SEDIMENTATION AND ITS COUNTERMEASURE AT THE OFF-TAKE AREA OF NEW DHALESWARI RIVER

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ABSTRACT

Present study proposes a method to mitigate sediment deposition at the off-take region based on an idea for the relation of the stream line curvature and associated secondary currents. We investigated numerically effects of spur dyke on the mitigation of sediment deposition, focusing on flow pattern, bed variation and off-take flow discharge as well as on location and size of spur dyke. A suitable size of spur dyke and its construction site are proposed based on the numerical predictions.

Keywords: Sediment deposition, curvature of flow, secondary current, bed variation, suitable spur dyke.

INTRODUCTION

New Dhaleswari River is the most prominent distributary channel of the mighty river Jamuna in terms of discharging water to the four major peripheral rivers of the Capital city of Bangladesh, Dhaka. This river route is expected to carry necessary discharge through the whole hydrological cycle every year. Jamuna, being a suspended sediment dominated river, injects huge volume of sediment in suspension with the discharge through this channel. Due to massive sediment deposition at the New Dhaleswari off-take area, the channel remains almost closed for five to six months in the dry season. Adjacent rivers of the capital city, Dhaka as well as the river network of central part of Bangladesh are badly affected with the reduced flow coming from Jamuna through this river route. The present study is to find a technical solution to the sedimentation problem at the New Dhaleswari Off-take area. The study includes the study area, problem to be solved, over-all goal, hydrologic and hydraulic characteristics of the study area, formulation of problem, explanation about the idea of the countermeasure, technique applied to test the validity of the idea, the governing equations employed in numerical computation, calculation conditions, scenario of flow pattern in case of flow and bed variation cases, sediment transportation characteristics and analysis of the effect of the idea over flow and sediment control and conclusion.

THEORY AND METHODOLOGY

The objective is to find a technical solution to closing of channel due to massive deposition of sediment at the New Dhaleswari Off-take area. To solve the problem, the idea of employing a spur dyke along the main channel at the off-take of Branch channel is introduced. The expectation is the spur dyke would control the curvature of flow and generate secondary current. That secondary current is expected to transport sediment from the off-take area towards the center part of the river and it diverts more clear water (less turbid water) into the branch channel. The spur dyke controls the flow pattern at the off-take area and resist closing of channel. Figure 1 summarizes the idea of present study. The numerical model proposed by Takebayashi et.al. (2009) is employed. This model is based on the depth integrated 2-D governing equations for water flow as well as on the governing equations on sediment transportation and associated bed evolution. These equations are as follows.

$$\frac{\partial h}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = 0 \tag{1}$$

In which, h is the flow depth, u and v are the x-component and y-component of velocity, respectively. The momentum conservation equations for flow along x and y-directions are described as

$$\frac{\partial uh}{\partial t} + \frac{\partial uuh}{\partial x} + \frac{\partial uvh}{\partial y} = -gh\frac{\partial}{\partial x}\left(h + z_b\right) - \frac{\tau_x}{\rho} + \frac{\partial}{\partial x}\left(h\,\sigma_{xx}\right) + \frac{\partial}{\partial y}\left(h\tau_{yx}\right) \tag{2}$$

$$\frac{\partial vh}{\partial t} + \frac{\partial uvh}{\partial x} + \frac{\partial vvh}{\partial y} = -gh\frac{\partial}{\partial y}\left(h + z_b\right) - \frac{\tau_y}{\rho} + \frac{\partial}{\partial y}\left(h\,\sigma_{yy}\right) + \frac{\partial}{\partial x}\left(h\tau_{yx}\right) \tag{3}$$

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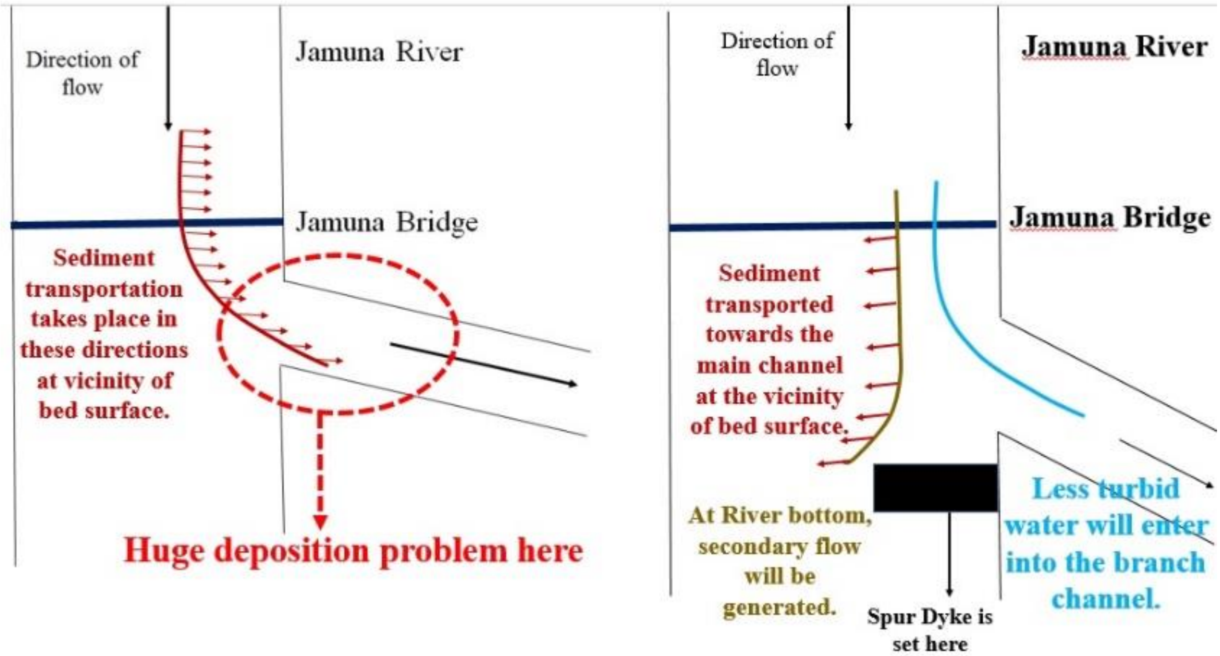

Figure 1 Idea and theoretical background of study.

In which,

$$\tau_x = \tau_b \frac{u_b}{\sqrt{u_b^2+v_b^2}},\ \tau_y = \tau_b \frac{v_b}{\sqrt{u_b^2+v_b^2}}, \frac{\tau_b}{\rho} = u_*^2 \tag{4}$$

$$\sigma_{xx} = 2\varepsilon\frac{\partial u}{\partial x},\ \sigma_{yy} = 2\varepsilon\frac{\partial v}{\partial y}, \tau_{xy} = \tau_{yx} = \varepsilon\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right) \tag{5}$$

Where, t = Time; x and y = the coordinates along the longitudinal and the transverse directions; u, v = depth-averaged flow velocity on bed along the longitudinal and the transverse directions; z = Water surface level; z_b = Bed elevation; h = Surface flow depth; $\tau_x,\ \tau_y$ = Shear Stress along the longitudinal and the transverse directions; $\tau_b =$ Bed Shear Stress; ε = Coefficient of eddy viscosity; $u_b\ and\ v_b$ = Velocity near the bed surface along the longitudinal and the transverse directions;

Mass Conservation Equation of Bed Sediment case, including suspended sediment part is as follows,

$$\frac{\partial z_b}{\partial t} + \frac{1}{1-\lambda}\sum_i\left(\frac{\partial q_{bix}}{\partial x}+\frac{\partial q_{biy}}{\partial y}+E_i-D_i\right)=0 \tag{6}$$

Where, z_b = Bed elevation. q_{bi} = bed load transport rate for grain size d_i.

q_{bx} = x-component of the bed load rate, $q_{bx} = \frac{u_{bx}}{\overline{u_b}} * q_b$.

q_{by} = y-component of the bed load rate, $q_{by} = \frac{u_{by}}{\overline{u_b}} * q_b$.

$\overline{u_b}$ = velocity at bed surface, h = bed elevation and flow depth, $E_i,\ D_i$ = Erosion and Deposition Rate of Suspended Sediment for grain size d_i; q_b is directed to the velocity. Velocity is a vector. After evaluating q_b, q_{bx} and q_{by} are determined automatically. Bed load discharge in the direction of bed load q_{bk} is calculated by Ashida and Michue's equation as follows:

$$q_{b*} = 17\,\tau_{*e}^{3/2}\left(1-\frac{\tau_{*c}}{\tau_*}\right)\left(1-\frac{u_{*c}}{u_*}\right) \tag{7}$$

Where, τ_{*e} = Non dimensional effective bed shear stress; τ_{*c} = Non dimensional critical bed shear stress for initiating sediment movement which is evaluated by Shields diagram. u_{*c} = Critical shear velocity; The effective bed shear stress is defined as

$$\tau_{*e} = \frac{u_{*e}^2}{\left(\frac{\sigma}{\rho}-1\right)gd} \tag{8}$$

Therein u_{*e} was evaluated using

$$\frac{v}{u_{*e}} = 6.0 + 2.5\ln\frac{h}{d(1+2\tau_*)} \tag{9}$$

Where, v = spatial average velocity;

Mass conservation equation of suspended sediment within the flow body is given by

$$\frac{\delta \bar{c} h}{\delta t} + \frac{\partial r_1 \bar{c} \bar{u} h}{\partial x} + \frac{\partial r_1 \bar{c} \bar{v} h}{\partial y} = \frac{\partial}{\partial x}\left(h \varepsilon_x \frac{\partial \bar{c}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial \bar{c}}{\partial y}\right) + \mathrm{E} - \mathrm{D} \qquad (10)$$

Here, $\bar{c}$, $\bar{u}$, $\bar{v}$ = depth avg. values for sediment concentration, x and y component of velocity.
ε_x, ε_y = x and y components of dispersion co-efficient (similar to turbulent diffusion co-efficient).
E & D = Erosion and Deposition rate of sediment, r_1 = correction factor.
Deposition rate can be evaluated using the formula written as

$$D = r w_0 \bar{c} \qquad (11)$$

Where, w_0 = fall velocity of sediment particle, c_b = sediment concentration at reference level in the vicinity of bed surface.

$$c_b = r\,\bar{c}\;,\ (r = \frac{c_b}{\bar{c}} \geq 1, \text{co-efficient}) \qquad (12)$$

Non-dimensional form of deposition rate formula is

$$\frac{D}{u_*} = r \frac{w_0}{u_*}\,\bar{c} \qquad (13)$$

Generally, deposition rate is evaluated using Eq. (11) or Eq. (13) in which r is estimated using sediment concentration profile in equilibrium condition. If it is supposed that the erosion rate is determined by flow characteristics (turbulence characteristics) near the bed, the erosion rate can be evaluated using equilibrium sediment concentration c_{be} at reference level,

$$E = D\ (= w_0 c_{be}) \qquad (14)$$

The equilibrium concentration of the suspended load at the reference height c_{be} of Lane & Kalinske's equation is as follows,

$$c_{be} = 5.55\left(\frac{1}{2}\frac{u_*}{w_0}\exp\left(-\frac{w_0}{u_*}\right)\right)^{1.61} f_{bk} \qquad (15)$$

Where, f_{bk} = Concentration of bed load layer for of k sediment size class. r_b = Function of the exchange layer thickness.

Sediment transport model under Morpho2D, iRIC software is used in this study. Morpho 2D is the unsteady horizontal two dimensional bed deformation analysis solver which is developed by Hiroshi Takebayashi, Kyoto University. The governing equations are written in boundary fitted general coordinate system (Takebayashi, 2009). Users can choose the calculation of water flow only or bed deformation analysis. Users can choose the calculation of bed load only or bed load + suspended load. Both uniform sediment and non-uniform sediment can be treated. When users choose non-uniform sediment, size distribution of sediment can be calculated (Takebayashi, 2009).

RESULTS AND DISCUSSION

To check the validity of the idea and establish the concept with a view to solving the sedimentation problem at the off-take area, a rectangular shaped simple experimental channel is made.

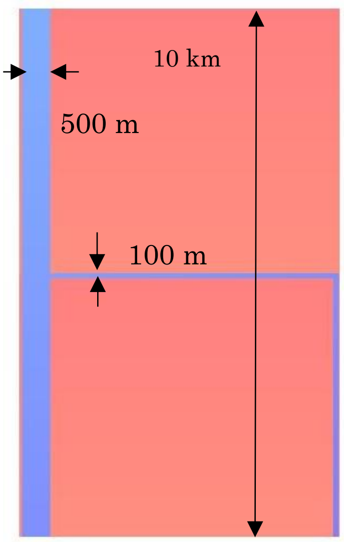

Figure 2: Computational domain with 10 m grid size to observe flow pattern over rigid and erodible bed conditions.

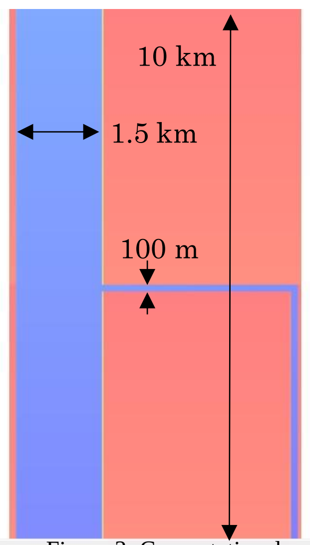

Figure 3: Computational domain with 20 m grid size to observe sediment transport characteristics over erodible bed conditions.

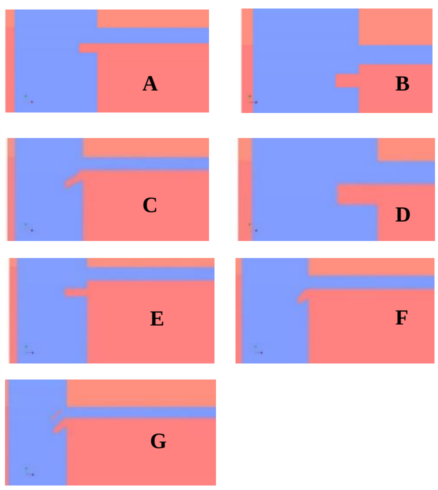

Figure 4: 07 types of spur dykes are considered for computation. A=100 m spur 1, B=100 m spur 2, C=100 m inclined spur, D=150 m spur 1, E=150 m spur 2, F=Inclined Spur 2, G= Inclined spur with wall.

(A) Analysis of annual and temporal changes along the Study reach

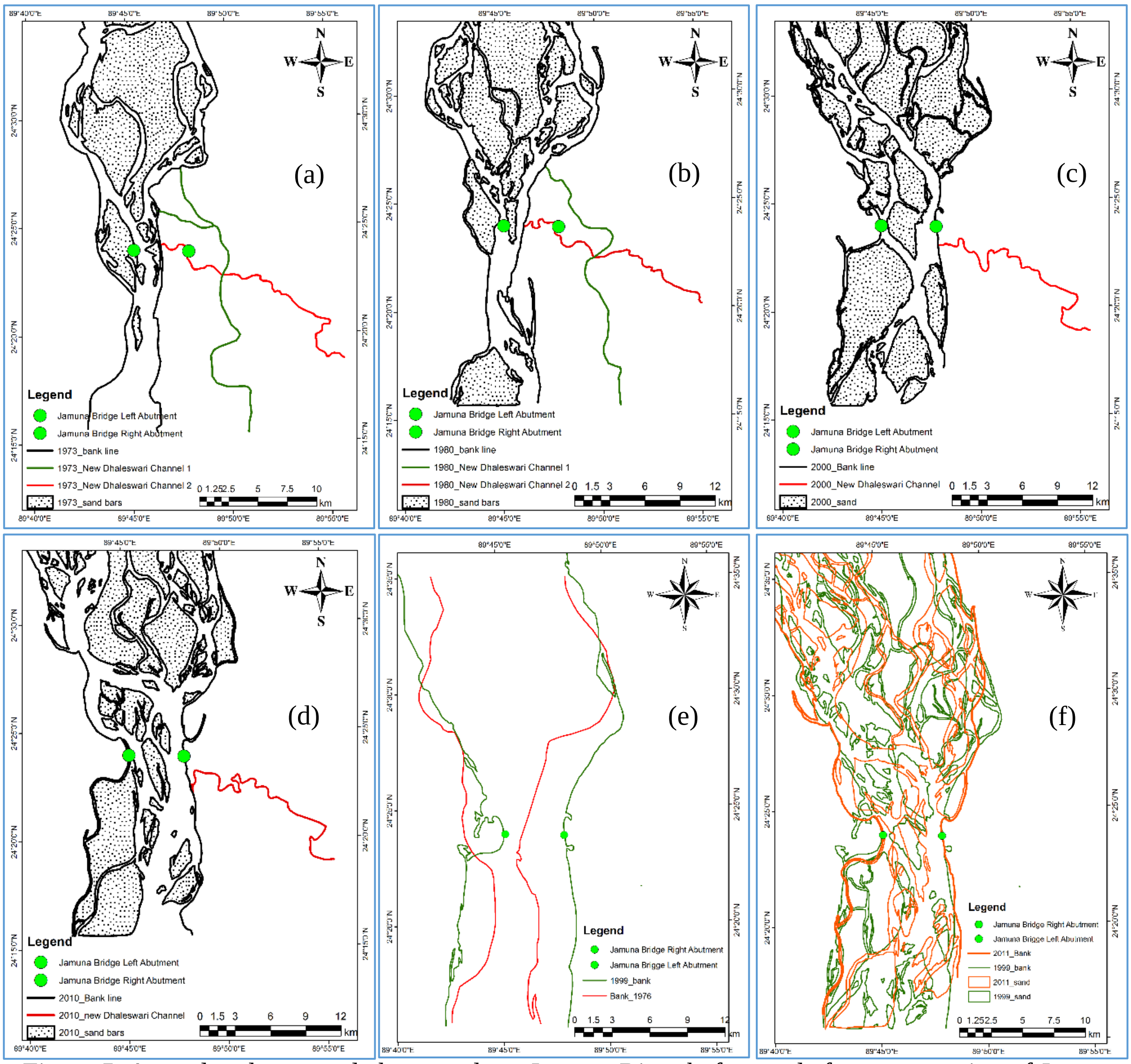

Figure 5: Annual and temporal changes along Jamuna River before and after construction of Jamuna Bridge. (a) 1973, (b) 1980, (c) 2000, (d) 2010, (e) Changes in bank line from 1976 to 1999, (f) Changes in bank line and sand bars from 1999 to 2011.

There used to be 02 off-takes of New Dhaleswari River (Green and Red channels) before construction of Jamuna Bridge (Fig. 5 (a) & (b)), whereas after construction of Jamuna Bridge, green channel is closed ((fig. 5 (c) & (d)). There is massive change is river shape before and after construction of Jamuna Bridge (fig. 5 (e)). Fig. 6 shows that the off-take point used to shift its location and river alignment used to vary in different years. Analysis is done from 1999 to 2011, this time period is after construction of Jamuna Bridge.

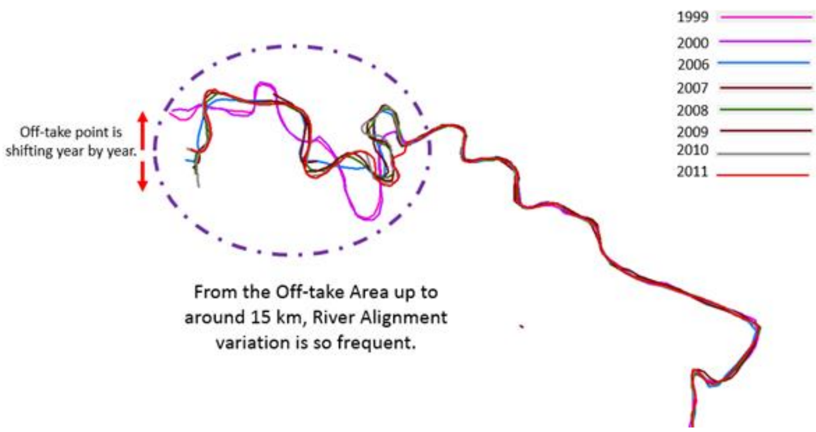

Figure 6: Annual changes of New Dhaleswari River off-take area.

(B) Comparison on flow pattern

After observing performances of 07 types of spurs dykes, 100 m spur 2 (Type B) is found most suitable form of spur dyke. For erodible bed case, from comparison of flow pattern, it is seen that without spur dyke, there is drop in velocity at the mouth and inside the branch channel at the off-take area, whereas after employing 100 m spur 2, velocity is increased considerably inside the branch channel at the off-take area.

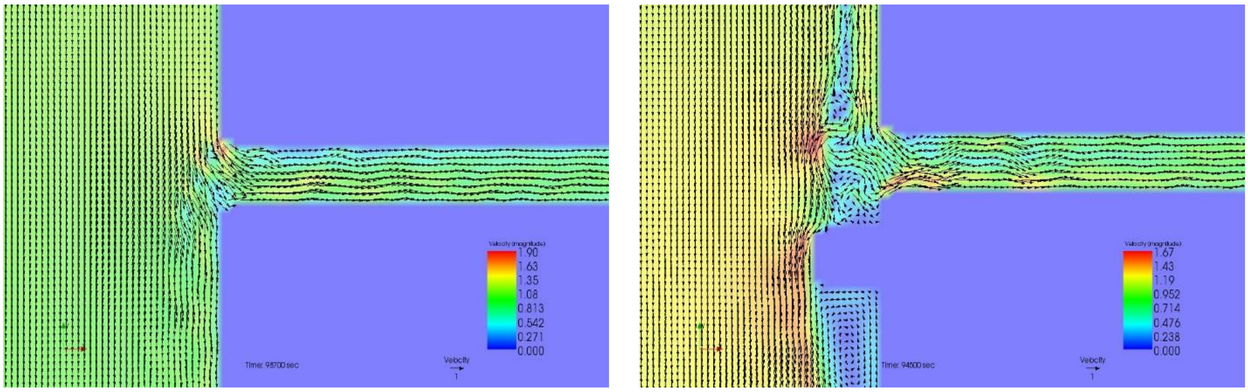

Figure 7: Flow pattern over erodible bed, without spur and 100 m spur 2 cases.

(C) Comparison of bed deformation

After 16 days of computation with discharge equivalent to 20000 m^3/sec, without spur dyke, there is clear tendency of closing of channel due to massive sediment deposition at the off-take area (blue marked). After employment of 100 m spur 2, it is seen that bed level is deepened and water can easily enter into the branch channel. For average flood discharge case i.e. discharge equivalent to 60000 m^3/sec, similar performance is observed in terms of sediment transport characteristics.

(D) Comparison of Discharge along branch channel

Figure 9 shows the comparison of discharge at erodible bed case and rigid bed case at different time steps from 0 to 16 days. Here, Qo is discharge over Rigid Bed case and Qt is Discharge over erodible bed at different time steps. Discharge is analysed at 1 km downstream of the off-take, along the

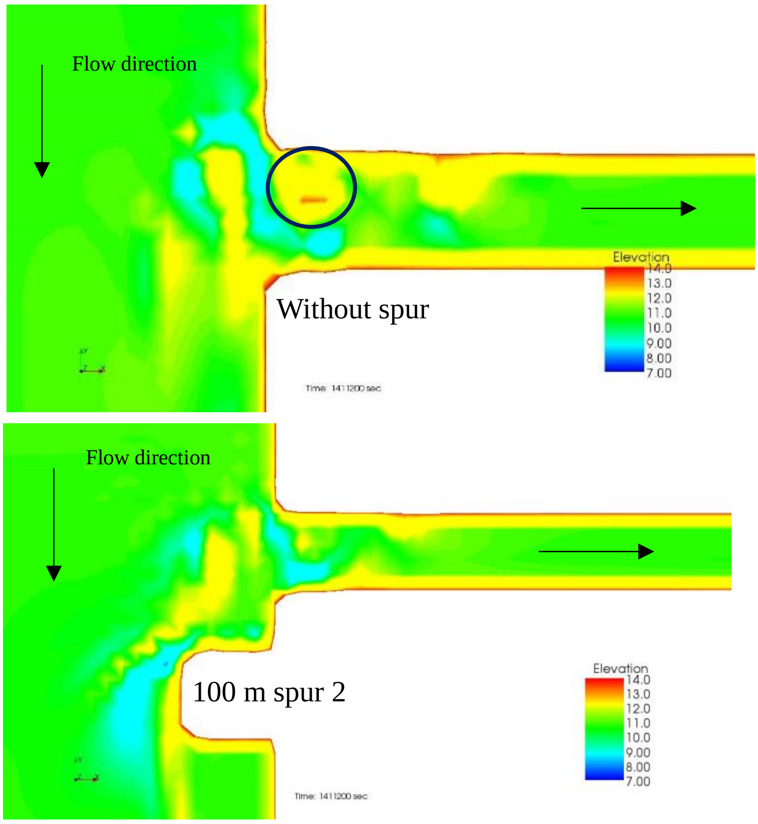

Figure 8: Comparison of bed deformation.

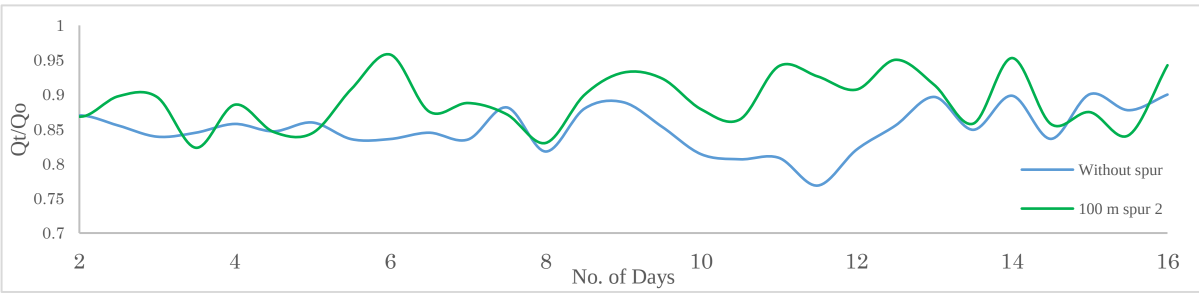

Figure 9: Comparison of Discharge for erodible bed case over rigid bed case for without spur dyke, 100 m spur 1 and 100 m spur 2 scenario.

branch channel. The figure says that flow discharge through the branch channel is increased considerably as effect of spur dyke.

(E) Comparison of non-dimensional bed shear stress

Without spur dyke case, from the off-take towards the branch channel, deposition character is found. But with 100 m spur 2 case, deposition character is reversed to erosion character which means deposition tendency at the off-take is reversed to erosion tendency. So, there is little possibility of closing of channel after employment of spur dyke.

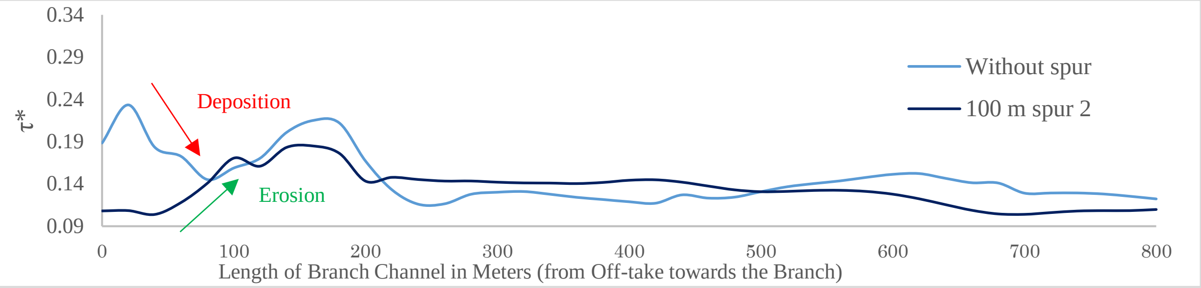

Figure 12: Comparison of non-dimensional bed shear stress for without spur and 100 m spur 2 cases.

CONCLUSIONS

The present study evaluates a technical solution to sedimentation problem at the off-take area of branch channel with introduction of spur dyke to control stream line curvature of flow and associated generation of secondary currents. That secondary current transports sediment from the off-take area towards the center part of the river and it diverts more clear water (less turbid water) into the branch channel. Sedimentation problem at the off-take of New Dhaleswari River, the most prominent distributary of Jamuna River is addressed under this study. Annual and temporal changes of Jamuna River at the vicinity of the off-take area are analyzed from 1972 to 2011. Numerical computations are done along experimental channels for different shapes of spur dykes at varying locations and flow pattern, bed variation characteristics, sediment transport behavior and discharge scenario are observed. 100 m spur 2 (100 m spur constructed at 50 m downstream of the off-take point) is found the most suitable form of spur dyke that establishes the idea of study. After employment of spur dyke, average velocity as well as discharge are increased at the Off-take area, possibility of closing of channel due to sediment deposition is diminished and sediment is being flushed from the off-take. The established idea can be implemented as solution to sedimentation problem at the New Dhaleswari River off-take area.

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