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NUMERICAL MODELLING TO ADDRESS RIVER INSTABILITY PROBLEMS AT AN UNDER-CONSTRUCTION BRIDGE SIDE: A CASE STUDY

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Abstract

A hydro-morphological study using numerical modelling techniques was carried out at River Research Institute (RRI) for completion of Wazed Miah Bridge on Karatoya river at 27th km of Sadullapur (Madargonj)-Pirgonj-Nawabgonj Road. The study results show that there is lateral instability problem at the under-construction bridge location and there is a possibility of outflanking of the bridge by the river. Chute cut-off may happen in the bend immediately upstream of the bridge causing large morphological developments at the bridge location. The right bank upstream of the bridge may experience rapid erosion after chute cut-off in the upstream bend which could be a threat for the existence of the right approach embankment. The design discharge and design flood level for bridge and river training works are 2081 m^3/s, 26.97 mPWD and 2368 m^3/s, 27.21 mPWD respectively. From long-term consideration, bank revetment will be needed on both banks at the bridge location to arrest bank erosion. From consideration of river instability situations at the bridge location and long-term perspective, the minimum length of the bridge (abutment to abutment distance) should be 290m which could be adopted by increasing length of the rightmost span whereas the present bridge length is 278.8m.

Keywords: *Bathymetry, bridge, discharge, hydro-morphology, instability, numerical modelling, simulation and water level.*

Introduction

Sadullahpur-Pirgonj-Nawabgonj Road is an important zila road which connects Sadullahpur upazila of Gaibandha district and Pirgonj upazila of Rangpur district with Nawabgonj upazila of Dinajpur district. This zila road is also connected with Dhaka - Utholia - Paturia-Natakhola - Bogra - Rangpur - Bangabandhu National Highway N5. However, this important zila road link is interrupted by non-existence of a roadway bridge over the Karatoya river at 27th km (Katchdaha ghat). In order to facilitate smooth inter-district road communication, Roads and Highways Department (RHD) undertook a project for construction of a bridge over the Karatoya river. Construction of pre-stressed girder bridge was started in 1999 and up to 2011 about 80 percent construction of bridge substructure (piers and abutment) has been completed.

The bridge as designed is 278.885m in length with 7 (seven) spans. The length of six out of seven spans is 42.68m each. The length of the remaining rightmost span is 18.3m. The detailed design and drawing of the bridge have been prepared with due consideration of soil investigation report, navigation clearance and other relevant matters. The bridge site has been selected at an apparently straight reach and over a period of 8 (eight) years since the commencement of bridge construction there has been no significant change in the position of main stream at bridge location. However, since 2009, considerable left bank erosion has taken place in the vicinity of the bridge to Gobindaganj. The Karatoya river at the Wazed Miah bridge location has started to shift towards the Pirgonj end and moved considerably during the last few years. By 2011, the river has shifted beyond the planned location of left abutment. The river pattern is meandering and the river follows the valley slope. There are scars of abandoned former meander loops. It appears that chute cutoff occurs at a relatively low value of cutoff ratio. The average sinuosity of the river in the study reach (18 km upstream and 12 km downstream of the bridge) is about 1.26. The average sinuosity of the river from Badarganj to bridge site is 1.41 and that from bridge site to Gobindaganj is 1.33. It means sinuosity of the river in the study reach is less than the river as a whole from Badarganj.It is, therefore, clear that the apparent stability in the bridge reach as is envisaged during the planning process has already gotten affected by bend migration. Under this circumstance, revision of the original planning of the bridge is needed to come up with concrete decisions for successful completion of bridge construction with appropriate bank protection measures, if necessary.

The study aims to evaluate the hydraulic design parameters and to provide protective measures for

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mitigating the river bank erosion and river bed scour around the piers including the river training works for the proposed bridge.

Setup of 2D Model

The two-dimensional model covers around 26.5 km stretch of the Jamuneswari-Karatoya. The upstream limit is around 15.5 km upstream of the Wazed Miah Bridge and the downstream limit is around 11km downstream of the bridge. The model setup consists of the following steps in chronological order below:

Generation of computational curvilinear grid

In view of different objectives to be met 3 (three) computational grids having different resolutions are generated to study different aspects of the bridge project within the stipulated time. These grids are used to study flow hydrodynamics and river morphology. The curvilinear computational grid for hydrodynamic calibration of the model has a dimension of 507m×21 m. It means the length and width of the study reach are represented in the model with 507 and 21 grid points respectively. The grid for morphological calibration of the model has a dimension of 750m×60m, which is fine enough with respect to hydrodynamic grid for reproduction of morphological changes in the river with acceptable accuracy. The hydrodynamic and morphological calibration are done without bridge and proposed river training works. After hydrodynamic and morphological calibration of the model a third grid (1200m×90m) has been generated considering incorporation of bridge and proposed structures. For planning and design of necessary river training works, the model with third computational grid has been applied.

Generation of boundary conditions

Preparation of bathymetry

After completion of the bathymetric survey the data is processed, the initial bathymetry is then prepared using standard MIKE21C bathymetry preparation module. Suitable interpolation procedure is followed to generate bathymetry information at locations where bed level information is unknown. The generated bathymetry is then checked for consistency. The initial bathymetry corresponding to the grids for hydrodynamic, morphological and hydraulic structures simulation is shown in **Fig. 1**. The rated discharge time series at Badargonj have been directly applied as upstream boundaries of the model. The influence of inflow to and outflow from the river in between Badargonj and model upstream boundary on discharge time series at the model upstream boundary is thought to be not much. The water level time series at the model downstream boundary have been determined by slope analysis. Slope information is obtained from recorded water levels at Badargonj and Siraj, bed slope in the model domain and model generated water level slopes for different discharges. Attempts have been made to calibrate the model using water level data at Siraj. However, no discharge data is available for the years in which recorded water levels at Siraj appear to be acceptable. It is decided to calibrate the model for 2010 event. Since the recorded water levels at Siraj during this event are found incorrect, the water level time series at Siraj have been determined from recorded water levels at Badargonj by slope analysis.

Establishment of initial condition

The initial condition of the model is initial surface elevation. It is selected judiciously so that the model attains steady state condition quickly.

Initial assessment of model input parameters

The input parameters of the model are described as follows:

Time Step: There are a number of time steps that have to be selected properly. The time steps include hydrodynamic time step, morphological time step and advection-dispersion time step.

Time steps are estimated based on standard formula. Little adjustment in the estimated time steps if required is done based on previous experience.

Bed Resistance: Bed resistance can be specified either as a constant value or as a map. It will be decided after observing the degree of variation in initial bed configuration. Chezy resistance factor is used to specify bed resistance.

Eddy Viscosity: Eddy viscosity is estimated using the relevant formula. It can be specified as a map or constant value considering its requiring. Flooding and Drying: Flooding and drying depths are specified in such a way that it causes minimum loss of computational points but prevent occurrence of instability during simulation.

Helical Flow: Before solving the advection-dispersion equation for the concentration of the suspended sediment, the advection-dispersion equation for the helical flow must be solved. The standard formulation is used for the helical flow.

Sediment Grain Size: The sediment grain size is set from the sediment sample survey. In case of variation in sediment size along the model domain a grain size map can be specified. Otherwise, a global value may be used.

Sediment Transport Predictor: The Van Rijn model is used for both bed and suspended load. There is sediment transport and sediment concentration data. Equilibrium concentration concept is, therefore, adopted.

Model Calibration

The model has been calibrated hydrodynamically first using discharge and water level boundaries for 2010 event. The event 2010 is selected because it almost corresponds to the recorded 2.33-year or average discharge and it has happened in the recent past. The hydrodynamic calibration is made in base condition (without bridge). Siraj is the water level gauge station within the model domain and water level time series obtained at Siraj is used for calibration of the model hydro-dynamically. During hydrodynamic calibration default values of flooding and drying depth are specified. It is anticipated that it will cause minimum loss of computational points. Different values of eddy viscosity have been tested and finally a map is prepared. Bed resistance in the model has been specified by Chezy number. A map for Chezy number is specified first in order to have a depth map. Afterwards based on that depth map, local variations in the Chezy number have been specified using a map of resistance number. Model generated water levels at Siraj have been compared with obtained ones at the same location in order to confirm that the model is hydrodynamically calibrated. It can be seen from **Fig. 2** that reasonable agreement is achieved between hydrodynamically simulated and obtained water levels at Siraj for monsoon 2010 data. After hydrodynamic calibration, the model is also morphologically calibrated in base condition and for the same event (2010) as is done for hydrodynamic calibration. Model generated water levels at Siraj are compared with obtained data to ensure that the model is morphologically calibrated. **Fig. 2** shows that reasonable agreement is achieved between morphologically simulated and obtained water levels at Siraj for monsoon 2010.

Assessment of River Training Work (RTW) Options

Since only revetment type structure has been selected for stabilizing the river bank at the bridge location options have been devised on the basis of dimensions of the structures. The main objectives of the option simulations are to arrive at a fair decision regarding optimum dimensions of the structures. Although at present the left bank at the bridge location is experiencing erosion problem revetment type protection measures have been considered for both bank at the location in consideration of long-term safety of the bridge. The devised RTW options are shown in **Fig. 3.** There arise constraints in introducing RTWs in the model to their planned dimensions due to varying sizes of grid cells in the model. The introduced dimensions of the RTWs under three different options appear in **Table 1** below

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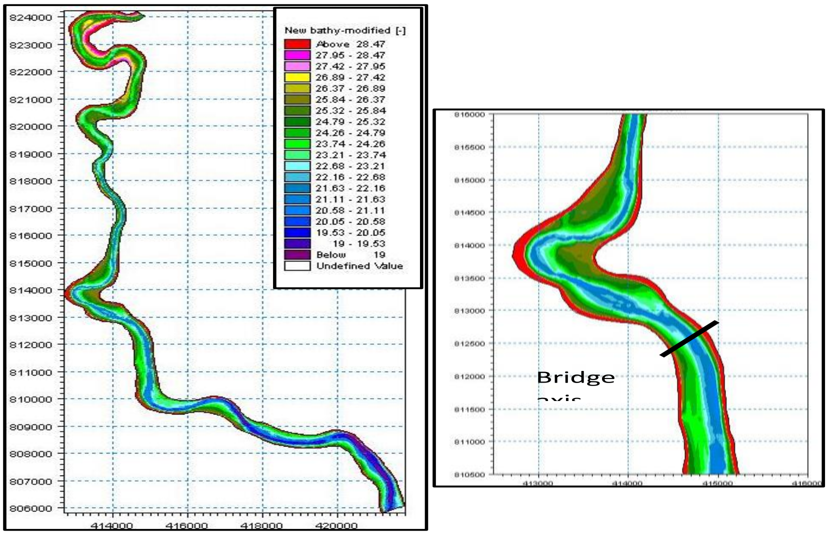

Fig. 1. Initial bathymetry of the model

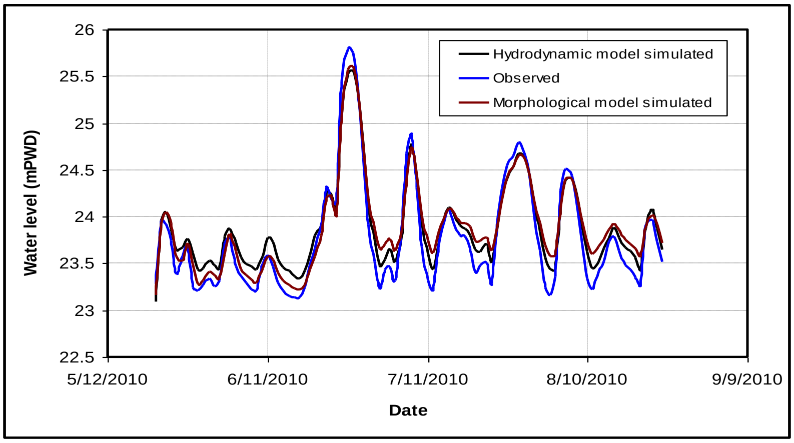

Fig. 2. Comparison between model simulated and observed water levels at Siraj for the year 2010.

Table 1. Dimensions of the RTWs (revetment) under three different options

Options / Structure	Total u/s distance	U/S straight distance	Total d/s distance	D/S straight distance
1/Left bank	80	61	30	23
1/Right bank	46	33	18	13
2/Left bank	101	75	36	29
2/Right bank	63	44	20	14
3/Left bank	160	111	43	34
3/Right bank	87	64	27	19

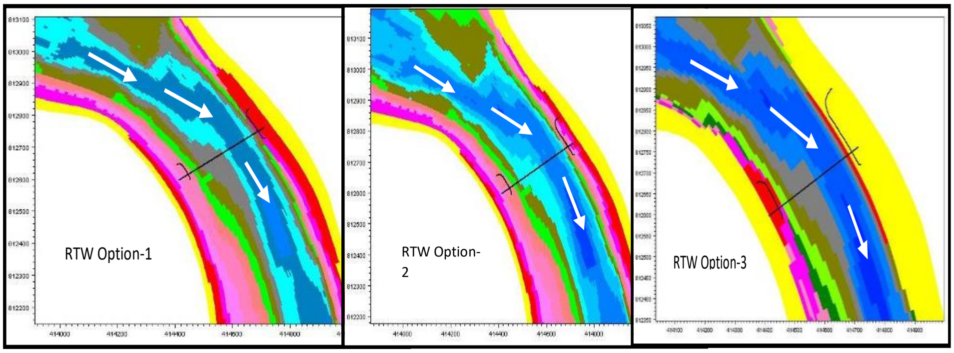

Fig. 3. Structural arrangement of river training works under Option-1, 2 & 3.

It is to be noted here that the u/s and d/s distances in **Table 1** indicate distances upstream and downstream from the bridge axis respectively. In all options the angle of sweep of curved upstream head is 90^0 and curved tail is 60^0.Option simulations with developed model have been conducted both hydrodynamically and morphologically. Since design discharge for river training works is considered as 100 year discharge the simulations have been made for 100-year discharge and 100-year event respectively. During option simulations the bridge piers have been introduced in the model to observe their effects on flow hydrodynamics and river morphology. Bank erosion model has been included in the morphological simulations to observe the effects of RTWs on bank erosion upstream and downstream of the bridge.

Results and discussion

It is observed from the model results that a chute cut-off **(Fig. 4)** may occur at the river bend immediately upstream of the under-construction bridge and it will have large bearing on the future morphological developments at the bridge location in terms of bank erosion. In short-term the present eroding left bank at the bridge location and right bank in the upstream of the bridge may experience accelerated erosion. In long-term the unabated right bank erosion in the upstream of the bridge may threaten the existence of right approach embankment.

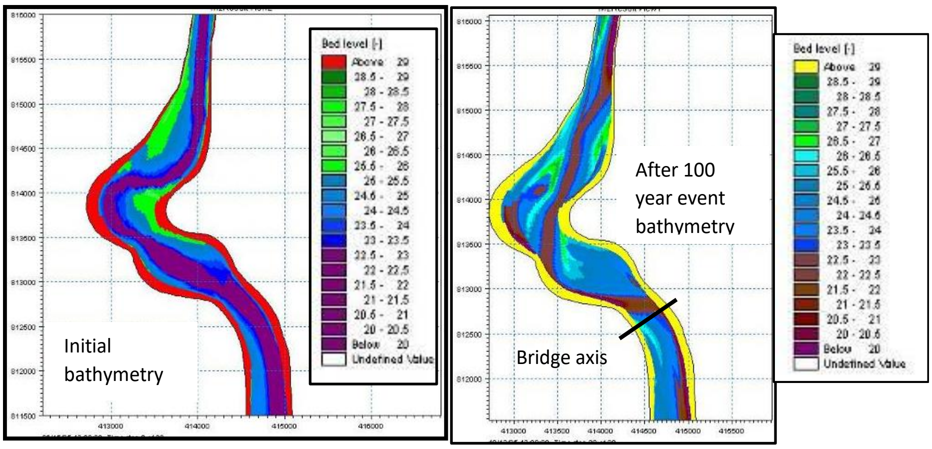

Fig. 4. Bathymetric planform development in the vicinity of the bridge under 100 years event.

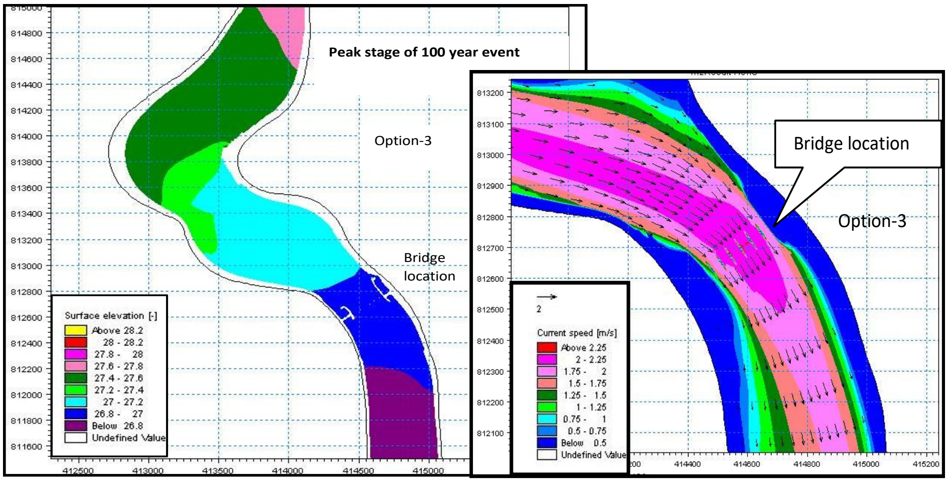

Fig. 5. Water level and velocity field at the vicinity of bridge (Opt-3) for 100 years discharge

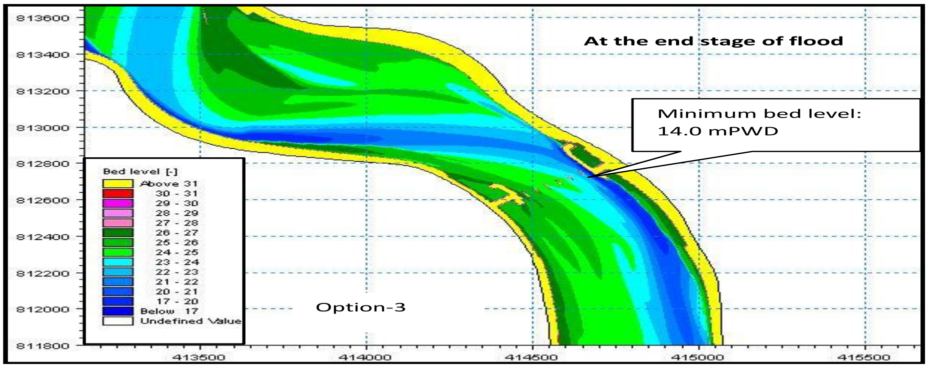

Fig. 6. Morphological conditions at the bridge location (Opt-3) after 100s year event

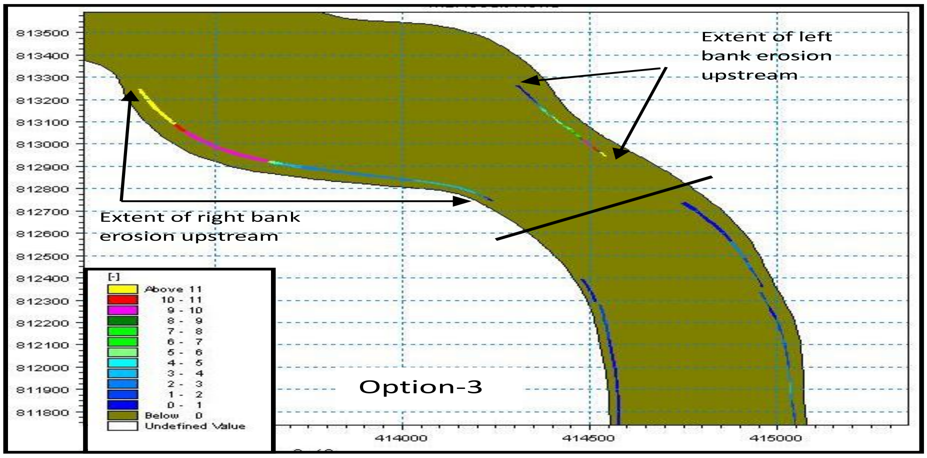

Fig. 7. Bank erosion u/s and d/s of bridge (Opt-3) for 100 years event

Given the present physical conditions of the river at the bridge location only revetment type structures will be appropriate for containing the eroding bank within the bridge limit. River responses to three different dimensions of bank revetment along both banks of the river at the bridge location have been investigated for an extreme event (100 year). The model investigation results show that there could be large scale morphological changes at the bridge location in the upcoming years. The immediacy of such developments, however, depends on the magnitude of flood events that may occur in the coming years. The river may abandon the bend in the immediate upstream of the bridge location by chute cut-off. It will result in rapid migration of the bend at the bridge location. In order to ensure safety of the under construction bridge the migrating left bank should be contained by adopting river training works.

Among the three tested options, Option-1 and Option-2 appear not to be technically feasible as the dimension of the left bank revetment is not enough to provide armour to entire length of eroding bank. Planned left bank revetment under Option-3, on the other hand, could stop caving of bank upstream and downstream of the same beyond certain limit and thus, would reduce the risk of failure of the structure against an extreme event. It is also revealed from the study that there is no risk of right bank erosion at the bridge location in short-term. However, after a chute cut-off in the upstream bend rapid right bank erosion may take place in the upstream of the bridge. The developments there should, therefore, be closely monitored. In order to ensure long-term safety of the bridge against such likely developments bank revetment is also needed along the right bank at the bridge location. Model simulation results indicate that the dimension, orientation and placement of revetment as in Option-3 may be appropriate to contain the river under the bridge.

The flow field at the bridge location under Optoion-3 for 100-year discharge is shown in **Fig. 5** shows the water level in the vicinity of the bridge at peak discharge of 100-year event. The likely morphological developments at the bridge location under Option-3 for 100-year event have been shown in **Fig. 6.** The extents of bank erosion upstream and downstream of the left and right bank revetment under Option-3 are shown in **Fig. 7.**

Conclusion

- Analysis of satellite images and recent cross-section data and model results show that there is lateral stability problem at the under construction Wazed Miah bridge location.
- Left bank erosion at the bridge location could vary from 0m to 16m in a year.
- Model simulated minimum bed level along the left bank revetment is 14.0 mPWD and it occurs near the downstream termination of the same.
- Chute cut-off may occur in the bend immediately upstream of the bridge. After chute cut-off the right bank may experience rapid erosion.
- The river appears to be vertically stable at the bridge location. The foundation levels of the bridge substructure are sufficiently below the expected maximum scour level.
- The bridge is, therefore, safe against bridge scour.
- The vertical and horizontal clearance of the bridge appear to be appropriate. The width of waterway for the bridge could vary from 207m to 290m depending on various factors.
- The planned length of the bridge including the width of the piers (278.885m) is, therefore, somewhat below the upper limit of the width of waterway for the bridge.
- The design discharge for bridge and river training works are 2081 m^3/s and 2368 m^3/s respectively.
- The design flood level for bridge and river training works are 26.97 mPWD and 27.21 mPWD respectively.
- Bank revetment is the appropriate type of protection measure for the eroding bank.
- Both the left and right bank revetment should be provided with suitable upstream and downstream terminations as per standard practices and the dimension, placement and orientation of the suggested measures may be refined by model application.

Recommendation

The river training measures suggested under this study should be adopted as per design. Stabilization of the eroding left bank should be done on priority basis. In consideration of river instability situations at the bridge location and from long-term perspective the minimum length of the bridge (abutment to abutment distance) should be 290m. The present length of the bridge is 278.8m. The minimum length of the bridge could be adopted by increasing length of the rightmost span. The developments in the river channel upstream of the bridge particularly at the bend locations should be monitored very closely. In case of any delay in implementation of the suggested river training measures, temporary measures should be considered to prevent the bridge from being outflanked by bank erosion

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