subjected to moderate and strong erosion. Beneficial effects of groins were evident from the model results. Groins as protective measures were to be constructed on the left bank, the locations and sizes of which are shown in Figure 8. However, the model tests were conducted with only four numbers of groynes. Visual observation indicated formation of strong eddies in between groynes, which could have been eliminated with more number of groins.

b) Suitable bank protection works for the reach between BIWTA workshop Jetty and Cargo Ghat should be taken up.

c) The blocked upstream mouth of the existing dredged channel at Launch Ghat should be opened up for flushing effect.

d) There was no noticeable adverse effect near the CSD Food jetty under the extent of test runs conducted.

e) It is recommended to RRI authority to provide modern computerized tide and wave generator and necessary survey equipment and higher training/degree for tidal and wave model study in future.

Acknowledgement

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