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Impact assessment of bridge hydraulics of Ulukhola bridge & Nagda bridge over Balu river for a flood level with 100-year return period

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ABSTRACT: Ulukhola Bridge (175m) & Nagda Bridge (150m), constructed over Baluriver, link the Dhaka Bypass Highway (N105) which connects the south-west region of the county with north-central & north-east region of the country. The purpose of this study is to identify and analyse the potential impacts, suitable alternatives if necessary. The major impacts that were considered in this study were water-level rise due to major flooding of the surrounding locality & scouring or erosion of river bed due to bridge abutment & piers. From the study it is seen that the vertical clearance of Nagda bridge is adequate enough due to less navigational activities but the vertical clearance of Ulukhola bridge is not adequate to support the navigational activities conducted all over the year. Hence a new bridge has been proposed in place of existing Ulukhola bridge with same span.

1 INTRODUCTION

Bangladesh is a delta with an extensive river network extending throughout the country. Any intervention in this very complex river system and floodplain can disturb the existing natural setting as well as social dynamics. Hence, investigation of any water intervention warrants an approach addressing all the impacts it may cause on environment, society & the habitats of the locality.

This study focuses the possible impact assessment on the surrounding locality of Ulukhola Bridge (175m) & Nagda Bridge (150m) which are located in Gazipur Sadar upazila. These two bridges will help to mitigate the transportation problem as well as increase the socio-economic development of the country as this road (N105) connects Rajshahi division, Mymensingh division with Chittagong division through Gazipur offering the opportunity to avoid the traffic congestion occurring in the capital city. The major impacts that were considered in this study were flooding of riverside localities, floodplains & scouring or erosion of river bed due to bridge abutment & piers. The hydro-morphological analysis started with the estimation of design discharge and water-level. A number of other hydraulic parameters (both for without bridge and with bridge conditions) were then derived using a one-dimensional hydraulic model. The design parameters of the bridge (e.g. bridge opening, bridge height, bridge alignment, etc.) were estimated based on the findings of the hydro-morphological study as well as taking into account the information obtained from the local people. Analysis was also conducted to estimate scours due to the bridge piers and the abutments. Necessary countermeasures for scour were also suggested.

The overall objectives of the study are to conduct hydrological, hydraulic and morphological study for the two bridge sites on the Balu River at Gazipur Sadar Upazila of Gazipur District for determining suitable bridge location, opening, and hydraulic design variables of the bridge piers, abutments and associated river training works.

2 STUDY AREA

2.1 *Bridge Site*

Gazipur Sadar Upazila (Gazipur District) with an area of 446.38 sq km is located in between 23°53’ and 24°11’north latitudes and in between 90°20’ and 92°30’ east longitudes. It is bounded by Sreepur (Gazipur) upazila on the north, Savar and Rupganj upazilas and Uttara thana on the south, Kaliganj (Gazipur) and Rupganj upazilas on the east, Kaliakar and Savar upazilas on the west. Main Water bodies of the Upazila are Balu, Turag Rivers & Tongikhal. The present project site at Gazipur Sadar Upazila is located in the Agro-ecological Zone (AEZ)- 9: ‘Old Brahmaputra Floodplain’ and part of Gazipur Sadar is occupied by AEZ-28: ‘Madhupur Tract’. A number of Jettys, ghats can be found on both upstream and downstream of the Ulukhola Bridge for offloading and uploading goods from Cargoes. (Banglapedia, 2006).

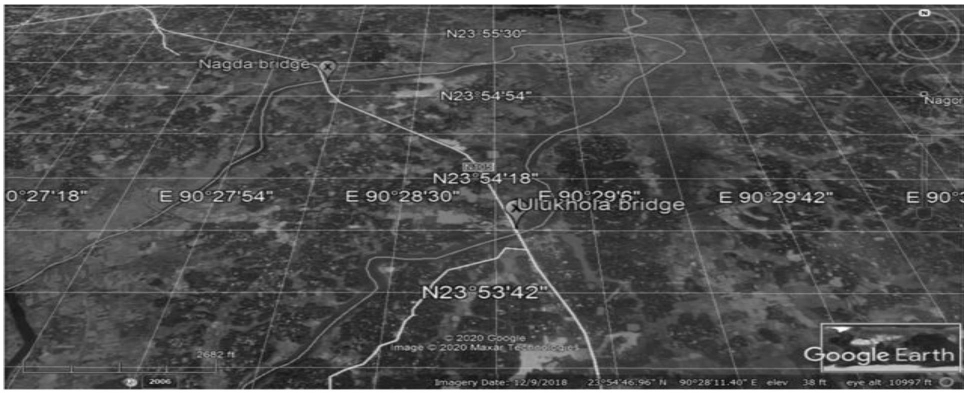


Figure 1. Site location of the two bridges.

2.2 *Bridge Information*

Ulukhola bridge has a a length of 174 m having 4 spans, each span of 43.5m in length, vertical abutment at each end, and 3 piers each with 1.3m in diameter. The bridge height above datum is 9.29m MSL & deck level is 11.6m MSL.

Nagda bridge has a a length of 150 m having 4 spans, each span of 37.5m in length, vertical abutment at each end, and 3 piers each with 1.8m in diameter. The bridge height above datum is 9.58m MSL & deck level is 11.927m MSL.

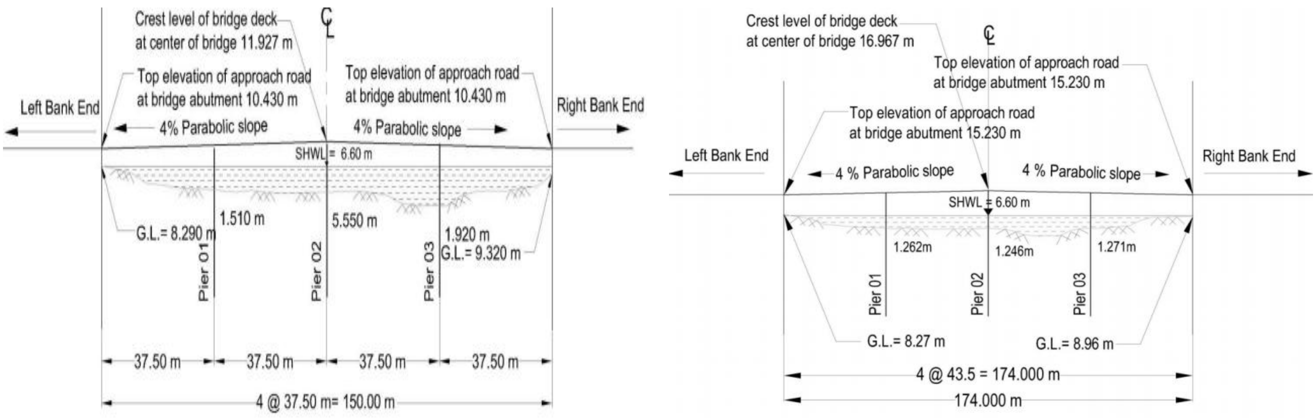


Figure 2. (a) Longitudinal profile of the Nagda Bridge. (b). Longitudinal profile of the Ulukhola Bridge.

2.3 *River System*

Balu is a tributary of the Shitalakshya River. It passes through the wetlands of Beel Belai and Dhaka before its confluence with the Shitalakhya at Demra. Balu follows a meandering path. Balu River is perennial. February to April are considered months of lowest flow. The high flow months are July-September. The slope of the river is 1.27 cm/km. Width of the river within 3 kilometer of the bridge varies from 80 m to 120 m. (Banglapedia, 2006)

3 METHODOLOGY

3.1 *Data Collection*

Field surveys were carried out to collect up-to-date bathymetric, bank line and topographic data covering a reach of 6 km to produce digital topographic and hydrographic maps to estimate cross-sections at different locations along the study reaches of the Balu River. Hydrological data were collected from BWDB. The Demra (SW7.5) and Pubail (SW7) are the closest gage stations to the proposed site on the Balu River. Pubail (SW7) station is non-tidal water level gage station of BWDB while Demra (SW7.5) is both non-tidal water level and discharge gage stations of BWDB. The locations of different gage stations close to the proposed bridge site are shown in Figure 3(a). Gazipur Sadar Upazila is located within North-Central hydrological region of Bangladesh. The nearest BMD station to the proposed bridge site at Gazipur Sadar Upazila is at Dhaka shown in figure 3(b) . Climatic data were collected from there.

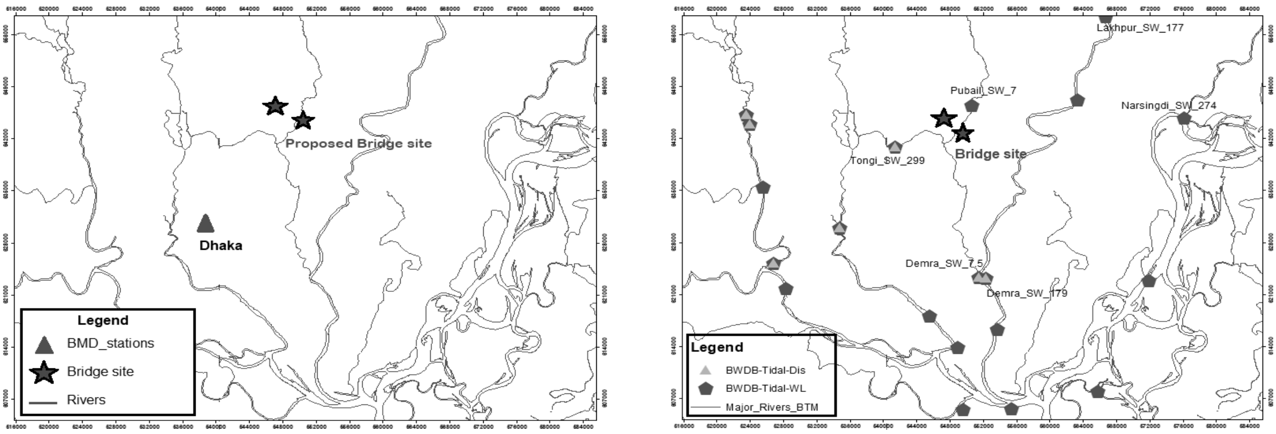


Figure 3. (a) Locations of BWDB stations near bridge site. (b) Locations of BMD stations near bridge site.

3.2 *Estimating Design Discharge & Water-Level by Hydrologic Analysis*

The hydrologic analysis involves frequency analysis with different probability distributions functions for the selected design return period where historical annual peak water level and discharge data at appropriate locations are available. In case where historical annual peak water level and discharge data are not available, the historical highest recorded water level at the proposed bridge site based on the local information is used and the discharge is estimated by a hydrodynamic model. The design return period is selected based on the size and importance of the proposed bridge. Five probability distribution functions (PDFs) viz. Two-Parameter Log Normal (LN2), Three Parameter Log Normal (LN3), Pearson Type III (P3), Log Pearson Type III (LP3) and Gumbel (EV1) were used for frequency analysis. The PDFs were tested based on probability plot correlation coefficient (PPCC) (Filliben, 1975) &goodness-of-fit study based on PPCC (Stedinger et al., 1993).

The fitted PDFs and the corresponding values of PPCC for annual maximum discharge of the Balu River at Demra are shown in Table 1. It is seen from Table 1 that the best fitted PDF is LP3 for annual maximum water level. It is seen that the observed values fall well within the 90% confidence interval of the fitted LP3 distribution for annual maximum water level. Given the size and importance of the proposed bridge, a 100-year return period has been selected as the design return period. The design discharge level corresponding to a 100-year return period at the gage station is 534 m^3/s.

Table 1. Fitted PDFs and the corresponding values of PPCC for annual maximum discharge (m^3/s) of the Balu River at Demra.

PDF	Return period				PPCC	Rank
	2.33	20	50	100		
LN2	335	521	590	640	0.95629	4
LN3	338	461	490	509	0.97995	3
P3	333	469	505	527	0.98211	2
LP3	348	481	514	534	0.98340	1
EV1	313	496	568	621	0.94879	5

The fitted PDFs and the corresponding values of PPCC for annual maximum water level of the Balu River at Pubail are shown in Table 2. It is seen from Table 2 that the best fitted PDF is LN2 for annual maximum water level. It is seen that the observed values fall well within the 90% confidence interval of the fitted EV1 distribution for annual maximum water level. Given the size and importance of the proposed bridge, a 100-year return period has been selected as the design return period. The design water level corresponding to a 100-year return period at the gage station is 7.50 m PWD. The hydraulic gradient has been estimated at 1.25cm/km during high water level. The gage station is located at a distance 4.7km downstream of the proposed bridge location. Thus the design high water level at the bridge site has been estimated at 7.44m PWD at the proposed bridge site.

Table 2. Fitted PDFs and the corresponding values of PPCC for annual maximum water level (m, PWD) of the Baluriver at Pubail.

PDF	Return period				PPCC	Rank
	2.33	20	50	100		
LN2	6.01	6.99	7.29	7.50	0.99381	1
LN3	5.97	6.94	7.24	7.45	0.99374	2
P3	5.98	6.92	7.20	7.39	0.99334	2
LP3	6.03	6.95	7.22	7.40	0.99311	4
EV1	5.89	7.03	7.47	7.80	0.98573	5

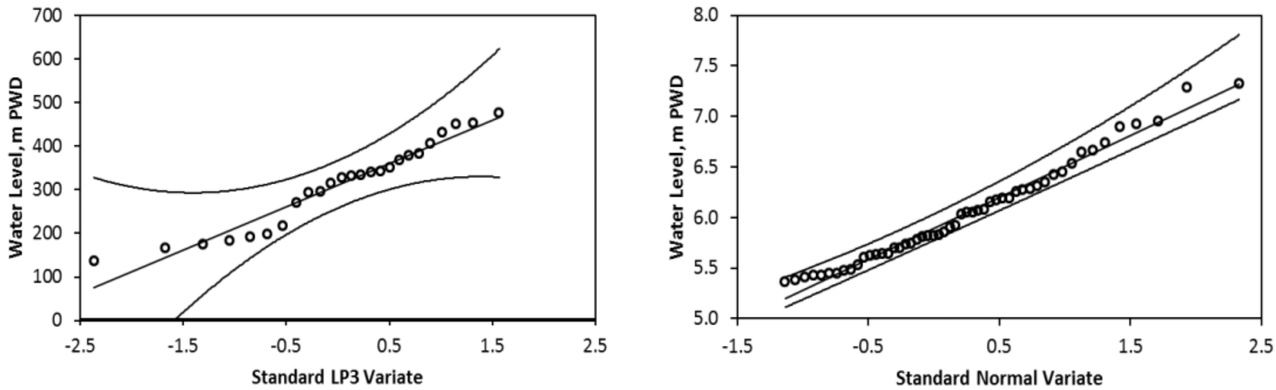


Figure 4. (a) Probability plot along with 90% confidence interval of the LP3 distribution fitted to the annual maximum water level data of the Balu River at Demra and (b) Probability plot along with 90% confidence interval of the LN2 distribution fitted to the annual maximum discharge of the Balu River at Pubail.

3.3 *Assessing the Impact of Climate Change on Design Water Level and Discharge*

In the backdrop of climate change, it is important to assess whether the anticipated climate change will have any impacts on design water level and discharge. Any change either in the intensity, frequency or total amount of precipitation over a river basin can cause change in the magnitude and timing of the river's discharge, thereby changing the mean discharges along with the intensity of floods and droughts (Immerzeel, 2008).

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) was used for simulating future discharges with the 11 different climate projections. SWAT has recently become one of the most commonly used hydrological models around the world for investigating climate change impacts on regional water resources because of its flexibility and robustness (Jha et al., 2006). Before initializing the calibration process, a global sensitivity analysis was performed on 26 hydrology-related parameters of SWAT using a separate independent tool called SWAT-CUP. Afterwards the most sensitive parameters were selected for performing the calibration process using Sequential Uncertainty Fitting II (SUFI-2) algorithm of SWAT-CUP (Abbaspour et al., 2007). Again, CORDEX dataset were used for bias correction in this process. Hence, considering the impact of climate change in the flow of the Brahmaputra river, the design discharge will be increased by 20% which was found to.

3.4 *Hydraulic Analysis HECRAS*

3.4.1 *HECRAS model setup*

A widely used one-dimensional hydraulic model HEC-RAS, developed by the U.S. Army Corps of Engineers (2005), was used to derive a number of hydraulic parameters at the bridge location for without and with bridge conditions.

In the present study for computation of design hydraulic parameters, the HEC-RAS with option for a steady-flow analysis was considered to be adequate. For boundary condition, "Normal depth" were selected for which energy gradient is required. Such gradient was estimated to be about 1.25cm/km & 1.27cm/km for reaches below Nagda bridge & Ulukhola bridge respectively from the annual maximum water level analysis of two nearby stations (Demra: SW7.5 and Pubail: SW7 ; approximately 30km apart) on the Balu River and was used in this study for the estimation of design hydraulic parameters at the bridge site. the Manning's roughness coefficient of 0.025 for the main river and 0.030 for the overbanks are considered to be reasonable and hence were used in the model. Measured cross sectional data at 17 locations – 8 in the upstream, 8 in the downstream and one at the bridge location – covering a length of about 6.0 km and a width of about 150-280 m were used in the model set-up.

As there's a divergence occurred in Balu River, an unsteady run was conducted in HECRAS to determine the percentage of water flowing through each reach. From analysis it is seen that around 82% of water flow passes through the reach below Ulukhola bridge & remaining water passes through the reach below Nagda Bridge. The 100-year flood flow was found to be 534 m^3/s based on frequency analysis and then the design discharge will be increased by 20% which was found to be 640.6 m3 /s at the gage station of Pubail. For the reach below Nagda Bridge, the model was then run using the water surface gradient of 1.25cm/km and the design discharge of 115.34 m^3/s and for the reach below Ulukhola bridge, the model was then run using the water surface gradient of 1.27cm/km and the design discharge of 525.46m^3/s ,by assuming to lateral inflow, to compute the design hydraulic parameters corresponding to this water level at the bridge site for both the 'without bridge' & 'with bridge' condition.

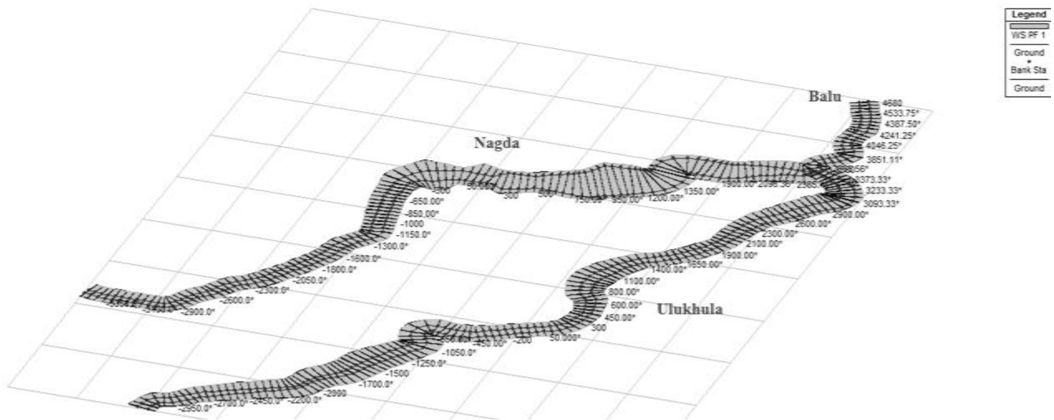
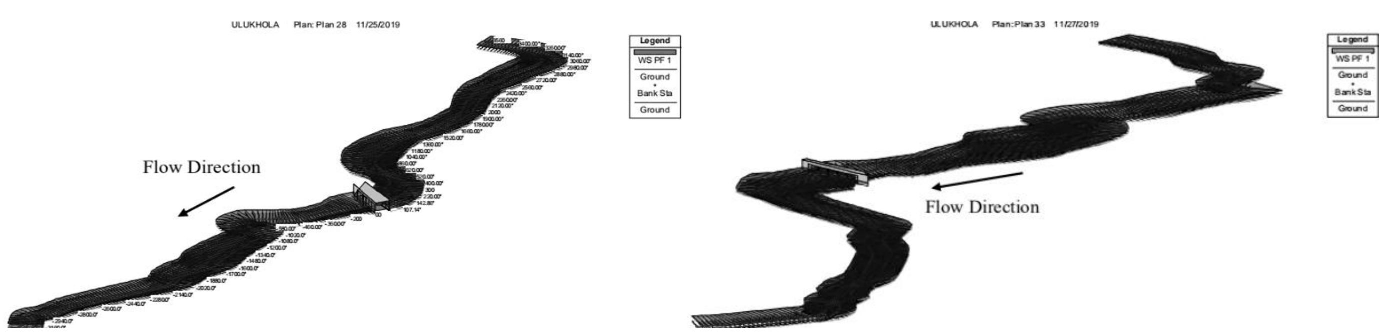


Figure 5. Divergence of Balu River into two reaches.

The 100-year flood level was found to be 7.50 m PWD at the gage station of Pubail on the Balu River based on frequency analysis as mentioned in Chapter Four. Using the latitude & longitude coordinate of the bridge site standard high water level was found to be 7.06m PWD. The proposed bridge sites are located at about 3.78km & 4.7km downstream of this gage station. Using a hydraulic gradient of 1.25cm/km & 1.27cm/km, the design water level at the bridge site was found to be 7.42m PWD &7.44m PWD for Nagda bridge site & Ulukhola bridge site respectively.

3.4.2 *Simulating HECRAS model with bridge*

Ulukhola Bridge : A bridge on the main channel with a length of 174 m having 4 spans, each span of 43.5 m in length, vertical abutment at each end, and 3 piers each with 1.3 m in diameter were included in the model. The cross section of the river with the proposed bridge and the location of the bridge in the selected river reach are shown in Figure 6(a). The model was then run for the design discharge condition.



(a) (b)

Figure 6. (a) Ulukhola bridge site in the river reach selected for analysis for 'with bridge' condition (b) Proposed bridge location in the river reach selected for analysis for 'with bridge' condition.

Nagda Bridge : A bridge on the main channel with a length of 150 m having 4 spans, each span of 37.5m in length, vertical abutment at each end, and 3 piers each with 1.8 m in diameter were included in the model. The cross section of the river with the proposed bridge and the location of the bridge in the selected river reach are shown in Figures 6(b). The model was then run for the design discharge condition.

3.4.3 *Scouring analysis due to bridge*

Scours at piers and abutments were also computed using the HEC-RAS model. For scouring analysis of river bed, Froehlich's equation was being used for both pier scour & abutment scour and CSU equation was used for pier scour also in HECRAS model. Since the bridge site has severe erosion and bank shifting problem, the same scour depth and level should be provided for all the piers even if the piers are on the floodplains. The depth of flow at the right abutment is relatively high and hence its scour depth is also high.

4 RESULTS & DISCUSSIONS

4.1 *Analysis of Hydraulic Parameters*

Ulukhola Bridge: Considering the model simulations with bridge condition, the maximum discharge and water level at the bridge site were found as 525.46 m^3/s and 7.41 m PWD (6.95 m MSL). It was found that there would be about 1 cm afflux due to the construction of the proposed bridge. Vertical clearance was found to be 2.34 m from the bridge height level (Figure 7).

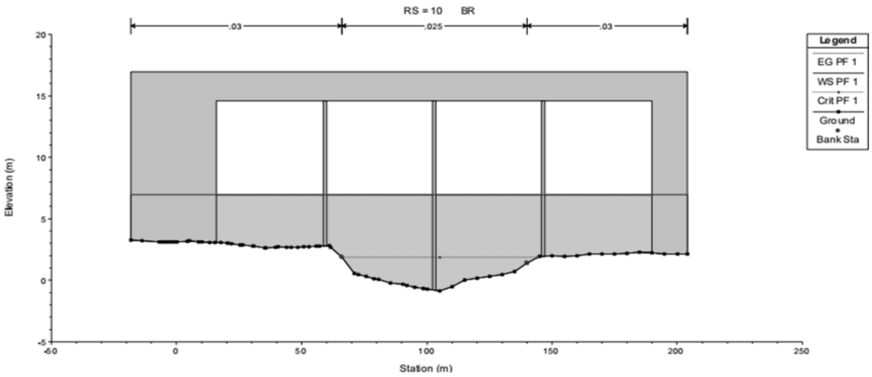
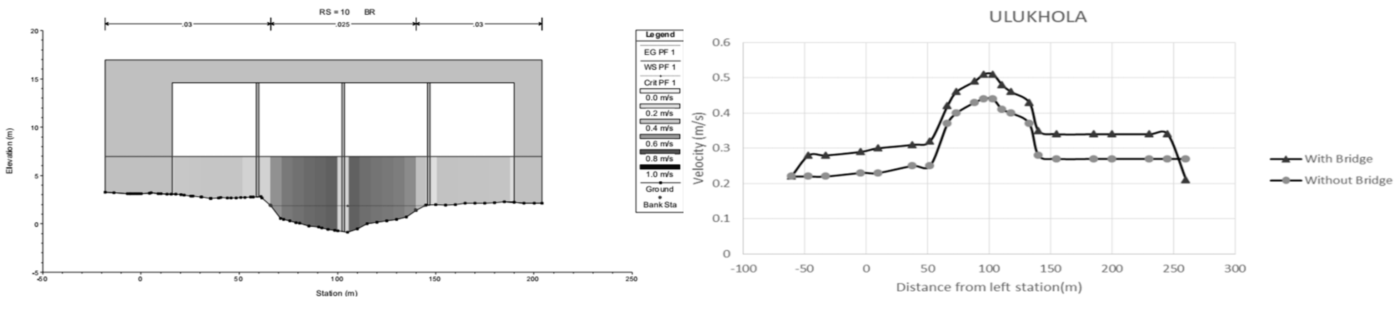


Figure 7. Cross section showing the flood level at the bridge location for a design discharge.

Simulation for the 'without bridge' condition at the design discharge yielded a velocity variation in the main channel from 0.33 m/s to 0.58 m/s, with an average velocity of 0.45 m/s. Velocities for the 'with bridge' condition would vary from 0.4 m/s to 0.68 m/s in the bridge section, with an average velocity of 0.51 m/s (Fig 8(a)).The maximum shear stress in a segment is found to be 1.10 N/m^2 under the 'without bridge' condition. Such stress under the 'with bridge' condition could be about 1.59 N/m^2. The possible changes in longitudinal velocities at different segments of a cross section due to the construction of the proposed bridge on the Balu River were also evaluated. (Figure 8(b)) Since the overall velocity after the construction of the bridge would not increase much, the bridge site may face any increased severe erosion due to the above increase in velocity.



(a) (b)

Figure 8. (a) Longitudinal velocity distribution at the bridge section for 'with bridge' condition (b) Longitudinal velocity distribution at the bridge section for 'without' and 'with' bridge conditions.

Nagda Bridge: Considering the model simulations with bridge condition, the maximum discharge and water level at the bridge site were found as 115.34 m3 /s and 7.423 m PWD (6.963 m MSL). It was found that there would be about 1 cm afflux due to the construction of the proposed bridge. Vertical clearance was fount to be 2.62m from the bridge height level (Figure 9).

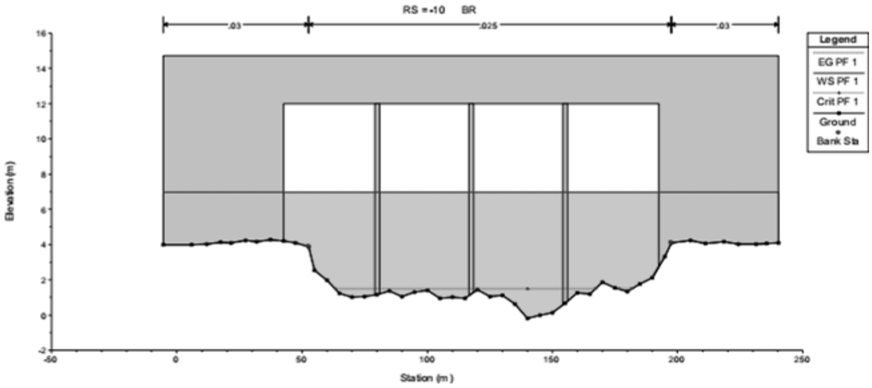


Figure 9. Cross section showing the flood level at the bridge location for a design discharge.

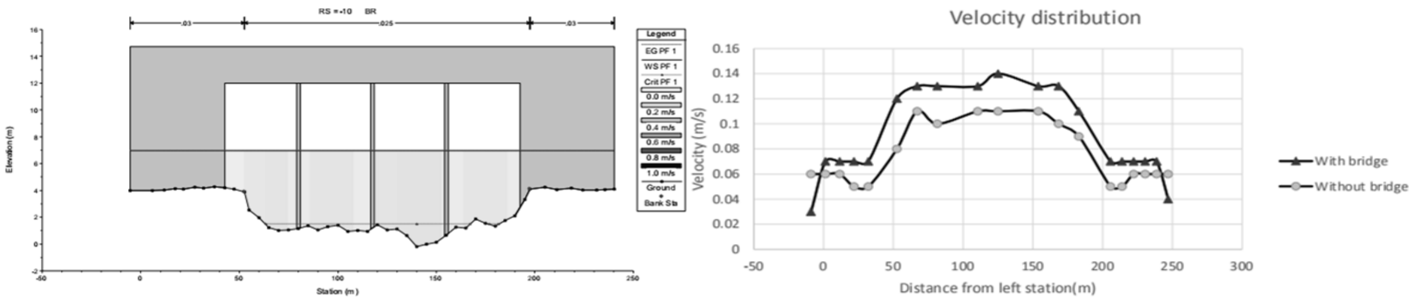
Simulation for the ‘without bridge’ condition at the design discharge yielded a velocity variation in the main channel from 0.06 m/s to 0.12 m/s, with an average velocity of 0.10 m/s. Velocities for the ‘with bridge’ condition would vary from 0.12 m/s to 0.15 m/s in the bridge section, with an average velocity in the main channel of 0.15m/s (Figure 10(a)). The maximum shear stress in a segment is found to be 0.05 N/m^2 under the ‘without bridge’ condition. Such stress under the ‘with bridge’ condition could be about 0.08 N/m^2.The possible changes in longitudinal velocities at different segments of a cross section due to the construction of the proposed bridge on the Balu River were also evaluated (Figure 10(b)). Since the overall velocity after the construction of the bridge would not increase much, the bridge site may face any increased severe erosion due to the above increase in velocity.

4.2 *Scour Analysis*

Scour analysis were conducted for both the bridges in HECRAS model using CSU equation & Froelinch’s equation for pier & abutment scouring.

Table 3. Scour estimated at piers and abutments of Ulukhola bridge.

Scour (m) at	Location of pier/abutment		
	Channel	Left overbank	Right overbank
Pier (Richardson (1990))	1.76 (Piers #2)	1.76 (Pier #1)	1.76 (Pier #3)
Pier (Froehlich (1988))	2.50 (Piers #2)	2.50 (Pier #1)	2.50 (Pier #3)
Abutment(Froehlich (1989))	-	7.90	8.49



(a) (b)

Figure 10. (a) Longitudinal velocity distribution at the bridge section for ‘with bridge’ condition (b) Longitudinal velocity distribution at the bridge section for ‘without’ and ‘with’ bridge conditions.

Table 4. Scour estimated at piers and abutments of Nagda bridge. (table 9.7 nag)

Scour (m) at	Location of pier/abutment		
	Channel	Left overbank	Right overbank
Pier (Richardson (1990))	1.09 (Piers #2)	1.09 (Pier #1)	1.09 (Pier #3)
Pier (Froehlich (1988))	2.64 (Piers #2)	2.64 (Pier #1)	2.64 (Pier #3)
Abutment (Froehlich (1989))	-	4.56	5.13

5 CONCLUSIONS

From the model study of bridge hydraulics of Ulukhola Bridge & Nagda Bridge it is seen that a vertical clearance of 2.34m & 2.62m has been obtained respectively from the bridge level above MSL datum. According BIWTA navigational route classification, rivers below Ulukhola bridge &Nagda bridge has been classified as class II & class IV respectively. River below Ulukhola Bridge remains busy with navigational activities all over the year while river below Nagda River is used by small vessel & some navigational activities especially during rainy season. So, the clearance obtained for Nagda Bridge (2.62m) has been considered adequate enough due to less navigational activities but for Ulukhola Bridge the clearance (2.34m) can't be accepted at all. Hence a new bridge has been proposed in place of existing Ulukhola bridge with same span (175m) but with a vertical clearance of 7.62m by designing the bridge height level at 14.22m MSL, deck level at 16.927m MSL with 43.5m horizontal openings consisted of 3 piers. Again, to resist scouring countermeasures have to be taken. For the piers, the pile cap should be buried within the river bed or at least flushed with the bed. Considering the safety of the piers against thalweg shifting, the maximum scour levels should be used for all the piers in the main channel. Abutments would be constructed based on the expected scour depth around the abutment. Slope protection for the abutments is recommended according to the conventional RHD practices.

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