Modelling Response to Flow and Sediment Regimes Changes due to Construction of a Bridge Upstream of an Existing Bridge

J Md. Abdul Hye[a] and S Jahan[a]

[a]*Surface Water Modelling Centre (SWMC), House No. 476, Road No. 32, New DOHS, Mohakhali, Dhaka 1206, Bangladesh (jah@swmc.bangla.net)*

Abstract Any kind of human intervention affects the natural systems in rivers, most contribute negatively and very few positively. This paper investigates the response to flow and sediment regimes changes in Meghna River in Bangladesh due to construction of a road bridge upstream of an existing railway bridge. The Meghna River flows in the northern part of Bangladesh, the river can be generally characterized as a meandering river, it has flood discharges up to 20,000 cumec in the monsoon. In connection with the construction of the proposed road bridge a numerical model study has been carried out with the application of the morphological modelling system MIKE21C developed by the DHI-Water & Environment. The bridge will be 110 meters upstream of an existing Railway Bridge over the Meghna River with an alignment parallel to the railway bridge. Incorporating the bridge into the model, various scenarios were run focussing extreme flood events. The increment of velocity due to constriction of the bridge piers has appeared in the modelling results, which ultimately causes scour in the river section at the bridge site in all model simulations. Most interesting and very effective simulation was to consider the movement of an island, just upstream of the bridge and the incorporation of various movements were successfully done.

Keywords: Mathematical Modelling; Morphologic; Prediction; Hydraulic; MIKE21C

1.0 INTRODUCTION

For the infrastructural development of the country, Government of Bangladesh has decided to construct several bridges over the major rivers. As a part of such schemes, Bhairab Road Bridge is proposed to be constructed over the Meghna River. This Road Bridge is to be built 110 meters upstream of the existing Railway Bridge with an alignment parallel to the Railway Bridge. he extension of the existing Railway Bridge is 900 m whereas the proposed Road Bridge extension is 980. The river training works will be provided at both banks to prevent the bank erosion and possible failure of the bridge abutments.

The Meghna River, on which the bridge is to be constructed, flows into the northeastern part of Bangladesh ranking third in size among the major rivers in Bangladesh. The river is characterized with the variation of flood from a discharge of almost zero to some 20,000 cumec. This river drains an area of 77,000 km^2 of which about 46500 km^2 is located in Bangladesh. At the upstream of this river, it carries the combined flow from two rivers (Surma and Kushiyara) and at the downstream; it joins to another major river, Padma. Figure 1 shows the Meghna river network within Bangladesh.

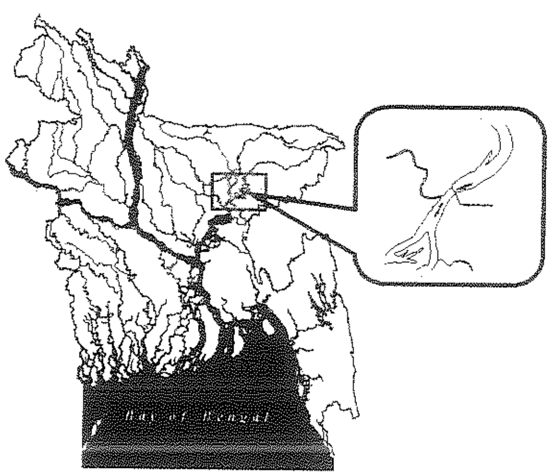


Figure 1. River network in Bangladesh and the 2d model area.

The flow variation is dependent of the rainfall (extreme annual totals of about 5000 mm) that is experienced in the mid June to September. Apart from the rainfall, another contributions are from the spill of Jamuna at the left bank of the Meghna River. In the low flow period, the tidal influence is dominant but reduces during the monsoon.

Any development works, like bridges over any river can be considered as the intervention of the flow. This intervention affects both flow pattern and flow intensity, which in turn change the river morphology and local channel geometry. Apart from this obstruction, the Meghna River near the project is already associated with the following characteristics;

- A large area of deposited riverbed material, known as a "Char", is located a short distance upstream of the new bridge on the left side of the river, see Figure 1. Historical data shows that the char has moved downstream in the past with an average speed of approximately 30 m/year. The submerged part of this feature already extends downstream of the proposed location of the bridge. The migration of the char and the introduction of the proposed road bridge are likely to affect the flow and morphology.
- Bank erosion is prominent at some of locations upstream and downstream on the Meghna River (especially at the downstream, lower Meghna)
- Implementation of proposed Bridge works in the Meghna along with existing Railway Bridge

For hydraulic design of the bridge, it is necessary to investigate the worst situation of the river that can happen during the lifetime of the bridge affecting the stability of the bridge and its associated structures. Moreover, the river having intervened by the bridge can also create impact, which can have unacceptable consequences.

This paper encompasses to investigate the hydro-morphological changes in the Upper Meghna, one of the major rivers in Bangladesh, being intervened by the Bhairab Road Bridge. This investigation (mathematical modelling) is carried with an advanced modelling tool, MIKE21C [DHI, 1999], developed by DHI-Water & Environment for the Meghna River reach of 20 km at the bridge area.

2. PURPOSE OF THE STUDY

The objectives of this study were to assist in reviewing the design of the Bridge and its associated works. Specifically,

- To assess the impact of the introduction of the proposed works on the flow pattern and on the bed topography
- To assess the impact of the migration of the char on general scour at the bridge site

3. STUDY AREA

The study area covers a reach of approximately 20 km extending from 10 km upstream of the Railway Bridge to 10 km downstream. Figure 1 shows the location of the study area with respect to Bangladesh.

4. APPROACH AND METHODOLOGY

To fulfil the above-mentioned criteria, model has been developed comprising the bathymetry of 1998 data for the reach of 20 km. In this reach, both bridges (the guide bunds and two railway bridge piers) have been incorporated. Having completed the model set up, two hydrological events have been applied at the upstream and downstream boundaries of the model to see the impact on the stability of the bridges and on the river morphology. The adopted modelling approach is the application of the MIKE 21C modelling system. MIKE21C has been extensively used in Bangladesh for river applications particularly where an accurate description of flow along the banks as well as helical three-dimensional flow is important.

MIKE21C operates on curvilinear computational grid. It incorporates fully unsteady flow, bed load as well as suspended load via a non-equilibrium transport formulation taking into account both phase and time lag effects in the adaptation of suspended load. It includes the dynamic bed level changes through simple sediment continuity, updates the alluvial resistance through a simple model of the power function of Chezy's C on depth and updates the planform through bank erosion model and vertical erosion model of the islands. It includes an analytical model for computing the secondary currents and thus provides the 3-D effects for a 2-D model.

5. MODEL SETUP

Two types of models were used for the present study. These are as follows:

Existing Conditions (Without project): This bathymetry incorporates neither the proposed road bridge nor any river training works.

Future Conditions (With project): The bathymetry to represent the proposed road bridge project conditions was prepared by superimposing the bridge works on the "without project" bathymetry.

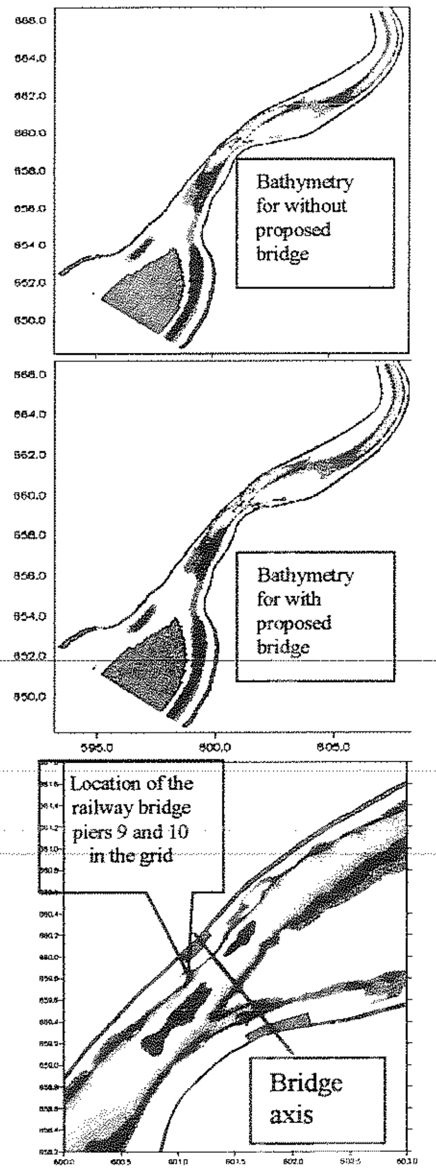


Figure 2. Bathymetry for different project condition and the zoomed view near the bridge area.

6. COMPUTATIONAL GRID

To include the bathymetry in the model and to compute different variables in terms of velocity, water depth, bed level, erosion, deposition etc. a computational grid is required. The boundaries of the grid are the two river banklines and two suitable open upstream and downstream lines enclosing the study area. The model computes the variables at each grid point.

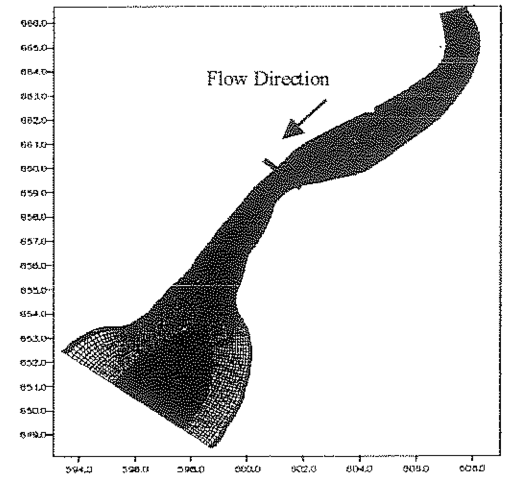


Figure 3. Computational grid for the modelling domain.

The computational grid generated from the bank lines of the observed bathymetry and satellite imagery had a resolution of 200m in the longitudinal direction (j = 0 to 200) and 52m in the transverse direction (k = 0 to 52) The grid was sufficiently orthogonal and fine enough to resolve detail of the engineering works in both the horizontal and transverse directions. Figure 3 shows the full extent of the grid used for computation in MIKE21C for the present case study.

1 in 2 year and 1 in 100 year flood events have been used for the scenario simulation and for calibration of the model, observed 1998 and monsoon data were used. In addition to the observed data, the results produced by the physical model were also used for calibration.

7. MODEL CALIBRATION

After setting up the model and compiling the data required for the MIKE21C model, it is necessary to verify the performance of the model. This verification is confirmed if the model can reproduce any real data. This process is known as calibration and reproduction of the real data is validation. Calibration is done to compare for hydrodynamic as well as for morphological results with the measured one.

7.1 Hydrodynamic Calibration

Hydrodynamic calibration is done to reproduce the water level and velocity at specified locations on the model area, which shows good agreement between the two.

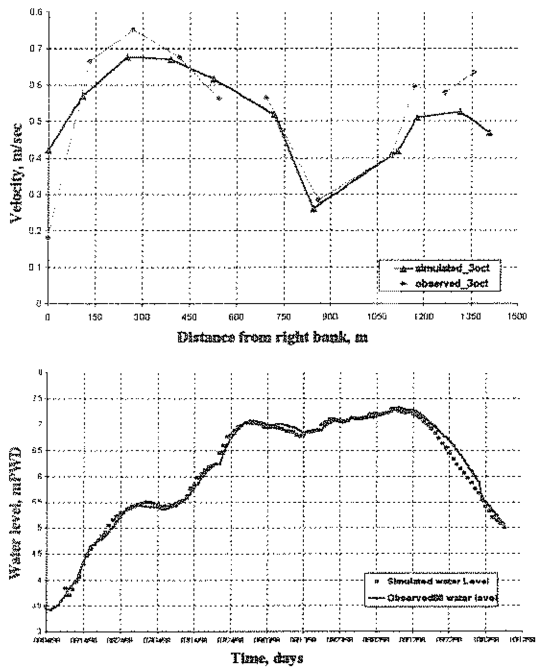


Figure 4. Comparison of the simulated and measured water level (lower) and the velocity (upper) near the bridge axis.

The parameters which contribute in adjusting the hydrodynamic misbalance or fine tuning the numerical models in the hydrodynamic field in MIKE21C are mainly roughness (Chezy's C), co-efficient of eddy viscosity (E) where Chezy's C influence in adjusting the water level and co-efficient of eddy viscosity used for the distribution of flow by exchanging lateral momentum of flow.

7.2 Sediment Transport Calibration of the Morphological Model

The calibration of the morphological model is basically meant in MIKE21 to deal with the sediment transport and it's associated parameters, such as the grain size diameter, the selection of the sediment transport formula, the helical flow strength, the bank erosion formula etc. Full verification of a morphological model requires detailed bathymetric data before and after a monsoon. For this present case the simulated bathymetry corresponding to post 1999 monsoon has been compared to the measured bathymetry of pre 2000 monsoon.

8. MODEL APPLICATIONS

Considering the worst case that can happen and to represent the future condition hydraulically as well as morphologically due to River Training Work (RTW) and different char movement, various simulations were carried out on the calibrated model. The period of each simulation run was 120 days, which covers the whole monsoon for Bangladesh, starting from 1st of June.

9. MODEL RESULTS

All the model results were derived in terms of changes of speed, on bed topography etc.

9.1 Constriction Effect on Flow

Due to the constriction effect the speed increases for both 1 in 2 and 1 in 100 year flood events and MIKE21C depicts this incremental effect in Figure 5.

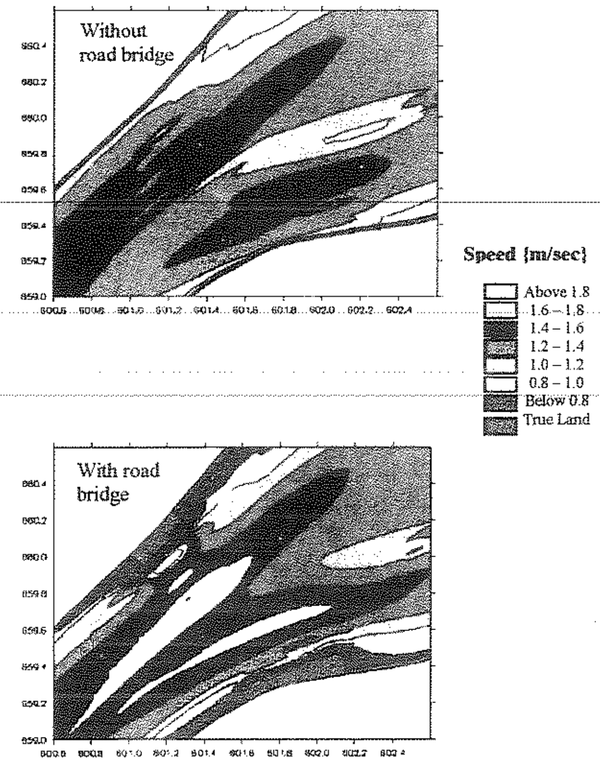


Figure 5. Speed contour at peak for with & without project for 100-year flood event (zoomed view).

Due to the direct effect of the increased speed, the scour has been prominent in the right main channel for both events, shown in Figure 6. It has been observed that the bank protection works for the proposed road bridge has eliminated the bank erosion along the river training works.

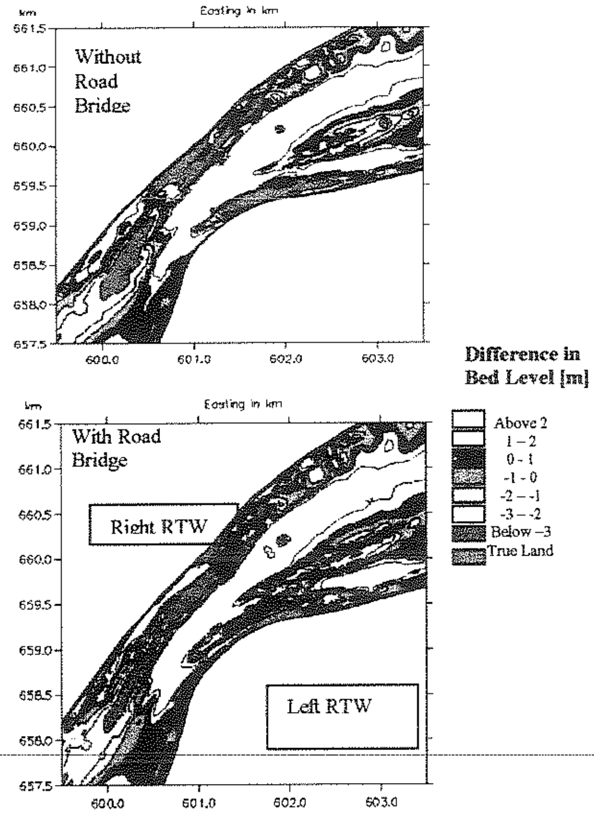


Figure 6. Impact on bed erosion, induced bed level change for 1 in 100 year flood event (difference in bed level, from simulated end bed level to initial bed level for with & without condition).

9.3 Channel Alignment along the Left Bank

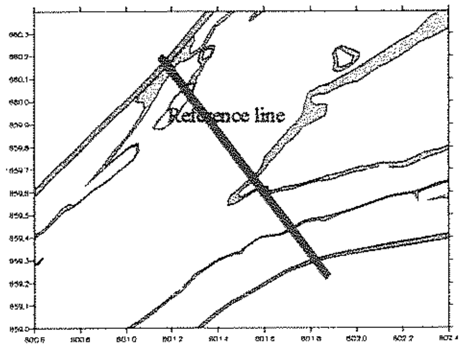
The channel along the left bank at the bridge site has been maintained during the 'with project' runs. The channel silts up during the 'without project' runs.

9.4 Effect on Backwatering

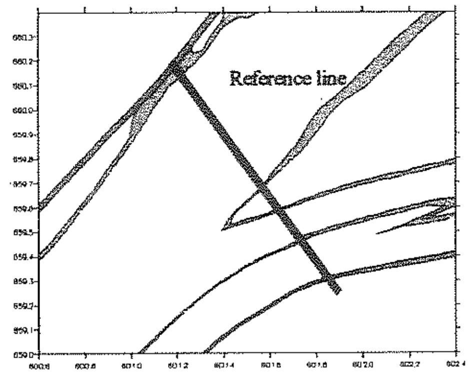
Due to the presence of the bridge, backwatering of the water surface has been well appeared in the modelling for both events.

9.5 Migration of the Char

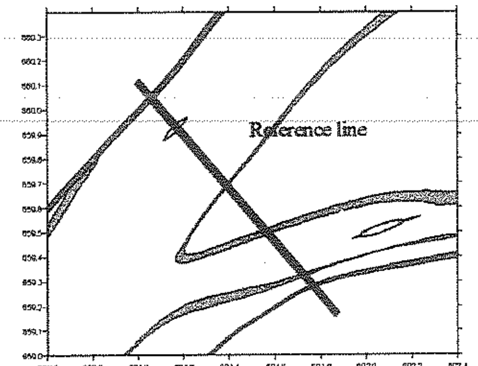
All the events for with bridge and without bridge scenarios show the migration of the char towards downstream direction, which is enhanced by the presence of the bridge. This phenomenon has been well portrayed in the MIKE21C simulation. Figure 7 & Figure 8 presented below verifies this trend.



Initial position of the char for without Project

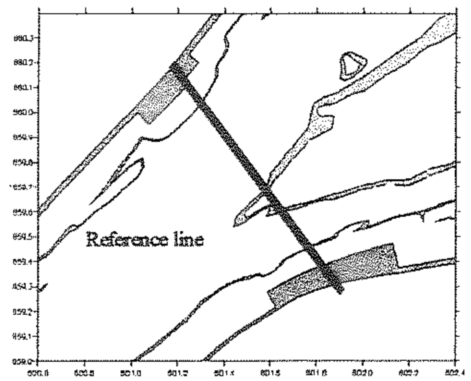


Simulated end char (for 1:2)

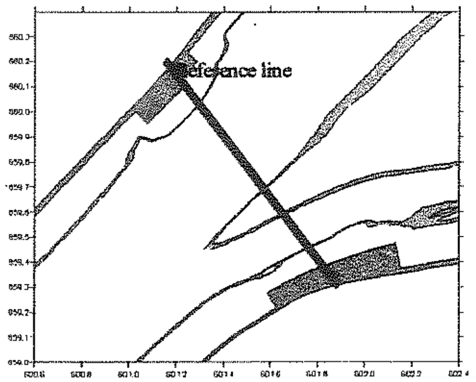


Simulated end char (for 1:100)

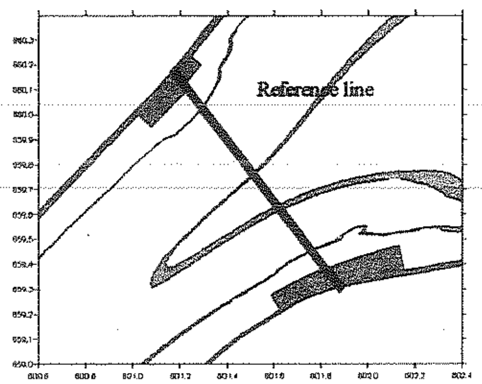
Figure 7. Movement of char for without bridge condition for different flood events.



Initial position of the char for with Project



Simulated end char (for 1:2)



Simulated end char (for 1:100)

Figure 8. Movement of char for with bridge condition for different flood.

9.6 Sedimentation of the River Section at the Bridge

The sediment transport across the bridge line shows the higher tendency for "with" project condition for both events, see Figure 9. This can also be explained as the direct effect of the increased speed.

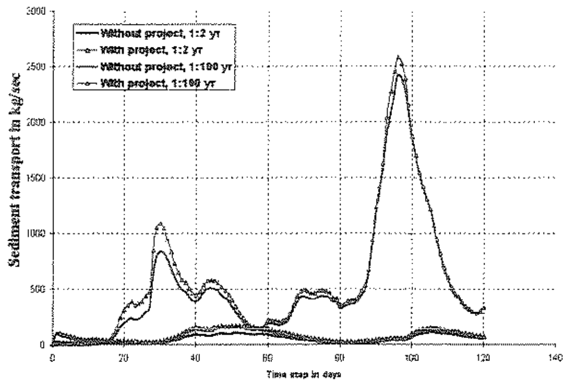


Figure 9. Sediment Transport rate for different flood event for different condition at the immediate downstream of the bridge axis.

10. CONCLUSION

The modelling with the modelling tool, MIKE21C reveals the fact that the largest fraction of the discharge passes through the right main channel at the bridge site. The velocity is in general higher at the bridge section for the existing situation. This phenomenon has been enhanced due to the presence of another road bridge. On account of the movement of the char located at the upstream of the bridge, the increment of the velocity is also influenced. In the existing conditions, there is scour at the bridge section in the main channel as well as along both banks. This scour has also developed for all kind of scenarios simulations.

This present study was intended to investigate the hydro-morphological phenomena using 2-Dimensional Modelling tool MIKE21C for the area at the vicinity of the two bridges. Modelling tool like MIKE21C can assist the planners and designers in adopting sound and realistic design parameters for the development of infrastructures.

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