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Effect of bridge pier on waterways constriction: a case study using 2-D mathematical modeling

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ABSTRACT: The purpose of bridge construction is to ensure and facilitate the communication over the flow of waterways conveniently. However, these structures have detrimental effects on the hydrology and morphology of the adjacent area of the streams as the waterways is constricted. In this paper the effect of constriction of waterways due to bridge construction is the major consideration. A significant amount of waterways is occupied by bridge construction by bridge pier in case of smaller rivers compared to larger rivers. There are different ways to find out the minimum waterway or opening of bridge depending on the shapes. Considering the aesthetical point of view pier may occupy more waterways and it's the engineers challenge to suggest suitable and substantial remedial measures for making the construction possible with nominal adverse effect on river morphology. In this paper Surma River in Kazirbazar, Sylhet is taken as the study area. Bridge pier construction has already been completed before the present study and some severe morphological response has been observed. At the bridge location both for the upstream and downstream it is affected by severe bank erosion, which was not, terminated with usual protective measures. Therefore, it is a major concern for the authority to acclimatize effective and sustainable measures to reduce or stop the current erosion incident. This study is carried out to ease the bridge construction without facing adverse morphological changes in the river.To solve this problem historical data on water level and discharge was analyzed and a two dimensional model was developed. The model was simulated with existing bridge piers. The model was calibrated with real field condition and apposite solution was outlined. In this study the simulated result was analyzed and a technique is proposed to avoid this sort of unexpected incident. The result may vary with the river but approach would be the same to resolve this type of difficulties in all rivers and water way.

1 INTRODUCTION

1.1 *Background*

During this study the bridge was not completely constructed and before coming into operation, right bank of the Surma at immediate downstream of the bridge started to erode. During 2008 monsoon, 150 m reach eroded engulfing important establishment (part of fish market, rice mills and other) and immediate upstream area started to face sedimentation which might pose threat to smooth navigability. Apparently, water area of river at bridge site was constricted severely (about 33 % due to consumption of four bridge piers) due to use of pier of great width compared to usual bridge pier. Under these circumstances, a study, considering hydraulic and morphological consequences, due to this under-construction bridge was carried out. The study was carried out with the application of mathematical model of the Surma. The model was simulated under different hydrological conditions and also with extensive analysis of the past data and information.

1.2 *Problem Statement*

Siltation of the Surma

The Surma is a meandering and dynamic river. It has travelled 215 km inside Bangladesh from the Indian boundary up to Sunamgang district. The bridge at Kazir bazaar is located at 111^{th} km of Surma river. In the vicinity of the study area Surma river flows in a single, irregularly meandering sand-bed channel that frequently deflects off bedrock and other inerodible deposits. Past studies and analysis of the cross sectional data indicate siltation in the Surma after taking off from the Barak. Due to this continued siltation, the conveyance capacity of this river is also reducing.

FAP 6 reveals that the width of this river is in the order of 170 m where mean depth is 8.6 m at bankful discharge. In 1992, the width of this river at Sylhet reached 40 m during dry period and the depth was only 2 m, though at downstream of Chattak, width became higher (250 m) and depth (10.2 m).

Obstruction generated by closely spaced three bridges

Within the study area of the Surma, there exists two more bridges (known as Kaen bridge and Notun or New ShahJalal bridge) which are closely apart (850 m) to the under construction road bridge. Generally the bridge obstructs the flow of the river and having obstructed, the flow tends to adapt its energy causing bed erosion at immediate downstream of the bridge. On the contrary, flow at upstream experiences backwater which accelerates siltation. In this present case, before adapting within the reach from Notun bridge to Kaen bridge, the flow again starts to face another obstruction by the under construction road bridge. Obstruction by three bridges within a very short reach would obviously disturb the hydraulic and morphological scenario.

Abrupt hydrological change of the Surma

This river is characterized with the flash flood. Sudden increase of flow causes to spill over the bank. On the contrary, this region faces also abrupt reduction of flow. Drastic changes of flow within short period if obstructed by the bridge may generate more adverse situation near the bridge. Though both the banks near the under construction bridge is well protected by the embankment except right bank at immediate downstream of the bridge, but combination of constriction with abrupt increase of flow may cause damage to this embankment.

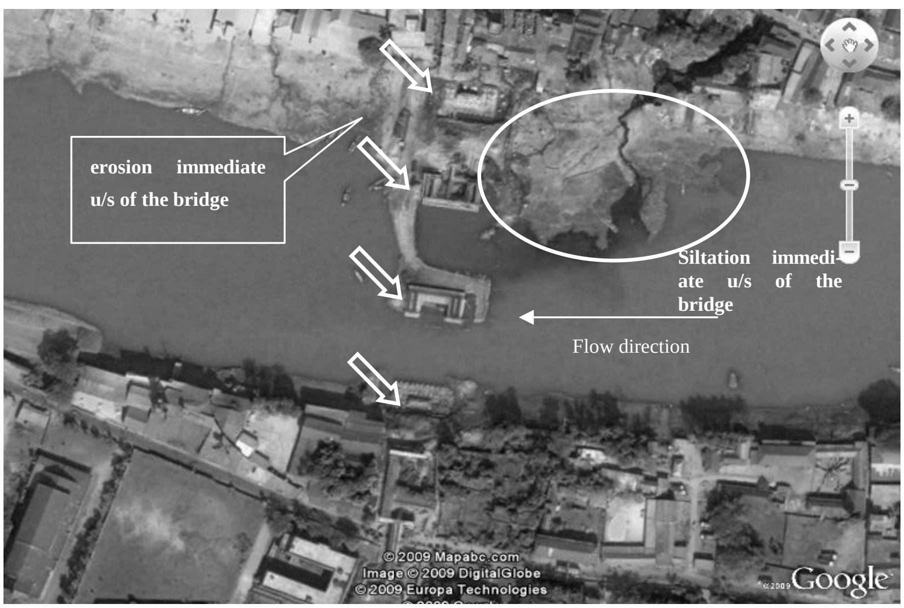

Figure 1.1 Arial photo graph of bridge location

1.3 *Approach and Methodology*

Key approach and methodology adopted to achieve the desired output is mainly mathematical modelling of the Surma River of the selected reach. In order to analyze the baseline and predicted hydrodynamic and morphological conditions at and around the bridge, a 2D morphological model has been developed using MIKE21C (Developed by DHI) modelling system. The developed two-dimensional morphological model of the Surma River is simulated for different scenarios to understand the short term changes of the river. This model extends from 12.5 km upstream of the Bridge to 12.5 km downstream covering total 25 km in length.

Prior to development of the mathematical modelling, data analysis have been done extensively to form the basis of hydraulic process related to the hydraulic and morphological condition in the vicinity of the Bridge. The analysis of the past hydro-morphological data (changes in the channel geometry, char movement, impinging flow, surface elevation etc) have not only formed the basis of understanding but also enhanced the confidence to interpret the model generated outputs.

Since the Brooklyn Bridge was built in New York City in the late 1800's virtually all main cables of major suspension bridges have been constructed of high strength galvanized steel wire. Until the mid-twentieth century, all large suspension bridge cables were air spun by pulling one or more pairs of wires at a time from one anchorage to the other and adjusting each wire to theoretically share the load equally with the others. In 1969, the Newport Bridge in Rhode Island was constructed using shop-fabricated parallel wire strands (PPWS), the method that has now gained favor for many new bridges.

Since John A. Roebling pioneered the art of suspension bridge design, the main cables of suspension bridges have typically been protected by a tight covering of soft wire wrapping bedded in a sealing paste, usually red-lead (Pb_3O_4) in linseed oil, and coated with paint. Some exceptions are notable, such as the Newport and Bidwell Bar (Oroville, California, U.S.A., 1965) Bridges where glass-reinforced acrylic was used, and the William Preston Lane Bridge (Maryland, U.S.A., 1973) where neoprene sheet was used.

Recognizing the advantage of using an impervious covering on the cables, a number of U.S. suspension bridges have been retrofitted with elastomeric coverings placed over the existing wrapping wire. There are now a number of bridges in Europe and Japan that use a dry-air injection system in conjunction with an elastomeric wrapping to ensure that no moisture can enter the cables. Some suspension bridges have also been constructed using twisted strands. The inspection is significantly different for this type of bridges and is therefore not covered in this paper.

2 MODEL DEVELOPMENT AND ASSESSMENT OF IMPACT OF BRIDGE

2.1 *Model Generation*

In order to determine the impact of the under construction bridge the model covers 25 km river reach representing the bed level of pre monsoon (March-April) 2009. River responses due to existing under construction kazirbazar bridge has been observed from the models being subject to different flood conditions and analysed in relation with the hydraulic and morphological characteristics of the Surma. Impact of the bridge in bank erosion, in flow thrust, bed erosion/deposition, back water etc has been determined comparing with the past and existing field condition. Attempt has been made to compare the river hydraulic and morphological characteristics between "with" and "without bridge" condition. In order to do so, "without bridge" condition has been generated in the model considering non existentence of kazir bazaar bridge. Model development actually covers the following steps sequentially

- Generation of computational grid or cell where each of the cell would contain the input and outputs;
- Preparation of model initial bathymetry (recently surveyed cross section @ 50m interval) which represents the river bed
- Determination of initial and boundary conditions and
- Calibration of the model for evaluating the performance of the model.

2.2 *Considering Event and Boundary condition*

In order to determine the consequence of the bridge, mathematical model of the Surma within the bridge has been applied for average and extreme flood events. Selection of these flood events is based on frequently occurrence of average flood and worst scenario. Having collected all the historical data of flow and water level, frequency analysis has been done to determine the design event to be used as the boundary condition of the numerical model.

In order to carry out the statistical analysis of the probable discharge of the Surma, discharge data measured at Sylhet gauge station from 1962 to 2007 has been used.

Two dimensional models have two boundaries. As per rule, upstream boundary is defined as a single discharge boundary or a discharge time series and downstream boundary is defined as corresponding single water level or water level time series. Available discharge data of Sylhet station is used as upstream boundary of the 2D model. For water level boundary is determined from the slope analysis using as a reference of Sylhet water level station. It is worth mentioning there that downstream boundary of the model is located at 12.5km from Sylhet water level station. In this case no inflow and outflow have been included since within the study area, there is no such inflow and outflow. The model was simulated for extreme event of 100 years return period (2004) and average flow (2.33 years return period which means 1985)

Table 2.1. Probable Discharges of Surma River at Sylhet station for different return periods

Return Period (Year)	Estimated Discharge(m^3/s) Log Normal Distribution	Corresponding Hydrological Year	Observed Peak Discharge(m^3/s)
2	1924	1985	1940
5	2152	1991	2150
10	2273	1988	2300
25	2404	1966	2340
50	2489	1976	2480
100	2600	2004	2500

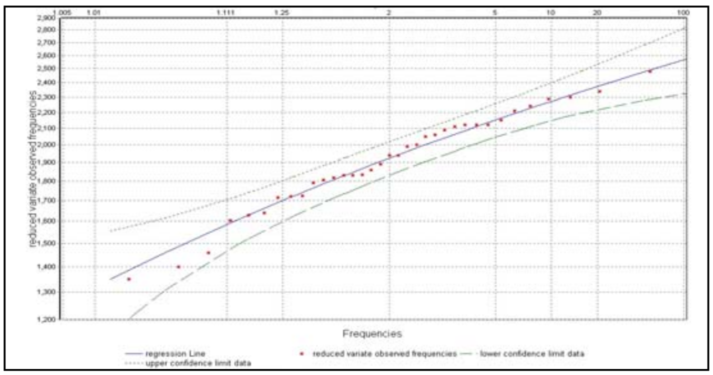

Figure 2.1 Probability graph for discharge of the Surma River at Sylhet station

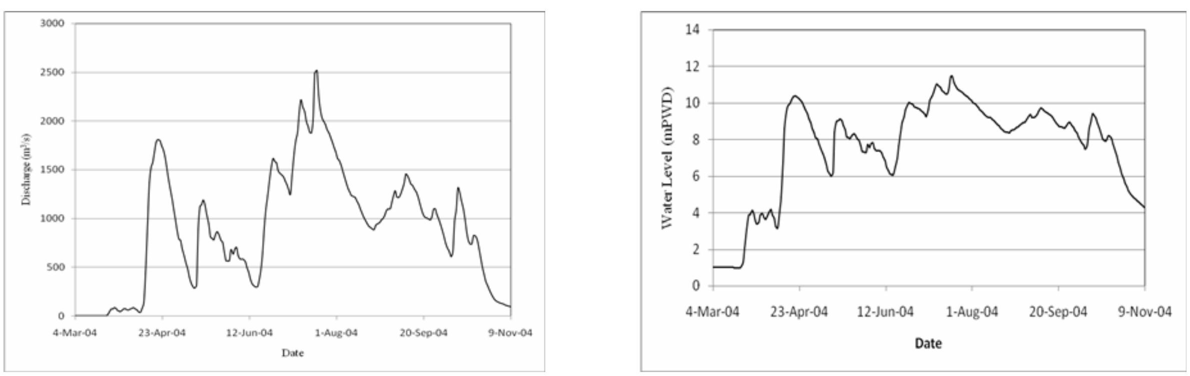

Figure 2.2. Boundary Condition for extreme flood event (100 yr return period)

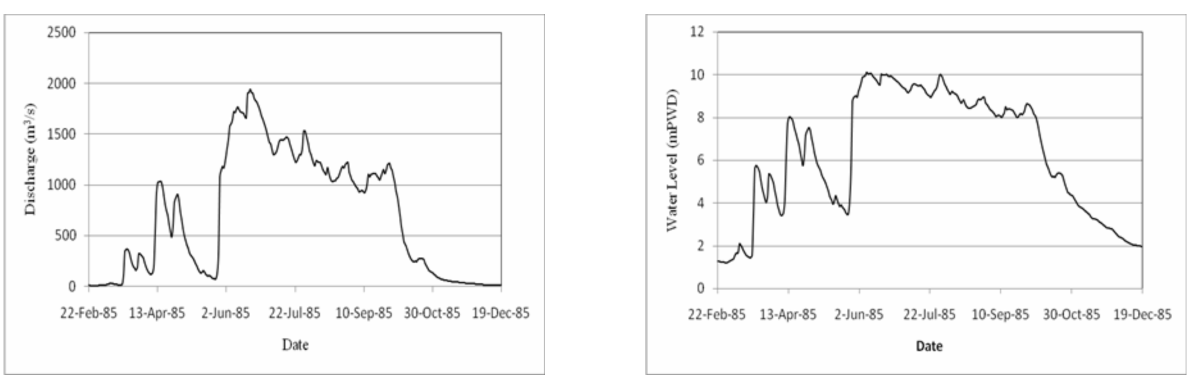

Figure 2.3. Boundary Condition for average flood event (2.33 yr return period)

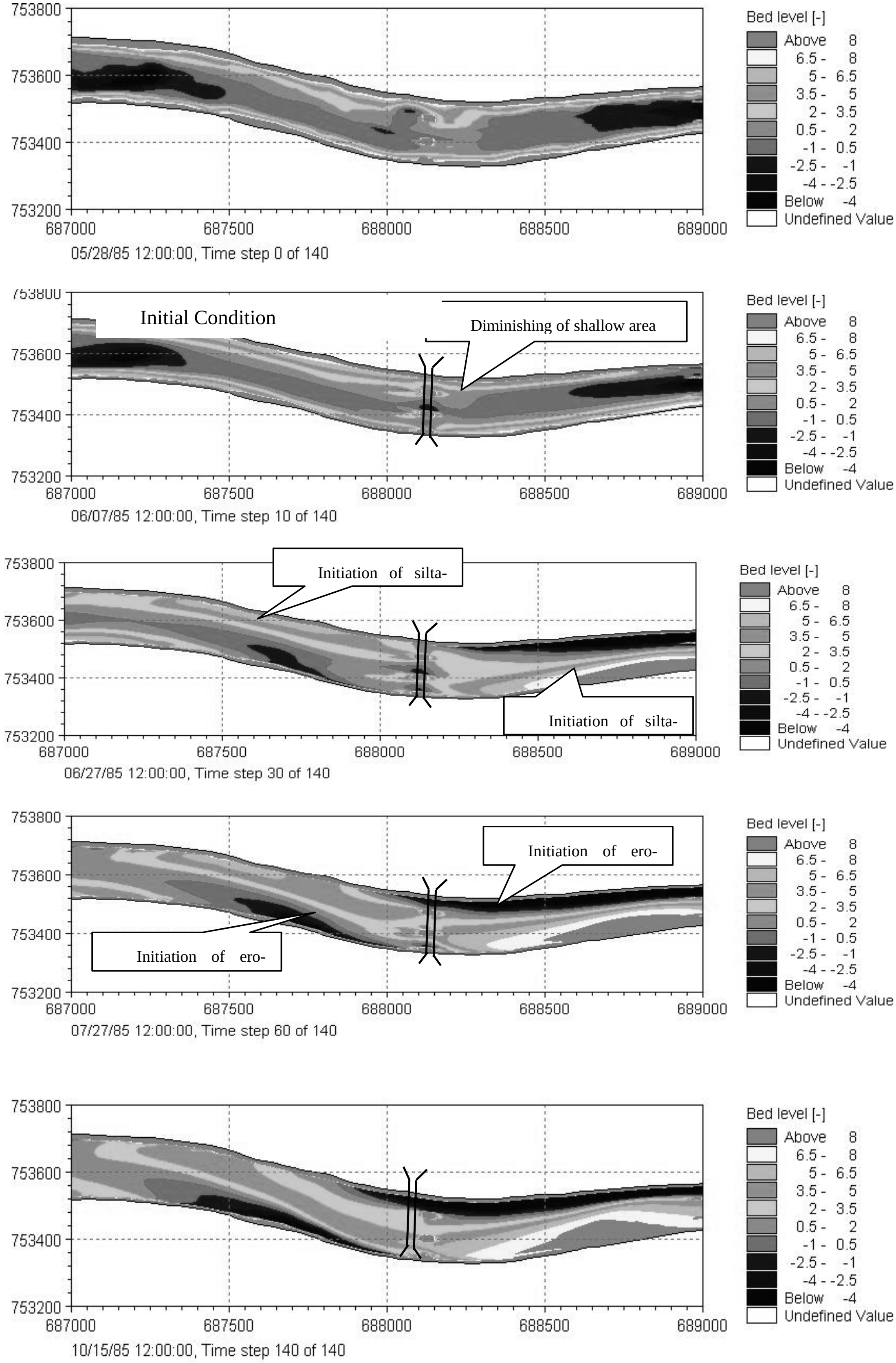

Figure 3.1. Bed level contour for average flood event (2.33 yr return period) at different stage of monsoon

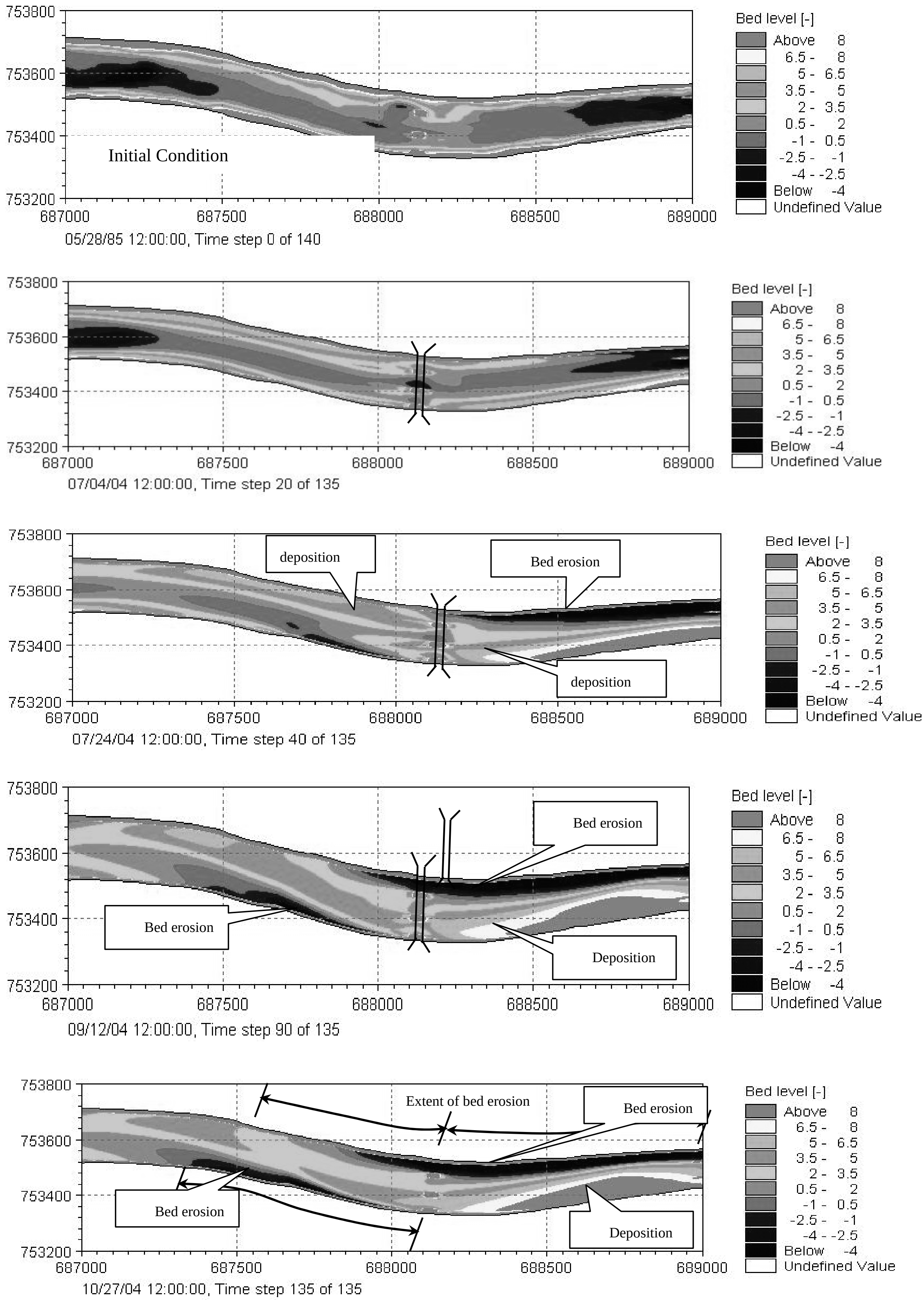

Figure 3.2. Bed level contour for extreme (100 yr return period) flood event at different stage of monsoon

3 ASSESSMENT OF IMPACT OF BRIDGE

In this study it was intended to investigate the siltation or bed scouring condition particularly at the bridge area. Model results including the bridge show huge deposition at upstream of the bridge along the left bank. Prior to simulation i.e. at the initial stage of the monsoon, thalweg was along the left bank at upstream but having undergone with the extreme or even average flood condition, thalweg shifted from left to right diminishing the shallow area near the right bank at immediate upstream of the bridge.On the contrary, huge bed scour is observed along both the banks of the Surma at and around under construction bridge. Bed degradation along the right bank extends from bridge area to about 500 m downstream whereas at upstream, it extends more than 1 km. Figure 3.1 and 3.2 show the bed level contours for average and extreme flood conditions. Both events present the same siltation phenomena at same locations with different severity.

Along with the spatial contour of the bed level at different stages of the monsoon, vertical extent of bed degradation with the help of the cross sectional profiles at the peak and at the end of the monsoon are also shown for different sections around the bridge, Figure 3.3 to 3.5. These plots show the variation of the bed scouring for extreme events with respect to the surveyed bed condition at April 2009. It is seen that at downstream of the bridge, bed scouring ranges from 1 to 5 meter associated with the thalweg movement from middle to left bank. Such changes i.e. bed scouring along the left bank extends approximately 1 km downstream from the bridge. At immediate upstream along the right bank, scouring is more severe than that at downstream. Bed level undergoes from 10 to 15 m from surveyed bed. Exactly at bridge location, bed scouring is not so substantial and remains within 8 m. Spatial extent of bed scouring along the right bank is from 1 km upstream to 500 m downstream of the bridge.

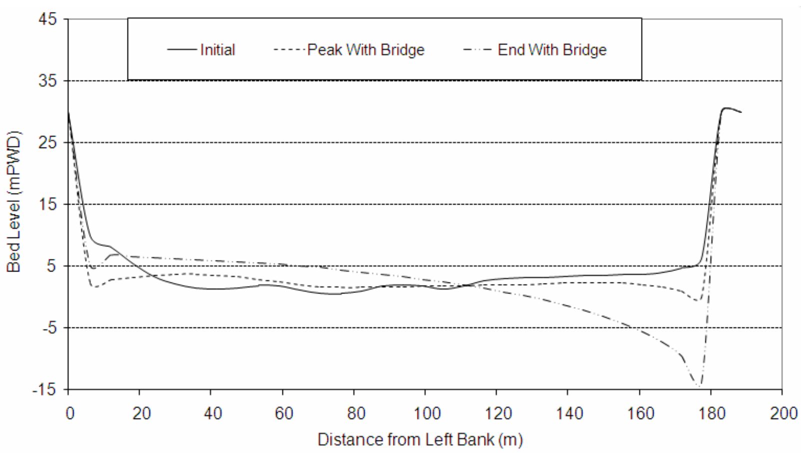

Figure 3.3: Simulated cross sections along with surveyed bed level at different stage of extreme flood event at 450 m upstream of the bridge

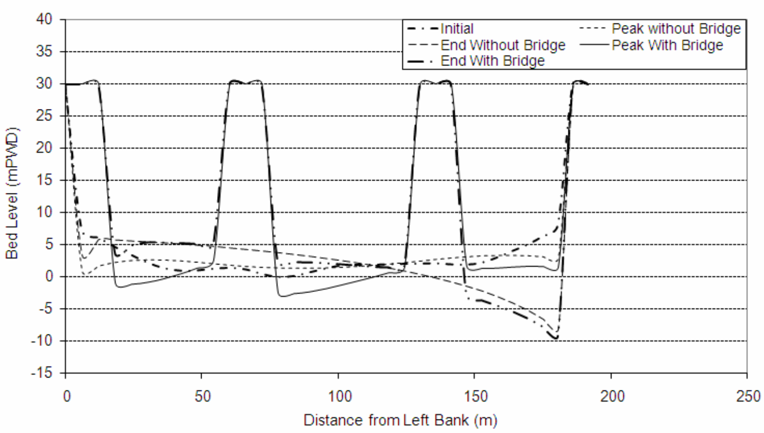

Figure 3.4: Simulated cross sections along with surveyed bed level at different stage of extreme flood event at bridge site

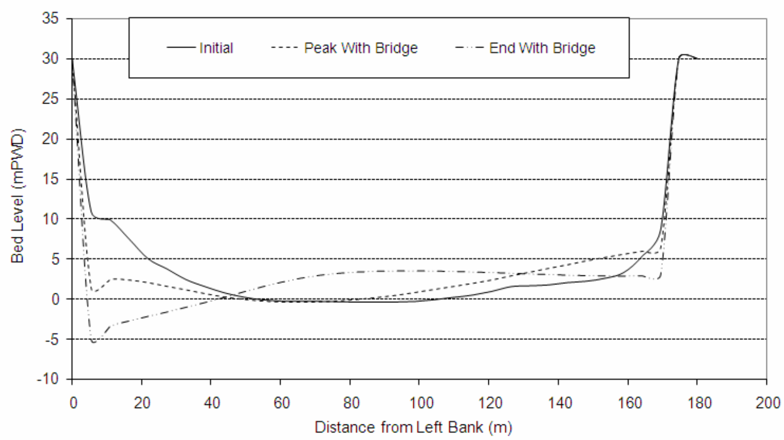

Figure 3.5: Simulated cross sections along with surveyed bed level at different stage of extreme flood event at 700 m downstream of the bridge

4 CONCLUSION

From this study it can be anticipated that if the water ways become constrict, bank erosion and scour beyond expected may be happened. To avoid this drastic situation, river training work from 1km upstream to 1 km downstream may be recommended and continuous monitoring should be conducted during and after construction of such type of structure at stated situation.

5 LIMITATIONS

The study output was only bed level change and bank erosion. There were differences in water level as well as current speed. The outcome of the study is based on existing condition of Surma river. The approach may be same for all river but possibility of deviation exists in the case of other base condition and other rivers. The result also varied with soil condition, current speed, wave action, tidal action, surface runoff and so on.

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