MORPHOLOGICAL CHANGES OF JAMUNA RIVER AND ITS COUNTERMEASURE IN SIRAJGANJ HARD POINT AREA

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ABSTRACT

Sirajganj Hard Point is a revetment constructed at 1999 to protect the Sirajganj town and also to guide the main flow of Jamuna River towards Jamuna Bridge. After completion of the revetment works, damages occurred during 2009, 2010, 2011 and 2013 by local scour around the Hard Point. To understand the morphodynamics, the author conducted a numerical simulation using a 2D depth integrated model for flow and bed deformation analysis. Numerical simulation results illustrate that 20.97 m of deep bed scouring occurs adjacent to the revetment work, thereafter sand bar forms around other sides of the channel. These results well described the actual phenomenon, which verify the numerical simulation. With the numerical method, we conduct the countermeasures with dredging sand. The sand in the river to orient the flow not to create the scour but deposit the sediment around the Hard Point. Among the four countermeasures, the case with curved channel and construction of artificial sand bar with the dredged earth induced significant sedimentation at the front of Hard Point, whose cost of countermeasure is reasonable and technic is feasible in Sirajganj Hard Point area.

Keywords: Jamuna River, Suspended Sediment, Deposition, Bank Erosion, Morphological Changes.

INTRODUCTION

Every year due to engulfing, a huge quantity of lands into the river due to bank erosion, displaced people are bound to migrate and settle in other places. Due to the river bank erosion, poor floodplain inhabitants not only lose their properties but also experience socioeconomic deprivation through income–loss, asset-loss and physical injury. Every year landlessness, unemployment, as well as poverty drastically increases due to the river bank erosion.

The nature of Jamuna is braiding. It has number of channels and sand bars in its river flow. It is often shifting its course of main flow from one channel to another. The present flow is heading towards the Sirajganj Hard Point. The course shifting is very much uncertain and unpredictable in terms of rate and extent. As a result of the course shifting and the attack of the dominant and oblique flow, tremendous scouring has occurred causing damages such as collapsing of the revetment. Even After completion of the river works, the damages occurred at 2009, 2010, 2011 and 2013.

The first objective of the present study is to investigate morphological changes of Jamuna River in terms of bar formation, deformation and migration in channel geometry, as well as flow pattern. The second objective of this study is to explore alternative dredging configuration to direct the main flow away from the revetment. To understand the morphodynamics, the authors conducted a numerical simulation using a 2D depth integrated model to simulate flow and sediment transport and to analyze bed deformation. With the numerical method, we also conducted the countermeasures with dredging. Effective countermeasure as well as cost effectiveness for countermeasures also analyzed in the present study.

METHODOLOGY

The governing equations for conducting the numerical simulation are the mass and momentum conservation equation for water flow, mass conservation equation for suspended sediment including wash load, mass conservation equation of bed sediment, and equation for sediment size distribution, equation for erosion and deposition rate.

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2D governing equations in Cartesian coordinate system are transformed into a general coordinate system. As suspended sediment dominates the morphological changes of Jamuna River, the most important equations are mass conservation equations of suspended sediment and bed sediment.
Mass conservation equation of suspended sediment can be described as follows:

$$\frac{\partial c_i h}{\partial t}+\frac{\partial r_1 u c_i h}{\partial x}+\frac{\partial r_1 v c_i h}{\partial y}=\frac{\partial}{\partial x}\left(h \in_x \frac{\partial c_i}{\partial x}\right)+\frac{\partial}{\partial y}\left(h \in_y \frac{\partial c_i}{\partial y}\right)+E_i-D_i \quad \text{(Eq.1)}$$

Mass conservation equation of bed sediment can be described as follows:

$$\frac{\partial z_b}{\partial t}+\frac{1}{1-\lambda}\sum_i \left(\frac{\partial q_{bix}}{\partial x}+\frac{\partial q_{biy}}{\partial y}+E_i-D_i\right)=0 \quad \text{(Eq.2)}$$

Where z_b is the bed elevation, q_{bi} is the bed load transport rate for grain size d_i, λ is the porosity, r_1 is the correction factor, C_i is the sediment concentration at size class d_i, ϵ_x and ϵ_y is the dispersion Co-efficient in x and y direction, E_i and D_i is the erosion and deposition rate of suspended sediment for grain size d_i which can be expressed as:

$E_i = w_{0i} c_{bei}$ .... (Eq.3)

$D_i = w_{0i} c_{bei}$ .... (Eq.4)

Where w_{0i} is the fall velocity of suspended sediment given by Rubey (1933) equation as follows:

$$w_{0i}=\left(\sqrt{\frac{2}{3}+\frac{36{v_0}^2}{(\rho_s/\rho-1)g{d_i}^3}}-\sqrt{\frac{36{v_0}^2}{(\rho_s/\rho-1)g{d_i}^3}}\right)\sqrt{(\rho_s/\rho-1)gd_i} \quad \text{(Eq.5)}$$

v_0 is the kinematic viscosity (= 0.01 cm^2/s) at 15^{0}C. c_{bei} is the equilibrium suspended concentration of *i* sediment size class at reference level evaluated by Lane and Kalinske (1941) as follows:

$$C_{bei}=5.55\left(\frac{1}{2}\frac{u_*}{w_{0i}}\exp\left(-\frac{w_{0i}}{u_*}\right)\right)^{1.61} f_{bi} r_b (unit: ppm) \quad \text{(Eq.6)}$$

Where u_* is the shear velocity, r_b is the saturation ratio of bed sediment. r_b =0 when there is no sediment on the bed surface and r_b =1 when there is sufficient sediment for transport capacity of flow water.
To construct the initial condition, PRISM-DSM has been used with resolution of 5 m. Actually with 30 m mesh the DSM was implemented after resampling with raster processing. Since the DSM obtained by remote sensing show only land surface but not the bathymetry, flow depth of underneath of water surface should be estimated. For this purpose, 1-D numerical estimation including water and sediment continuity equations as well as momentum equation is implemented. Flow depth calculation from governing equation of 1-Dimensional numerical calculation is as follows:

$$h_1 = h_0\left(\frac{B_1}{B_0}\right)^{\frac{-24}{35}} \quad \text{(Eq.7)}$$

Where, h_0 = Flow depth in reference point, B_0 = Flow width in reference point, B_1 = Flow width based on satellite information, h_1 = Unknown flow depth. Therefore, the flow depth at the each cross-section can be estimated with known B_0 and h_0. It should be mentioned that the flow depth is initially flat with estimated flow depth.
The grids are generated by defining two polygons, one is model domain and another is the low flow. The generated grid size is approximately 500m by 500m and also has a numbers of 154 cells along the river course and 34 cells across the river width. After modifying the cross-sections final grid system has been generated for model set up. Boundary conditions are given as a discharge time series at the upstream model boundary (at Bahadurabad Ghat station) with steady flow condition of 65,000 m^3/s and water level time series at the downstream model boundary (at Mathura station) which were collected by Bangladesh Water Development Board (BWDB). Satellite images over the study reach are collected from Centre for Environmental and Geographic Information System (CEGIS). Median grain sizes (d_{50}) of the bed material are taken from Kabir et. al, 1996 under river survey project (FAP-24). For numerical computations assuming uniform bed material with d_{50} = 0.264 mm, bed slope s = 1/10000, Manning's roughness co-efficient n = 0.025, computational time step dt =10 sec, co-efficient related to the intensity of secondary flow N_* =7 and thickness of exchange layer = 1.00 m.

RESULTS AND DISCUSSION

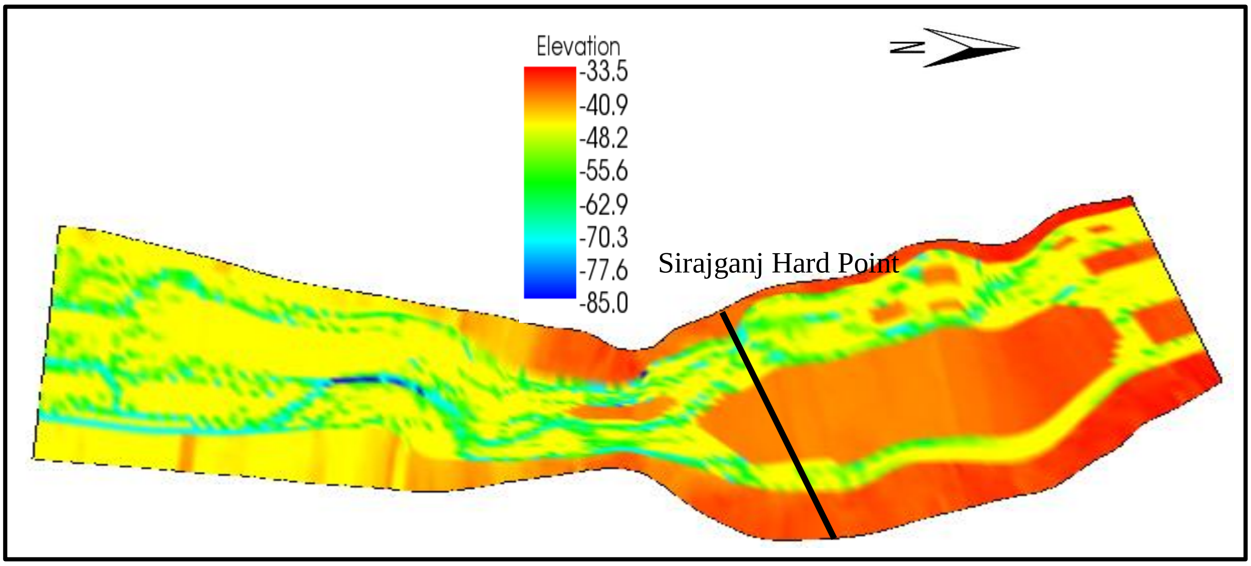

Figure 1 Bed elevation (m) plan form result for 80 days. Black line represents the observation point.

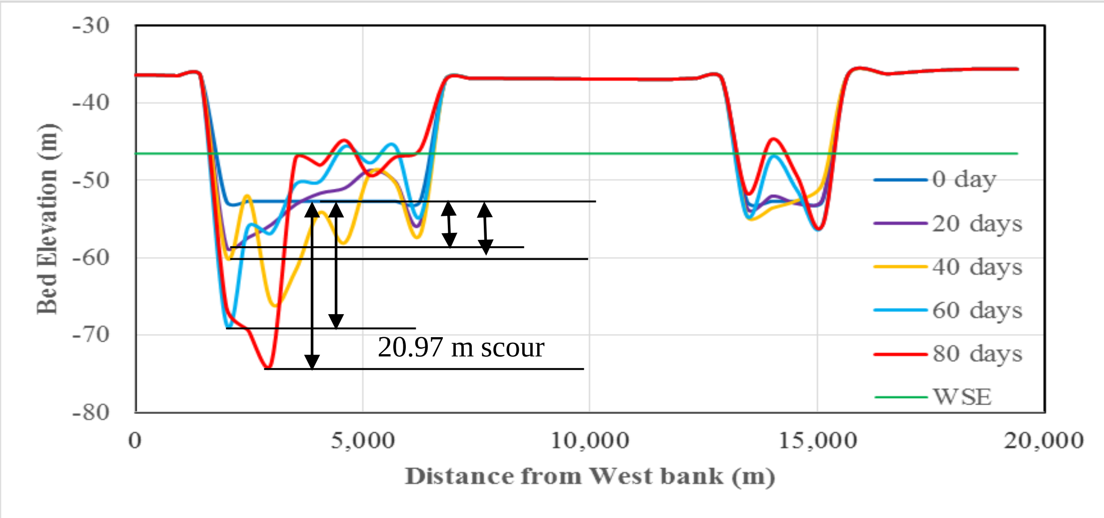

Figure 2 Comparison of cross-sectional shapes after 20, 40, 60 and 80 days respectively.

Figure 1 shows numerical simulation result in terms of bed elevation change in plan view after 80 days simulation. It has been observed that in a single stream sand bars form and then single channel becomes braided. This figure also illustrate that the sand bar formation (deposition), sand bar deformation (erosion) takes place within the study reach. Figure 2 shows timely changes of the river cross-sectional shapes obtained by the numerical computation at the section, which is indicated as black line in figure 1. As it shows 5.92 m, 7.13 m, 15.86 m and 20.97 m scouring occur adjacent to the revetment work after 20 days, 40 days, 60 days and 80 days respectively. This results indicates the progress of the scour at vicinity of the Hard Point area, which is reasonable to the point of the field engineers.
Based on this numerical simulation results the total suspended sediment transportation volume over 80 days can be calculated as 567.93 million tons. Islam et.al, 1999 calculated the suspended sediment discharge as 70,000 kg/s by using rating curve based on 1990 year data. It can be converted as 483.84 million tons within 80 days. Therefore, the simulated result from the model can be considered as rational compared with the previous study.
In order to protect the Sirajganj Hard Point from damages through severe local scour, this study propose the countermeasures as shown in Table 1. Common works for all cases are dredging the earth with size

and shape as shown in table 1 and refill back them at the upstream side of the revetment works. Option-A and B are dredging with straight line, whereas Option C and D are that with curvature aiming to create the flow pattern of inner side by the curved channel to induce the active deposition. Regarding to the numerical simulation, the results of figure 1 was employed as the initial condition in this countermeasure study. The cost for four countermeasure options has been estimated on the basis of per unit dredging volume cost, which has been taken from completed dredging work of Sirajganj Hard Point area.

Table 1 Proposed dredging configurations for four different options.

Counter measures	Width (km)	Depth (m)	Length (km)	Radius of curvature (km)	Dredging volume (Mm^3)	Cost (US $ million)	Channel type
Option-A	1.00	15.00	8.00	--	120.00	420.00	Straight
Option-B	3.00	15.00	18.00	--	810.00	2,835.00	Straight
Option-C	2.00	15.00	--	3.00	188.00	663.00	Curved
Option-D	1.00	15.00	--	3.00	82.00	290.00	Curved

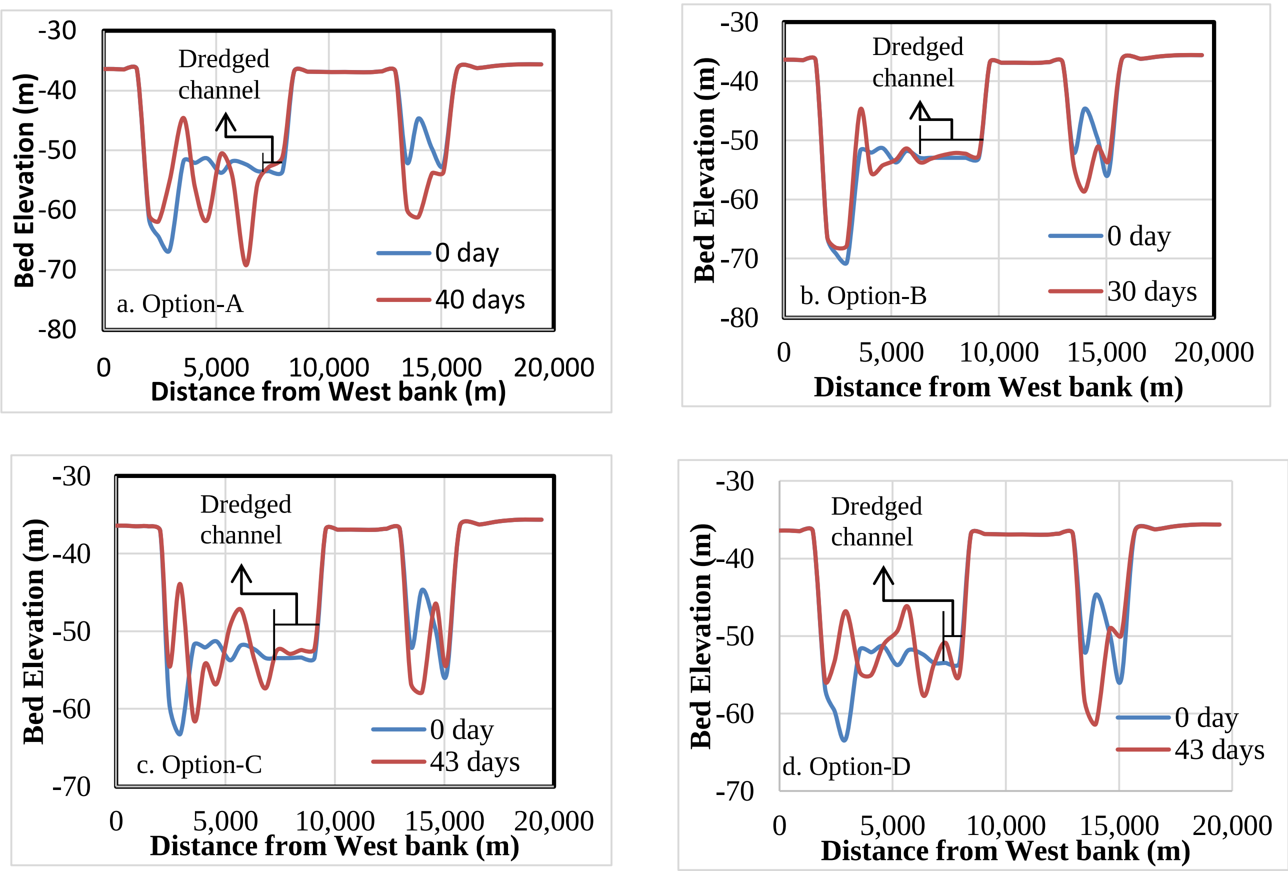

Figure 3 a-d Comparison of cross-sectional shapes for options A, B, C and D respectively.

Figure 3 a-d shows numerical simulation results of the countermeasures of option A, B, C and D indicating the cross-sectional shapes of before and after countermeasures. In those figures, 0 days indicates the bathymetry before countermeasure. As figure 3 a-d shows, deposition takes place very close to the revetment work for all options and siltation takes place within the dredged section in the most cases (in case of option-A, B and C). It should be highlighted that, the volume of deposition is depend on the cases, e.g. option A and B does not have much deposition, whereas option C and D has very active deposition, such as 19.24 m and 16.42 m respectively. It might be inferred that aiming for creating the flow pattern as inner curved channel is successfully created. Since there are not much difference between option –C and option-D in terms of sediment deposition in the Hard Point for concerning about economically viability option-D is selected in this study as the best method.

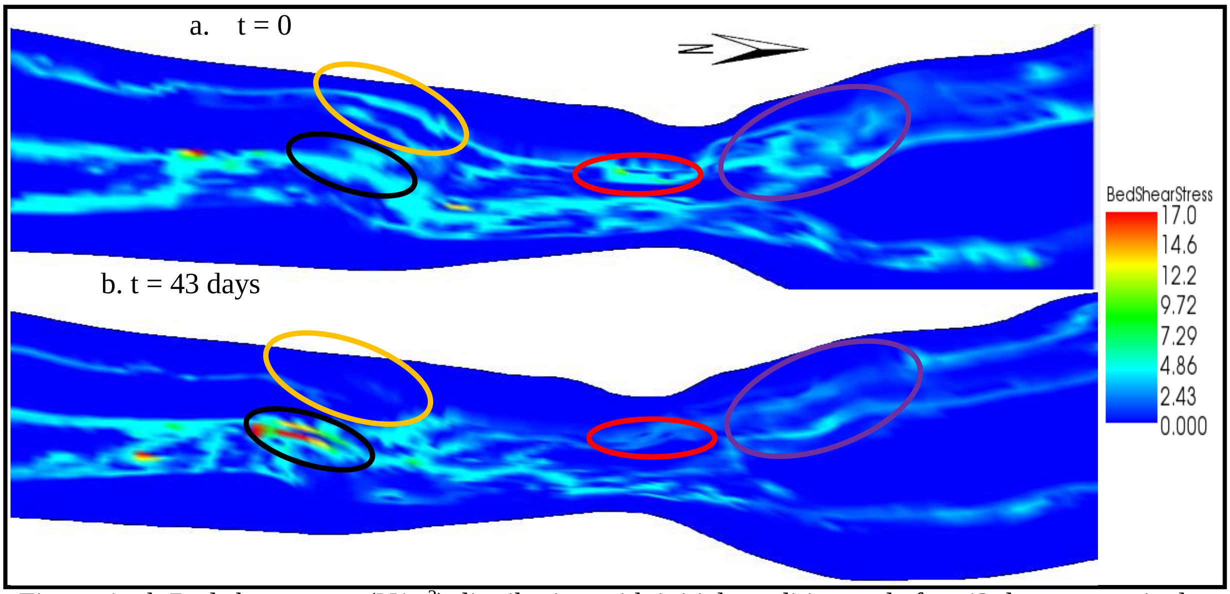

Figure 4 a-b Bed shear stress (N/m^2) distribution with initial condition and after 43 days respectively.

For considering the influence of the countermeasure to the downstream side, bed shear stress distribution is examined as figure 4 a-b indicated. Shear stress decreases at the location marked by purple, red and orange colors along the west bank of Jamuna River. On the other hand, high shear stress in the mid channel of the river takes place which is marked by black circle. Those lower and higher shear stress certainly contribute to deposition and erosion respectively. Since lower shear stress located in the west bank, whereas higher shear stress located in the mid-channel, deposition and erosion occurred in the west bank and mid-channel respectively. Based on the figure 4 a-b, it could be concluded that countermeasure option-D is effective in terms of protection of not only the Hard Point but also downstream side.

CONCLUSION

Computation results shows that side bank erosion as well as deep scour (20.97 m) occurs along Sirajganj Hard Point after 80 days simulation. Numerical simulation results in terms of cross-sectional shape it has been observed that deep erosion takes place along both banks of the river within the study reach. Numerical simulations also conducted considering four different options of dredging configurations for countermeasures. In case of option-D numerical simulation result suggest that significant sediment deposition takes place along the revetment work and deep erosion occurs within the artificial channel. From the analysis of four countermeasures effect within the study reach it has been observed that option-D provide good result in terms of sediment deposition along both banks of the river within the study reach. The total estimated cost for countermeasures option-A, option-B, option-C and option-D are US $ 420 million, US $ 2835 million, US $ 663 million and US $ 290 million respectively. So, option-D is considered as comparatively effective countermeasure.

RECOMMENDATION

This study shows the set-up of the initial condition with satellite information data, numerical simulation with averaged discharge to understand the flow and morphological change, and the counter measures. Overall, the results obtained by this model is reasonable. For the future study, implementation of the non-uniform sediment condition, vegetation density information can be considered. Also, the field study to obtain the actual bathymetry during flooding and bed-load/suspended sediment observation should be recommended to understand deeply about the Jamuna river, and verifying the calculation results.

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