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A STUDY ON OPTIMIZATION OF RIVER TRAINING AND BANK PROTECTION WORK FOR PAIRA BRIDGE PROTECTION

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Abstract

A study was undertaken to optimize the river training and bank protection work for the safeguard of the bridge on the Paira River on Barisal-Patuakhali Road using scale modelling. About 3.0 km river reach including the bridge was reproduced in this study. The study shows that the length of the revetment required along the Paira river bank is 921 m & 554 m respectively at the upstream & downstream of the Varani khal mouth. The curved length of the upstream & downstream termination of revetment in the Paira river at the crest (top) of embankment is 41.9 m, at the inner side (end of slope pitching) 60.2 m and at the outer side (end of launching apron) 206.8 m. The research also reveals that maximum local scour near the revetment is 19 m (-52.5 mPWD), Pier No.18 experiences maximum local scour around it which is 8m (-30.5 mPWD). It is found that maximum velocity around the revetment and bridge piers is 3.04 ms^{-1} and 2.88 ms^{-1} respectively. Maximum velocity of 2.2 ms^{-1} is found around the pier no. P18 and maximum velocity is 3.1 ms^{-1} at the downstream termination of revetment with 100-year return period discharge. The maximum velocity along the left bank at upstream of bank revetment is found 2.62 $ms^{-1}$and at downstream of it is 3.04 ms^{-1}. Severe flow concentration at the left bank of Paira River adjacent to the Varani khal and Paira bridge is observed with present planform and ebb flow condition.

Keywords: *Bridge, Bank protection, Optimization, Pier, Revetment, River training, Scour, Velocity.*

Introduction

At present, Paira Bridge is constructed over the Paira River. But the model study was done at RRI before its construction in the real field. The bridge is constructed as per recommendations based on model study conducted at RRI. The objectives of the model study were to find out the maximum scour around the bridge piers, sheet piles, abutments etc. with detail analysis and give necessary recommendations with priorities after installing sand on river bed, to find out the maximum scour around the river training structures with detail analysis and give necessary recommendations, to find out the maximum velocity around the structures and river behaviour around the bridge during peak flooding condition, to find out the flow field around the structures and to find out the scour and sedimentation around the structures and also to suggest the dredging area sedimentation phenomenon occurred by bed loads. The bridge should be protected in a manner to guarantee the stability of the bridge for its intended design life. Under the above circumstances, it was mandatory to carry out research through scale modelling at RRI to address the present and future existing problems. The river width at the ferry terminal is about 450m (as per survey) and the river is a tidal one with reported tidal variation of (+/-) 2m. The Paira River originates from Pandab River in Koloskati union of Bakerganj upazilla of Barisal district. The river flowing down southwards by the side of Lebukhali, meets the Patuakhali River just at the upstream of the ferry terminal and the combined flow moves further down as Paira River and crosses Amtoli of Barguna district. The river is about 90km long. Its recorded depth at Amtoli was 20m in monsoon and 12.5m in winter. Its catchment area is reported to be 557 km^2. The normal direction of flow is from north to south. The existing ferry ghat is located just below the confluence of the Paira and Patuakhali rivers. At proposed bridge location the maximum depth from water surface was about 43.4 m. Deepest elevation of river bed at bridge location was (-) 42.4 mPWD. It moves further southwards and falls in the Bay of Bengal as Burisshawr River. (RRI, 2016)

Design discharge at HFL 3.24 mPWD was 12,697.94 m^3s-1 at proposed bridge location and the corresponding average velocity 1.57 ms^{-1} were mainly considered in the model study (Volume I, Hydraulic and Morphological Study Report, 2014, Paira Bridge in Bangladesh). But other WL and discharge were also used for 25, 50 & 100-year return period as advised and supplied by Mr. Tapas Das, Senior Hydraulic/River Training Engineer of ICT Ltd. India. The slope was 8.27cm.km^{-1} within the study area, which was considered to estimate the water level at the proposed bridge location. As per requirement, RRI conducted test runs to determine the maximum scour and velocity around the bridge piers & bank protection works and to optimize the bank protection works. It is required to make proper Environmental Management Plan (EMP) and Environmental Impact Assessment (EIA) due to construction of Paira bridge at Lebukhali area under Patuakhali district. Md. Hamidul Islam et al, 2014 studied the EMP due to industrialization at Lebukhali area under Patuakhali district. According to them, enhancement of tree plantation programs, dredging of river, waste management and use of environmentally friendly technology ensures proper EMP. Islam *et al.* (2017) studied the EIA due to Paira bridge at Lebukhali area under Patuakhali district. According to them, the major environmental impact would be air pollution, water pollution and waste siltation, river erosion, migration, loss of agricultural land etc. They designed an EIA on the basis of ecological, physio-chemical and human interest for construction of bridge. They also prepared EMP to minimize and control of negative impacts during pre-construction, construction and operation/management stages for its sustainability. The study found that there were no significantly sensitive ecological, physicochemical socio-cultural impact in the area. The environmental impact value was estimated +2 (Positive two) shows the acceptance of this project. This bridge will help to mitigate the transportation

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problem as well as increase the socio-economic development of southern coastal region of Bangladesh.

Alam *et al.* (2020), studied the use of high strength concrete (C-60) in Paira bridge (Lebukhali bridge), Bangladesh. They observed high cement content, low water cement ratio, high quality materials, chemical admixtures and mineral admixtures such as silica fume, fly ash and slag with appropriate proportion would result in a high strength concrete. Proper curing of concrete is also necessary in this regard. Selection of mix proportion for concrete grade-60 was finalized in Paira bridge after doing many trial mixes with low water cement ratio and higher cementitious material since these two are the key way to obtain high strength concrete. High strength concrete like C-60 can be used in large infrastructure for its added advantages.

Paira Bridge is one of the first bridges in Bangladesh to have a bridge health monitoring system. The length of the bridge is 1.48 km. The bridge has been constructed at a height of 18.3 meters above the water level to facilitate navigation. Not more than one pillar of this bridge has been placed in the river. N. Alam *et al*. (2020) also studied the Bridge Health Monitoring System (BHMS) of Paira bridge. They concluded that life span of structures needs to be increased to ensure sustainable development. With proper health monitoring life of structure could be increased. BHMS give us opportunity to know about any structural damage in real time. So, it is possible to repair quickly and protect structure from greater damage. Proper use of BHMS would increase bridge sustainability. Beg and Beg (2013) tried to reduce the depth of scour by placing the riprap around the pier, providing an array of piles in front of the pier, a collar around the pier, submerged vanes, a delta-wing-like fin in front of the pier, a slot through the pier and partial pier-groups and tetrahedron frames placed around the pier. He also presented a detailed review of the up-to-date work on scour reduction around bridge piers including all possible aspects, such as flow field, scouring process, parameters affecting scour depth, time-variation of scour. Shunyi *et al.* (2019) presented the protective effect of one active countermeasure named an "anti-scour collar" on local scour around the commonly used cylindrical bridge pier. According to the experimental results, it can be concluded the application of an anti-scour collar alleviates the local scour at the pier effectively and the protection effect decreases with an increase in the collar installation height, but increases with an increase in the collar external diameter and the protection range.

Methodology

About 3.0 km length of the river including tentatively 1.5 km upstream and 1.5 km downstream of the proposed bridge was reproduced in the movable bed model. It was an undistorted model having horizontal and vertical scale 1: 100. Model bed and bank were composed of fine sand having d_{50} about 0.085mm. Maximum flood discharge (50-year return period) of about 12698 m^3s^{-1} was taken to investigate the model with two different velocity scales. One was Froudian discharge, and the other was scouring discharge for scour development. Froudian discharge provided the flow pattern and velocity field as a whole and the scour discharge focused on the scour simulation and sediment transport. The water level and velocity during spring tide and ebb tide were taken into account. This model was run with severe flow condition (flood discharge) in one direction only since the proper development of the local scour around the structure was concerned. Each test of the model continued about 16-20 hours until a dynamic equilibrium scour was reached.

Table 1. Hydro-morphological Parameters for the Paira Bridge Model.

Description	Unit	Prototype	Model	Scale
Length, L	m	4000	40	100
Top width at CSU27	m	956	9.56	100
Avg. water depth, h	m	10	0.10	100
Water surface slope, i	-	0.00008	0.00008	1
Average velocity, v	ms^{-1}	1.40	0.14	10
Cross-sectional area, A	m^2	9892	0.99	10000
Roughness height (K_s)	m	-	0.025	-
Critical velocity by van Rijn, v_{cr}	ms^{-1}	-	0.125	-
Chezy roughness co-efficient, C	$m^{1/2}s^{-1}$	60	30	-
50-yr discharge, Q	m^3s^{-1}	13861	0.139	100000
Scour discharge, Q_s	m^3s^{-1}	-	0.248	-
Median particle diameter, D_{50}	m	0.00008	0.000085	-
Dimensionless particle diameter, D*	-	1.79	1.90	-
Shields parameter, Θ	-	6.33	0.06	-
Critical Shields parameter, Θ_{cr}	-	0.13	0.13	-
Froude number, Fr	-	0.14	0.14	1
Shear velocity, v*	ms^{-1}	0.091	0.009	-
Critical shear velocity, $v*_{cr}$	ms^{-1}	0.013	0.013	-
Particle Reynolds number, Re*	-	0.88	0.93	-
Reynolds number, Re	-	11798935	11799	-
Sediment Transport by Enguland-Hansen	m^3hr^{-1}	6307	0.09	72130
Critical velocity by Sheilds, v_{cr}	ms^{-1}	0.252	0.126	-
Fall velocity, w	ms^{-1}	0.0048	0.0054	-
Shear velocity/fall velocity, v*/w	-	18.88	1.67	-

There was a close water circulation system in the model controlled by discharge measurement weirs, tail gates for water level control, gate valve for water flow etc. The performance of each model test runs was analysed and evaluated and accordingly the next test run had been planned/finalized after discussing with the client to achieve a concluding recommendation. he model was calibrated on the basis of prototype water levels, flow velocities and sediment transport data. The sediment feeding in the model was done artificially for sediment balance in the model and it was done manually looking at the formation of the bed forms. Continuous monitoring of the model bed was done by taking soundings of the model bed. Generally, the rate of sediment feeding for a particular model discharge was determined first by using sediment transport formulae/ relation proposed by different researchers. For this model the sediment transport formulae proposed by Engelund and Hansen (1967) had been used to determine the initial sediment feeding rate. The sediment feeding rate, however, had been calibrated. The calibration of sediment feeding rate had been done by taking measurements of bed levels along a few cross-sections located at different parts of the model at a regular interval of time. Calibration of sediment feeding rate involved a condition where bed level remained more or less unchanged. It means whatever sediment is fed into the model is transported out of the model. In **Table 1**, the scale factors for the prototype and model have been obtained for different parameters (RRI, 2017).

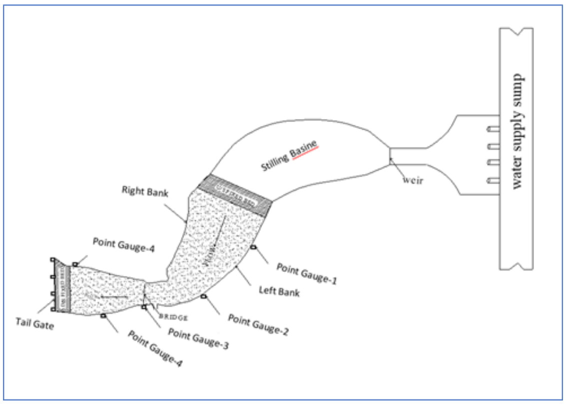

Fig. 1. Layout of the model**.**

The model was setup in the indoor model bed (100m X 30m) of RRI. The length of river reproduced in the model was about 3.0 km (1.5 km upstream and 1.5 km downstream of the proposed bridge and full width of the river). The model bed was constructed on the basis of topographic, bank and bathymetric survey of September 2016. After calibration of the model the application tests were conducted with 50-year return period discharge of 12,698 m^3s^{-1} at the bridge section and corresponding water level of 3.24 mPWD. These data were used to measure the flow velocity, scour depth and float tracking. The model setup consisted of model bed preparation, water circulation system, construction of stilling pond, installation of point gauges and measurement of water level, discharge, velocity and outflow condition. The model setup for this model was done using the available indoor facilities of RRI. The model layout is shown in **Fig. 1**.

Results and Discussion

Bank erosion is found in all the tests at the left bank, upstream of the Paira bridge. However, the proposed upstream termination for bank protection work is sufficient to protect the embayment of the bank protection works from bank erosion with present flow condition and planform **(Fig 2).** Bank erosion at the left bank downstream of protection works is also observed but it will not be harmful for the bank protection works. Maximum local scour measured near the bank protection works varies about 5.9m (-23.2 mPWD) to 19m (-52.5 mPWD) around the cross sections CS-16US (T5) and CS-06DS (T2) respectively **(Table 3).** Local scour is measured at bridge piers P17, P18 and P19 and in front of the bank protection structure in the region of cross section CS-20US to CS-10DS **(Table 4).** A typical cross- section showing the local scour near the bridge is shown in **Fig. 3** (T4).

Fig. 2. U/S termination of revetment prevents the embayment due to river bank erosion (T5).

Table 3. Summary of maximum local scour near the revetment in different tests.

Test No.	C/S No.	Dist. from L/B (m)	Final bed level (mPWD)	Initial bed level (mPWD)	Net scour (-) / deposition (+) (m)
T2	CS-06DS	110	-52.5	-33.5	-19
T3	CS-08DS	88	-44	-29.5	-14.5
T4	CS-06DS	82	-50.8	-34	-16.8
T5	CS-16US	71	-23.2	-17.3	-5.9

Table 4. Summary of maximum local scour around piers in different tests.

Test No.	Maximum scour, (m)	Initial bed level (mPWD)	Final bed level (mPWD)	Remarks
T2	-3.40	-20.3	-23.7	No protection works around P18
T3	-6.50	-22.50	-29.00	Mild protection works around P18
T4	-8.00	-22.5	-30.5	Mild protection works around P18
T5	-2.00	-27	-29	More protection works around P18

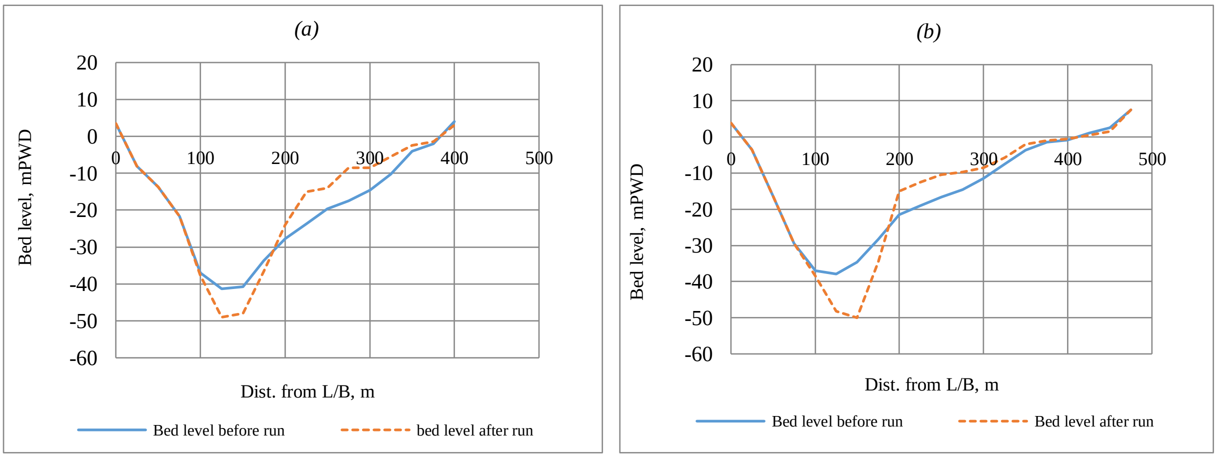

Fig. 3. Local scour at (a) u/s (CS-02) and (b) d/s (CS-02) of bridge in test run (T4).

There is sedimentation tendency at the right bank (CS-00 to CS-26DS) just opposite to the Paira bridge and also at Pier-19 for the present approach flow condition. The existing working jetty is also restricting the bank erosion at this location and accelerating sedimentation along the right bank (**Fig. 4**). This influences more flow concentration between the left bank protection works and the pier P18 after inclusion of the proposed structures. A typical cross section showing the local scour near the bridge is shown in **Fig. 5** (T5).

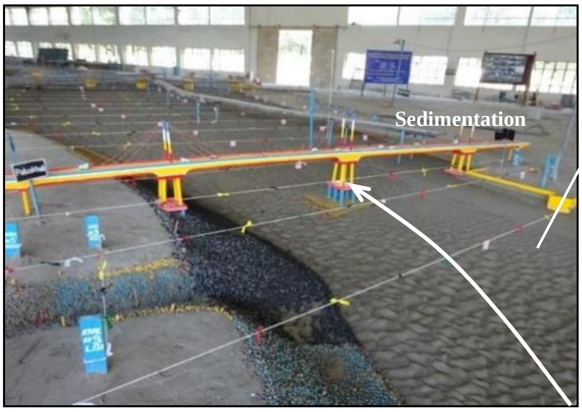

Fig. 4. A view of model bed showing the sedimentation at the right bank.

Scour depths have been found by using scale model tests and empirical formula as shown in **Table 5**. There are a lot of empirical formula to determine the scour around bridge piers. These empirical formulas have been selected randomly. The scour depths obtained from the model study are less than that of from empirical formula. There may be several reasons. The empirical formulas have some limitations where the values of some parameters are assumed. Scale modelling has also some limitations such as scale effects. As a result, sour depths did not match. Scale modelling can provide better results than empirical formula if scale effects are carefully assessed. For this reason, scale modelling is recommended for the vital water resources projects of the world. The project will not be economically viable if more scour depth than the required is considered for design. On the other hand, if the less scour depth is considered, the structure will be unsafe. Sometimes, it is necessary to visit the field condition by the designer. So, optimum scour depth will be considered from design point of view. In this case, the designer should carefully select the required scour depth around bridge pier considering the above factors. **Table 6** shows the comparison of scour, velocity and protective materials among different tests.

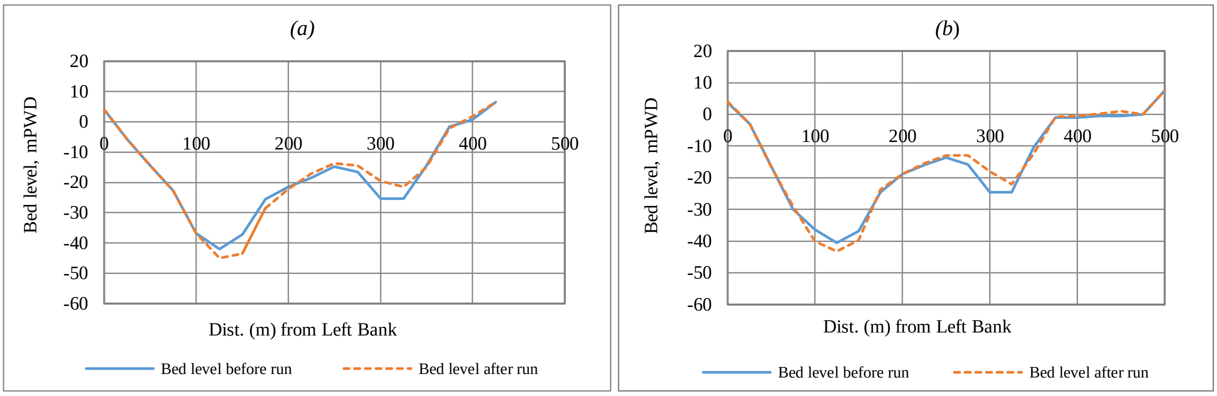

Fig. 5. Local scour at (a) u/s (CS-02) and (b) d/s (CS-02) of the bridge and the corresponding initial & final bed level in test T5.

Table 5. Comparison of Scour Depth by Using Scale Modelling and Empirical Formula.

*Scour determination by Empirical Formula around pier P18		Scour measured from model tests around pier P18		
Using Empirical Formula	Scour, m	Tests	Scour, m	Remarks
1) C.S.U. Formula $\frac{d_s}{y}=2\times k_1\times k_2\times k_3\times k_4\times(\frac{b}{y})^{0.65}\times(Fr)^{0.43}$ Here k_1 : Following pier shapes correction factor 1 k_2 : About the angle of incidence flowing correction factor 1 k_3 : About river bed condition correction factor 1.1 k_4 : About size of river bed material correction factor 1	6.73	T1	1.30	No pier protection
2) Neill Formula $\frac{d_s}{b}=1.5\times(\frac{y}{b})^{0.3}$	9.95	T2	3.40	No pier protection
3) Laursen Formula $\frac{b}{y}=5.5\times\frac{d_s}{y}\times[(\frac{d_s}{11.5\times y}+1)^{1.7}-1]$	11.2	T3	6.50	• Pier protected by cc blocks (top) and geo-bags (bottom) Unprotected space is more between toes of pier protection and revetment protection
4) Melville Formula $\Rightarrow Fr < 0.5$ $11.5\times y=\frac{d_s}{(1+\frac{0.182}{\frac{d_s}{b}})^{0.589}-1}$	11.22	T4	8.00	▪ Pier protected by cc blocks (top) and geo-bags (bottom) • Unprotected space is more between toes of pier protection and revetment protection
5) Froehlich Formula $\frac{d_s}{b}=0.32\times\Phi\times(\frac{b'}{b})^{0.62}\times(\frac{y}{b})^{0.46}\times Fr^{0.2}\times(\frac{b}{D_{50}})^{0.08}+1$ Here, Quadrangular pier : 1.3 Circular pier : 1.0 Sharp pier : 0.7	8.16	T5.3	2.00	▪ Pier protected by hard rocks (top) and geo-bags (bottom) ▪ Revetment and pier protection have been increased in test T5 relative to test T4. ▪ Unprotected space is more between toes of pier protection and revetment protection

Table 6. Comparison of Scour, Velocity and Protective Materials among Different Tests.

Test No.	Discharge and Water Level	Maximum scour around pier, m	Maximum scour around revetment, m	Maximum velocity around pier, ms^{-1}	Maximum velocity around revetment, ms^{-1}	Protective materials
T1	Q=13861 m^3s^{-1} WL=3.24 mPWD	-	-	1.84 (P17)	2.31	Only Sheet pile
T2	Q=13861 m^3s^{-1} WL=3.24 mPWD	-3.40 (P18)	-19 (-52.5 mPWD)	2.52 (P17)	2.35	Sheet pile + revetment (cc block + geo-bag).
T3	Q=13861 m^3s^{-1} WL=3.24 mPWD	-6.50 (P18)	-14.5 (-44.0 mPWD)	2.88 (P17)	2.94	Revetment (cc block + geo-bag) modified by RRI
T4	Q=13861 m^3s^{-1} WL=3.24 mPWD	-8.00 (P18)	-16.8 (-50.8 mPWD)	2.74 (P17)	2.64	Revetment [hard rock (200m u/s and200m d/s of pier P17 along left bank) + rest portion cc blocks] + geo-bag
T5.3	Q=15266 m^3s^{-1} (100-year RP) WL=2.50 mPWD	-2.00 (P18)	-5.9 (-23.2 mPWD)	2.20 (P18)	3.10	Revised design of revetment (hard rock + geo-bag) and dredged channel

Conclusion

The following conclusions can be drawn based on the scale model investigation.

Maximum local scour near the bank protection works is measured from 5.9 m (-23.2 mPWD) to 19 m (-52.5 mPWD). Pier no.17, 18 and 19 are in the river. Pier no.17 is located on the left bank which is protected by the hard materials, so no scour is occurred around it. Pier no.18 experiences local scour around its protection and its magnitude is within 2 m (-29 mPWD) to 8 m (-30.5 mPWD) at different locations. Pier no.19 is on the right bank side of the river, where maximum deposition of 1.9 m (-0.6 mPWD) is measured. So, with the present planform and flow condition, there is no possibility of scour around it in near future (within 2-5 years).

Maximum velocity measured around the bank protection works is within 2.35 ms^{-1} to 3.04 ms^{-1}. Maximum velocity around the piers is found to vary from 1.84 ms^{-1} to 2.88 ms^{-1}. Maximum velocity of 2.2 ms^{-1} is found around the pier no. P18. Maximum velocity of 3.1 ms^{-1} is measured at the d/s termination of revetment with 100-year return period discharge. Maximum velocity at different tests along the left bank upstream of the bank revetment is found from 1.81 ms^{-1} to 2.62 ms^{-1} and at the downstream it is 1.92 ms^{-1} to 3.04 ms^{-1}. Severe flow concentration at the left bank adjacent to the Varani khal and Paira bridge is observed with present planform and ebb flow condition. So, this location requires special attention.

The findings of model test in T5.3 (WL 2.50 mPWD and discharge 15266 m^3s^{-1} can be followed for river training works of 100-year return period which produces more severe condition and more representative than Test T4. River training/bank revetment is optimized based on the performance/effectiveness of various design in different tests and also considering the local scour value.

Recommendation

The following recommendations can be drawn based on the scale model investigation.

The length of the upstream bank revetment along the Paira River should be 921m from the centre of Varani khal mouth. The length of the downstream bank revetment along the Paira River is 554m from the centre of Varani khal mouth. The length of the upstream termination in the Paira River at the crest (top) of embankment is 41.9m, at the inner side (end of slope pitching) 60.2m and at the outer side (end of launching apron) 206.8m. The length of the downstream termination in the Paira River is same as upstream termination.

References

BUET and IWM (2008). Manual on Hydrologic and Hydraulic Design of Bridges, Bangladesh University of Engineering & Technology, Dhaka 1000 and Institute of Water Modelling, Mohakhali, Dhaka 1206.

BWDB (1993). Guide to planning and design of river training and bank protection works, design manual. Bangladesh Water Development Board, Ministry of Water Resources, Government of the People's Republic of Bangladesh, Dhaka.

Engelund, F. and Hansen, E. (1967). A Monograph on Sediment Transport in Alluvial Streams. Teknish Forlag, Copenhagen, p. 62.

Hydraulic and Morphological Study Report, Volume I, 2014, Paira Bridge in Bangladesh.

Islam, M. H., Rani, C. and Jahan, R. (2014). Study on environmental management plan (EMP) of proposed leather industry in Lebukhali, Patuakhali, published in the International Journal of Renewable Energy and Environmental Engineering, Vol. 02, No. 04, October.

Islam, M. S., Majumder, M. S. I., Hasan, I., Yeasmin, T., Islam, M. K., Rahman, M. M., Hawlader, N. H. and Sultana, I. (2017). Environmental Impact Assessment of Lebukhali Bridge Construction Project over the River of Paira, Bangladesh. *Journal of Energy, Environmental & Chemical Engineering.* 2(1): 10-15. https://www.doi.org/10.11648/j.jeece.20170201.13

Beg, M. and Beg, S. (2013). Scour Reduction around Bridge Piers: A Review. *International Journal of Engineering Inventions.* 2(7): 07-15.

Alam, N., Shajib, A. S., Hasan, K. and Elahi, M. N. (2020). Use of high strength concrete (C-60) in Paira bridge (Lebukhali bridge), Bangladesh. IABSE-JSCE Joint Conference on Advances in Bridge Engineering-IV, August 26-27, 2020, Dhaka, Bangladesh ISBN: 978-984-34-8313-3.

Alam, N., Shajib, A. S., Hasan, K. and Mamun, M. A. (2020). Bridge health monitoring system. IABSE-JSCE Joint Conference on Advances in Bridge Engineering-IV, August 26-27, 2020, Dhaka, Bangladesh ISBN: 978-984-34-8313-3.

RRI (2017). Physical model investigation for the protection of Paira Bridge over the river Paira under Patuakhali district, Final Report.

RRI (2016). Physical model study for the protection of Paira Bridge over the river Paira under Patuakhali district, Interim Report.

Wang, S., Wei, K., Shen, Z. and Xiang, Q. (2019). Experimental Investigation of Local Scour Protection for Cylindrical Bridge Piers Using Anti-Scour Collars. Department of Bridge Engineering, Southwest Jiaotong University, Chengdu 610031, China, published in the MDPI (Multidisciplinary Digital Publishing Institute).

Viaduct drawings (excluding foundations), vol. 4 of 5, March 2015 for consultancy services for design and construction supervision of Paira Bridge (Lebukhali Bridge) over the river Paira on Barisal-Patuakhali Road (N8), Bangladesh. (KFAED-841).