Tech. J. River Res. Inst. 15(1): 21-30, 2020 (August), ISSN: 1606-9277

NUMERICAL SIMULATION OF FLOODING IN HAOR AREA TO SUPPORT HYDROLOGIC AND HYDRAULIC DESIGN OF ROAD AND ROAD STRUCTURES: A CASE STUDY

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Abstract

River Research Institute has taken up a numerical model study aiming at establishment of the proposed Dirai-Sullah road link and assessment of the devised options to select suitable road alignment and also to determine appropriate type, location and dimension of the road structures in the low laying haor area. At present there is partially completed road link between Dirai and Sullah upazilla headquarters. Establishment of this road link is hampered by the fact that the project area is situated in complex physical and hydrological settings. The study area is hydrologically influenced by the combination of old Surma River and the Champti-Darain River together with many other drainage routes. Rainfall in the adjacent Indian state of Meghalaya largely affects flooding in the study area and the Surma-Kushiyara basin receives water from the transboundary catchments of the Meghalaya, the Barak and the Tripura. A comprehensive hydro-morphological study has been conducted for assessing the existing Madanpur-Dirai-Sullah road (Dirai-Sullah portion) and road structures to determine the appropriateness and adequacy of the existing road alignment and road structures in terms of their sustainability under critical and design hydrological scenarios to suggest appropriate road alignment and type, location, dimension and hydraulic design variables of the proposed road structures, to assess the need for slope protection works and devise their hydraulic design variables. A field survey campaign has been conducted to collect the recent bathymetric and bank line data of the rivers, nearby road alignment and road elevation data, information on existing road structures and physical features in the study area, water level and sediment data etc. as well as DEM of the study area. The study is based on extensive primary and secondary data. A two-dimensional model covering an extent of about 23km of the Champti-Darain River and parts of the Old Surma and other rivers in the study area together with parts of their floodplains has been developed using modelling software MIKE21C. The initial bathymetry of the model is formed by use of the recently surveyed bathymetric data of rivers and topographic data as well as DEM of the study area. The probable discharges and water levels have been identified based on the hydrological data analysis. The model boundary conditions for different returned period discharges have been determined by flood frequency analysis. At some upstream boundaries where measured data were not available, discharge was calculated by slope area method for different return period of flood (20 year and 50 year). The study results shows that the existing Derai-Sullah road alignment except some portion of road and bridge approaches is found to be suitable under likely hydrological and hydraulic conditions. Some portions of the road, the top level of the road is below the design formation level (8.5mPWD). In order to ensure smooth passage of an extreme field discharge one new bridge (103 m) and five new culverts has been suggested with their appropriate locations and dimensions.

Key Words: *Haor, Drainage, Scour, Wave runup, Flooding*

Introduction

Sunamganj district is located in the north-east region of Bangladesh. Dirai and Sullah are two upazilas under Sunamganj district. These upazilas are naturally resourceful with rice and fish cultivation. At present, there is no smooth road communication between these upazilas as the road link between the Dirai and Sullah upazila headquarters is not yet suitable for vehicular movement. While the Dirai upazila headquarter is connected with national road network by RHD zilla road most of the people of these two upazilas can not avail this opportunity easily. The study area is shown in **Fig.-1**. The Dirai and Sullah upazila are situated in the low-lying haor area where in the monsoon season haor starts to get filled by floodwater and by the month of July most of the area in these two upazilas get deeply flooded. As a result, people of this region have to solely depend on waterway communication to move from one place to another. Therefore, in order to connect these isolated upazilas to national road network it is essential to construct and improve the existing Dirai-Sullah road.

If this road is constructed and improved to the status of RHD zilla road,

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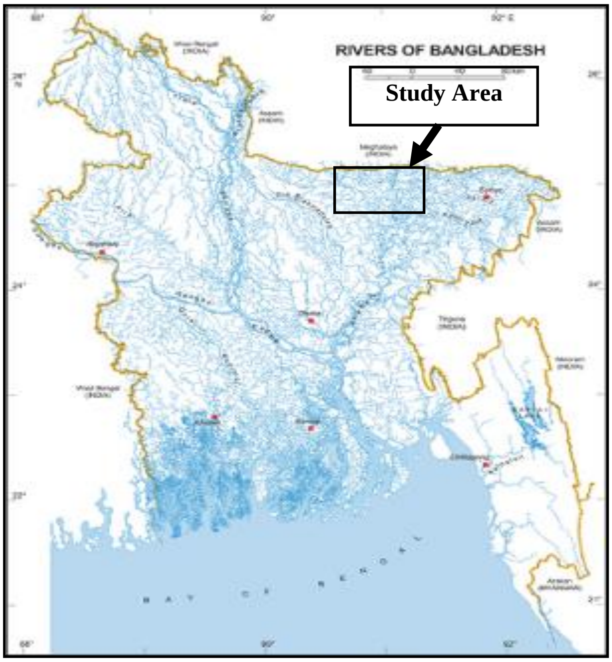

Fig. 1. Location of study area

it will be easier to transport agricultural products from these upazilas to other parts of the country, and people of this region will get transport facilities throughout the year (RHD, Request proposal, 2017). It will connect Sullah upazilla headquarter to the district town and rest of the country. Schools, madrasas and small cottage industries will reap benefit from this roadway communication. As a result, socio-economic condition of the people will improve.

The main purpose of this project is to establish a direct all weather roadway connection between Sullah upazila headquarter and district headquarter Sunamganj as well as rest of the country. The proposed road embankment through the haor will create obstruction to natural flow and will be subjected to wave action on it (BUET, 2008). Bridges often constrict the flow area and bridge piers also enhance this constriction resulting in increase in the velocity, acceleration of scouring process, backwater effect etc.

In this study, MIKE21C tool is suited for river and floodplain hydro-morphological studies and includes modules to describe flow hydrodynamics, sediment transport, alluvial resistance, scour and deposition, bank erosion and planform changes. The modules can run interactively, incorporating feedback from variations in the alluvial resistance, bed topography and bankline geometry to the flow hydrodynamics and sediment transport (DHI 2006).

The main objective study is to determine the parameters for s sustainable road alignment along with structures (bridges and culverts) and to provide the hydraulic design variables including the river training and protective work from hydrological and morphological considerations.

Methodology

In order to conduct the study, needed primary and secondary data and other relevant information have been collected. The primary data have been collected by conducting field survey which includes road alignment, road levels, road cross-sections, location and dimension of existing road embankment, slope protection works, cross-sections of rivers, khals and floodplains, soil and sediment samples etc. The secondary data include historical discharge and water level, digital elevation model (DEM) and satellite images of the study area. The collected data have been processed to derive inputs for the developed of two-dimensional model. The initial bathymetry of the model has been prepared based on field survey data together with DEM of the study area. The road structure data (alignment and elevation, opening and other physical features in the study area) have been used to incorporate the existing road and associated road structures in the model.

A two-dimensional model covering an extent of about 23km stretch of the road from Derai upzilla to Sullah Upazilla which also covered the Champti-Darain River and parts of the Old Surma and other rivers in the study area together with parts of their floodplains has been developed. A curvilinear computational grid of the model has a dimension of 238×5049. It means the length and width of the study reach are represented in the model with 238 and 5049 grid points respectively. The grid is generated covering an extent of floodplain on the both sides of the road. The collected data have been processed for model use format. The initial bathymetry has been prepared using recently surveyed bathymetric (2018) data of the rivers and topographic data. The computational grid and initial bathymetry of the model is shown in **Fig. 2** and **Fig. 3** respectively**.**

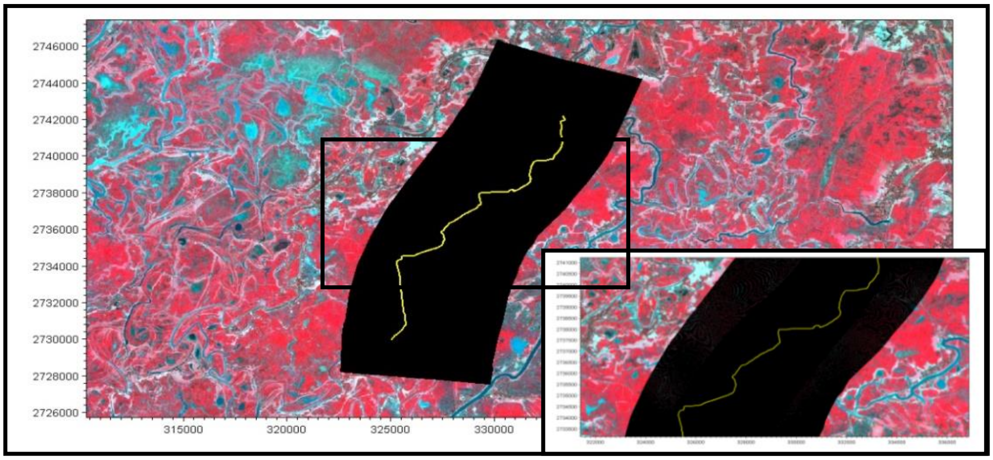

Fig. 2. Computational grid of the model

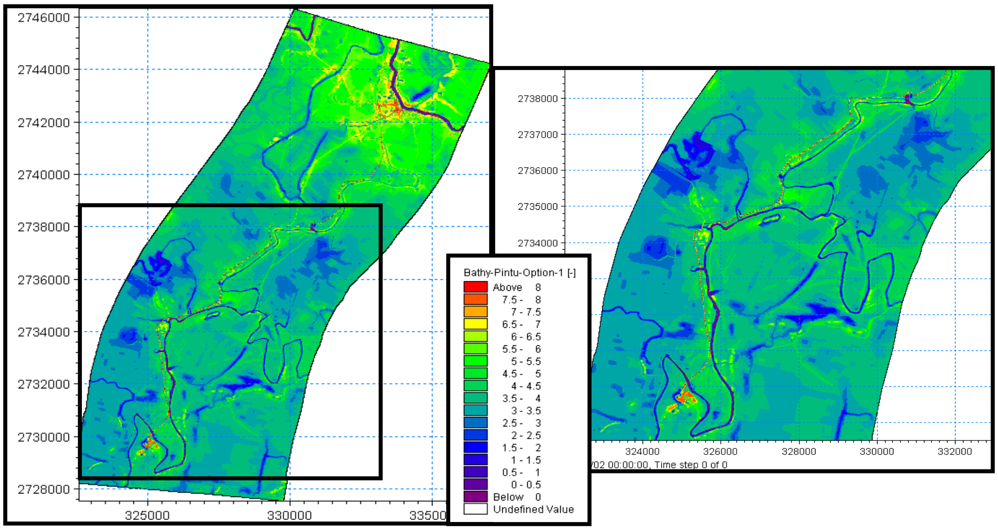

Fig. 3. Initial bathymetry of the model (MIKE 21C)

There is no discharge and water level gauge station within the model area. The flow enters into the model domain through two boundaries and leaves model domain through one boundary. The flow of the Old Surma River enters into the model domain through north and east boundaries. Water leaves the model domain through downstream boundary which covers a long stretch of floodplain. Flow in the study area occurs from northeast to southwest direction. Land slope in the study area also follows the same direction. Since haors act as storage reservoir during monsoon, majority of the flow leaves the model domain through downstream boundary. Downstream boundary data of the model are obtainable from the recorded historical water level data at Markuli and Ajmiriganj that are not much away from the downstream boundary. On the other hand, upstream boundary data of the model are obtainable from the recorded historical discharge data at Sunamganj. At the Old Surma off-take, the discharge of the Surma River gets divided between the Old Surma River and present course of the Surma River. Majority of the Surma river flow occurs through the new course. There is no other discharge gauge station between Sunamganj town and model upstream boundary. Therefore, the discharge records at Sunamganj town have been used to determine the model upstream boundary.The discharge distribution at the bifurcation point has been determined based on measured cross-sections of the two rivers nearby. Steady state simulations have been made with two return period discharges and water levels. 50 year flood is considered as critical hydrological condition for the road project. The probable water levels have been determined from historical record of annual maximum water levels by frequency analysis using GEV and EVI distribution. On the other hand, the discharges corresponding to design and other water levels have been determined using slope area method. This is done because no discharge data of the small rivers that cross the road is available.

Since the road is already in place in incomplete manner and there is not any scope for selection of a better alternative as the existing road passes through the relatively high elevation land along the Champti-Darain river where there are scattered human settlements. However, there is scope for small modifications in existing road alignment. There are two large road gaps at Nayagaon and Kashipur and local people want these gaps to be closed permanently. At present BWDB constructs submersible closures across these gaps every year to prevent the early flood water from entering the crop land. In view of this fact, three options have been devised for hydrological and hydraulic assessment using the developed model. It is to be noted here that all the three options are almost similar except a little variation in road alignment and some variation in the total road opening.

The model investigation is made to assess the hydrodynamic response of the structures in terms of discharge and velocity through the structures, water level at and along the structures, flood depths around the structures, afflux etc. The analysis is made to assess the performance of the structures under design and extreme discharge conditions.

In Option-1, the alignment of the road and road structures are kept as they are except a bit modification is made to keep the horizontal curve smooth. However, the road gaps at Nayagaon (226m) and Kashipur (161m) are kept closed according to the public demand. The total length of the road (including road structures) under this option is about 18.4km. The road alignment under this option is shown in **Fig. 4**.

The road alignment in **Option-2** follows the same as in Option-1 except a little shift of the road position towards the west at about 614m (along the road) north from the bridge at Sullah upazila headquarter and to the south of the road gap at Kashipur considering straight connection between two ends of the existing road at two road gap locations. This shift in road position at these two locations has been considered for keeping the road away from the river bank as at present there is little or no setback distance between the road and river bank margin. The road gaps at Nayagaon and Kashipur have been kept open allowing the oncoming flow to pass through these gaps. The total length of the road (including road structures) under this option is about 17.7km. The road alignment under this option is shown in **Fig. 4**.

The road alignment under Option-3 follows the same way as in Option-2 but additional 2 (two) road bridges in two road gaps and 5 (five) culverts have been introduced. It is done to avoid blockage of natural connectivity between the river and the floodplain at these locations. The total length of the road (including road structures) under this option is about 17.834km.The road alignment under this option is shown in **Fig. 4**.

Results and Discussions

The hydrologic and hydraulic analysis of road and associated road structures have been conducted by the use of developed two-dimensional numerical model. With the road and associated road structures under three different options in place, the hydraulic performance of the devised options have been assessed with two different return period discharges (20 year and 50 year).

The model investigation is made to assess the hydrodynamic response of the structures in terms of discharge through the structures, through structure velocity, water level and flow depth at the structures and along the road, afflux caused by the road etc. The analysis is made to assess the performance of the structures under design and extreme discharge conditions. The results of the analysis are described below:

Velocity fields

The velocity field at and around the road and associated road structures for different options have been furnished in **Fig. 4**. Due to presence of the road the flow directions have undergone substantial local changes. For all the options, the flow velocity on the floodplain is very low in magnitude (0.0m/s to 0.3m/s) for 50 year discharge. However, through structure velocity is relatively high ranging from 0.28m/s to 0.71m/s (RRI 2018) for the same 50 year discharge. The discharge through the different existing road structures under different options appears in **Table 1**

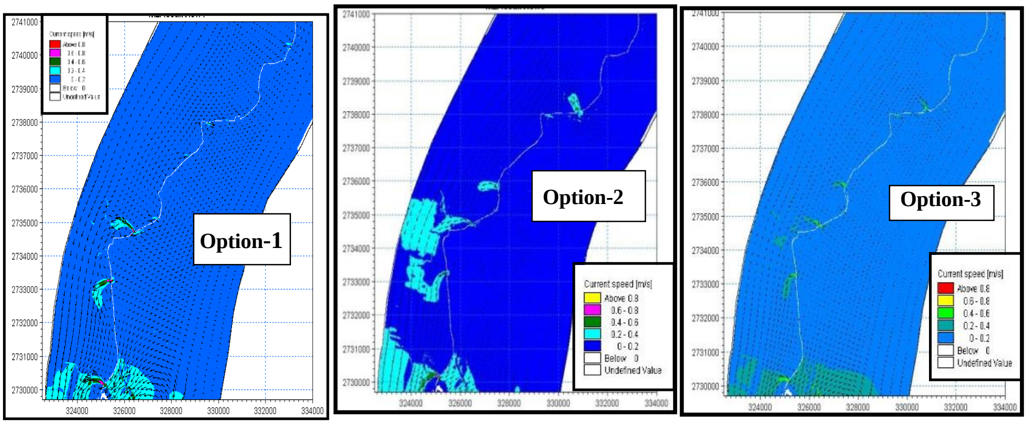

Fig. 4. Velocity field in different Options at and around structures of Derai-Sullah road for 50 year discharge

Since the road structures should be designed for 50-year discharge, the magnitude of flow through each structure corresponding to this discharge and also average and maximum through structure velocity under each option have been extracted from model simulation results. It is found that under Option-1 magnitude of flow as well as velocity through the structure is relatively high for most of the road structures compared to that under Option- 2 and Option -3. It happens due to complete closure of two existing large road gaps at Nayagaon and Kashipur. On the other hand, under Option-2 both discharge and flow velocity through the existing road structures reduce substantially for keeping the same road gaps open. It is revealed from the model simulation results for Option-2 that large flow occurs through these road gaps. Therefore, it will be wise to bridge these gaps against the public demand as it will help maintain natural flow conditions to some extent. Since these gaps are very large it will also not be feasible to construct very long bridge there. Therefore, two bridges of 103m and 76m clear opening and also five culverts in addition to existing ones have been considered under Option-3. It gives fairly reasonable results in terms of flow and velocity through the structures. Total flow through the considered road structures is also reasonable compared to Option-2 condition.

Table 1. Velocity and flow through different road structures under different options for 50 year discharge

SL. No.	Structure description	Option-1		Option-2		Option-3	
		Velocity (m/s) Avg/Max	Discharge (m3/s)	Velocity (m/s) Avg/Max	Discharge (m3/s)	Velocity (m/s) Avg/Max	Discharge (m3/s)
1	Rajapur culvert (3 vent)	0.50/0.55	42	0.31/0.33	26	0.3/0.33	25
2	Rajapur culvert (2 vent)	0.52/0.56	29	0.32/0.33	18	0.32/0.33	18
3	Islampur culvert (1 vent)	0.48/0.48	13	0.28/0.28	8	0.3/0.30	8
4	Nayagaon culvert (1vent)	0.44/0.44	12	0.26/0.26	7	0.28/0.28	8
5	Nayagaon culvert (1vent)	0.44/0.44	13	0.24/0.24	7	0.33/0.33	10
6	Nayagaon culvert(2 vent)	0.45/0.48	25	0.26/0.28	14	0.36/0.39	20
7	Nayagaon bridge (103m)	-	-	-	-	0.52/0.57	188
8	Dhanpur culvert (3 vent)	0.40/0.42	37	0.32/0.33	30	0.4/0.43	37
9	Dhanpur culvert (1 vent)	0.30/0.30	8	0.15/0.15	4	0.31/0.31	8
10	Chandipur culvert(1 vent)	0.35/0.35	10	0.18/0.18	5	0.32/0.32	9
11	Chandipur culvert (2 vent)	-	-	-	-	0.53/0.56	31
12	Kashipur culvert (3 vent)	0.44/0.48	35	0.28/0.29	22	0.46/0.50	36
13	Kashipur culvert (1 vent)	0.38/0.38	10	0.22/0.22	6	0.38/0.38	10
14	Kashipur bridge (76m)	-	-	-	-	0.43/0.46	169
15	Darain culvert (3 vent)	0.49/0.56	43	0.35/0.38	31	0.51/0.56	45
16	Bholanagar bridge (94.16m)	0.60/0.64	244	0.42/0.46	170	0.62/0.70	251
17	Giridhar Culvert(3 vent)	0.54/0.54	15	0.37/0.37	10	0.55/0.59	53
18	Giridhar culvert (1 vent)	0.52/0.52	15	0.29/0.29	8	0.48/0.48	14
19	Giridhar culvert (1 vent)	-	-	-	-	0.43/0.43	12
20	Anandapur culvert (2vent)	-	-	-	-	0.51/0.55	27
21	Anandapur bridge(64m)	0.73/0.84	319	0.55/0.61	240	0.62/0.71	270
22	Sukline culvert (1 vent)	0.58/0.58	17	0.39/0.39	11	0.46/0.46	13
23	Angaruabari culvert (1vent)	0.54/0.54	15	0.38/0.38	11	0.44.0.44	12
24	Angaruabari culvert(2vent)	-	-	-	-	0.5/0.53	28
25	Sullah culvert (3 vent)	-	-	-	-	0.41/0.45	34
26	Sullah bridge(94.16m)	0.65/0.74	413	0.43/0.45	273	0.48/0.53	305

Water Levels along the Roads

The two-dimensional plots of the water levels at and around the road and associated road structures in the study area for different options have been furnished in **Fig. 5**. It is evident from the figures that the afflux caused by the road and road structures is not much high for the considered extreme hydrological condition. Afflux caused by the road varies from 2.0 cm to 4.0 cm. It is clear that water surface slope in the study area is very mild. The water level along the road from Dirai end to Sullah end varies from 7.74 cm to 7.70 cm for 50 year discharge whereas it varies from 7.44 cm to 7.40 cm for 20 year discharge.

Water Depth

The Dirai-Sullah road runs across the low-lying haors and beels that are unique in their hydro-ecological characteristics. In the monsoon season this low-lying haor area starts to get filled by floodwater coming from the trans boundary catchments through both Surma and Champti-Darain systems. Flood (water) depths in the study area and at and around the road for different Option are revealed in **Fig. 6.**

Since the road and road structures are already in place the hydraulic analysis is made incorporating them in the model according to their placement, dimension and orientation as accurately as possible. The Dirai-Sullah road is situated in a low lying area that goes under water during flood season. Therefore, there is possibility that the road embankment could be subjected to wave run-up. At some locations the existing road runs more or less parallel to the rivers that flow through the haor area and the distance between the road and the river bank margin is very less.

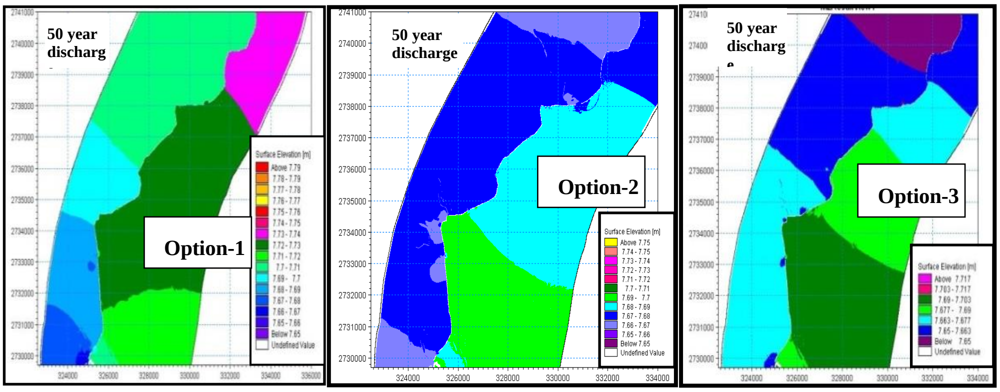

Fig. 5. Simulated two-dimensional plots of water level in the study area for 50 year discharge condition at and around structures of Derai-Sullah road

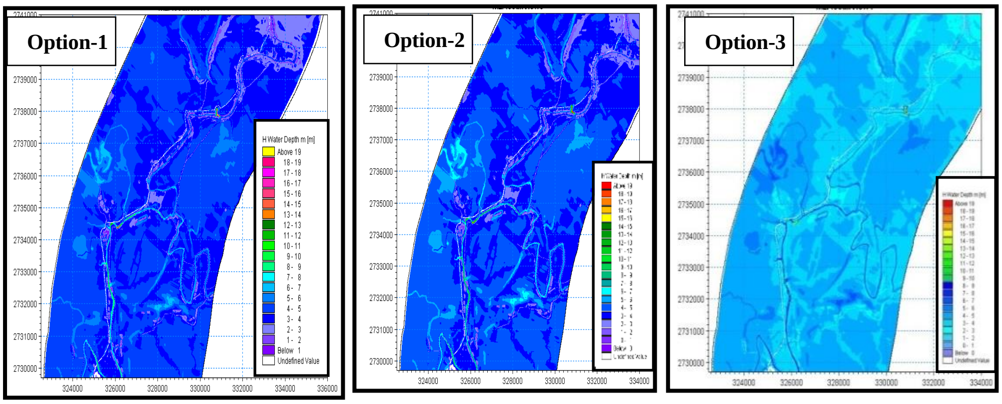

Fig. 5. Simulated two-dimensional plots of water Depth in the study area for 50 year discharge at and around structures of Derai-Sullah Road

Therefore, Option-2 and Option-3 have been devised by changing the existing road alignment locally at some locations where there is no or very less setback distance between the road and the river bank margin.

It is evident that due to blockage of two major flow routes under option-1, most of the flow finds its way southward. As a result, flow concentration occurs at and around the Sullah Upazila Headquarter causing an increase in the flow velocity there. It shows that about 1314m^3/s of flow passes through the 19 (nineteen) existing structures of which 732 m^3/s passes under the two bridges at Sullah and Anandapur. On the other hand, a total of about 1081 m^3/s of discharge passes through the 8 (eight) road structures (3 bridges and 5 culverts) in the downstream (southwest direction) of the blockage at Kashipur, which is about 82% of the total flow that passes through all the existing structures on the Dirai-Sullah road. It means first 11 (eleven) road structures starting from the Dirai end convey only about 18% of the total flow. In Option-2, total flow through the existing structures is 899m^3/s compared to 1314m^3/s under Option-1. However, flow through the two road gaps at Nayagaon and Kashipur is found to be 450m^3/s and 244m^3/s respectively. Therefore, total cross-flow under this condition is 1593m3/s, which is higher than that under Option-1 condition. As in Option-1, majority of flow (about 76%) occurs through the three bridges at Bholanagar, Anandapur and Sullah. It indicates the gaps at Nayagaon and Kashipur should be bridged instead of keeping closed. In Option-3 condition, the total flow across the Dirai-Sullah road is 1641 m^3/s of which 104m^3/s passes through 10(ten) 6m culverts that already exist. The total flow through the five 12m and six 18m culverts is122m^3/s and 223m^3/s respectively. On the other hand, the total discharge through the five bridges including the two newly suggested ones is 1183m^3/s. It means under Option-3, over 72% of the total flow passes through the bridges. It is marked that due to introduction of 7 (seven) newly proposed structures, the average flow velocity through majority of the existing structures decreases compared to Option-1condition. Noticeable decrease occurs in the flow through Anandapur bridge and Sullah bridge. However, a slight increase in the flow through the Bholanagar bridge is noticeable. It appears from the model results that Option-3 is the best among three considered options as it will allow for safe passage of an extreme flood discharge with relatively low flow velocity through the structures. The flood flow through the newly suggested bridges at Nayagaon and Kashipur is found to be 188m^3/s and 169m^3/s respectively. Also under Option-3 condition total cross-flow is higher than that under Option-1 and Option-2 conditions. level along the road varies from Also under Option-3 condition total cross-flow is higher than that under Option-1 and Option-2 conditions. Water 7.65cm to 7.70cm. The average water level is 7.675mPWD.

Slope Protection Works

The road runs through a low lying area. During extreme flood this low area experiences average flood depth of more than 3.0 m with low velocity. Along the existing road 26 road structures (culverts and bridges) have been suggested to allow for safe passage of flood water. The structures have been constructed mainly over the drainage routes that cross the road. No hydro-morphological study has been conducted to decide about hydrologic and hydraulic design parameters of most of these structures. Some of the road structure approaches have got damaged due to hydraulic actions and other reasons. Due to blockage of normal floodplain flow by constructing road, flow occurs parallel to the road embankment that causes damage to road embankment and approaches of the road structures. Therefore, slope of the approaches of road structures is vulnerable to damage by parallel current and thereby, needs protection against such hydraulic actions.

It is revealed from the study that the approach embankment slope protection works will be needed at all bridge approaches and also at 12 stretches of the proposed road. Some of the identified road stretches where slope protection works will be needed have been shown in **Fig. 6**. The hydraulic design data for the existing and newly suggested bridges and slope protection works have been furnished in **Table 2** and **Table 3** respectively.

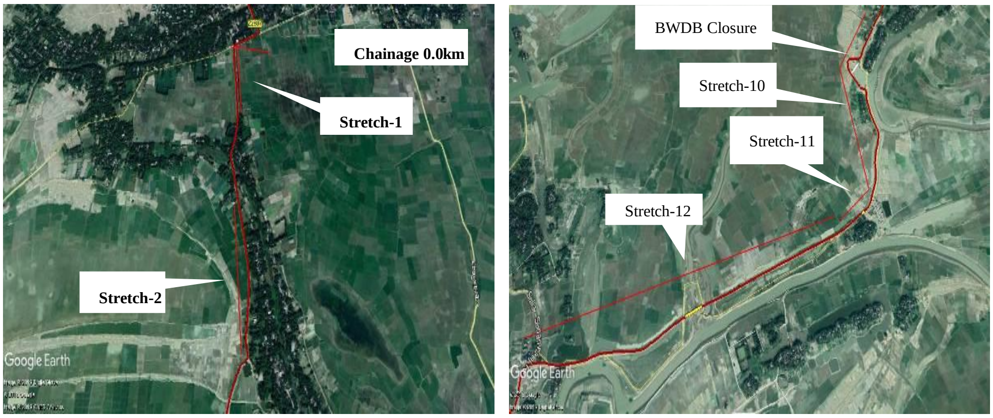

Fig. 6. Some location of vulnerable road Slope Protection Works

Table 2. The hydraulic design parameters of suggested and existing bridges

Road Structure description	Chainage (km)	Length (m)	Design discharge (m^3/s)	Design water level (mPWD)	Maximum velocity (m/s)	Pier Scour level (mPWD)	Abutment scour level (mPWD)
Nayagaon bridge (suggested)	5.40	103.0	188	7.68	0.57	-6.19	-7.6
Kashipur bridge (suggested)	10.02	76.0	169	7.68	0.46	-5.95	-7.43
Bholanagar bridge (existing)	11.94	94.16	251	7.68	0.70	-	-
Anandapur bridge (existing)	14.46	64.0	270	7.68	0.71	-	-
Sullah bridge (existing)	17.63	94.16	305	7.68	0.53	-	-

Table 3. Design parameters for slope protection works

Design flood level	: 7.68mPWD
Velocity	: 0.8 m/s
d_m of silt	: 0.06mm
Depth of flow	: 3m to 5m
Wind speed	: 30 m/s
Fetch length	: 7 km
Wind duration	: 2 hours
Wave height	: 1.4m
Wave period	: 3.6 seconds
Wave runup	: 1.12 m

Navigational Clearances

The rivers and drainage routes that the proposed road crosses do not fall under BIWTA navigational route classification. From June to November the study area remains under water and waterway communication becomes the only means for the people to go from one place to another and to transport goods. Generally people use motor driven boats for this purpose. Based on the information obtained from the local people regarding navigation condition a vertical clearance of 1.5m has been proposed for two newly suggested bridges at Nayagaon (Dhanpur) and Kashipur. The suggested length of these two bridges is 103m and 76m respectively.

Conclusion

Establishment of smooth road communication between Dirai and Sullah upazila headquarters for vehicular movement is complicated because of a number of physical and hydrological factors. The partially constructed road and slope protection works have already been subjected to damage to some extent at different locations due to hydraulic actions and other reasons. The existing road alignment lies on relatively high elevation area along the right side of the Champti-Darain river. This road alignment is suitable with some modifications particularly at places where the setback distance between the road and bank margin is very less. There are twenty existing road structures (bridges and culverts). However, approaches of most of these structures are either not yet constructed or have gotten damaged fully or partially. There are instances of road damage in the form of settlement of road pavement and erosion or washout of approach embankment materials. The road embankment slope failure at unprotected locations and full or partial damage of slope protection works at many protected locations are noticeable. The identified causes of approach and road damage are poor quality of locally available fill material, inadequate compaction, long standing high depth floodwater on both sides of the road, parallel current and wave action.

The flood level corresponding to 50 year discharge varies from 7.65mPWD to 7.70mPWD along the road. The water level slope is very mild. The average flood level is 7.675mPWD. On the other hand, the average flood level corresponding to 20 year discharge is 7.375mPWD. At present the existing top level of a number of road stretches is below the formation level of the road. The formation level of the road is 8.5mPWD. The afflux caused by the road and road structures is not high and varies from 1.0 cm to 4.0 cm for the considered hydrological condition. During flood season very low velocity is observed on the floodplain whereas relatively high velocity is observed only along the main river courses. Two new bridges and five new culverts should be introduced on the road at suggested locations in addition to the existing ones for smooth passage of a extreme flood discharge. These structures should be constructed as per suggested dimensions. Since there is strong public opposition for construction of a bridge as Kashipur it may be omitted and instead the clear opening of the proposed bridge at Nayagaon may be increased by 30m to compensate for this to some extent.

At some stretches of the road, there is no or very less setback distance between the road and the river right bank margin. It will be wise to retire the existing road embankment at those locations to avoid potential risk of road damage due to hydraulic actions. The road gaps at Nayagaon and Kashipur are important for maintaining river and floodplain connectivity. The road embankment may come under wave action at some locations and estimated wave runup is 1.12m. The model simulated flow velocity through the different existing and proposed road structures varies from 0.28 m/s to 0.71 m/s for recommended measures.

Road embankment slope protection works will be needed against the occurrence of parallel flow along the road embankment and wave action. Long standing high water depth on both sides of the road should also be considered as a factor of potential road damage. Approach road slope protection measures should be undertaken at suggested locations and road stretches vulnerable to parallel current, long standing high water depth and wave action.

ACKNOWLEDGEMENT

The authors like to pay gratitude to Road Division, Sunamganj, Roads and Highways Department, Bangladesh for providing financial support and data and information available with them for successful completion of the study.

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