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Morphological analysis & scour analysis of Kanchan bridge over Shitalakhya river for a flood level with 100-year return period

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ABSTRACT: Morphological analysis is the process that determines whether a particular bridge section is morphologically stable or not and whether river training and bank protection works are necessary for controlling river shifting and erosion. Again, statistical surveys conducted on investigation of reasons of bridge failures implied that majority of bridges have failed because of excessive scouring at infrastructural elements. Planform analysis during the period from 1972 to 2018 shows that the river at the proposed bridge site has no significant shifting during the observation period. Scour analysis results from these analytical methods were somehow a little different from the model simulated scour analysis results. Pier scour was further analyzed for different pier diameters to evaluate its effect on scouring that presents scouring increases the scour depth increases around the piers.

1 INTRODUCTION

Bridges are structures, usually built over water body to provide a passage to pass over the water body but sometimes rivers are unstable & tend to shift from their course. So A bridge, crossing an alluvial river, should therefore be designed properly with reference to possibility of this phenomena. The bridge location and alignment are mostly dictated by the morphology of the river reach.

Kanchan Bridge (415m), located in Rupganjupazila, is constructed over Shitalakhya river linking the Dhaka Bypass Highway (N105). This bridge connects the south-west region with north-central & north-east region of the country. So this bridge is really important for the trade & commerce fof the country. The purpose of this study is to check if there is any possibility of river shifting & erosion at the bridge section, perform scouring analysis of river bed, propose suitable countermeasure for minimal damage. For monitoring river shifting, Planform analysis of the proposed bridge was conducted using Landsat Thematic Mapper (TM) and Landsat 8 images. This image processing system, was used to manipulate scanned maps, plans and aerial photographs to enable detailed analysis of historical river channel planform change. Again erosion of river bed due to bridge pier, abutment is a common phenomena at bridge site. Hence, for performing scour analysis, the HECRAS model was developed for Shitalakhya River & the simulated. Moreover, a comparison was made between model produced scouring result & several analytical methods of scouring computation. It was also checked whether there’s any relation between pier diameter & amount of scouring.

The main purposes of the study are to conduct hydrological, hydraulic and morphological analysis of the Kanchan bridge sites on the Shitalakhya River for determining suitable bridge location, necessity of river training works & estimating scouring of river bed due to the bridge piers, abutments and associated river training works.

2 STUDY AREA

2.1 *Bridge Site*

The proposed 415m long bridge would be located on the Shitalakhya River at Rupganj Upazila in Narayanganj. (Figure 1). The bridge site is at a place near Kanchan Pourashava where there is an existing bridge for the existing 2 lane road. The bridge would improve communication and foster economic growth of this region.

Rupganj Upazila (Narayanganj District) with an area of 247.97 sq km is located in between 23°42' and 23°54' north latitudes and in between 90°28' and 90°37' east longitudes. It is bounded by Kaliganj (Gazipur) and Gazipur Sadar Upazilas on the north, Sonargaon Upazila on the south, Araihazar, Narsingdi Sadar and Palash Upazilas on the east and Demra, Badda and Uttara Thanas and Gazipur Sadar Upazila on the west. (Banglapedia, 2006).

Figure 1. Location of Kanchan bridge site.

2.2 *Bridge Information*

Kanchan Bridge has a length of 415.1 m having 8 spans, each span of 49.6 m in length, vertical abutment at each end, and 7 piers each with 2.0 m in diameter. The bridge height level above datum is 15.45m MSL & deck level is 18.32m MSL (Figure 2).

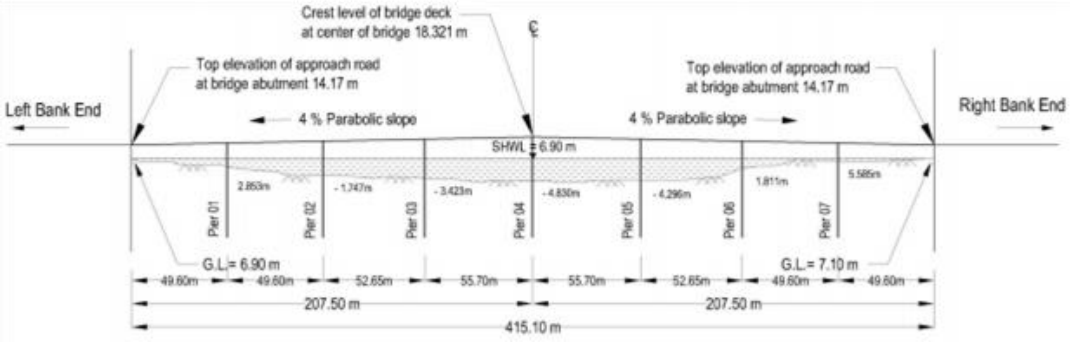


Figure 2. Longitudinal profile of Kanchan Bridge.

2.3 *River System*

Shitalakhya is a cross boundary river that originates from the Barak river at the border between Bangladesh and India at Amalshid point at Rupganj Upazila under Narayanganj district. It follows north easterly direction at the beginning. The river later changes direction to flow westward and falls into Baulai River at Dharmapasha Upazila of Sunamganj District. It has a number of tributaries and branches along its course. Shitalakhya has a total length of 415 km and follows a meandering path. The slope of the river is 1.87 cm/km. Width of the river within 3 kilometer of the bridge varies from 185 m to 310 m. The river is classified as Class II navigational route by BIWTA at its lower reach while the upper reach is classified as Class-III navigational route. The river shows bank erosion at different reaches. The river carries large volume of sands and also receives flow from numerous hilly streams from the Meghalaya (Banglapedia, 2006).

3 METHODOLOGY

3.1 *Data Collection*

Hydrological data, bathymetric data were collected from BWDB. The Demra (SW179) and Lakhapur (SW177) are the closest gage stations to the proposed site on the Shitalakhya River. Both the stations are non-tidal water level and discharge gage stations of BWDB. Rupganj Upazila is located within North-Central hydrological region of Bangladesh. The nearest BMD station to the proposed bridge site at Rupganj Upazila is at Dhaka. Soil samples were collected from both banks of the bridge to calculate d50, d95 which are needed for scour analysis.

3.2 *HECRAS Model Setup*

HECRAS model was used primarily for computing hydraulic parameters of the bridge site. This entire process has to be done prior to scour analysis computation using HECRAS. “Normal depth” was selected for the Boundary condition for the simulation. From frequency analysis of annual maximum discharge & water level, design discharge & water level was computed using 5 probability distribution functions(PDF) based on probability plot correlation coefficient (PPCC) (Filliben, 1975) & goodness-of-fit study based on PPCC (Stedinger et al., 1993). From the frequency analysis, the design discharge & water level was computed to be $2738m^3$/s & 7.50m PWD. However, considering climate impact changes these discharge is increased about 20% & the model was then run using the water surface gradient of 1.87 cm/km and the design discharge of 3286 m^3/s (by assuming to lateral inflow) to compute the design hydraulic parameters corresponding to this water level at the bridge site for the ‘with bridge’ condition after bridge parameters being input.

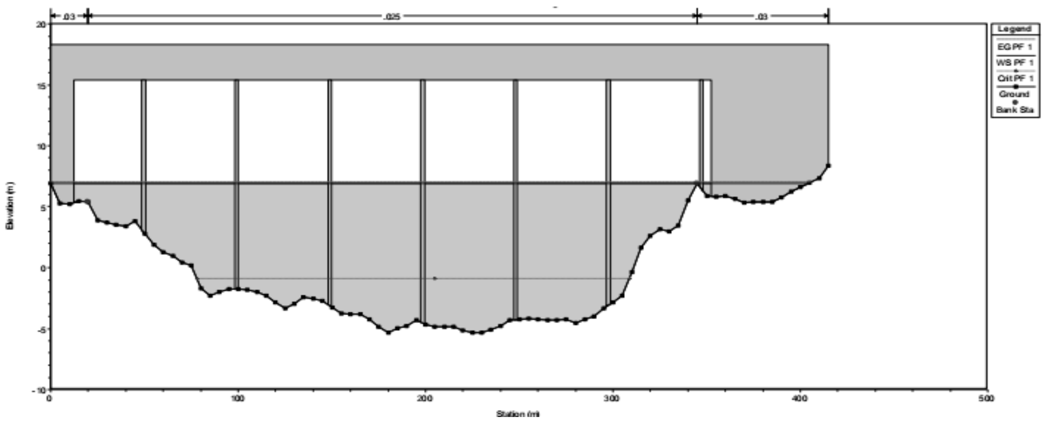


Figure 3. Cross section showing the flood-level the bridge site for design discharge.

3.3 *Scour Analysis using HECRAS*

For scouring analysis of river bed in HECRAS, Froehlich’s equation was being used for both pier scour & abutment scour and CSU equation was used for pier scour only in HECRAS model. Equations are mentioned in Table 1 and 2.

In the CSU equation for pier scour, the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9 respectively & it is applicable for tidal and clear water. Froehlich’s equation for abutment scour is applicable for vertical-wall (= 90^0) and sloped-wall abutment as well under clear-water scouring condition.

3.4 *Theoretical Methods of Scour Estimation*

3.4.1 *Scouring due to pier*

From many available methods for the prediction of the maximum scour depth around piers, only some selected methods are discussed Table 1. Pier scour was further analyzed for different pier diameters such as 1m , 1.5m , 2m , 2.5m , 3m to evaluate its effect on scouring.

3.4.2 *Scouring due to abutment*

Only a number of selected formulae are summarized from many available formulae for the prediction of the maximum scour depth around abutments which are listed in Table 2.

Melville’s slope factors are extrapolated by means of Rahman and Haque’s (2004) formulation as in the bridge site, side slope would be around 1V:2H. The value of b/h= 10 is used in equations for the estimation of local scour depth around abutments.

Table 1. List of formulae considered for pier scour depth prediction.

Reference	Equation	Notes
Breusers (1965)	$\frac{d_s}{b_p} = 1.4$	For tidal flow
Laursen (1963)	At the threshold condition: $d_s / b_p = 1.34(h / b_p)^{0.5}$	applicable for clear-water scouring
Neill (1987)	At the threshold condition: $d_s / b_p = K_s$	K_s =1.5 for round nose and circular pier and =2.0 for rectangular piers
Jain and Fischer (1980)	At the threshold condition: $d_s / b_p = 1.86(h / b_p)^{0.5}$	applicable for clear-water scouring condition
Chitale (1988)	At the threshold condition: $d_s / b_p = 2.5$	applicable for clear-water scouring condition
Melville (1997)	At the threshold condition: $b_p/h<0.7$: $d_s / b_p = 2.4$ $0.7<b_p/h<5$: $d_s / b_p = 2(h / b_p)^{0.5}$ $b_p/h>5$: $d_s / b_p = 4.5(h / b_p)$	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively
Richardson and Davis (1990) (HEC-18)	At the threshold condition: $d_s / b_p = 2 * K_s K_\theta K_3 K_4 (h / b_p)^{0.35} * Fr\wedge^{0.43}$	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively. Applicable for tidal and clear water

Note: b_p = pier diameter and d_s = scour depth below the initial bed level, K_3= factor for mode of sediment transport, K_4= factor for armouring by bed material, K_s= shape factor and K_Θ= alignment factor.

Table 2. List of formulae considered for abutment scour depth prediction.

References	Equation	Notes
Laursen (1963)	at the threshold condition: $d_s / h = 2.09\sqrt{b / h}$ (9.11)	applicable for vertical-wall abutment in clear-water scouring condition only
Melville (1997)	at the threshold condition: $b/h<1$: $d_s / h = 2(b / h)$ $1<b/h<25$: $d_s / h = 2\sqrt{b / h}$ $b/h>25$: $d_s / h = 10$ (9.12)	derived for vertical-wall abutment in clear water scouring and applicable for sloped-wall abutment as well using slope factors described in Table 9.4 (up to V1H1.5)
Lim (1997)	at the threshold condition; $d_s / h = 2\left(\left\{1.2(b / h)^{0.5} + 1\right\}^{3/4} - 1\right)$ (9.13)	developed for the vertical-wall abutment and expected to use Melville's shape factors for sloped-wall abutments
Rahman and Haque (2004)	at the threshold condition: $d_s / h = \sqrt{a_3 \ (b / h)}$ (9.14) $a_3 = \{\beta / \tan\phi(1-\beta) + 1/2\tan\theta\}^{-1}$	applicable for vertical-wall (□ = 90⁰) and sloped-wall abutment as well under clear-water scouring condition
Froehlich (1989) (HEC-18)	$d_s / h = 2.27 * K_s K_\theta (b / h)^{0.43} * Fr\wedge^{0.61}$ (9.15)	applicable for vertical-wall (□ = 90⁰) and sloped-wall abutment as well under clear-water scouring condition

3.5 *Satellite Image Processing*

Historical satellite images are used to evaluate the characteristic features of channel shifting and to estimate erosion. As satellite images at different times are available for the study reach, the analysis of the stability of the study river reach using satellite images is presented in this section. Images had to be processed in ArcGIS before starting planform analysis which was done by converting the multispectral image into composite band image (RGB).

3.6 *Planform Analysis*

Planform analysis of the proposed bridge was conducted using Landsat Thematic Mapper (TM) and Landsat 8 images. Five images (Figures 4(a-e)) of the years 1972, 1989, 2001, 2010 and 2018 were used. In this process, false color composite band (RGB) has been used. In figure 4(a-e), bridge location is shown by yellow color dot and the center line is shown by red color lines. It can be found that the river reach has experienced no significant erosion and deposition over the last 46 years at the bridge site and 1km upstream or downstream of the river.

3.7 *Cross-Sectional Analysis*

The cross-section data of a river are measured to investigate the shape and morphology of a river, to compare straight and meandering sections of the same river, to investigate discharge and velocity and the factors which influence it, both across the channel and along its length, to investigate changes in channel morphology along the length of the river, and to compare rivers in different locations.

For this bridge, cross sections are measured covering a total about 6 km reach of the river. Cross sections are measured at intervals varying between 100m to 500m. All the measured cross sections are shown in Appendix A. The sections show mild bank slopes at the bridge location and no significant bank erosion activities.

4 RESULT & DISCUSSION

4.1 *Computation of Scour Analysis*

Scouring Results from HECRAS**:** The model estimated scour is given in table 3 and he variation in the scour depth is provided in figure 5. 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.

Table 3. Scour estimated at piers and abutments using the HEC-RAS model.

Scour (m) at	Location of pier/abutment		
	Channel	Left overbank	Right overbank
Pier (Richardson 1990)	3.34 (Piers #2 to #6)	3.34 (Pier #1)	3.34 (Pier #7)
Pier (Froehlich 1988)	4.22 (Piers #2 to #6)	4.22 (Pier #1)	4.22 (Pier #7)
Abutment (Froehlich 1989)	-	5.55	0.92

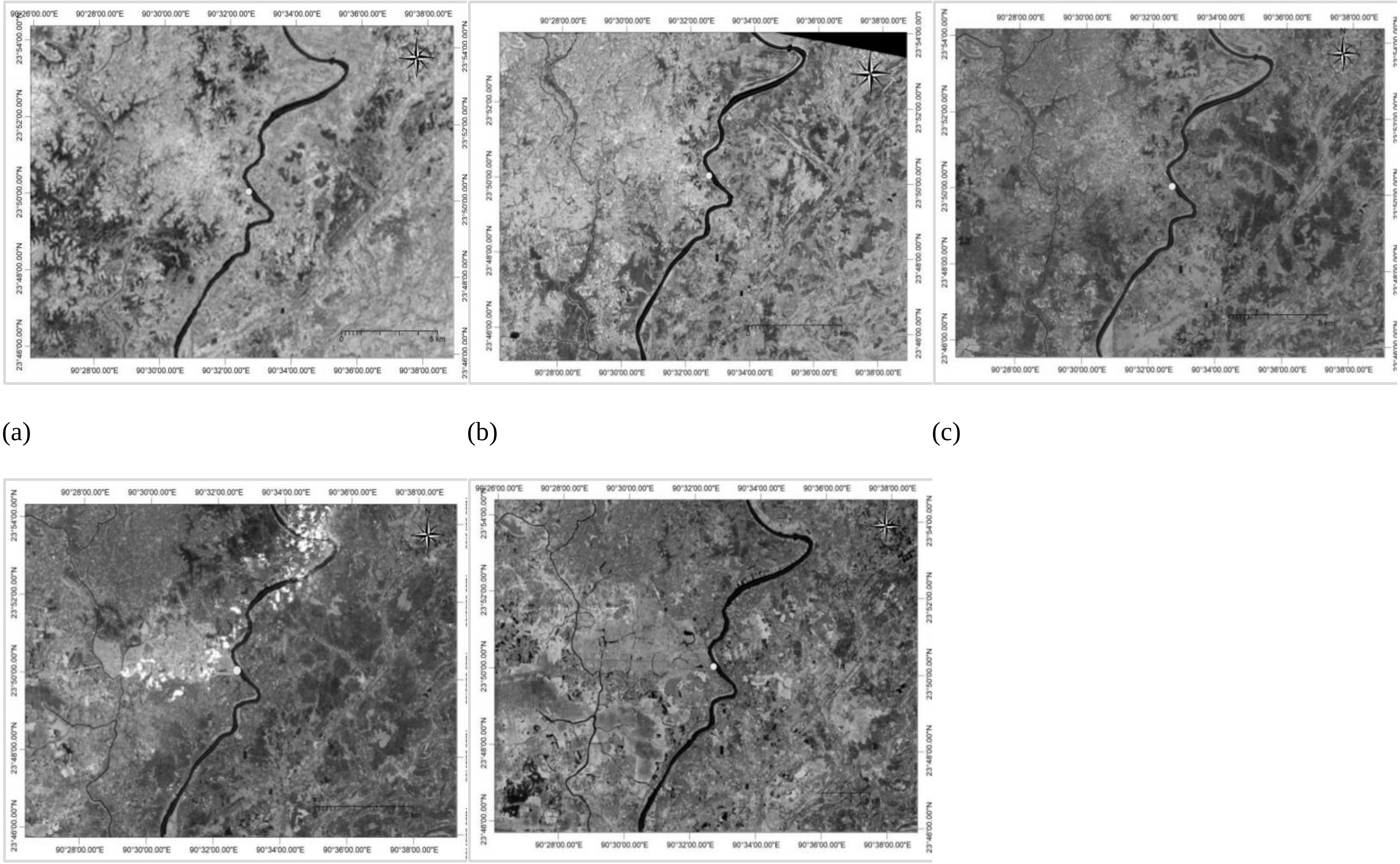
Comparing Results of HECRAS & Analytical Methods**:** From the study it’s observed that the maximum pier scour of the analytical methods obtained from Chitale’s equation is the higher than that obtained from the HEC-RAS model. On the other hand, the maximum abutment scour of the analytcial methods obtained from Laursen’s equation is lower than that from the HEC-RAS model. The summary of scour depths around piers and abutments is given in Table 4.

Table 4. Comparison of local scour depth around piers using different formulae.

Equation No. and Reference	Scour depth below initial bed level (m)	Scour level, (m) MSL	Scour depth below SHWL (+ 6.95 m, MSL)
(9.3) Breusers (1965)	3.21	-8.54	15.49
(9.4) Laursen (1963)	3.22	-8.55	15.50
(9.5) Neill (1987)	3.41	-8.74	15.69
(9.6) Jain and Fischer (1980)	4.30	-9.63	16.58
(9.7) Chitale (1988)	5.41	-10.74	17.69
(9.8) Melville (1997)	4.73	-10.06	17.01

Table 5. Comparison of local scour depth around abutment using different formulae.

Equation and Reference	Local scour depth below initial bed level at Abutment (+6.9 m MSL), m	Scour level, (m) MSL	Scour depth below SHWL (+ 6.95 m, MSL), m
Laursen (1963)	1.91	4.99	1.96
Melville (1997)	1.83	5.07	1.88
Lim (1997)	1.20	5.70	1.25
Rahman and Haque (2004)	1.86	5.04	1.91



(a) (b) (c)

(d) (e)

Figure 4. (a) False color composite of Landsat TM image on 28 December 1972, (b): False color composite of Landsat TM image on 13 February 1989, (c): False color composite of Landsat TM image on 29 January 2001, (d): False color composite of Landsat TM image on 15 February 2010, (e): False color composite of Landsat TM image on 21 February 2018.

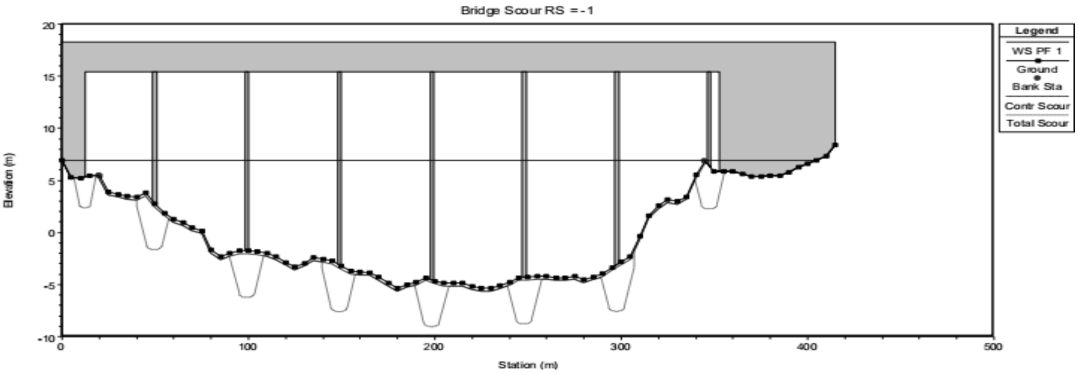


Figure 5. Variation in scour at piers and abutments.

Pier Size & Scouring**:** In the case of proposed bridge, the pier width is assumed to be 2.0 m. It was seen that if this diameter is increased the scour depth increases around the piers. (Table 6)

Table 6. Scour depth around variable pier width (9.9).

Pier Diameter	Local scour depth below lowest initial bed level at Pier (-5.5m MSL), m	Scour level, (m) MSL	Scour depth below SHWL (+ 6.95 m, MSL)
1.00	2.91	-8.24	15.19
1.50	4.16	-9.49	16.44
2.00	5.41	-10.74	17.69
2.50	6.60	-11.93	18.88
3.00	7.50	-12.83	19.78

4.2 *Countermeasure against Scouring*

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 as shown in figure 6(a). Considering the safety of the piers against thalweg shifting, the maximum scour levels should be used for all the piers in the main channel. The typical arrangement of the pile group in the bridge site is as shown in Figure 6(b).

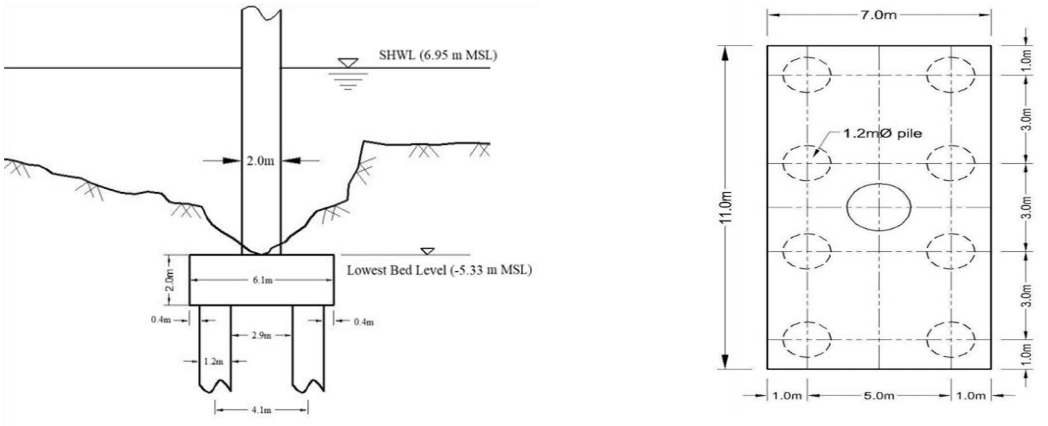


Figure 6. (a) Location of pile cap with respect to the river bed (b) Typical arrangement of the pile group (source: Design Unit, RHD).

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. The recommended protection of slope for the abutment would be with CC blocks with dimensions of 400mm×400mm×200mm, while the apron would be protected with the mixture of 300 mm (40%) and 400 mm (60%) CC cubes in order to sustain flow velocities produced during extreme flow conditions.

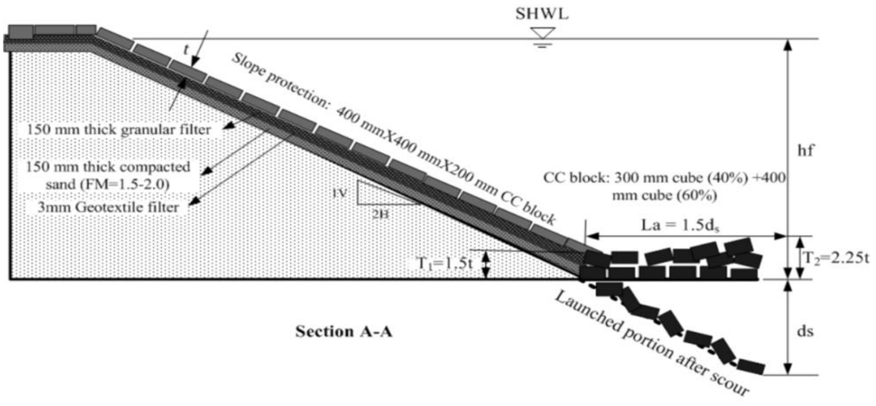


Figure 7. Typical abutment protection (t = 450 mm, Apron length (La) = 1.5 times of the scour depth around abutments, T1 and T2 are inner and outer edge thickness of apron, respectively).

5.4 *Planform Analysis*

The change in planform over the 46-year period over the bridge site is shown in figure 8. Planform analysis during the period from 1972 to 2018 shows that the river at the proposed bridge site has no significant shifting during the observation period. Cross sectional analysis shows steep bank slope at the outer bank of the river at the bridge section which is indicative of no recent bank erosion activity. Historical evidences (from planform analysis), recent measured and observational evidences (from cross sectional analysis, plan view)– all show no evidences of significant bank erosion at the river reach in the bridge section.

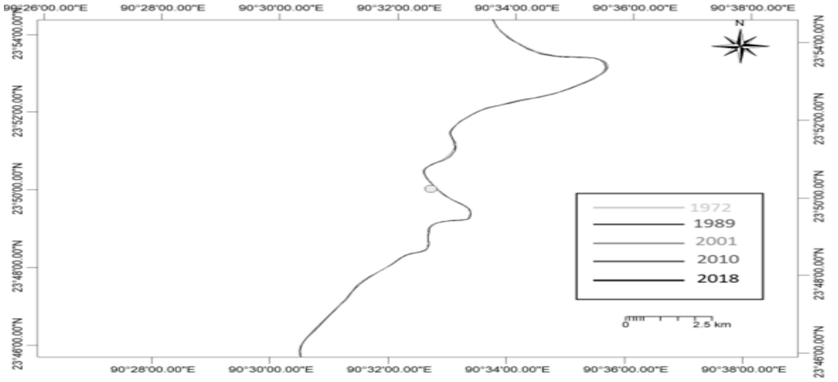


Figure 8. Shifting of center line of the river around the proposed bridge.

5 CONCLUSIONS

Planfrom analysis showed no major shifting of the Shitalakhya river near the Kanchan bridge site. Again, cross-sectional analysis, plan-view observation of the site showed no evidence of significant bank erosion. at the bridge site shows that right bank of the river is already protected at the bridge site. This bank protection will serve the purpose for the safety of the bridge. However, both right and left bank should be monitored for bank erosion and if needed protection should be provided following the existing protection work at the proposed bridge site.

Summarizing the scour analysis of this study of the Kanchan bridge site it is observed that, estimated results of pier scouring obtained from analytical method produced higher amount than the model produced scouring while estimated results of abutment scouring obtained from analytical method produced lower amount than the model produced scouring. Another findings from the study was that scour was increasing as the pier size was being increased.

On construction of a bridge, possibility of river shifting & river bed scouring should be examined regularly throughout the service life spans to take necessary actions promptly. It is however difficult to use & requires deliberations to run proper simulations. Further development of computational simulation & visualization technologies is necessary & will help place computer aided bridge simulations into the hands of practitioners.

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