ASSESSMENT OF EROSION VULNERABILITY NEAR THE HYDRAULIC STRUCTURES BY COMPARING THE EROSIVE RESISTNCE OF NON-COHESIVE SOIL WITH FLOW VELOCITY

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ABSTRACT
Major rivers of Bangladesh are very dynamic in nature, among which the Jamuna is the extreme example. About twenty thousands of people along the Jamuna River become landless and homeless every year due to erosion. In this regard, BWDB has implemented many structures along the Jamuna River. In this study, vulnerability of erosion is assessed for various important hydraulic structures along the Jamuna River near Bangabandhu Bridge area. This is the largest bridge in Bangladesh that have mainly four important hydraulic structures at the upstream of bridge to guide the flow under the bridge including two guide bunds and two Hard Points. These structures are always under threat due to the dynamic behavior of the Jamuna River. So erosion assessment and monitoring is the primary concern of these structures. Erosion starts when a particle overcomes its incipient motion. The erosion resistance of river bank and river bed can be estimated on the assumption that the load can be characterized by the maximum occurring shear stress or velocity, while the resistance is given in terms of the critical shear stress or velocity. This critical velocity is estimated by using the method of shear stress. Then the actual velocity of the flow near a structure is compared whether it has crossed the critical velocity to initiate the motion of the sediment particle. Results from the study show that the ratios between actual flow velocity to critical velocity near the structures are much higher from unity. So all the structures can be considered as vulnerable according to the study and these need continuous monitoring and erosion preparedness.

Keywords: Erosion; hydraulic structures; incipient motion; critical velocity

INTRODUCTION
Bangladesh is formed by the alluvial deposition of soil in the major river systems and their numerous tributaries and distributaries. So bank erosion is a very common phenomenon for the rivers. Many people living along the river lost their land due to erosion. Among all the rivers, the Jamuna is the most dynamic and complex one. Different types of structures based on the requirements were implemented in this river by Bangladesh Water Development Board. Some of the structures were successful and some of those failed due to lack of understanding about the vulnerability. The Bangabandhu Bridge is one of the most important structures on the Jamuna River. In addition, there are other four major structures in the vicinity of the Bridge. Those are: East Guide Bund, West Guide Bund, Sirajganj Hard point, Bhuapur Hard point. The purpose of these structures is to guide the flow of the river under the bridge. However, these structures are getting vulnerable during the monsoon period. Thus assessment of erosion vulnerability of those structures is necessary. In this study, erosion vulnerability near the hydraulic structures has been assessed by comparing the flow velocity with the critical velocity.

STUDY AREA
The study area covers the Bangabandhu Bridge and its adjacent structures, i.e. East Guide Bund, West Guide Bund, Sirajganj Hardpoint and Bhuapur Hardpoint, Figure 1 shows the study area near Bangabandhu Bridge in the Jamuna River.
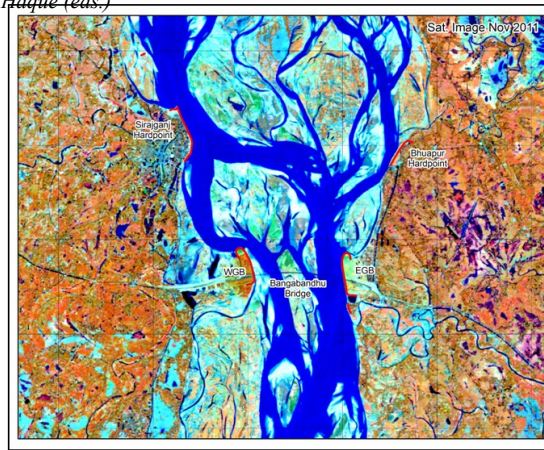
Fig 1: Location of the study area near Bangabandhu Bridge

METHODOLOGY

Description of the Model Setup

To setup a two dimensional morphological model for calculating velocity along various structures of the Jamuna River, MIKE21C (an advanced two-dimensional mathematical modelling software developed by DHI Water & Environment, Denmark) has been used. A number of simulations have been conducted for different hydrological year to get a range of velocity passing along the structures. Setting up of a 2D morphological model comprises firstly, computational grid generation and secondly, preparation of the bathymetry on these grid cells. Figure 2 shows the grid and the bathymetry, respectively. The Curvilinear grid has been generated using the surveyed bankline of 2010 and the initial bathymetry has been prepared by interpolating the surveyed cross-sectional data of December 2010. The upstream boundary and downstream boundary have been set up according to the model area and finally simulations have been carried out for different flood events, e.g. 1 in 10, 1 in 100 and 1 in 2.33 years corresponding to the hydrological years of 1995, 1998 and 2005, respectively. The model was calibrated for the 2010 hydrological year.
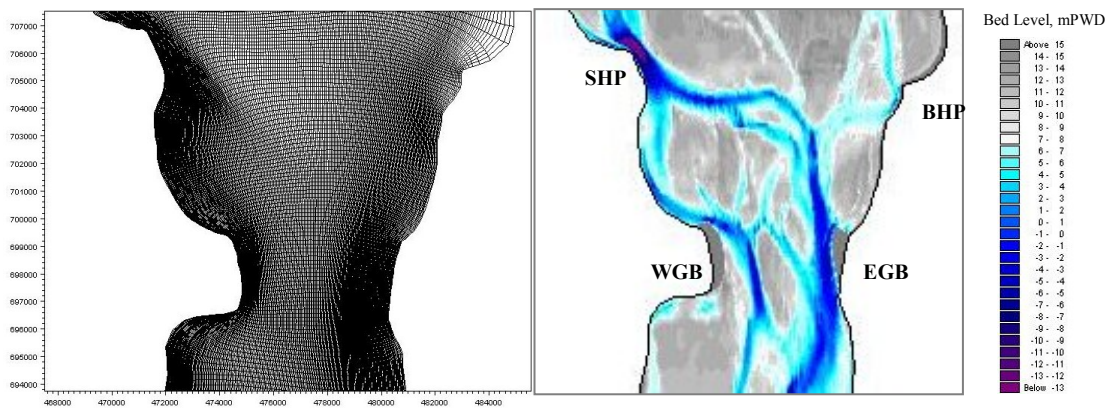

Fig 2: Computational curvilinear grid and Bathymetry corresponding to the year of 2010.

Determination of Critical Velocity

Critical velocity is the velocity needed to transport sediment load (Bull, 2012). For non cohesive soil, assuming a steady uniform flow, the basic stability criterion can be expressed as-

$$\tau_{cr} = \Psi_{cr}(\rho_s - \rho_w).g.D > \tau_o \qquad (1)$$

Where,

τ_{cr} = critical shear stress (N/m^2), τ_o = shear stress exerted along the bank/bed boundaries(N/m^2), ψ_{cr} = dimensionless critical Shields shear stress parameter for specific material, D= mean grain size (m), ρ_s = density of soil (kg/m^2) and ρ_w = density of water (kg/m^2)

The value of Ψ_{cr} depends on particle shape, velocity profile, etc. For fine sediments with D< 4 mm, the Shields parameter can be written as:

$$\Psi_{cr} = \frac{\tau_c}{(\gamma_s - \gamma_w)D} = \frac{U_*^2}{\Delta_m g.D} \quad (2)$$

where,

$$U_* = \sqrt{g \cdot R \cdot S} = \frac{u \cdot \sqrt{g}}{C} \quad (3)$$

where,

Δ_m (-) = $(\rho_s-\rho_w)/\rho_w$, i.e., relative density of submerged material, U_*= shear velocity (m/s), R= hydraulic radius or water depth (m), S = slope of energy line, u= mean velocity (m/s), C= Chezy coefficient ($m^{0.5}$/s) and h= depth of flow (m).

For practical cases the following formulas can be used to estimate the critical velocity (U_c) causing subsoil erosion:

$$U_c = (\sqrt{g \cdot \Delta \cdot D_{50}} \sqrt{\psi_{cr}}) * 5.75 * \log \frac{6h}{D_{50}} \quad \text{(For finer sediment)} \quad (4)$$

$$U_c = (\sqrt{g \cdot \Delta \cdot D_{50}} \sqrt{\psi_{cr}}) * 5.75 * \log \frac{2h}{D_{50}} \quad \text{(For coarser sediment)} \quad (5)$$

Determination of Dimensionless Instantaneous Velocity

Incipient motion is important in the study of sediment transport, as this motion of sediment particles in alluvial rivers is a key process for mobility. It represents the difference between bed stability and bed mobility (Matin, 1994). Due to the stochastic nature of sediment movement along an alluvial bed, it is difficult to define precisely at what flow condition a sediment particle will begin to move (Yang, 2012). Consequently, it depends more or less on an investigator's definition of incipient motion.

The initiation of motion of a particle could be identified by comparing the instantaneous velocity with the critical velocity. Therefore if the ratio between instantaneous velocity and the critical velocity is higher than unity, the particle would initiate its motion. In this study, the instantaneous velocity along the structures has been extracted from the model simulation for different flood events and finally dimensionless velocity has been calculated at the expected location.

RESULTS AND DISCUSSION

As mentioned earlier, the vulnerability of erosion has been predicted for the East Guide Bund, West Guide Bund, Sirajganj Hardpoint and Bhuapur Hardpoint. However, it is seen that for 1in100 year flood event the critical velocity ratio exceeds the value 1 for all the four structures. Therefore, average (1in2.33) flood event has been considered here to evaluate the structures vulnerability. The critical velocity for those structures is shown in Table 1.

Table 1: Calculation of Critical Velocity along the structures

Name of the structures	Average water depth, h (m)	Average velocity, u (m/s)	Critical velocity, u_c (m/s)
East Guide Bund	7.13	0.531	0.5
West Guide Bund	3.55	0.722	0.677
Sirajganj	3.67	0.841	0.788
Bhuapur	4.28	0.661	0.62

Summary of Results
East Guide Bund (EGB)

From calculation, the critical velocity is found about 0.5m/s in this location (Table 1). This critical value has been compared with the model simulated maximum velocity along the East Guide Bund at different

location shown in Figure 2, to check the risk of bed scour. Table 2 shows that the probable velocity for different hydrological year along the East Guide Bund varies from 0.21 to 1.43m/sec. It has been observed that the ratio between model estimated velocity and calculated critical velocity is higher along the straight portion of EGB. So straight part of guide bund is vulnerable to bed scour for present bathymetry.

Table 2: Dimensionless Velocity at different point of East Guide Bund for different hydrological year

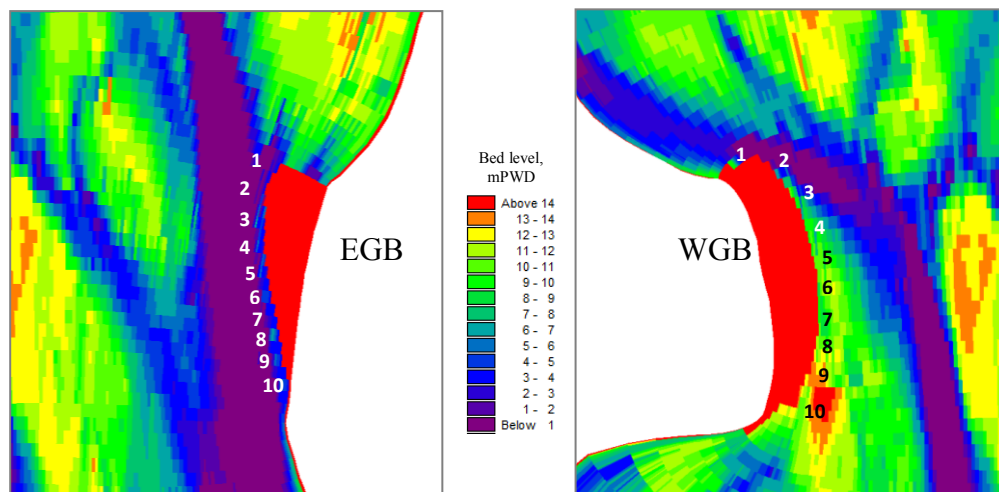| Position	1 in 100		1 in 10		1 in 2.33	
	Velocity, u	u/u_c	Velocity, u in	u/u_c	Velocity, u	u/u_c
1	0.26	0.52	0.32	0.64	0.21	0.41
2	1.66	3.32	1.60	3.21	1.75	3.50
3	1.18	2.35	1.14	2.28	1.22	2.43
4	1.34	2.69	1.30	2.60	1.34	2.68
5	1.40	2.81	1.34	2.68	1.33	2.65
6	1.43	2.86	1.35	2.71	1.28	2.56
7	1.33	2.65	1.25	2.49	1.19	2.38
8	1.34	2.69	1.27	2.53	1.23	2.45
9	1.37	2.74	1.29	2.57	1.27	2.53
10	1.17	2.33	1.18	2.37	1.16	2.33

Fig 3: Different location of velocity along the East Guide Bund and West Guide Bund

West Guide Bund (WGB)
From Table 1, the critical velocity is found about 0.677m/s in this location. To check the risk of bed scour, this critical value has been compared with the model simulated velocity along the West Guide Bund. Table 3 shows that the probable velocities along the West Guide Bund vary between 0.24m/sec to 2.05m/sec for different hydrological year. The ratio between model estimated velocity and calculated critical velocity along the upstream termination of West Guide Bund exceeds the value 1.0, which indicates that the upstream location is vulnerable for bed scour for present bathymetry.

Sirajganj Hard Point (SHP)
From Table 1, the critical velocity is found about 0.788m/s for Sirajganj Hard Point. This critical value has been compared with the model simulated velocity along the Sirajganj Hard Point to check the risk of bed scour. Table 4 shows that the probable velocities along the Sirajganj Hard Point vary from 1.00 to 2.77m/sec for different hydrological year. The ratio between model estimated velocity and calculated critical velocity exceeds the value 1 at every point along the Sirajganj Hard Point that indicates that this structure is highly vulnerable for present bathymetry.

Table 3: Critical Velocity Ratio at different point of West Guide Bund for different hydrological year

Position	1 in 100		1 in 10		1 in 2.33	
	Velocity, u	u/u_c	Velocity, u in	u/u_c	Velocity, u	u/u_c
1	0.79	1.16	0.70	1.03	0.61	0.91
2	1.26	1.87	1.18	1.74	1.06	1.57
3	1.35	2.00	1.22	1.80	1.11	1.64
4	1.44	2.12	1.27	1.87	1.14	1.69
5	1.37	2.02	1.20	1.77	1.04	1.53
6	1.32	1.95	1.13	1.67	0.93	1.37
7	2.05	3.02	1.73	2.55	1.32	1.95
8	1.77	2.62	1.43	2.11	1.10	1.63
9	0.24	0.35	0.28	0.42	0.06	0.09
10	0.08	0.12	0.00	0.001	0.02	0.02

Table 4: Dimensionless Velocity at different point of Sirajganj Hardpoint for different hydrological year

Position	1 in 100		1 in 10		1 in 2.33	
	Velocity, u	u/u_c	Velocity, u in	u/u_c	Velocity, u	u/u_c
1	1.17	1.49	1.62	2.06	1.09	1.38
2	2.12	2.69	2.77	3.51	1.91	2.42
3	1.75	2.22	2.06	2.62	1.50	1.90
4	1.49	1.90	1.71	2.17	1.27	1.61
5	1.34	1.70	1.54	1.95	1.15	1.46
6	1.22	1.55	1.44	1.83	1.07	1.36
7	1.13	1.43	1.37	1.74	1.01	1.28
8	1.13	1.44	1.34	1.70	1.00	1.26
9	1.16	1.47	1.35	1.72	1.02	1.30
10	1.18	1.50	1.39	1.76	1.05	1.33

Bhuapur Hard Point (BHP)

The critical velocity is found 0.62m/s along the Bhuapur Hard Point (Table 1). This value has been compared with the model simulated maximum velocity adjacent to the Bhuapur Hard Point as shown in Table 5. It is seen that the estimated velocity along the hard point exceeds the critical value (0.62m/s). The ratio between model simulated maximum velocity and calculated critical velocity at 10 different points along the Bhuapur Hard Point exceeds 1.0, which indicates that this location is in risk for bed scour for present bathymetry.

Table 5: Dimensionless Velocity at different point of Bhuapur Hardpoint for different hydrological year

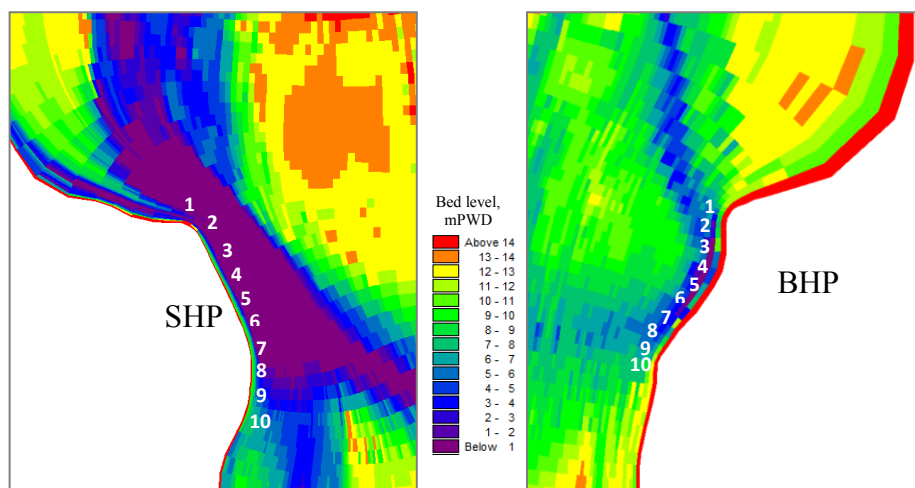| Position	1 in 100		1 in 10		1 in 2.33	
	Velocity, u	u/ u_c	Velocity, u in	u/ u_c	Velocity, u	u/ u_c
1	1.33	2.15	1.19	1.91	1.36	2.19
2	1.21	1.95	1.14	1.84	1.30	2.09
3	1.18	1.91	1.11	1.79	1.34	2.16
4	1.32	2.14	1.26	2.03	1.47	2.37
5	1.51	2.43	1.46	2.36	1.63	2.63
6	1.61	2.60	1.57	2.54	1.72	2.78
7	1.71	2.76	1.68	2.71	1.81	2.92
8	1.78	2.87	1.76	2.84	1.85	2.99
9	1.73	2.79	1.76	2.84	1.78	2.87
10	1.68	2.71	1.73	2.79	1.70	2.74

Fig 4: Different location of velocity along the Sirajganj Hard Point and Bhuapur Hard Point

Identification of Vulnerable Locations

The risk areas were categorized according to the Guidelines and Design Manual for Standardized Bank Protection Structures, published in December 2001 in connection with Bank Protection Pilot Project FAP 21. Table 6 shows the vulnerable reaches of the Jamuna River, in the vicinity of the Bangabandhu Bridge.

Table 6: Identified Vulnerable Reaches of the Jamuna

Locations	Remarks
Upstream termination of	Vulnerable
Straight part of SHP	Vulnerable
Upstream termination of	Vulnerable
Straight part of WGB	Not Vulnerable
Upstream termination of	Not Vulnerable
Straight part of EGB	Vulnerable
Upstream part of BHP	Vulnerable
Straight part of BHP	Vulnerable

CONCLUSIONS

It has been observed that all the structures near Bangabandhu Bridge area are vulnerable to bed scour for the bathymetry of 2010. The vulnerability of structures depends on the water depth near the structure. Therefore, the vulnerability will be varying for the next year bathymetry.

Due to the stochastic nature of sediment movement along an alluvial bed, it is difficult to predict at what flow condition bed would start eroding. Comparing the erosive resistance of non-cohesive soil with flow velocity allows for a quick assessment of vulnerability of a hydraulic structure. Moreover, this technique will also be helpful for monitoring and disaster preparedness. The assessment of vulnerability would be more accurate if velocity at the toe level of the structure could be calculated through 3D model or field measurement.

ACKNOWLEDGMENTS

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