Appendix-7 River Engineering

7.1 INTRODUCTION

7.1.1 Necessity of River Study for Bridge Planning

In order to avoid or alleviate the river-related problems of the bridge project, river studies should be undertaken along with the bridge plan study. The river study first clarifies the river conditions such as physical features of the river and basin, meteorological and hydrological situation, historical changes of river channel, flood and sediment flow conditions, etc. Then, crossing location of the bridge is selected appropriately based on the understanding of river conditions, and hydraulic values for the design of relevant facilities are established. In more concrete term, the river study is necessary for bridge plan on the following grounds:

Selection of Crossing Site: River changes its plan-form and cross section from time to time. Selection of crossing site regardless of channel stability may bring about difficulty in operation and maintenance after the construction of bridge. Stability of river and riverbanks are key factors for minimiz ing river work cost and ensuring the sustainable use of the bridge.

Hydraulic Design Values: Design of bridge, approach roads and other relevant facilities needs hydraulic values standardiz ed based on statistical analysis. The facility design and work plan with less understanding of river nature would bring about collapse of the facilities and suspension of the works.

Design of River Works: A bridge site should be trained by river works so that the river flows always take route under the designed bridge opening without causing serious erosion and scouring damages. The river works for the bridge project crossing for such a large river as the Padma require a large amount of cost, and the river study would contribute to minimiz e the cost reasonably.

Influence to Flows: Bridge facilities, especially the substructure and approach roads may influence the flood flows in the river channel and inundation conditions in the adjacent flood plain. These facilities can be planned and designed so as to alleviate the adverse effects based on the river study.

7.1.2 Tasks of River Study

In view of the above, major tasks of the river study for the Padma Bridge project are:

1) To clarify meteorological and hydrological conditions of the Study Area,
2) To grasp historical movements of the river course and riverbanks of the Padma,
3) To establish hydraulic criteria for facility design in due understanding the flood flows and sediment transport at the crossing locations, and
4) To propose river works to guide river flows and protect bridge structures.

Out of the above, the 1st and 2nd tasks are discussed in APPENDIX-5 and APPENDIX-6. Main topics to be discussed here in this APPENDIX-7 are the 3rd and 4th tasks of the above.

7.1.3 Approach to Study

(1) Procedures of River Study

In order to accomplish the tasks, the river study for bridge plan is carried out as illustrated in Figure 7.1.1.

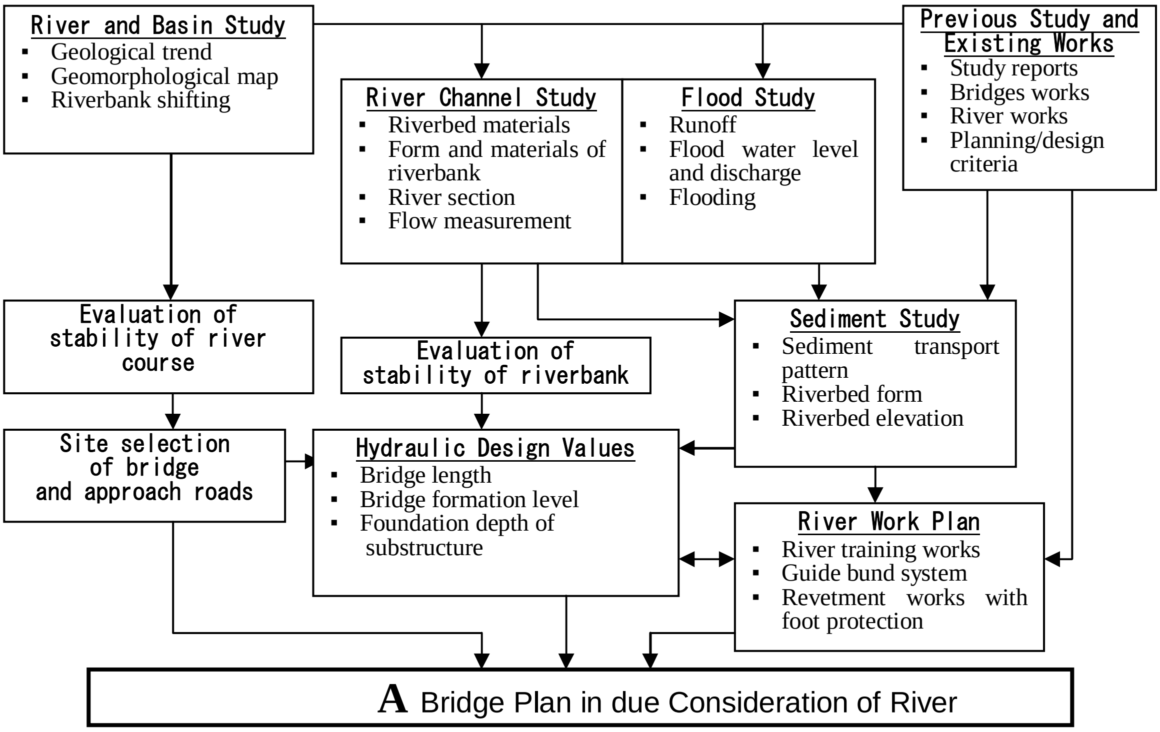


Figure 7.1.1 River Study for Bridge Plan

The study starts from (1) the studies of river and basin characteristics and (2) reviews of previous studies and works. Then, river engineering studies for (3) initial screening and (4) optimum site selection are carried out. Finally (5) the preliminary design of river facilities is prepared for the site finally selected.

(2) Data Collection

Data and information required for the river study were collected from variables agencies and organiz ations. Kinds of data and the source agencies are listed below.

1) Topographic and River Morphologic Data:
- Survey of Bangladesh (SOB)
- Geological Survey of Bangladesh (GSB)
- Bangladesh Space Research and Remote Sensing Organiz ation (SPARRSO)
- Center for Environmental and Geographic Information Services (CEGIS)
- GIS Application Center of Asian Institute of Technology (AIT)

2) Hydrologic and Hydraulic Data:
- Bangladesh Water Development Board (BWDB)
- Bangladesh Meteorological Department (BMD)
- Bangladesh Inland Water Transport Authority (BIWTA)
- Institute of Water Modeling (IWM)
- River Research Institute (RRI)

3) Bridge and Highway Projects Data:
   - Jamuna Multipurpose Bridge Authority (JMBA)
   - Roads and Highways Department (RHD)

In addition to those mentioned above, data and information were colleted also from private consulting firms and individual experts of Bangladesh.

(3) Site Reconnaissance

The Study Area is located near Dhaka. During the field work periods in Bangladesh, site reconnaissance was made from time to time as required. Main objections of the site reconnaissance were:

1) To grasp physical and social conditions of the river and basin in general during the flood rising to flood peak period;
2) To inspect conceivable crossing locations: River channel and bank conditions, approach road, land use, etc;
3) To collect information regarding riverbank stability and flooding/inundation conditions through interview to the local residents;
4) To inspect existing bridges especially for river works; and
5) To inspect existing hydrologic observation facilities.

Due to its wide river channel and difficulty in accessibility of the Padma, finding and information to be obtained by reconnaissance on land are limited. Inspections from the air by helicopter were also carried out before flood season and during flood season, to supplement the land reconnaissance.

7.2 PREVIOUS STUDIES AND WORKS

The Ganges-Jamuna-Meghna is one of the largest river systems in the world and the rivers constituting the system have unique hydrologic and geomorphologic characteristics. In recent years, river engineering especially for the bank protection has made outstanding progress in Bangladesh through the experience of large-scale bridge projects and bank protection projects with international cooperation.

Since 1990s, several bridges have been planed and constructed in Bangladesh. Across the Upper Meghna River, Meghna Bridge (930 m long) and Meghna Gumuti Bridge (1,150 m long) were constructed in 1991 and 1995, respectively. Jamuna Bridge (4,800 m long) was constructed in 1998 across the Jamuna River. Bhairab Bridge (929 m long) across the Upper Meghna River was constructed in 2001 and Paksey Bridge (1,800 m long) across the Ganges River in 2004. Arial Khan Bridge (450 m long) is now under construction across the Arial Khan River. For the implementation of these projects, intensive studies on river morphology and river training works have been carried out.

Studies and projects for Flood Action Plan (FAP) were commenced in early 1990s. The FAP studies, among others FAP-21/22 (Bank Protection and River Training Pilot Project), and other bank protection projects such as JMREMP (the Jamuna-Meghna River Erosion Mitigation Project) contribute much to the development of technology in this field. Besides these, guidelines and standards have been prepared compiling conventional river works developed in Bangladesh, India and other surrounding countries and available for the present study.

In 1999/2000, Pre-feasibility Study of Padma Bridge was conducted. The study includes basic considerations and suggestions applicable to the present Padma Bridge study.

These studies and projects were reviewed hereunder mainly from river engineering point of view.

7.2.1 Jamuna Bridge

Feasibility Study for the construction of Jamuna Bridge was conducted by United Nations Development Programme (UNDP) and World Bank through the consultants, Rendel Palmer & Tritton (RPT), Netherlands Engineering Consultants (NEDECO) and Bangladesh Consultants Ltd (BCL). The study was undertaken in two phases, i.e., Phase-I Feasibility Study from 1986 mainly for selection of the most favorable location for the bridge, and Phase-II Feasibility Study from 1987 to 1989 mainly for development of appropriate configuration for the bridge geometry and preparation of detailed designs for approaches and river training works. After the funding arrangements with IDA, ADB and OECF, physical implementation of the project commenced in October 1994 and the bridge was inaugurated in June 1998 with the name of the Bangabandhu Bridge as a multipurpose bridge with road, rail and gas connections.

Main river related issues for the bridge construction and measures and arrangement taken are introduced below in brief quoting from the study reports.

(1) Response to Risk of River Course Change

The risk of a sudden change in river course, like the flow change from the Old Brahmaputra into the present Jamuna, cannot be completely discounted. However, such a change would take several years to develop and could be diagnosed at an early stage.

Although the west-ward move of the Jamuna River is likely to continue in future, it is concluded that these movements are gradual and can be remedied if the bridge were endangered. As to the west-ward move of the Jamuna River, checking of the past river survey data by BWDB in Phase-II Study could not confirm any significant shifting of the Jamuna River in either direction.

(2) Selection of Crossing Location

Seven possible crossing locations were studied. They are corridors at Bahadurabad, Madarganj, Sirajganj, Mabarpur and Aricha across the Jamuna, and those at Goalundo and Mawa across the Padma.

Evaluation of these corridors on morphological grounds and cost of river-cum-bridge works indicate a preference for the Sirajganj corridor, where a single channel exists and river training works can be connected to existing fixed banks of the river.

During Phase-II Study the existence of hard points, i.e., town protection works at Sirajganj and erosion resistant bank near Bhuapur Ferry Ghat were identified from the aerial photographs and satellite images. Physical model test with movable bed confirmed the effective function of these hard points to prevent outflanking and erosion of approach roads.

The crossing location was decided at about 8 km south of Sirajganj, provided that the hard points can be preserved.

(3) River Width and Bridge Length

The width of the river can be constricted to the width of main channels without causing serious increase in scour depth or backwater effects.

The Dhaleswari River which branches off to the left just north of the bridge is to be closed by an embankment of the eastern approach road to create a proper concentration of the Jamuna River flow towards the bridge.

Based on the existing river width, bridge length was recommended as approximately 6,200m in the Phase-I Study. In the Phase-II Study the bridge length was revised to 4,800m based on the river width at the final crossing location adding 450m-wide areas required for the construction works on each bank.

(4) Working Conditions

Construction of river training works in the channel of the Jamuna would be possible, in principle. In this case large quantities of hard materials resistant to the heavy current forces during construction have to be procured, which would render river training works prohibitively expensive.

Acceptable working conditions could be created by dredging a construction pit in the flood plains. It is further conceivable that such conditions can also be created on sand banks or in shallow channels. In this case the cost of river training would be higher in general, but one could reduce the bridge length and therefore bridge cost. The construction site of guide bund should be decided at least cost basis of bridge-cum-river training works.

(5) Falling Apron

Guide bund is a dike-type earth structure with a crest sufficiently high to prevent overtopping during flood stages. The slope must be protected to resist forces from currents and waves. The river-side slope has to reach down to the maximum expected scour depth.

In the Phase-I Study, the principle of a falling apron was proposed for the under water slope protection to reduce excessive construction cost for complete protection of the slope.

An application of a falling apron reduces the dredging volume and thus the cost considerably, but increases the risk of failure of the guide bund. In the Phase-II Study a special study of the behavior of a falling apron was carried out using physical model in Delft Hydraulics. Finally the falling apron concept was adopted, provided that its behavior and associated risks could be predicted with more certainly.

(6) Guide Bunds or Groynes

During the Phase-II Study, it has been considered whether the application of groynes only, or in combination with shorter guide bunds, could be a viable and feasible solution for constricting the river and guiding the flow under the bridge. From the physical model tests the conclusion was derived that a system of groynes only would not prevent outflanking channels to reach the bridge approaches.

Meanwhile the physical model test demonstrated that a guide bund system performed their function more suitably to counter oblique attack of river flow with their geometry keeping river channel away from the abutment and approach embankments.

A groyne would not cope with the scouring, unless it is protected in the similar manner as the guide bund, and the protection for the groyne would be more complicated than for guide bund.

(7) River Training Work (RTW)

Guide bund (GB) for the Jamuna Bridge was initially proposed, in Phase-I Study, to be 9,800m in total consisting of West GB 3,600m, East GB 3,800m, and 2,400m as additional bank protection along the east bank near Bhuapur ferry ghat.

In the Phase-II Study, it was proposed that the following facilities constitute the RTW for the Jamuna Bridge:

1) Hard points to be maintained at Bhurpur and Sirajganj,
2) Two guide bunds having a length of 2,700m at each bank, and
3) Two groynes, one on each bank, between the hard points and the guide bunds.

(8) Final Decision of Location of Guide Bunds and Abutments

After the recession of the extreme 1988 flood, substantial erosion occurred on the east bank of the Jamuna. Particularly near the bridge site, the erosion was of the order of 500m in width. Owing to this erosion, the location of the East GB had to be reconsidered. It is however difficult to decide exact location since no one can predict how the site conditions change until the commencement of the works.

Therefore it was decided to fix the exact locations on the basis of the overall construction schedule as follows:

1) Location of east guide bund and east bridge abutment after recession of 1990 flood.
2) Location of west guide bund and west bridge abutment after recession of 1991 flood.

(9) Outline of Design Features

Further studies and modification on the project facilities were made in the course of detailed design and construction works, the final design features are outlined below (Figure7.2.1).

1) Length of bridge: 4,800m
2) Length of guide bund: East GB 3,100m +West GB 3,200m
3) Design flood (return period of 100 years)
    - Design high water level: +15.1 m PWD
    - Design discharge: 91,000 m^3/s
4) Maximum expected scour depth: -30 m PWD

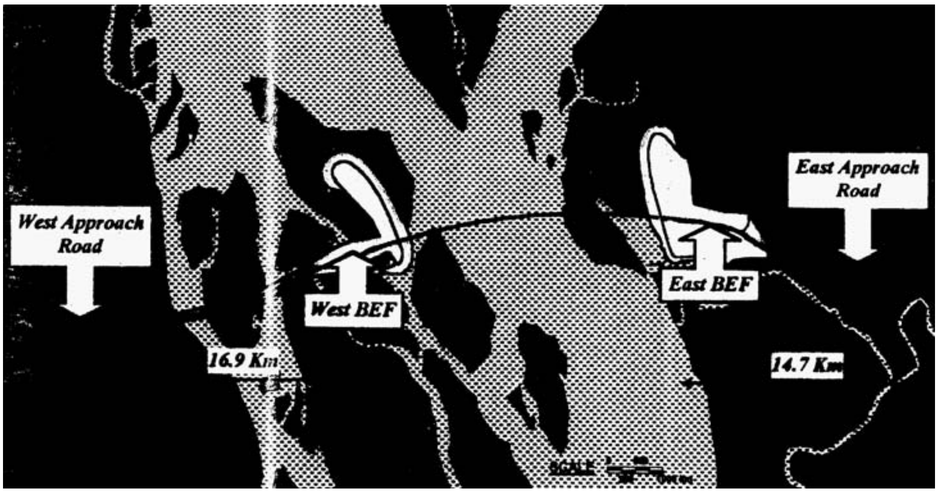


Figure 7.2.1 (a) Jamuna Bridge: General Layout

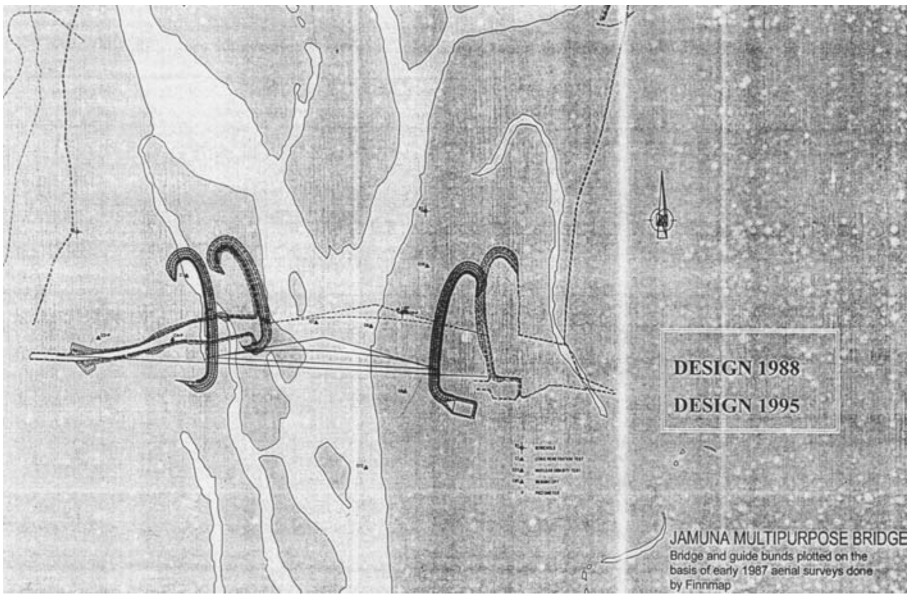


Figure 7.2.1 (b) Jamuna Bridge: Layout of Guide Bunds (1988- and 1995-Designs)

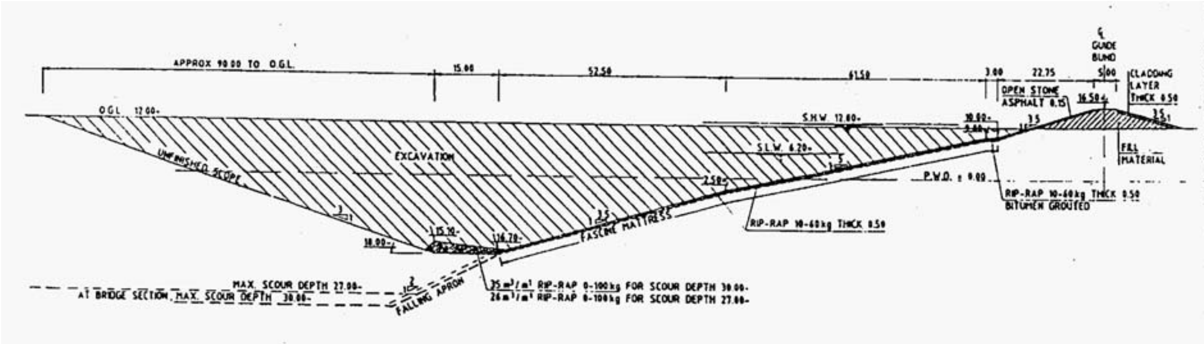


Figure 7.2.1 (c) Jamuna Bridge: Typical Cross Section of Guide Bund

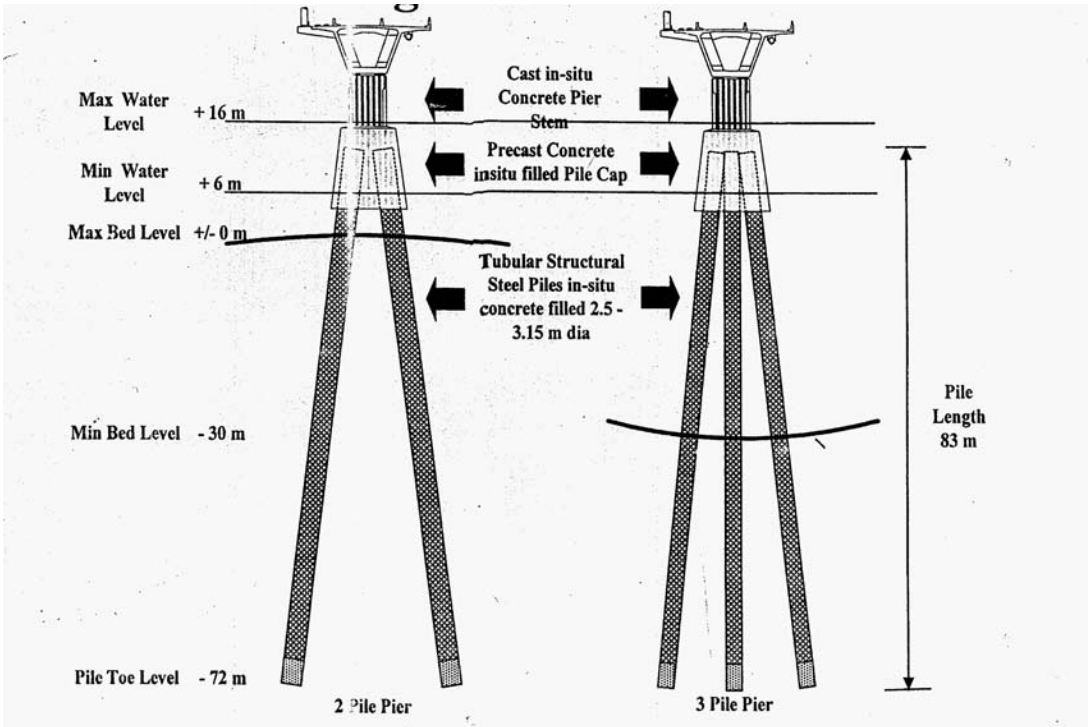


Figure 7.2.1 (d) Jamuna Bridge: Substructure and Foundation

7.2.2 Paksey Bridge

Paksey bridge has total length of 1,786m crossing the Ganges River about 300m downstream of Hardinge Bridge (railway bridge). Detailed design for the bridge was completed in 1996 and the construction works are ongoing with a financial assistance of JBIC. Experience of existing Hardinge Bridge and Jamuna Bridge which was then under construction was incorporated into the planning and design of Paksey Bridge. Major technical issues related with river training works are introduced below.

(1) Lesson Learnt from Hardinge Bridge

Hardinge Bridge was completed in 1915, but after the completion it required very considerable amount of money to repair, extend and replace the river training works during 1920s and 1930s. The reason for this would be essentially that the training works were under-designed. It is also noted that the piers of Hardinge Bridge were protected from local scours by continuous placing rocks, and the rocks have been regularly placed until recent years. For the new bridge, such a recurrent expenditure is unacceptable and it is therefore necessary to engineer so that the river training works perform as planned with minimal maintenance.

Paksey Bridge was planned and designed relying on the existing training works of Hardinge Bridge. Hydraulic design values were also established based on the long period of records kept at Hardinge Bridge.

(2) Protection against Scour

The maximum expected scour depth was estimated at –37.0 m PWD which is 52.2m below the Design Flood Level (+15.2 m PWD). Piers of Paksey Bridge were designed to have no scour protection around them unlike Hardinge Bridge to avoid the very heavy maintenance cost. Coping with the deep scour, slopes of the guide bank above –15 m PWD are protected with revetment set at 1:2.5 and 1:3.5, and below the elevation, launching apron was placed horizontally for 20m in width.

The launching apron had been proven to work well in particular where the river bed and banks were highly erodible and uniform. The method however does not always work well on clay strata or any other material resistant to erosion forming a steep cliff. The frequent failures of the protection works at Hardinge Bridge are said attributed to the presence of layers of clay and other erosion resistant material in the banks.

For the launching apron at the very bottom of the revetment, dumped stone is considered the only viable option, but it should be used to a limited degree below the depth where dredging is practically difficult.

(3) River Training Works

River training works for Paksey Bridge are planned in principle to extend the existing guide bank of Hardinge Bridge.

Main morphological issue in the project area is that the riverbank on the right (west) side downstream of Hardinge Bridge is steadily eroded over the past decade or more. This brings about the difficult selection whether the right guide bank should be extended with the work under water or the bridge should be extended with an extra span. The left bank work is easier allowing construction of deep revetment works away from flowing water.

(4) Outline of Design Features

Figure 7.2.2 shows the outline of design features of Paksey Bridge which is now under construction.

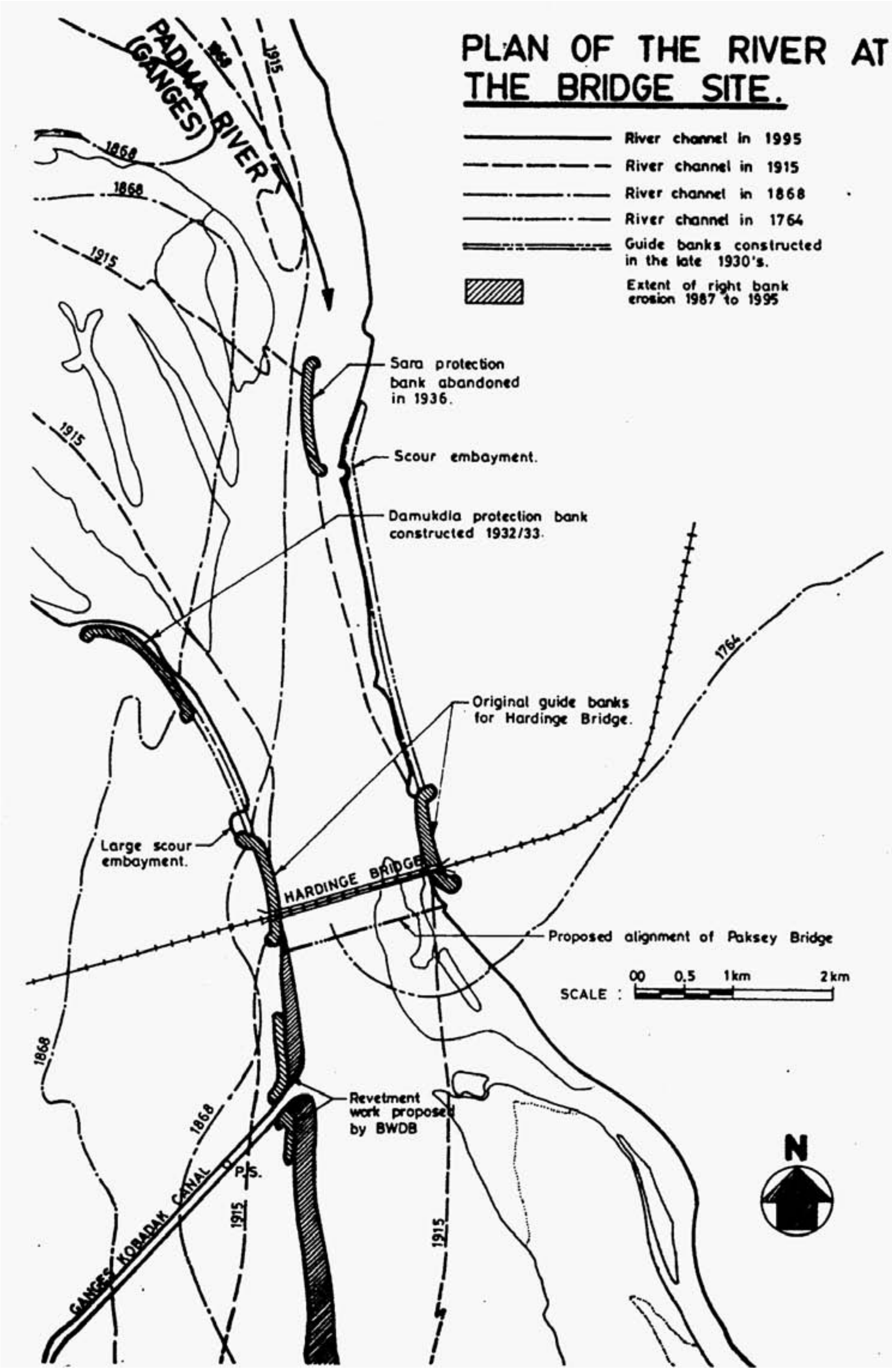


Figure 7.2.2 (a) Paksey Bridge: General Location Map

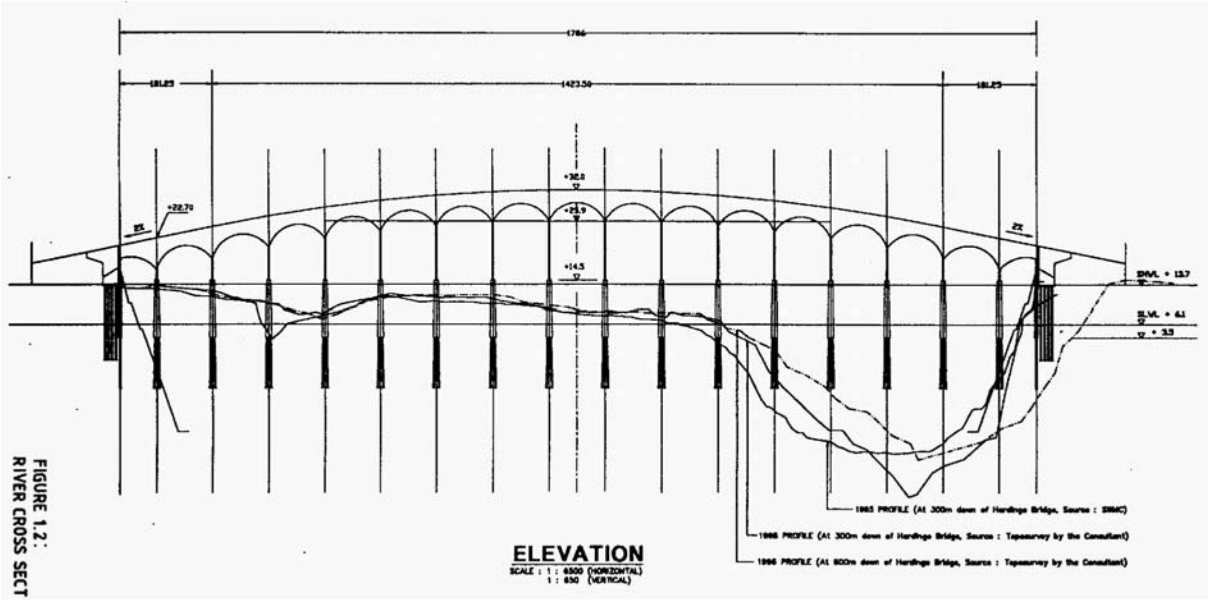


Figure 7.2.2 (b) Paksey Bridge: Elevation

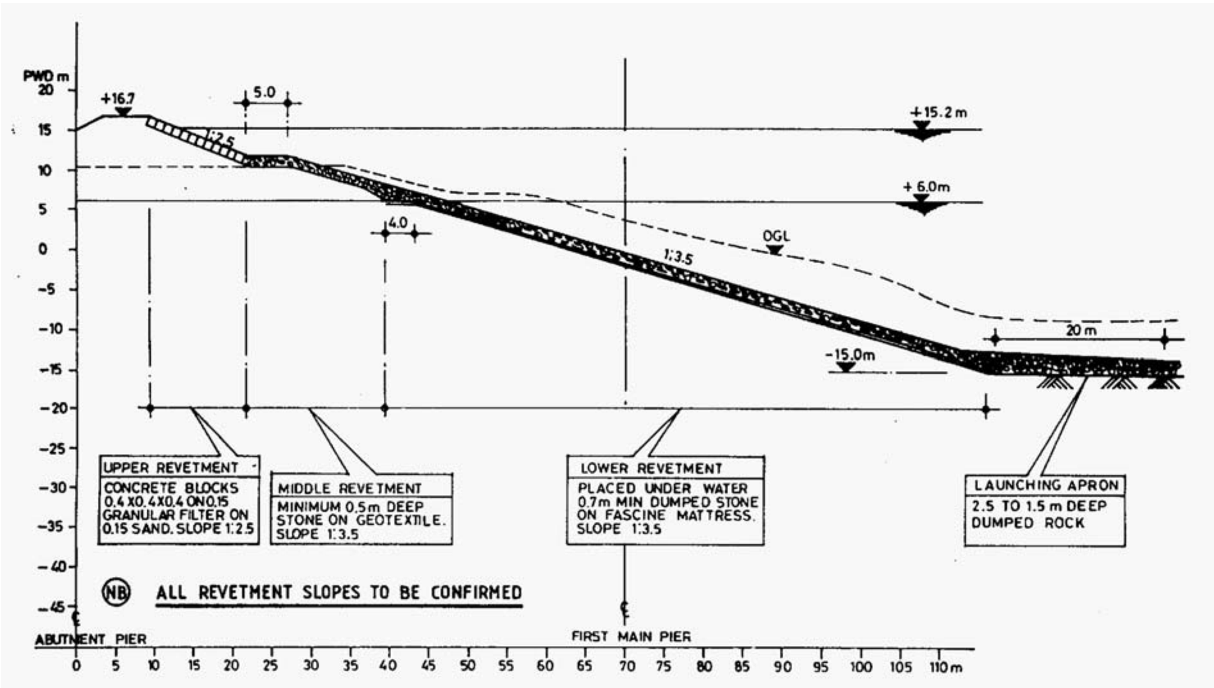


Figure 7.2.2 (c) Paksey Bridge: Cross Section of Guide Bank

7.2.3 Pre-feasibility Study of Padma Bridge

Pre-feasibility Study (F/S) of the Padma Bridge was carried out during the period from May to October in 1999 covering the surveys, studies, preliminary designs, cost estimates, economic and traffic evaluation. Going through with the studies in site identification and scheme selection phases, Pre-feasibility Study Report of Padma Bridge was prepared in February 2000. The study was carried out by the consultants that executed planning and design of Jamuna Bridge, namely Rendel Palmer & Tritton (RPT) and Netherlands Engineering Consultants (NEDECO) in association with Bangladesh Consultants Ltd (BCL). Therefore the report is useful to see how the experience and technical know-how obtained through the Jamuna Bridge project were applied to the Padma Bridge project as well as obtaining prior information on site conditions and technical issues. Some technical issues related to the river training works are introduced below.

(1) Selection of Crossing Location

Mawa corridor and Goalundo corridor were selected for the study. These corridors form nodal section and have relatively stable riverbanks on left. As a result of study Mawa site was recommended from river engineering perspective, since there are no overriding reasons to select Goalundo as the preferred crossing site, in contrast there are many good reasons to opt for the Mawa site as follows:

1) Presence of clay on the left bank at Mawa site
2) Less complicated current attack at Mawa than Goalundo just downstream of the confluence of the Jamuna and the Ganges rivers.
3) Negligible disturbance of the flow to the Arial Khan River
4) Slightly more favorable seismic situation.

The preference for Mawa to Goalundo corridor from a river engineering perspective coincides with the preferences from a transport economic point of view.

(2) River Training Works (RTW)

Guide bund was planned only for right side bank for Mawa site, while a pair of guide bunds was planned on both bank for Goalundo site. On the left bank of Mawa site, only revetment works were planned owing to the presence of clayey layer.

(3) Proposed Design Features of Bridges at Mawa and Goalundo

Design features of the bridges at Mawa and Goalundo are summarized below and the Mawa site was recommended as a preferable crossing location. These are also shown in Figure 7.2.3.

	(Mawa)	(Goalundo)
1) Length of bridge	6,030 m	6,030 m
2) Length of guide bund	4,500 m x 1 side	4,500m x 2 sides
3) Design flood water level (100 years)	+7.22 m PWD	+9.52 m PWD
4) Maximum expected scour	-37.5 m PWD	-33.8 m PWD

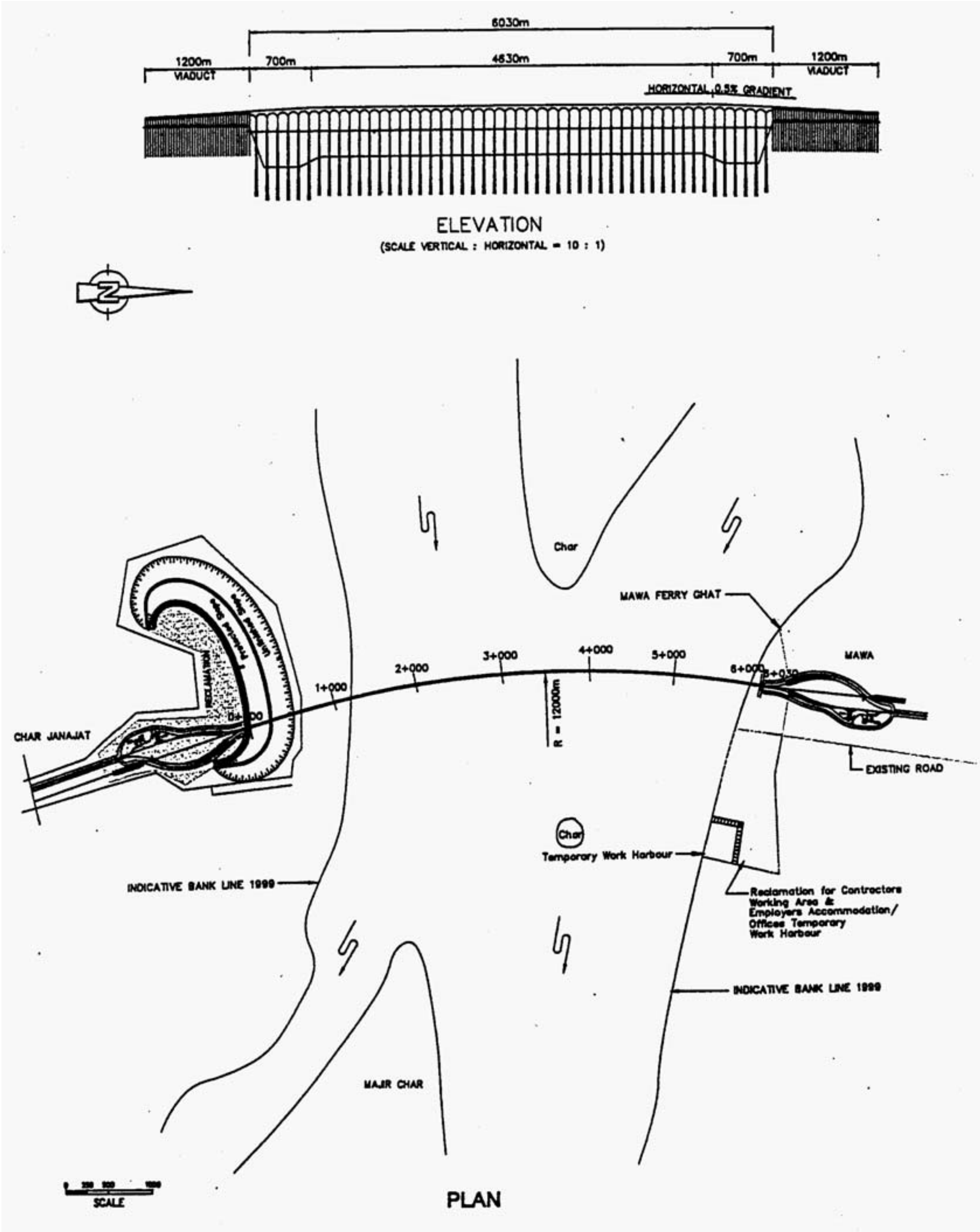


Figure 7.2.3 (a) Padma Bridge at Mawa (Pre-F/S): Elevation and Plan

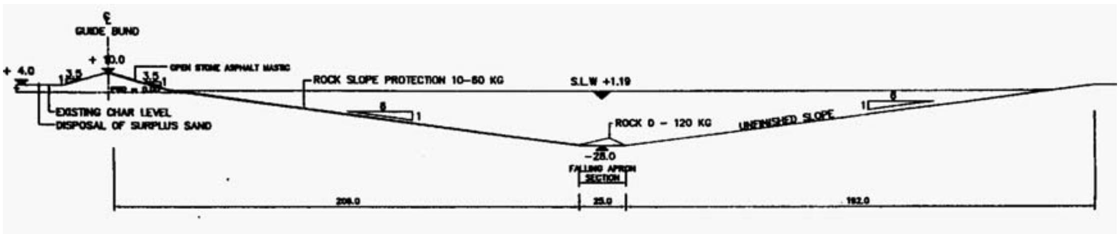


Figure 7.2.3 (b) Padma Bridge at Mawa (Pre-F/S): Typical Cross Section of Guide Bund

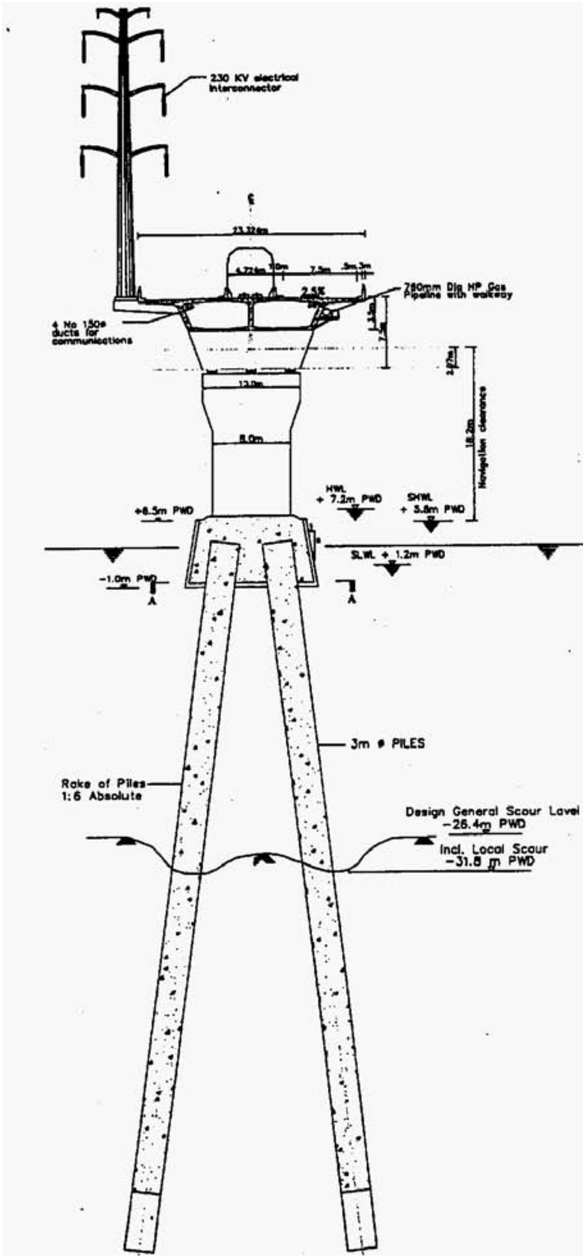


Figure 7.2.3 (c) Padma Bridge at Mawa (Pre-F/S): Substructure and Foundation

(4) Other Technical Issues to be Considered

Main findings and planning consideration related to the river works are briefed below quoting from the Pre-feasibility Report.

1) **Seismic Study:** Bangladesh has experienced several large earthquakes in the last 130 years. Among them seven have had a magnitude greater than 7.0. Two of them, the Bengal earthquake in 1885 and the Srimangal earthquake in 1918, had their epicenters in Bangladesh territory. The major earthquakes that a effected Bangladesh were the Cachar earthquake in 1869, the Bengal earthquake in 1885, the Great Assam earthquake in 1897, the Srimangal earthquake in 1918, the Dubri earthquake in 1930 and Bihar-Nepal earthquake in 1934. According to a preliminary site-specific seismic study for the Padma crossing, estimated maximum horizontal accelerations for the bridge design have been assessed at 0.125g at Mawa and 0.15g at Goalundo.

2) **Geotechnical Investigation:** The investigation in the area of Mawa corridor comprised three 120m deep boreholes each and five 40m deep boreholes. Following a review of the Padma River system it was decided that the Goalundo corridor should also be further investigated. A 120m deep borehole was drilled on the northeast bank of the Padma about 6.5km downstream of the Aricha ferry ghat to supplement existing borehole data in the area. Main purpose of this borehole was to investigate the alluvial deposits and to enable a comparison with those located on the north river bank at Mawa. The ground investigation showed the presence of extensive deposits of clayey silt to the depths of 39.0m and 31.5m on the north bank river approaches at and upstream of Mawa ferry ghat.

3) **Liquefaction Potential:** From the analysis of the liquefaction potential of the river bed materials it can be concluded that liquefaction could occur up to depths of 6m and 9m below scour level respectively for the Mawa and Goalundo corridors. Detailed foundation design therefore needs to consider potential soil liquefaction and slope failure of the riverbanks.

4) **Difference in Types of River:** While there are many similarities between the Jamuna and the Padma rivers, there are also differences. Care should be taken in adopting the experience gained on the other projects and in other studies. While the Jamuna River can be characterized as a braiding river, the Padma River is said to be on the transition between meandering and braiding (wandering river). Its behavior is somewhat less erratic than that of the Jamuna River, but that does not imply that drastic changes in the distribution of water does not take place or that bank erosion rates are less spectacular.

5) **Layout of River Training Works:** Tentative layouts for river training works at Mawa and Goalundo are indicated in Figures 7.2.4 and 7.2.5. No guide bund was proposed for Mawa site, as the river bank at Mawa was apparently not subject to heavy erosion. This is undoubtedly due to the presence of clayey soil, which offers a natural erosion protection. Though the percentage of clay in the subsoil is not very high, generally not more than 5 to 10 percent, this clayey soil already has high erosion resistance when compared to soil that does not contain clay.

6) **Slope of Sufficient Tolerance:** Experience on the Jamuna River shows that slope of 1V to 6H has sufficient tolerance to undrained disturbance for slope heights up to 30m, provided that (1) the dredging is done in relatively thin layers, (2) a uniform slope with no locally steep sections near the toe is produced, (3) and there is sufficient time between successive cuts to prevent the build up of excess pore pressures. The upper soils at the Padma are generally siltier than those at the Jamuna Bridge site and are likely therefore to be more tolerant to undrained disturbance. A steeper slope of 1V to 3.5H should be only acceptable above standard low water level.

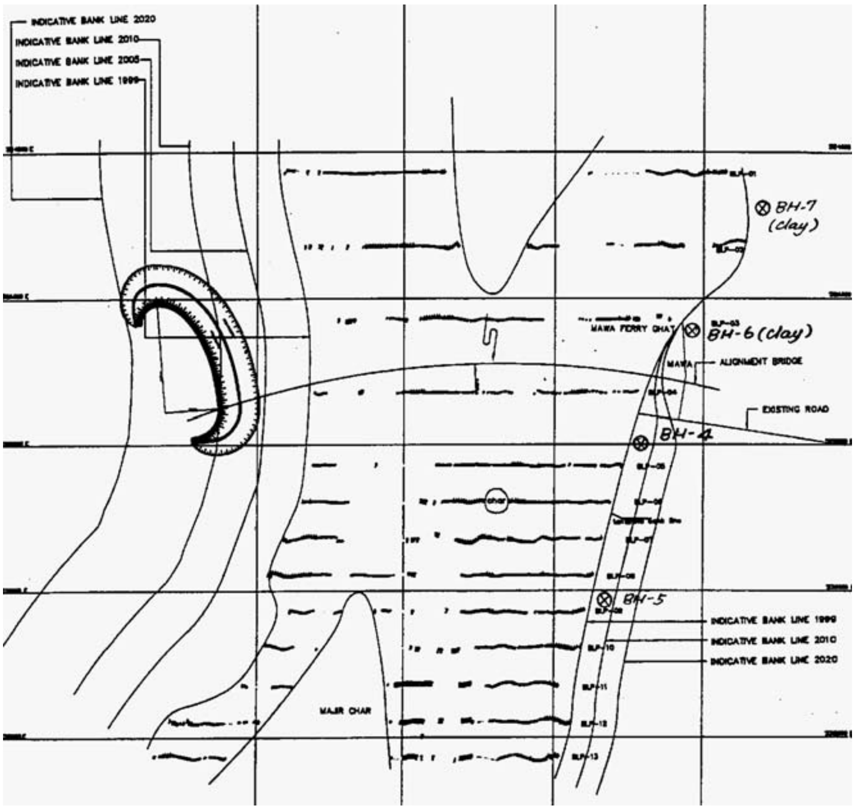


Figure 7.2.4 Layout of Guide Bund: Padma Bridge at Mawa (Pre-F/S)

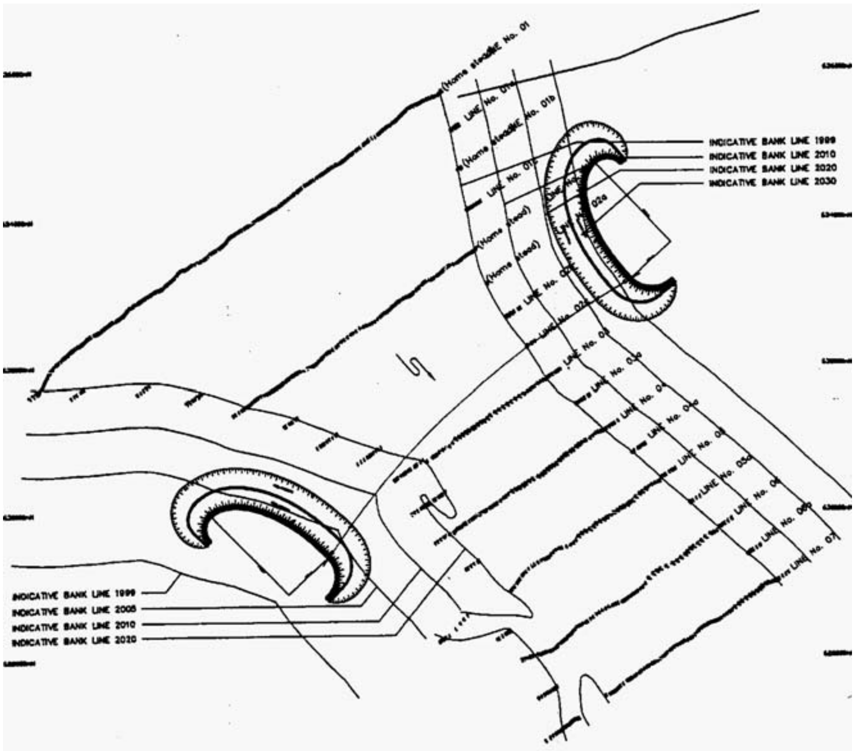


Figure 7.2.5 Layout of Guide Bund: Padma Bridge at Goalundo (Pre-F/S)

7.2.4 Guidelines for Conventional River Works

Guidelines and standards have been prepared compiling conventional river training works developed in Bangladesh, India and other surrounding countries and available for the present study. The “Guidelines for Design and Construction of River Training and Control Works for Road and Bridges (the Guideline)” prepared by Subcommittee of the Bridge Committee of India in 1985 are introduced as an example. The Guideline provides concise standards for design of guide bunds, groynes, riverbank protection, approach road protection, river training and control works, and model studies.

(1) Riverbank Protection (Revetment)

The Guidelines describe the design particulars for riverbank protection dividing into five parts, i.e., grading, free board, pitching, filter material and apron.

(2) Guide Bunds

The Guidelines defines the guide bunds as “embankments meant to confine and guide the river flow past a bridge without causing damage to it and its approaches, and are generally constructed in the direction of flow both upstream and downstream of the structure at the end of the bridge, on one or both flanks, depending on the site conditions”. The guide bund is classified in three types according to their form in plan, namely, divergent, convergent and parallel guide bunds, and further classified by their geometrical shapes as straight and elliptical guide bunds.

It is recognized that application of guide bund is assumed to meandering rivers in alluvial flood plains, aiming to ensure the stability of river crossing structure. It should also be noted that the guide bund can be appropriately designed and constructed where the Khadir (high bank or limit of alluvium) is identified in certain distance from river bank. From this point of view, the condition of Mawa-Janjira site is different in nature, because the Padma River has a nature between braided and meandering rivers. Thus, concept of the conventional guide bund presented in the Guidelines cannot be applied directly to the river works for Padma Bridge. However, the Guidelines provide appropriate indications to determine design parameters of river facilities.

(3) Groynes (Spurs)

The Guidelines defines the groynes as “structures constructed traverse to the flow of the river and extend from the bank into the river and generally intended to keep the flow away from the point of attack, by creating a slack flow with the object of silting up the area in the vicinity, thus protecting the bank under attack and also helping to train the river along the desired course”. In the Guidelines, procedures to design permeable groyne with piles is described in detail rather than impermeable groynes.

7.2.5 Bank Protection and River Training (FAP-21/22)

(1) Outlines of Flood Action Plan (FAP)

After the experience of deluge occurred in 1987 and 1988 in Bangladesh, studies for Flood Action Plan (FAP) were started in collaboration with various donor countries such as Japan, United States, United Kingdom, etc. under the initiative of the World Bank. A total of 26 studies were conducted on the regional and sectorial flood issues as shown in Table 7.2.1. The studies were completed in December 1995 and some of the proposed works are still being implemented.

Table 7.2.1 List of Studies/Projects for Flood Action Plan (FAP)

FAP No.	Name of Flood Action Plan
1	River Training Studies of Brahmaputra River
2	North West Regional Study
3	North Central Regional Study
3.1	Jamalpur Priority Project
4	South West Area Water Resources Management Project
5	South East Regional Study
5	Gumti Phase II (Feasibility Study)
5	Noakhali North Drainage & Irrigation Project (Feasibility Study)
6	North East Regional Study
7	Cyclone Protection Project-II
8A	Greater Dhaka Protection Project
8B	Dhaka Integrated Flood Protection Project
9A	Secondary Town Flood Protection Project
9B	Meghna River Bank Protection Short Term Study
10	Flood Forecasting and Warning
11	Disaster Preparedness (Prepared by Disaster Management Bureau)
12	FCD/I Agricultural Study
13	Operation & Maintenance Study
14	Flood Response Study
14/23	Flood Response Study/ Flood Proofing
15	Land Acquisition & Resettlement Study
16	Environmental Study
17	Fisheries Study & Pilot Project
18	Topographic Mapping
19	Geographic Information System (GIS)
20	Compartmentalization Pilot Project
20	Sirajganj Interim Report
21/22	Bank Protection & River Training (AFPM)
23	Flood Proofing
24	River Survey
25	Flood Modeling Management Project
26	Institutional Development Programme

All of these studies have more or less concern to the present Study. Among others, the study on Bank Protection and River Training (FAP-21/22) summarized the principal features of the river and river morphology of Bangladesh and discussed on the riverbank protection and river training measures. The guideline and design manual prepared as a result of the study is an invaluable source data to be referred in planning the river works for Padma Bridge.

(2) FAP-21/22: Bank Protection & River Training

FAP-21 (Bank Protection & River Training) study aims to find improved solution for protection measures against bank erosion by designing and implementing test structures such as revetment and groynes, and monitoring geomorphologic response to them. While FAP-22 aims to find methods of appropriate interventions (river training works) in the active flood plains of the main rivers, in particular the Brahmaputra/Jamuna River. In the study, “soft” recurrent measures were discussed as well as classical approach applying “hard” permanent measures.

For FAP-21 study, the pilot structures of revetment were constructed at Bahadurabad and Ghutail on the left bank of the northern part of the Jamuna River. The revetment length at Bahadurabad is 780 along the crest line protecting a bank-line of approx. 680 m. Total ten combinations of different material for cover layer, filter, launching apron and falling apron were constructed for test. At Ghutail, the length of protection is 500 m along the bank-line.

On the other hand, the groynes were constructed at Kamarjani on the right bank approximately 25 km downstream from the confluence of the Tista River. A total of six groynes of permeable and impermeable types were constructed at the intervals of around 250 m for test.

(3) Review of Recent Bank Protection Projects in Bangladesh

FAP-21/22 also reviewed and summarized of the recent bank protection works constructed in past ten years in Bangladesh, which covered those constructed under Jamuna Multipurpose Bridge, FAP-1 Project, FAP-21 Pilot Project, and other bank protection works mostly by BWDB.

(4) Guidelines and Design Manual for Standardized Bank Protection Structures

As an output of FAP-21/22 Study, Guidelines and Design Manual for Standardized Bank Protection Structures (FAP-21 Manual) was prepared in December 2001. The FAP-21 Manual would be the first attempt to compile, in comprehensive manners, the technical guideline/manual for bank protection structures in the country. Numerous practical information and design data are compiled in the FAP-21 Manual, dividing it into three parts, i.e., Part 1- Guideline, Part 2- Manual, and Part- 3 Design Plates.

7.2.6 Jamuna-Meghna River Erosion Mitigation Project (JMREMP)

(1) Outline of the Project

The Jamuna-Meghna River Erosion Mitigation Project (JMREMP) was undertaken as a technical assistance of ADB divided into two parts, i.e., Phase 1 study dealing with Flood Monitoring and Data Collection (3.5 months) followed by Phase 2 study preparing a River Erosion Management Project (6.5 months). Phase 2 study was commenced in October 2001 and completed in March 2002 by the consulting group led by Halcraw Group Ltd. of UK.

The main objective of the Phase 2 study is to prepare a feasible investment project to mitigate the effects of riverbank erosion threat to PIRDP and MDIP. This was based on (i) appropriate measures that are sustainable and cost effective; and (ii) implementing a system for riverbank management incorporating local participation. The strategy has therefore encompassed structural and non-structural measures that include information management, O&M institutions, stakeholder participation and sustainable financing arrangement.

(2) Options for Erosion Mitigation

JMREMP first assessed the mitigation options. Three structural options were considered:

(i) erosion mitigation option 1- revetment; (ii) erosion mitigation option 2 - solid spur; and (iii) embankment retirement option. Geo-bags were selected for the design of the erosion mitigation options. Following a multi criteria analysis, both the erosion mitigation options were taken forward for the feasibility study with the revetment option preferred. The embankment retirement option was not considered appropriate at this stage. This option would need to be considered if alternative structural options are not viable.

(3) Project Components

The Project includes structural and non-structural components to be implemented over a 7-year period and comprises the following components:

- Erosion mitigation works at PIRDP and MDIP;
- Information management, monitoring and evaluation;
- Resettlement and social development;
- Capacity development;
- Disaster preparedness; and
- Riverbank stabilization studies

The erosion mitigation works are based on an "adaptive approach" that is sympathetic to the river morphology and provides flexibility to adapt to morphological changes. The main works comprise bank stabilization revetments incorporating geo-bag aprons, and Vetivar-grass turfing at the upstream and downstream terminations. The new revetment lengths will be 2.7 km at PIRDP and 1.97 km at MDIP.

7.2.7 Expertise Owned by Agencies Concerned

The bridge projects and FAP studies have mobilized many experts from various parts of the world. Through the collaborative study works with these experts, capacity building and organizational renovation of the agencies concerned of the Government of Bangladesh and the private sectors have been promoted. Effective use of these agencies and their expertise would contribute much for the success of the Padma Bridge Project.

In the course of the study following agencies were identified to have good experience and expertise in particular with regard to river study. They are aware of actual features of the rivers in Bangladesh and have expertise to handle them in different ways:

1) **Center for Environmental and Geographic Information Services (CEGIS):** The CEGIS (former Environmental and GIS Support Project for Water Planning Sector: EGIS) is now an independent organization for integrated environmental analysis using geographic information system (GIS), remote sensing, information technology and databases. As far as the river study concern, it has good expertise on river morphology and remote sensing making use of satellite images.

2) **Institute of Water Modeling (IWM):** IWM (former Surface Water Modeling Center: SWMC) is governed by the Board of thirteen trustee drawn from different ministries, departments and organizations of Bangladesh and outside. River Engineering Division of IWM in particular has concern with the river study. This division has a lot of experience in mathematical hydraulic and morphological modeling of the river systems in Bangladesh including those for Jamuna Multipurpose Bridge Project and other important river projects of the country.

3) **River Research Institute (RRI):** RRI is a multidisciplinary research organization of the Government of Bangladesh situated at Faridpur. RRI was established in 1977 merging Hydraulic Research Laboratory established in 1948. The institute has two

directorates i.e., Hydraulic Research Directorate and Geo-technical Research Directorate. RRI has carried out various physical model tests for Jamuna Multipurpose Bridge and other important bridge and bank protection projects of the country.

7.3 RIVER STUDY FOR INITIAL SCREENING

7.3.1 Method of Screening

Although the Pre-feasibility Study in 1999/2000 was conducted for two crossing sites at Goalundo and Mawa, the JICA Study Team looked into the Padma River again so as not to overlook important bridge site. Following sites including those for the Pre-feasibility Study were identified as conceivable sites:

Site-1: Paturia-Goalundo Site
Site-2: Dohar-Charbhadrasan Site
Site-3: Mawa-Janjira Site
Site-4: Chandpur-Bhedarganj Site

In order to select two preferable locations out of four, advantage and disadvantage of each location were discussed mainly based on the data available at the initial stage.

Study was limited to the items and depth to weed out two disadvantageous locations. In-depth study to delineate actual site conditions and project features would be made for the selected two locations in next step of the current study to select an optimum location. In this section, the following items were discussed:

1) General river conditions
2) Stability of river
3) River works
4) Evaluation from river perspective

7.3.2 General River Conditions

According to the latest satellite images and site reconnaissance from land and air, general conditions of the Padma River and the conceivable crossing locations were summarized below.

Padma River: The Padma River from the Ganges-Jamuna confluence (Goalundo) to the Padma-Meghna confluence (Chandpur) takes straight river course as a whole toward southeastern direction, having swollen plan-forms with islands at three reaches. Flood plain on the left bank seems relatively old and consolidated in comparison with that on the right bank where numerous vestiges of recent river channels are left.

Site-1 (Paturia-Goalundo Site): The crossing site is located immediately downstream of the confluence of the Ganges and the Jamuna rivers. The site forms a complete nodal section. Present river width measured on the satellite images (Jan. 2003) is about 4.8 km including attached sandbar. On the right bank distributaries from the right bank of the Ganges bypass the site. The ferry ghat (port) of Goalundo is located at one of those outlets. Attached sandbar is seen along the right riverbank.

Site-2 (Dohar-Charbhadrasan Site): The site is sandwiched between the first and second swollen river sections from the uppermost point. On both banks of the crossing section, low-lying flood plains develop. These low-lying plains could be a part of river channel to convey flood water. The site forms a nodal section but seems incomplete. Present river width measured on the satellite image (Jan. 2003) is about 4.4 km. From the right bank downstream the crossing location, the Arial Khan River bifurcates.

Site-3 (Mawa-Janjira Site): The crossing site forms a complete nodal section just downstream of the second swollen river section of which right side channel seems diminishing. Present river width measured on the satellite image (Jan. 2003) is about 4.9 km including attached sandbar. According to the Pre-feasibility Study of Padma Bridge, thick clayey layer exists on the left bank at this site.

Site-4 (Chandpur-Bhedarganj Site): The crossing section forms a very narrow section immediately downstream of the confluence of the Padma and the Meghna rivers. Present river width is 2.7 km only on the satellite image (Jan. 2003). But it has wide low-lying flood plain on the right bank where some bypass channels from the Padma are found. Reflecting the narrow river section and probably the tidal influence, river flow is said dangerously fast and river depth was surveyed as deep as -65 m PWD at Chandpur (May 2002). The left river bank is now suffering from severe erosion.

7.3.3 Stability of River

As discussed in APPENDIX-5, the stability of river channel and river banks at the conceivable crossing locations was preliminarily evaluated based on the satellite images in the past 30 years as follows:

Site-1 (Paturia-Goalundo): Stable

- Change in river width (W_{min} to W_{max}): 2.44 to 5.00 km
- Average river width (W_{ave}): 4.27 km
- Coefficient of variation = $(W_{max}-W_{min})/W_{ave}$: 0.61
- Maximum river extent during 30 years: 5.20 km

Site-2 (Dohar-Charbhadrasan): Less stable

- Change in river width (W_{min} to W_{max}): 3.56 to 8.48 km
- Average river width (W_{ave}): 5.25 km
- Coefficient of variation = $(W_{max}-W_{min})/W_{ave}$: 0.94
- Maximum river extent during 30 years: 8.88 km

Site-3 (Mawa-Janjira): Stable

- Change in river width (W_{min} to W_{max}): 2.00 to 4.92 km
- Average river width (W_{ave}): 3.81 km
- Coefficient of variation = $(W_{max}-W_{min})/W_{ave}$: 0.60
- Maximum river extent during 30 years: 5.24 km

Site-4 (Chandpur-Bhedarganj): Less stable

- Change in river width (W_{min} to W_{max}): 2.68 to 9.60 km
- Average river width (W_{ave}): 5.31 km
- Coefficient of variation = $(W_{max}-W_{min})/W_{ave}$: 1.30
- Maximum river extent during 30 years: 9.60 km

7.3.4 Expected River Works

The expected river works for the Padma Bridge are guide bund works, other river training works and channel works on the flood plain. From the river works, Site-1 and Site-3 apparently have advantages over the remaining sites owing to the following reasons:

1) Guide Bund Works: At the present stage of study, there is no reason to mark advantage or disadvantage for any of the crossing sites.
2) Other River Training Works (RTW): Because of less stable river conditions at Site-2 and Site-4, these sites require more works to train the river course and flows.
3) Channel Works on Flood Plain: The Site-2 and Site-4 require longer approach road to connect with the highway. The longer approach road traversing flood plain would require more works for the treatment of minor river channels and drainage in the plain area.

7.3.5 Evaluation from River Perspective

The above discussions on the four crossing locations are summarized in Table 7.3.1 below.

Table 7.3.1 Evaluation of Crossing Locations from River Perspective

	Site-1	Site-2	Site-3	Site-4
River Scale				
River width	4.8 km	4.4 km	4.9 km	2.7 km
Max. depth surveyed	21 m	22 m	30 m	65 m
Low-lying flood plain	-	3.8km in total on both banks	-	7.4km on right bank
Stability (1973-2003)				
Change in river width	2.44 to 5.00km	3.56 to 8.48km	2.00 to 4.92km	2.68 to 9.60km
Average river width	4.27 km	5.25 km	3.81 km	5.31 km
Coefficient of variation	0.61	0.94	0.60	1.30
Max. river extent	5.20 km	8.88 km	5.24 km	9.60 km
River banks	Left bank fairly stable	-	Left bank fairly stable	Left bank fairly stable
River Work				
Guide bund works	No significant difference	No significant difference	No significant difference	No significant difference
Additional RTW	-	More works anticipated because of less stable channel	-	More works anticipated because of less stable channel
Flood plain works	-	More works anticipated because of longer approach road.	-	More works anticipated because of longer approach road.

From river perspective, Site-1 (Paturia-Goalundo) and Site-3 (Mawa-Janjira) are by far favorable to the crossing location comparing to the other sites.

7.4 RIVER STUDIES FOR SELECTION OF OPTIMUM SITE

7.4.1 Principles for Planning

River works were planned and designed preliminarily for Paturia-Goalundo site (PG-site) and Mawa-Janjira site (MJ-site) for the selection of an optimum crossing site for Padma

Bridge. The following considerations and principles were introduced for the planning and preliminary design of the river works in consideration of the purpose of the present study:

(1) Large Scale River Shifting

Considering active river shifting in the past, possibility of large scale river course changes in the Ganges-Jamuna river system like activation of the Old Brahmaputra River cannot be denied. It is also natural to assume that the northeastward transmigration of the Padma River would continue in future. Such a large scale changes, however, would progress gradually for a long period as an integration of minor changes, probably far beyond the project life of the bridge.

In order to cope with such changes, intensive efforts would also be exerted by various organizations and individuals related to the water and river, since land and water uses along the river are enhanced nowadays. From the bridge maintenance point of view, necessary measures to maintain the bridge functions would also be taken observing the progress of river changes and other coping activities.

The bridge plan under consideration will not handle the issue of large scale river shifting, and the study will focus to cross the Padma River under the present condition.

(2) Stable Riverbank

Left bank of the Padma River is relatively stable as a whole. Especially near Paturia and Mawa, the left bank has been markedly stable at least in these 78 years. According to the investigation on the erodibility of riverbank, the left banks at the proposed crossing locations were evaluated as relatively erosion resistant with annual erosion rate ranging from 0 to 15 m/year, consisting of relatively old geological formation made of silty and clayey soil.

The stable or less erodible left river bank near the alternative crossing locations at Paturia and Mawa could be effectively used for the river works as a sort of natural hard point.

(3) Waterway Opening

Historical average width of low-water channel is 6.3 km at CS-P7 near PG-site and 3.5 km at CS-P2.1 near MJ-site, while the existing low-water channel is 3.0 km at PG-site and 3.6 km at MJ-site according to the latest survey result by the Study Team. Waterway opening for bridge crossing is to be determined considering the following:

1) **Channel Width:** In order to maintain present river regime of the Padma at the crossing locations, it is desirable to keep the waterway opening at least 4.7 km for PG-site and 4.4 km for MJ-site, assuming Lacey's coefficient C = 12 (m-sec units). By so doing, the existing low-water channel will not be constricted, and accordingly afflux due to the bridge would be negligible small, associated with gradual rise of water level and fine riverbed materials of the Padma River.

2) **Workability:** Bridge abutments and river works for them are to be located on riverbanks, considering the difficulty in execution of reliable works in the river flows.

(4) River Works

Guide bund works (GBW), abutment protection works (APW) and bank protection works (BPW) are considered as major river works. The GBW aims to guide river flow to the bridge opening and to protect bridge abutments and approach road from erosion. The

APW is a sort of bank protection works aiming to protect bridge abutment from erosion. Bridge abutment is to be protected by the GBW or APW.

The bank protection works (BPW) aim to ensure the function of the GBW and APW by protecting riverbank from erosion and maintaining present flow conditions around the crossing location of the bridge. Safety level of these BPW could be planned lower than the GBW and APW.

7.4.2 Preliminary Design of River Works

Besides with the principles set forth in the above, design standards and criteria applied to previous works were reviewed and major bridge sites in Bangladesh were visited to see the actual situation of the river works for bridge (Table 7.4.1). Technical standards for the river works in Bangladesh and India were also reviewed.

Then, the river works at PG-site and MJ-site for the Padma Bridge were designed preliminarily for the alternative studies for selection of optimum site based on the following design criteria. Typical design section of river works is shown in Figure 7.4.1.

(1) Guide Bund Works (GBW)

1) Length: 3,200 m based on Gale's empirical relation considering the head and tail loops
2) Crest elevation: DHWL (Design High Water Level) + 1.50m (Free board)
3) Crest width: 10 m, considering the transportation of materials for construction and maintenance.
4) Slope: 1V to 6H, following the designs of Jamuna bridge and other existing works
5) Toe elevation: Maximum scour depth of the Padma River
6) Material: Dumped rock and boulder (20-240 kg)
7) Construction method: Works on bank and in stilling water area dredged

(2) Abutment Protection Works (APW)

1) Length: 500 m considering plan-form of the abutment and head and tail loops.
2) Crest elevation: DHWL (Design High Water Level) + 1.50m (Free board)
3) Slope: 1V to 3H
4) Toe elevation: Variable depending on the site conditions.
5) Material: Concrete cube (450x450x450)
6) Construction method: On the bank.

(3) Bank Protection Works (BPW)

1) Length: Variable depending on the site conditions
2) Crest elevation: SHWL (Standard High Water Level)
3) Crest width: 10m, considering the transportation of materials for construction and maintenance.
4) Slope: 1V to 6H, following the designs of Jamuna bridge and other existing works
5) Toe elevation: At MWL– 15m, considering the dredging depth of dredgers available in Bangladesh.
6) Material: Dumped rock and boulder (20-240 kg)
7) Construction method: Works on bank and in stilling water area dredged

Table 7.4.1 Major Bridge Works in Bangladesh

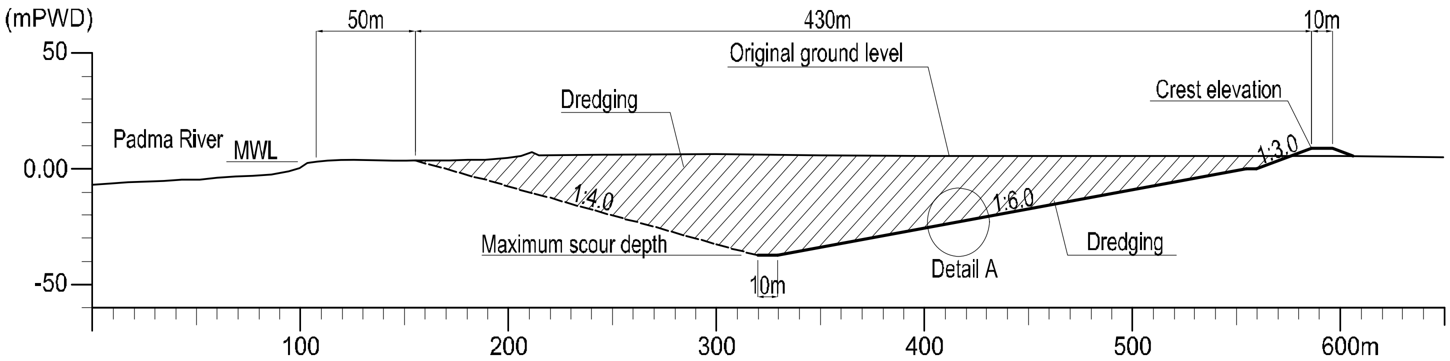
Location / Item	Unit	Bhairab Bridge	Meghna Bridge	Meghna Gumuti Bridge	Jamuna Bridge	Arial Khan Bridge	Rupusa Bridge	Paksey Bridge	Sirajganj City protection
Main bridge lenghth	(m)	929	930	1150	4800	450	640	1800	No bridge
River		Bhairab	Meghna	Meghna	Jamuna	Arial Khan	Pusar	Padma (Ganges	Jamuna
Design flood	(year)	100	N.A.	N.A.	100	100	100	100	N.A.
Discharge	(m3/s)	22,000	13,500	10,000	100,000	6,949	4,000	85,000	N.A.
Water levels									
Standard high wate	(PWD)	7.2	5.1		12.9	6	3.77	13.7	N.A.
Standard low water	(PWD)	1.25	1.1	N.A.	6.2	1	-1.26	5.9	6.8
Design water level	(PWD)	7.2	5.1		15	7.52	3.77	15.2	15.75
Flow velocity	(m/s)	2	1	N.A.	3.1	2.33	N.A.	4	3.7
Scour General	(PWD)	-34	-30	N.A.	-30	-24	-35	-32	-30
Local scour	(m)					4		5	
RTW									
Guide bund/Bank protection B.P.:Bank protection		B.P.	B.P. (Steel sheet	N.A.	Guide bund	Guide bund	B.P.	Guide bund	B.P.
Crest	(PWD)	8.3	6		16.5	8.52	4.2	16.7	N.A.
Free board	(m)	1.1	0.9		1.5	1	0.43	1.5	
Crest width	(m)	10			5	4	5	7	
Toe of slope	(PWD)	-10			-18	0.7	-10	-10	
Slope Above		0.0 mPWD 1:4.0	1:2.0		10.0 mPWD 1:3.0	5.5 mPWD 1:2.5	-1.26 mPWD :2.5, 1:12.	10.4 mPWD 1:2.5	1:4.0
Slope Below		0.0 mPWD 1:6.0			10.0 mPWD 1:5.0	5.5 mPWD 1:3.0	-1.26 mPWD 1:2.0	10.4 mPWD 1:5.0	
Material		Above 0.0 : t=650, Boulder 20-240kg	Boulder:75 to 300mm Botu:50 to 150 Shingle:5		Above 10.0 Open stone asphalt, t=15	CC block 400x400 x300	Above -1.26 CC cube350 & 250	Above 10.4 CC cuve 350	CC cube 450 & 650
		Below 0.0 : t=350, 2-20kg			Below 10.0 Boulder 10-60kg, t=500		Below -1.26 Angular stone t=750	Below 10.4 Rock, t=500-700	
Falling Apron			None	N.A.					
Set up	(PWD)	-23			-18	0.7	-10	-10	-18
Depth below SLWL	(m)	24.25			24.2	0.3	8.74	15.9	24.8
Length	(m)	12			15	28	7.5	25	20
Thickness	(m)	2.1			3	2.4	1.5	5	
Material		Boulder 1-50kg			Boulder 1-115kg	CC cube 500, 400, 300	Angular stone	Rock	CC cube 450
Complention Date	(year)	2001	1991	1995	1998	une,2005	May,2005	Mar,2004	1998
Construction cost for RTW	(m.usd)	25	1.2	0.8	323	4.33	0.7	20	73.5
RTW length	(m)	1070	150	N.A.	6330	1020	150	1000	2650
unit cost per m	(usd)	23,400	8,000	N.A.	51,000	4,200	4,700	20,000	27,700

Note : N.A. Not available

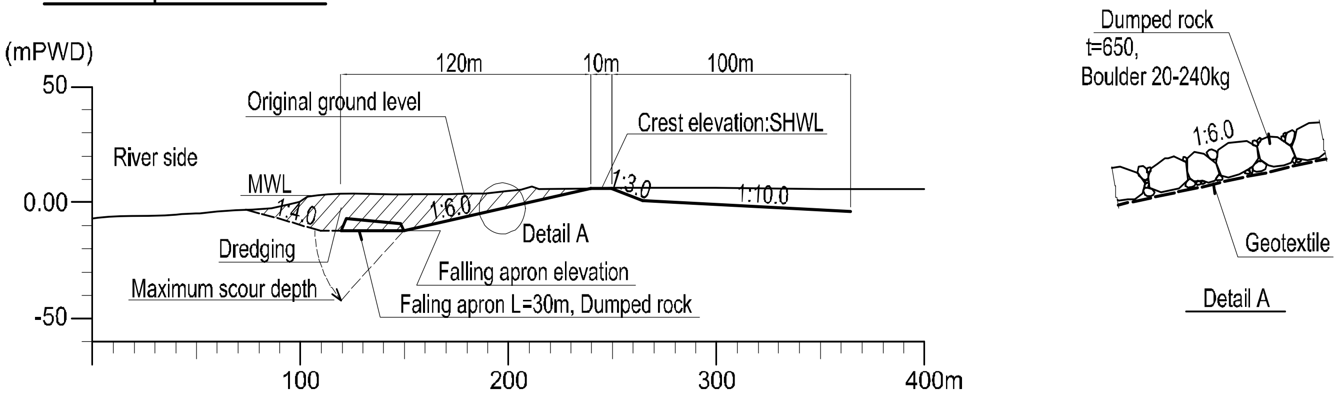
Source : Tender document:Bhairab bridge, Jamuna bridge, Rupsa bridge
Construction document::Meghna bridge, Ari Al Khan bridge, Paksey bridge
Jamuna bridge:The Making of The BANGABANDHU BRIDGE, JMBA, June 1998
Sirajganj city protection:Meghna Dhonagoda Irrigation Project Final Report, Nov 2000

Guide bund

		Patria-Goalundo	Mawa-Janjira
Crest elevation	(mPWD)	11.22(=9.72+1.50)	8.85(=7.35+1.50)
Maximum scour depth	(mPWD)	-33.8	-37.5
Original ground level	(mPWD)	8	6



Bank protection



		Patria-Goalundo	Mawa-Janjira	Remarks
Crest elevation(SHWL)	(mPWD)	7.94	5.81	SHWL:Standard High Water Level
Mean Watel Level(MWL)	(mPWD)	4.21	3.02	
Falling apron elevation	(mPWD)	-11	-12	MWL-15

Figure 7.4.1 Typical Section of River Works

7.4.3 Preliminary Design of River Works for PG-site

(1) General Site Conditions

General location of Paturia-Goalundo site (PG-site) is shown in Figure 7.4.2. Left bank of the Padma River sticks to the stable left bank. Historically the width of low-water channel and the location of thalweg vary broadly depending on the fluctuations of water and sediment flows of the Ganges and Jamuna rivers.

The permanent bank so-called "Khadir" is identified on the right bank around at 8 km away from the left riverbank. This permanent bank is said to be the old riverbank of the Ganges River. Main stream of the Padma River takes route close to the stable left bank, and high-water channel or floodplain extends on right side bank of the main stream.

Some anabranches from the Ganges flow on the high-water channel. Goalundo ferry ghat is located at the outlet of one of such anabranches. Development of these anabranches may adversely affect the crossing section of Padma Bridge. Behind the stable bank on the left bank, the Ichamati River flow in parallel to the Padma River. The Ichamati River, a distributary from the Jamuna River, is a source of floodwater and a main drainage of the surrounding area as well. Careful treatment is necessary for the Ichamati River in relation with river works and approach road works.

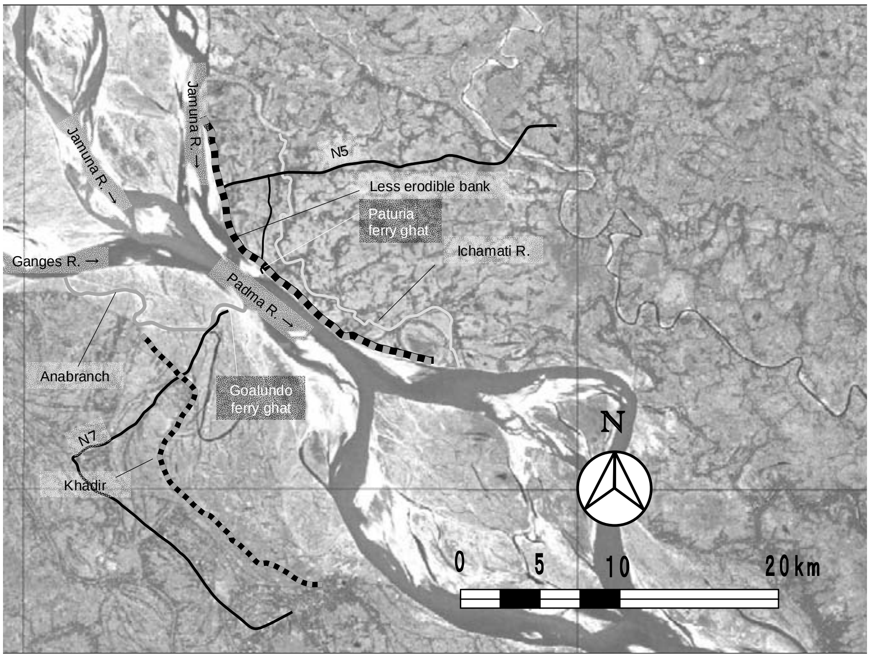


Figure 7.4.2 General Location of PG-site

(2) Alternative Schemes

Planning Considerations: Following considerations were given in planning the river works for PG-site:

1) **River Works:** Bridge abutment is to be protected by guide bund works (GBW) or abutment protection works (APW). The GBW aim to guide river flow to the bridge opening and to protect bridge abutment and approach road from erosion. The APW aim to protect bridge abutment from erosion. Bank protection works (BPW) aim to ensure the function of the GBW and the APW, maintaining present river flow conditions.

2) **Works for Left Bank Abutment:** GBW and APW can be considered as alternative schemes. The GBW (3,200 m) is to be proposed on the riverbank directly facing to main flow of the Padma River. The APW (500 m) for the left abutment is to be located at least 1 km behind the stable riverbank. The distance was reserved to be free from erosion of the Padma, considering the past erosion rate of the left bank. The depth of foundation of the APW can be designed shallower depending on the local conditions.

3) **Works for Right Bank Abutment:** According to the results of study and investigation results on historical plan-form changes and the erodibility of riverbank, it was judged that the right bank abutment should be protected by the GBW or the equivalent to secure the safety of the abutment, even if it was located at the permanent riverbank (Khadir). Therefore, the GBW (3,200 m) is to be planned on the right riverbank directly facing to the main flow of the Padma River to minimize bridge length.

4) **Bank Protection Works:** Bank protection works (BPW) such as groyne and other works to protect riverbank is necessary to ensure the functions of the GBW and APW discussed above for maintaining present flow conditions at Ganges-Jamuna confluence, and checking activation of anabranches from the Ganges River. Safely level of these works can be planned lower than the GBW and APW.

5) **Ichamati River:** In case GBW is planned on the left bank the Ichamati River should be joined with the Padma upstream of the GBW, while in case APW is planned the abutment should be located on the left (east) bank of the Ichamati River at about 1.5 km landside from the existing riverbank.

Alternative River Work Schemes: Two schemes can be considered in combination of the GBW and APW discussed above. These alternative schemes are outlined in Figures 7.4.3 and 7.4.4.

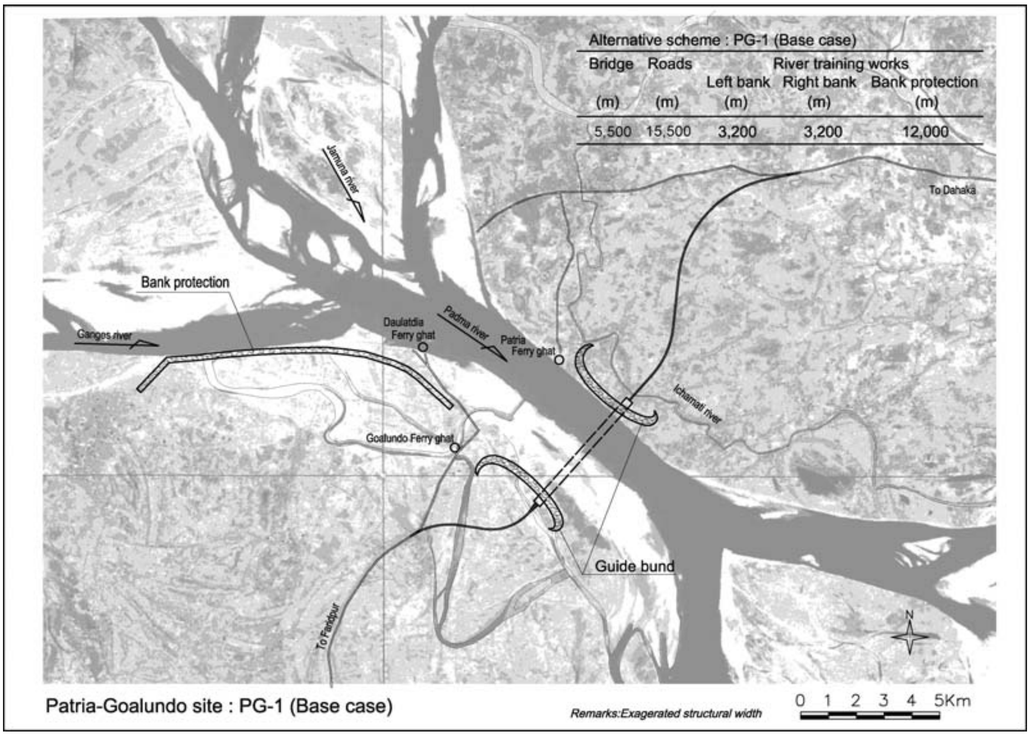


Figure 7.4.3 Alternative Scheme: PG-1

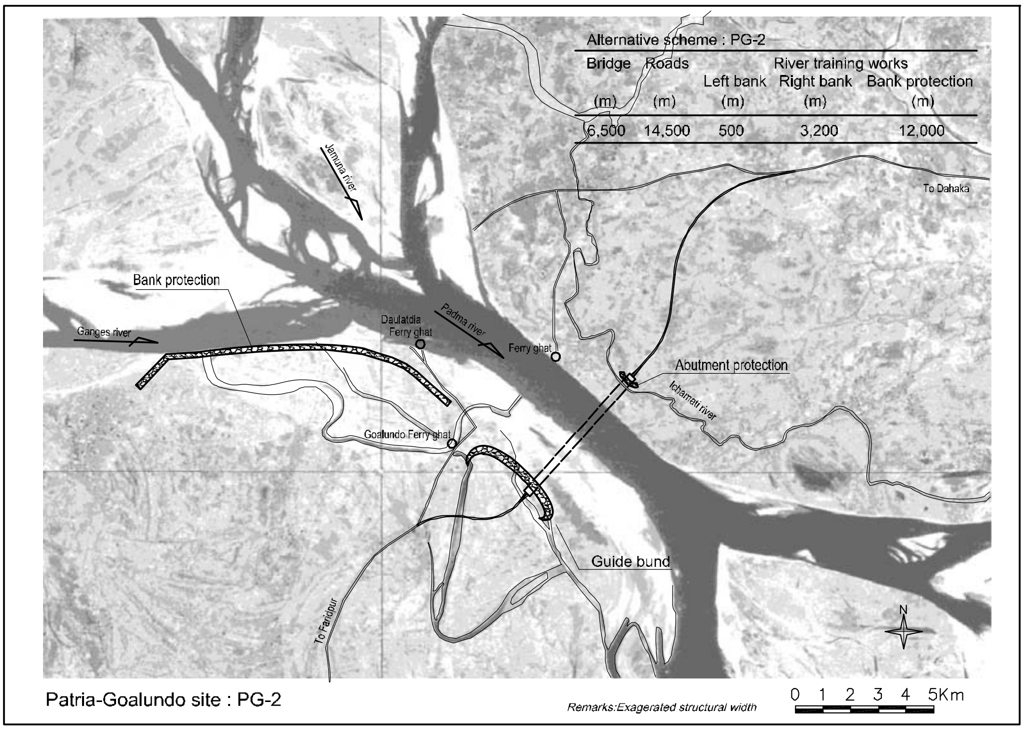


Figure 7.4.4 Alternative Scheme: PG-2

(3) Selection of Optimum Scheme for PG-site

Based on the unit work cost of the Jamuna Bridge in principle, direct construction cost of each scheme was preliminarily estimated. According to the result of estimates, the scheme PG-2 requires 91% of the cost of PG-1. Besides the cost, GBW on the left bank as in scheme PG-1 have risk of disturbing present stable riverbank.

The scheme PG-2 with APW for the left bank, GBW for the right bank and BPW along the right bank of the Ganges River is proposed for PG-site.

7.4.4 Preliminary Design of River Works for MJ-site

(1) General Site Conditions

General location of Mawa-Janjira site (MJ-site) is shown in Figure 7.4.5. Historically the low-water channel and the thalweg were in general located in the right side or center of the river at MJ-site. When southeastern channel of Char Kawrakandi becomes active, the thalweg is pushed toward the stable left bank and causes deep scour. Evolution of Char Kawrakandi and the southeastern channel behind the Char is an important factor to the stability of the river section at MJ-site.

On the right bank near the Arialkhan River, permanent riverbank (Khadir) is identified at around 12 km away from the left bank. From the right riverbank some minor channels divert from the Padma River taking route along the old river courses. Some of them return to the Padma River and others flow into the Arialkhan River. These diversion channels are dried up during the dry season.

On the left bank, the Srinagar River flows into the Padma River at the downstream of MJ-site. The Srinagar River functions as a main drainage canal of the marshy lands on the left bank.

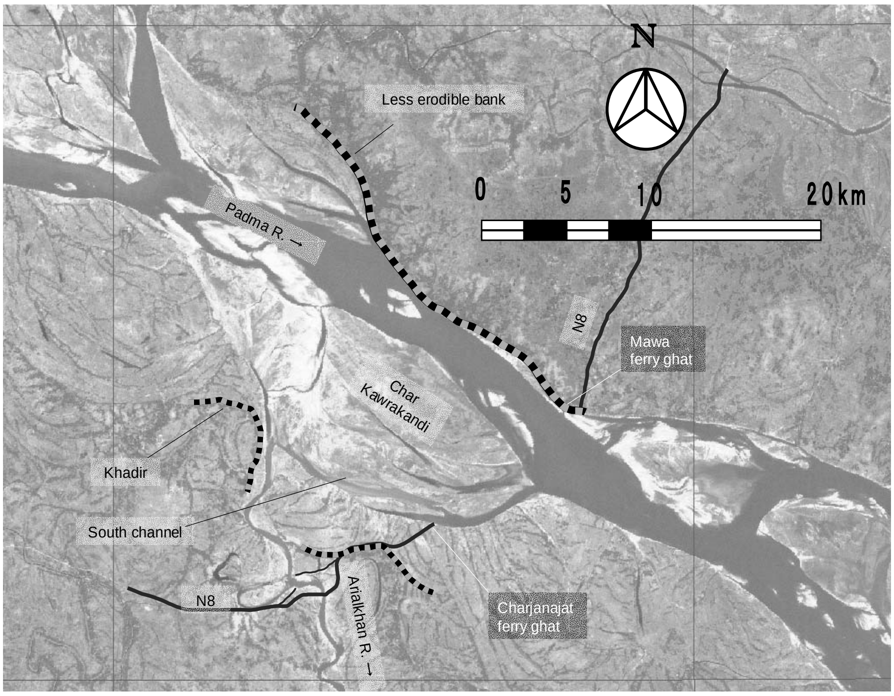


Figure 7.4.5 General Location of MJ-site

(2) Alternative Schemes

Planning Consideration: In planning river works for MJ-site, following considerations were given:

1) **River Works:** Bridge abutment is to be protected by guide bund works (GBW) or abutment protection works (APW). The GBW aims to guide river flow to the bridge opening and to protect bridge abutments and approach road from erosion. The APW aim to protect bridge abutment from erosion. Bank protection works (BPW) aim to ensure the function of the GBW and the APW, maintaining present river flow conditions.

2) **Works for Left Bank Abutment:** The GBW (3,200 m) is to be proposed on the left riverbank facing to main flow of the Padma River, and the APW at about 1 km behind the stable left riverbank with shallower foundation. The distance of 1 km was assumed considering the erosion rate of the left riverbank in the past.

3) **Works for Right Bank Abutment:** According to the study and investigation results on historical plan-form changes and the erodibility of riverbank, it was judged that the right bank abutment should be protected by the GBW or the equivalent even if it was located at the permanent riverbank (Khadir) to secure the safety of the abutment. Therefore, the GBW (3,200 m) is to be planned on the right riverbank directly facing to the Padma to minimize the bridge length.

4) **Bank Protection Works:** Bank protection works (BPW) such as groyne and other works to protect riverbank would be necessary in case the guide bund is planned on the right bank of the south channel of Char Kawrakandi, to ensure the function of GBW and to protect the right approach road from the erosion by the southeastern channel.

Alternative River Work Schemes: Two schemes can be considered in combination of the GBW and APW. Outline of these alternative schemes are shown in Figures 7.4.6 and 7.4.7.

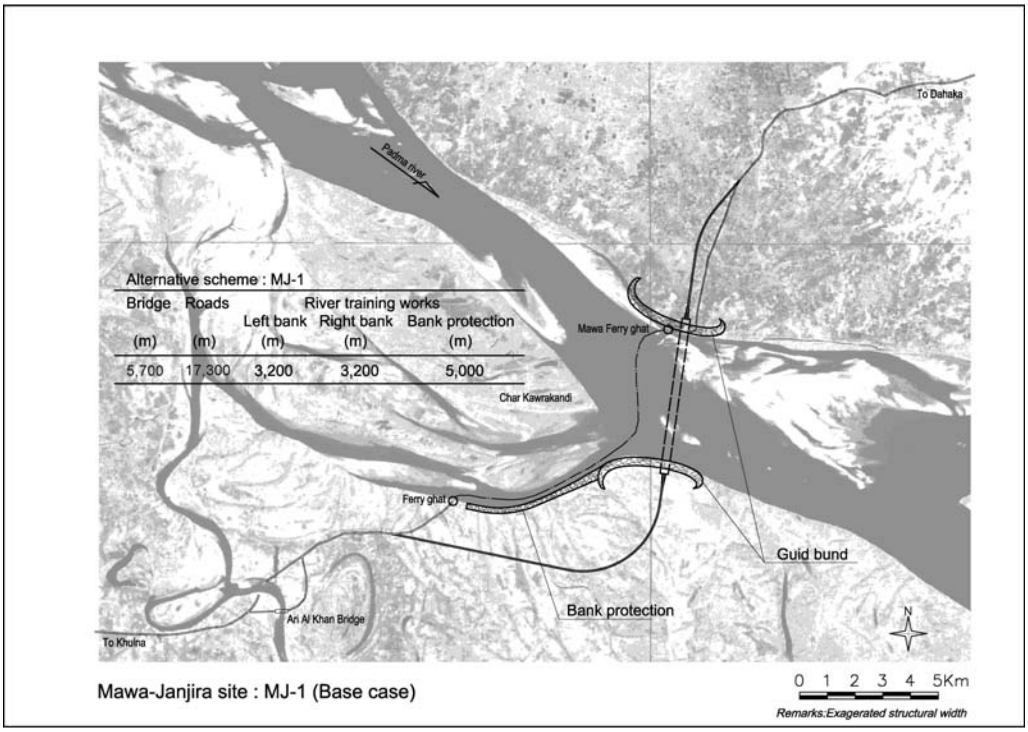


Figure 7.4.6 Alternative Scheme: MJ-1

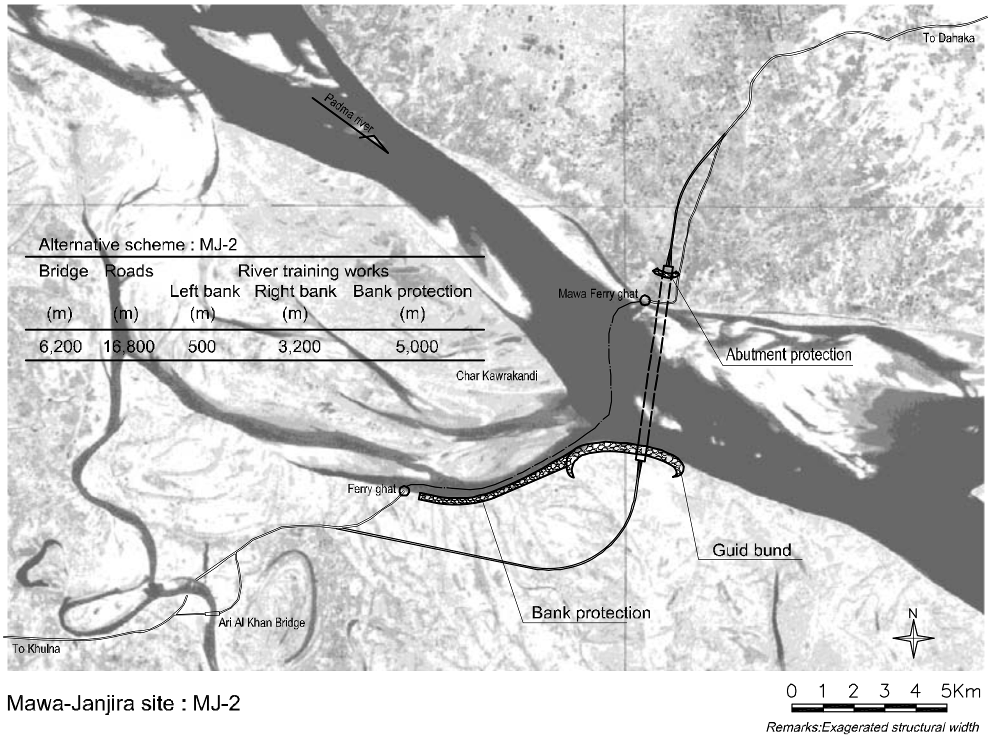


Figure 7.4.7 Alternative Scheme: MJ-2

(3) Selection of Optimum Schemes for MJ-site

Based on the unit work cost of the Jamuna Bridge in principle, direct construction cost of each scheme was estimated preliminarily. According to the result of estimates, the scheme MJ-2 requires 86% of the cost of MJ-1. Besides the cost, GBW on the left bank as in scheme MJ-1 have risk of disturbing present stable riverbank.

Scheme MJ-2 with APW for the left bank, GBW for the right bank and BPW along the southwestern channel of Char Kawrakandi is proposed for MJ-site.

7.5 ESTABLISHMENT OF DESIGN PRINCIPLES FOR OPTIMUM SITE

7.5.1 Flow of Preliminary Design

The Padma Bridge is planned across the Padma River, which will be if realized the longest one in the country. In Bangladesh, several large-scale bridges have been constructed across major rivers such as the Jamuna, Ganges and Meghna rivers, etc. In relation with these projects, numerous studies and researches on river training and bank protection works have been undertaken with international technical and financial assistance. Through the experience, technical know-how has been accumulated in the country.

Under these circumstances, four key studies/projects were reviewed in order to establish principles for preliminary design of river facilities related to the Padma Bridge. The sequence and interconnection of relevant work items to complete the preliminary design of the bank protection works are shown in Figure 7.5.1.

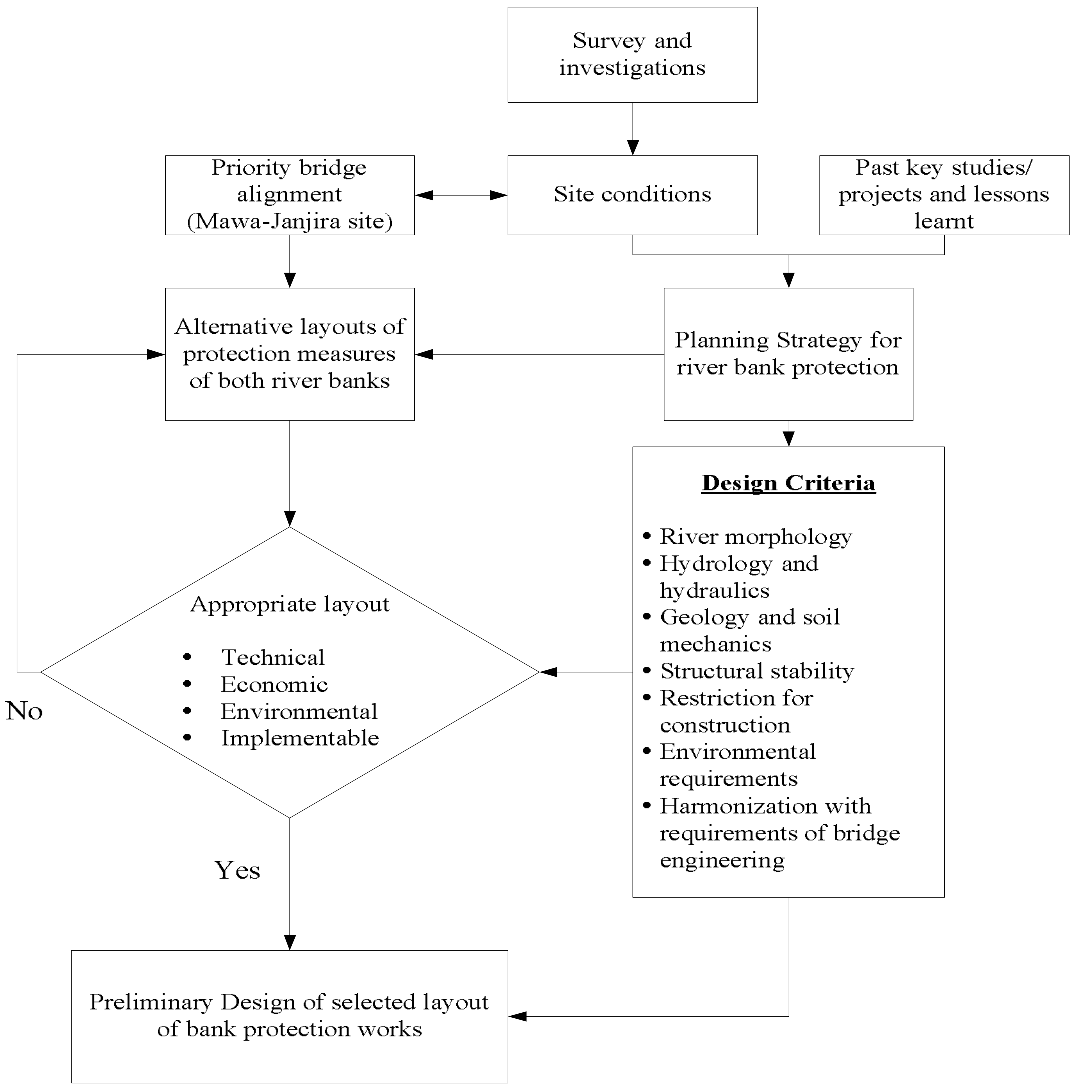


Figure 7.5.1 Flow of Preliminary Design of River Facilities

7.5.2 Strategy for Planning River Facilities

Based on the studies made so far on the geomorphologic characteristics of the river channels, existing hydrological and other physical conditions of the site, and review of the past studies and works in Bangladesh, following strategies for planning river facilities were established:

(1) Objectives of River Works

Main objectives of river works are:

1) To ensure the stability of river section by maintaining existing river and flow conditions, and
2) To protect firmly the bridge structures.

In order to materialize the objectives, strategies presented in the following paragraphs were established.

(2) Principle for Planning River Facilities: Existing favorable river conditions as bridge site shall be maintained and strengthened by river works, giving less impact to the river and river flow.

Mawa-Janjira site (MJ-site) was selected at the channel forming a narrow and single section without chars. The selected site provides favorable physical conditions for bridge crossing, and the conditions have been kept for more than 40 years. As to the left bank, it stays at the present location for more than 90 years. It is very natural to use such favorable conditions for bridge crossing, strengthening by river facilities. As far as the existing river and river flow conditions are maintained, the favorable site conditions shall also be maintained. And the bank protection measures developed through Jamuna Bridge Project, FAP-21 study and other recent efforts enable to realize it.

(3) River Width: Existing perennial river width will not be constricted.

According to the latest river survey the perennial river width at the crossing location is about 5.3 km. River facilities for Padma Bridge are to be constructed on the riverbank to avoid current attack during construction, which in result leaves the existing perennial channel not constricted.

There might be a opinion to narrow the river width further to shorten the bridge length. In order to narrow the perennial river width, intensive river works must be executed in the water current. It is difficult to execute such works in the big river as the Padma, especially for maintaining embankment slope and placing mattress or launching apron under the water. Even if it were done, quality of the work could not be guaranteed.

For the same reason, guide bunds of Jamuna Bridge were constructed on land, i.e., West Guide Bund on the char and East Guide Bund on the bank.

(4) Bank Protection Measures: Conventional measures and state-of-the-art bank protection technologies developed in Bangladesh should be employed in combination, in due consideration of the characteristics of the Padma River:

The Padma River is the so-called “wandering river” which changes its regime between the meandering and straight rivers, while the lower Ganges River is meandering and the Jamuna River braided.

In Bangladesh guide bund works have been used conventionally. Recently much progress in river studies and development of bank protection measures have been made mainly in relation with Jamuna Bridge construction project, FAP studies/projects and other bank protection efforts. In order to attain the objectives of the river works for the Padma Bridge, all the applicable measures from the conventional to state-of-the-art technologies should be employed in combination, considering their functions and applicable river regimes.will avail to this. Outlines on these measures and studies are introduced below.

Guide Bunds: Guide bund works are conventional measures developed for the meandering river, i) to confine the flow to a single channel, ii) to regulate the flow distribution and direction across the waterway, iii) to break up meander patterns, and iv) to prevent erosion of approach roads. The Hardinge Bridge constructed in 1915 across the Lower Ganges River provides one of the typical guide bunds. Design standards for guide bunds are available integrating a long time experience, mostly based on the empirical relations with the parameters of the meandering rivers. Underwater bank slope of the Hardinge Bridge was protected by the falling apron which would then be the most reliable choice.

Jamuna Bridge: Jamuna Bridge was constructed in 1998 across the Jamuna River which is a typical braided river. Jamuna Bridge has guide bunds and hard points in the upstream reaches. However, the design standards for the guide bund prepared for the meandering rivers were not always applied to these designs. It is noteworthy that the launching apron placed on dredged bank slope was adopted in combination with the falling apron, in order to execute securely the slope protection subject to deep scour.

FAP-21Project: In order to find improved solutions for bank protection measures, FAP-21 project was commenced in 1991 and continued until 2001. This project included various activities relevant to improvement of bank protection measures for the Jamuna River in focus, i.e., planning and study, physical model tests, construction of pilot bank protection structures at three sites, monitoring and evaluation, and preparation of guidelines and design manual for standardized bank protection structures. This study provides state-of-the-art bank protection technologies developed for rivers in Bangladesh.

Jamuna-Meghna River Erosion Mitigation Project: The project was undertaken in 2001 and 2002, and the proposed erosion mitigation works are now under execution. This erosion mitigation works are unique in its “adaptive approach” that is sympathetic to the river morphology and provides flexibility to adapt to morphological changes under a through prepared management system supported by the latest monitoring devices.

(5) Maintenance Repair: River facilities shall be planned and designed presupposing monitoring and maintenance repair after the construction, considering total cost during the project life.

Unlike bridge structures, the river facilities are, in general, made of earth materials and segments like concrete block or stone, and they are relatively easy to repair part by part. In addition, the construction of permanent facility with full durability from the beginning would be ridiculously high cost. Therefore, it is common to design river facilities initially at a certain safety level and maintain the function by maintenance repair in the course of use.

The river facilities are to be designed based on 25 years return period for ordinary bank protection work following the FAP pilot works and 100 years for those of bridge structures to be protected firmly.

Whatever the bank protection works are designed based on 25 year or 100 year floods, the bank would be protected always in safe, in association with the monitoring and maintenance repairs. The difference among the two would be the recurrence of repair works.

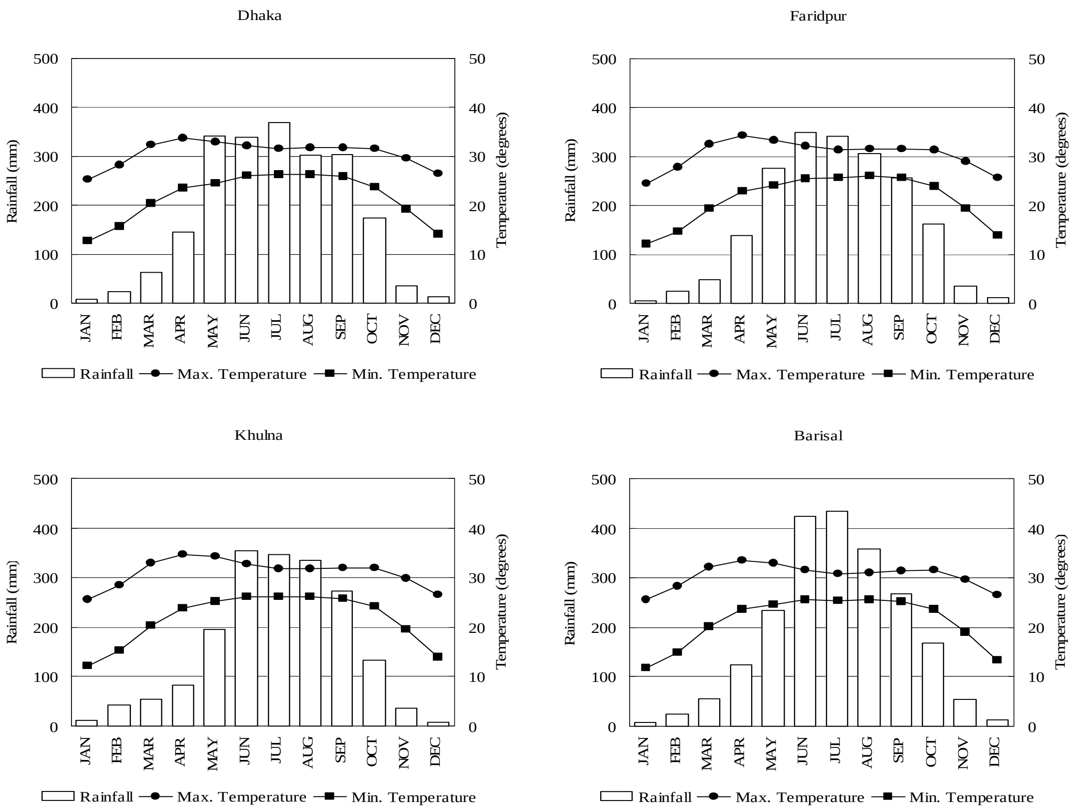
7.5.3 Basis for Design of River Facilities

(1) Standard and Studies to be Referred

- Study reports and design documents for Jamuna Bridge, 1989 - 1998
- Standard Design Manual, BWDB, 1994
- Evaluation Report of Bank Protection and River Training Pilot Project and Guidelines and Design Manual for Standardized Bank Protection Structures (FAP-21/22, 2001)
- Reports on Jamuna-Meghna River Erosion Mitigation Project (2002) and other bank protection projects in Bangladesh
- Standards, guidelines and research papers in India, Japan and other countries

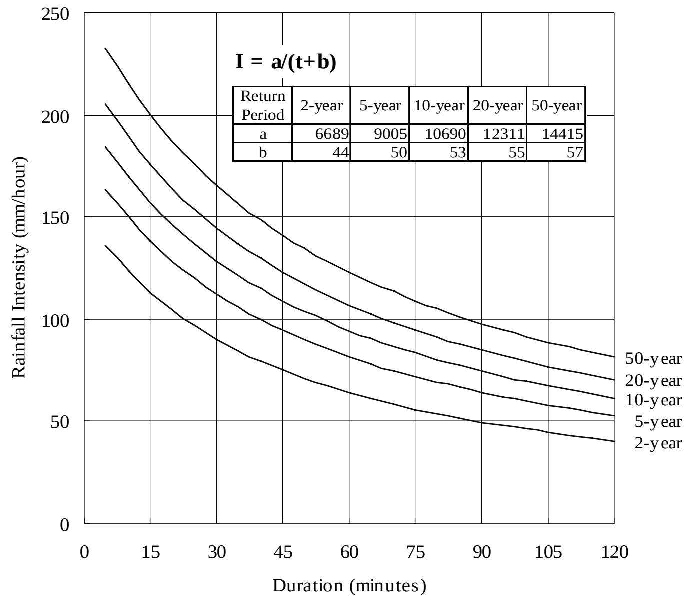
(2) Rainfall and Meteorology

1) **Meteorology:** Rainfall is the most distinctive parameter of the meteorological features of the study area. Dhaka, the nearest meteorological station to the proposed bridge site, receives annual rainfall of 2,118 mm on average. The rainy months (> 200 mm) continue for 5 months from May to September.



Monthly Rainfall and Temperature around Study Area

2) **Rainfall Intensity:** The relationships of rainfall intensity, duration and frequency (IDF) for short duration rainfall developed by FAP-8A (Greater Dhaka Protection Project, JICA, 1992) are as shown below.



Rainfall Intensity, Duration, Frequency Curves

3) **Number of Rainy Days:** Number of rainy days counted by daily rainfall depth exceeding 5, 10, and 20 mm is shown below for Dhaka and Faridpur. The number of rainy days is related to workable days for construction works at bridge site.

Number of Rainy Days

Daily Rainfall > 5 mm

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dhaka	0.4	1.5	2.3	6.0	11.2	12.3	13.9	13.0	11.3	6.1	1.2	0.6	79.9
Faridpur	0.3	1.5	2.2	5.5	9.5	11.1	13.8	12.3	10.7	5.4	1.0	0.5	73.7

Daily Rainfall > 10 mm

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dhaka	0.2	0.9	1.7	4.6	8.8	9.2	9.7	8.7	7.9	4.4	0.8	0.4	57.2
Faridpur	0.2	0.9	1.5	4.2	7.6	8.7	9.8	8.4	7.4	4.1	0.7	0.3	53.7

Daily Rainfall > 20 mm

Observatory	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dhaka	0.1	0.3	1.1	2.6	6.2	5.4	5.7	4.6	4.9	2.9	0.5	0.3	34.6
Faridpur	0.0	0.3	0.8	2.5	4.7	5.0	5.0	4.4	4.4	2.6	0.5	0.2	30.4

4) **Past Major Floods:** According to the flood statistics since 1954, the floods occurred in 1987, 1988 and 1998 are the historic severe events in Bangladesh.

(3) Water Level and Discharge

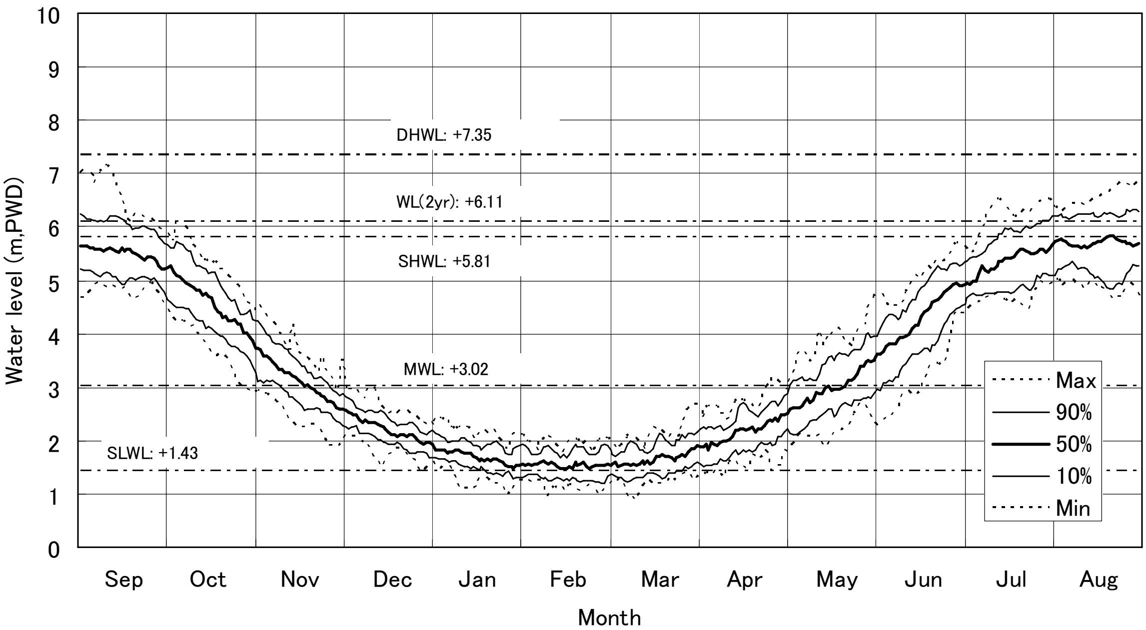
1) **Design High Water Levels and Design Discharge:** The Design High Water Levels and Design Flood Discharges are estimated based on the BWDB data at Mawa station for various other return periods as follows;

Design High Water Levels and Design Discharge

Return Period	Design Water Levels (m PWD)	Design Discharges (m^3/sec)
2-year	6.11	90,100
5-year	6.44	102,400
10-year	6.66	110,300
25-year	6.94	120,100
50-year	7.14	127,300
100-year	7.35	134,400

2) Standard Water Level: The Standard High and Low Water Levels are defined by BIWTA as average water levels of 5% and 95% exceedance in each year. Based on the BWDB data at Mawa station, the Standard High/Low Water Levels were estimated at the crossing location as follows;
   - Period of data : 1968/69 – 2002/03
   - Standard High water Level (SHWL) : +5.81 m PWD
   - Mean water Level (MWL) : +3.02 m PWD
   - Standard Low water Level (SLWL) : +1.43 m PWD

3) Annual Water Level Change: Statistic water levels of the Padma River shall be referred for planning the work program. Water levels at Mawa station are shown below for the maximum, minimum, and dependability of 90%, 50% and 10%.



Annual Water Level Change

(4) Other Hydraulic Design Parameters

1) **Design Flow Velocity:** Depth averaged flow velocity (v_m) shall calculated by Manning's formula based on coefficient of roughness n = 0.015 for flood flow and n = 0.025 for flows in dry season.

$$v_m = (1/n) \times h^{2/3} \times I^{1/2}$$

where,

h: Water depth (m)
I: River slope
Velocity at riverbed (v_b) is assumed to be $v_b = 0.6 \times v_m$.

2) **Design Wave:** Design wave in the Padma River determined by SMB-method (Sverdrup-Munk- Bretschneider) for wind speed 25 m/sec and fetch length 5.4 km (river width) is follows.
   - Design wave height = 1.4 m, with cycle time = 3.5 sec

3) **Design Maximum Scour Depth (DSMD):** The Design Maximum Scour Depth (DSMD) is estimated based on the FAP-21 Manual and other related studies. The riverbed elevations under the design maximum scour conditions are summarized as below;

Riverbed Elevation under Design Maximum Scour

Description	100-yr (m PWD)	25-yr (m PWD)
For permeable groyne	-28.2	-26.5
For revetment/guide bund	-37.6	-35.3
For bridge structure		
- In the middle of river section	-23.6	-
- Adjacent to riverbank	-37.6	-

(5) Topographic, Geotechnical and Geomorphologic Aspects

1) **Topographic Configurations:** The topographic data surveyed in June to July 2004 shall be utilized for the design, though it may change before the construction.

2) **Seismic Factor:** The seismic factor applied to MJ-site shall be 0.125 according to the "Seismic Zoning Map of Bangladesh" (originally from "Guide to Planning and Design of River Training and Bank Protection Works, BWDB)

3) **Cutting Slope Underwater:** According to the recommendation of FAP-21 study, the cutting slope underwater is to be designed not steeper than 1V : 6H.

4) **Stability of Riverbanks:**
   - Left Bank: Consideration should be given to conserve the existing less erodible left bank as much as possible in designing, execution of works and maintenance. The average annual erosion rate in the past 30 years was about 5 m/year.
   - Right Bank: Higher erodibility of right bank should be taken account into the study of construction method and plan.

(6) Other Terms to be Considered

1) **Tributaries and Branch Channels:** Tributaries and branch channels of the Padma River shall be, in principle, remained open to minimize the impact to the present flow conditions.

2) **Completion of River Works before Flood Season:** Bank protection works shall be planned and designed to complete the construction works in durable state against flood flow before the flood season begins, considering the workable period based on the statistic annual water level change.

3) **Upstream Termination:** Upstream termination of the bank protection works shall be designed, giving special attention to minimize flow concentration and formation of eddies due to flow separation.

4) **Consideration on Maintenance Repair:** Bank protection works with deep scour at the foot inherently require periodical and emergency maintenance repair. Therefore, the structure shall be planned and designed so as to enable the remedial measures with less effort coping with unpredicted failure after construction. Use of local techniques resources shall also be considered at the maximum extent.

7.6 PRELIMINARY DESIGN OF RIVER FACILITIES

7.6.1 Layout Plan and Applicable Works

(1) Crossing Route

Mawa-Janjira site (MJ-site) has been selected as the crossing location for Padma Bridge, and the crossing route at MJ-site was proposed along the route connecting the following points across the stable and single section of the Padma River:

1) Left Bank: About 1 km downstream from Mawa Ghat, just on the extended line of National Highway-N8. This point falls at the lowest end of less erodible bank and stiff clayey layer is observed on riverbank during low water period. At Mawa Ghat, bank-line protrudes somewhat toward the main flow and the crossing route is located, at present, at the wake of the protrusion.
2) Right Bank: About 2 km downstream from the confluence of the South Channel, an anabranch behind Char Kawrakandi. Facing directly to the main flow of the Padma River, the riverbank at this point is susceptible to erosion like other portion of right riverbank.

Topography of MJ-site and the cross section of the Padma River along the crossing route are shown in Figures 7.6.1 and 7.6.2. These were surveyed in July 2004 by the Study Team.

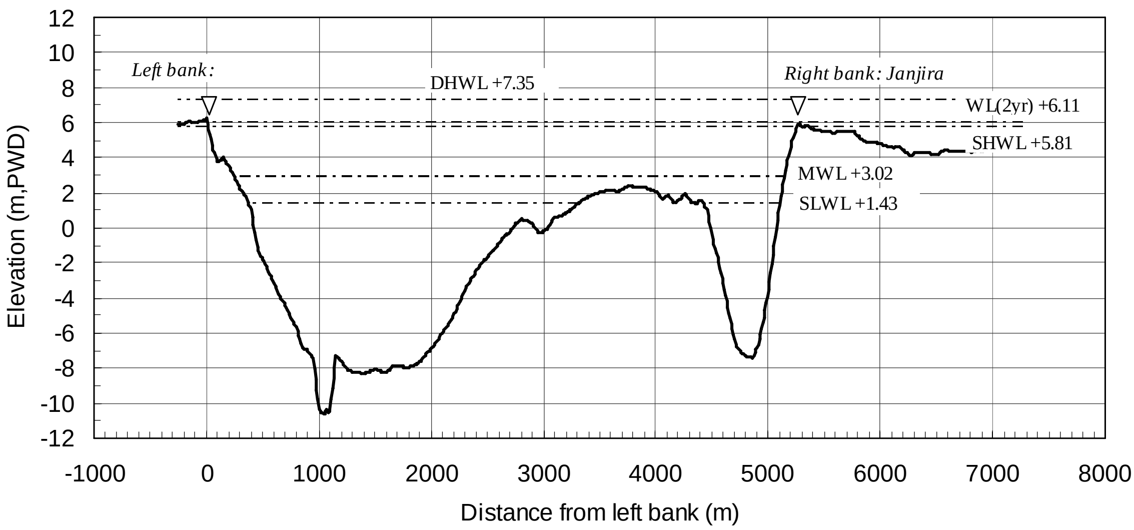


Figure 7.6.1 Cross-Section of Padma River at Crossing Route

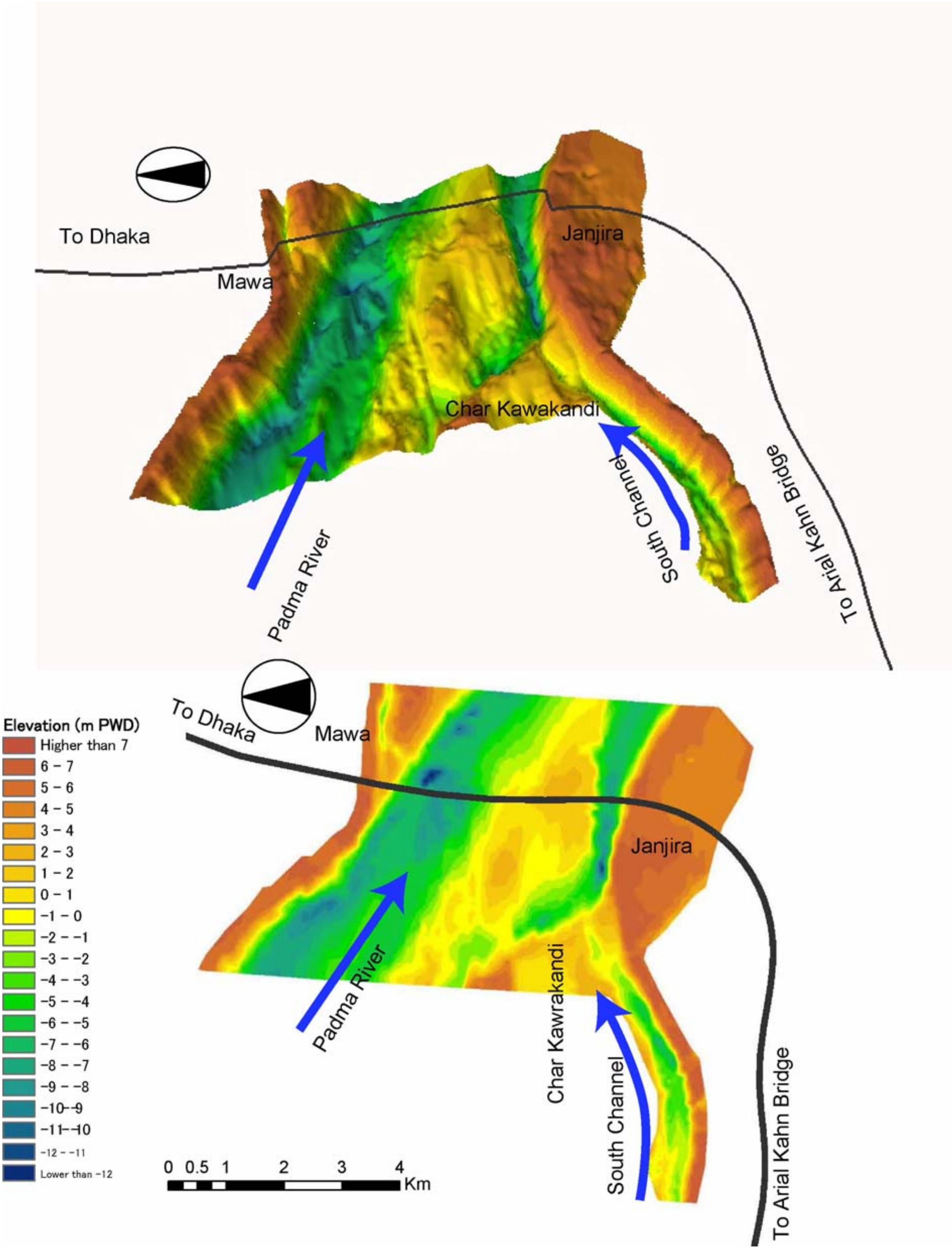


Figure 7.6.2 Topography of Mawa-Janjira Site

Present main stream of the Padma River approaches to the bridge opening straightly along side the left bank, and then it crosses the bridge axis on the skew. The main stream flows further in straight and attack to the right bank some 10 km downstream from the proposed landing point of the bridge. Along the right bank there is a stream collecting flows from the South Channel and a part of the main Padma flow. The right side stream seems to be confined by the sediment flow due to the main stream of the Padma and right bank forming relatively deep scour at the foot of right bank.

One may conceive a route connecting Narisha on the left bank and Char Kawrakandi in order to minimize the bridge length, for the Padma River forms a narrow section at present. This scheme, however, is not acceptable, because it has various defects as bridge site and risky as follows:

1) The river section at Narisha is markedly instable alternating conditions with and without island, and the existing Char Kawrakandi is quite young created in around 1990.
2) With this scheme, the South Channel needs to be closed to prevent outflanking and flood flow over the island would be completely closed by right approach road. This brings about concentration of flood flow into a waterway across the bridge. Although the existing left bank is less erodible, the bank would not be strong enough to cope with the flows and scours due to concentrated flow. The left bank also needs to be protected by intensive and costly river works as well as the right bank. Furthermore, numerous village houses settled on the left natural levee would have to be relocated owing to the construction of intensive river works.
3) The Arialkhan bifurcates from the Padma at the upper tip of Char Kawrakandi. The closure of the South Channel might influence seriously the flow diverging into the Arialkhan River which used to be the main stream of the Padma River until some 150 years ago. Geomorphologic behavior under such conditions is complicated and unforeseen if the uncertain hydrological phenomena are also taken into account.

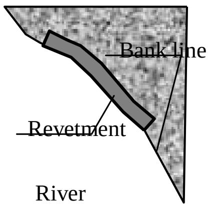
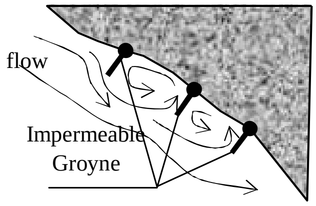
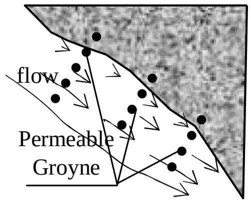
(2) Bank Protection Measures Applicable

Revetment and groyne works are the typical measures for the bank protection. Principal features of these works and application to the bank protection works (BPW) for the Padma Bridge are summarized in Table 7.6.1 comparatively.

Revetment Works: The revetment can be applicable to all locations of the BPW for Padma Bridge. Local materials and manpower could be largely adopted. In addition the revetment works are conventional and construction techniques and equipment available in Bangladesh could be employed. The revetment works, however, induce deep scour at the foot. Since the works are preferable to be executed above water, workable period for the revetment is limited to short in general. The work can be executed even under water, but careful design arrangement and construction management are necessary to attain the required quality. Execution of the revetment works in water current is difficult in such a big river as the Padma.

Impermeable Groyne Works: The groyne works are classified permeable and impermeable groynes. The permeable groynes are used generally for relatively steep-slope rivers with coarse bed materials, while the impermeable groynes are applied to mild-slope rivers like the Padma River. Impermeable groyne constructed on the fine sand bed causes deep secure at its tip and are difficult to secure the stability of the groyne itself. Impermeable groyne is not recommendable for the Padma River.

Table 7.6.1 Comparison of Revetment and Groynes

Article	Revetments	Groynes	
		Impermeable groynes	**Permeable groynes**
Descriptions of work and function	Revetments protect riverbank directly covering its surface against flow attack. The revetments do not disturve the river flow significantly, but are apt to form deep scour along the structure. The revetment consists of slope protection and toe protection in general, and the toe protection may consists of launching apron and falling apron. The slope protection is a main part of the revetment and the toe protection protects the main part coping with scour at the foot of the revetment. 	Groynes protect riverbank by deflecting or repelling the attacking flow from the bank or creating slack flow in the vicinity of riverbank. The groynes are commonly constructed in a series. Groyne works can be classified permeable and impermeable groynes. Impermeable groynes deflect the attacking flow away from the bank. Flow lines are narrowed at the groyne tips and resulting in deep local scour. 	Permeable groynes decrease flow velocities near the bank creating a groyne field of slack flow in front of the riverbank. Local scour due to the work is, therefore, not so deep. FAP-21 Manual recommends steel pile groynes as standard. 
Advantages for application to BPW of Padma River	* Certain tolerant to wave attack and unexpected change of hydraulic load. * Standard revetment by FAP-21 Manual can be executed on land in dry condition. * Construction techniques, materials and equipment are mostly available locally. * Job opportunities for local people can be expected.	* Lower construction cost per unit riverbank length. * Lower land acquisition demand. * Construction techniques, materials and equipment are mostly available locally. * Job opportunities for local people can be expected.	* Lower construction cost per unit length of riverbank. * Works can be done in river and construction period can be taken relatively longer. * Lower land acquisition demand. * Low frequency of maintenance.
Disadvantages for application to BPW of Padma River	* Relatively higher construction cost per unit length of riverbank. * Continuous monitoring and timely repair are required	* Uncertain tolerance to wave attack and unexpected change of hydraulic load.. * Continuous monitoring and maintenance repair may be necessary to cope with damages due to local scour.	* Uncertain tolerance to wave attack and unexpected changes of hydraulic load. * Main material (large diameter steel piles) have to be imported. * Heavy equipment for pile driving is not available locally.
Applicable sites	**Applicable to all sites** of bank protection works for Padma Bridge.	**Not recommendable** because of deep scour and changeable flow conditions.	**Applicable to left bank works and South Channel works** in due consideration of the characteristics of hydraulic load.

Permeable Groyne Works: The permeable groyne as recommended by FAP-21 is attractive for its less scour depth around the works and the workability which enable to work even in water current. The disadvantages of the groyne works, both for permeable and impermeable groynes, are that the function is not certain against the wave attack, oblique flows and unexpected change of hydraulic loads. In view of this, the permeable groyne would be applicable to strengthen the existing less erodible left bank, though careful consideration should be given to the characteristics of hydraulic loads. The groyne works, however, were not adopted to the present study because of the anxiety for uncertain function under variable flow conditions and use of imported materials mostly.

Proposed Works: After a comparative study on the revetment and groyne works in the above, the revetment works were selected for the bank protection at the present stage of the study.

(3) Protection Line of Left Bank

The protection line of left bank was first proposed to set 1 km away from the existing riverbank assuming possible future erosion of the less erodible bank. In this case bank protection work was not taken into account (Scheme-L1).

Later geomorphologic and geotechnical conditions of the less erodible bank was studied further for preliminary facility design, and a scheme was conceived to shift the protection line to the existing bank-line, strengthening it by 6 km long bank protection works covering neighboring bank of bridge structures and protrusive bank upstream of Mawa ghat (Scheme-L2).

Direct cost for both schemes were estimated preliminarily covering the bank protection and main bridge works and compared each other as shown in Table 7.6.2.

Table 7.6.2 Alternative Schemes for Left Bank Protection

Alternative scheme	Scheme - L1	Scheme - L2
Description of scheme	Protection line is set 1 km landside from the existing riverbank for future riverbank migration.	Protection line of the left bank is set at the existing riverbank strengthening the existing less erodible bank.
Scope of works		
Bank protection	**No work**	**6 km**
Main Bridge length	**6.4 km**	**5.4 km**
Direct work cost		
Bank protection [1)]	$0 mill.	**$66 mill.**
Bridge [2)]	$586 mill.	**$495 mill.**
Total	$586 mill	**$561 mill.**
Maintenance	Little maintenance for bank protection	Maintenance is required. But the cost would not be much because of less erodible bank.
Economic and social impacts	No change from the present	Protected riverbank would also serve for local community.
Evaluation	**Scheme-L2 is selected for its less cost and favorable impacts to the local communities**	

Note: Following unit costs are applied to the direct cost estimation.
1) Bank protection:$11,000/m, 2) Bridge: $91,6000/m

In conclusion, Scheme-L2 to set protection line at the existing riverbank strengthening existing less erodible bank was selected, since the Scheme-L2 requires less total direct cost and provides the local communities with erosion-free land along the Padma River.

(4) Sites to be Protected

The right and left riverbanks at MJ-site shall be protected from erosion, so as to maintain the existing bank-lines. Continuous bank protection works are located on both banks to fix the riverbanks in a converging shape. The bank protection works on both banks would guide the flow of the Padma River smoothly to the bridge opening wherever the Padma River may take route between the existing bank-lines. General layout of the bank protection works proposed for Padma Bridge is shown in Figure 7.6.3.

Protection Sites on Left Bank

Since the left bank is less erodible, extensive bank protection works would not be necessary. The sites that require protection are the bank around bridge structures and a protrusive bank-line upstream from Mawa ferry ghat. The protrusive bank-line has suffered from severe scouring repeatedly from the latter part of 1960's to the early 1980's. Landing point of the bridge on the left bank is located behind the protrusive bank-line protected from erosion.

In order to secure the stability of left bank and firmly protect the bridge structure, bank protection works for a continuous length of 6 km were proposed to strengthen the existing bank, covering the neighboring bank of bridge structures and the protrusive bank. The bank proposed for protection was divided into thee (3) work sites depending on their locations and required functions as follows:

Work Site-L1: Site-L1 is located in front of the landing point of the proposed bridge along the main Padma River. This is the core facility to protect bridge structures on the left bank in association with adjoining sites on both ends and the existing less erodible bank. The protection length of Site-L1 is determined to be 1 km considering the width of bridge structures and approach road embankment.

Work Site-L2: Site-L2 is located at the downstream end of Site-L1 with a crest length of 1 km. The bank protection works at this site functions as downstream termination of Site-L1 works.

Work Site-L3: Site-L3 is located next to Site-L1 upstream, extending over a length of 4 km covering the whole protruding bank-line. Strengthening the existing less erodible bank, Site-L3 works protect the protruding bank-line from erosion due to direct current attack of the Padma River.

Protection Sites on Right Bank

The right bank is composed of loose fine sand and vulnerable to erosion. In order to secure the stability of right bank and firmly protect the bridge structures, bank protection works for a continuous length of 10.3 km bank-line was proposed along the main Padma River and the South Channel.

Considering direct current attack of the Padma River, bank protection from the South Channel confluence to downstream termination is required for the riverbank in front of the bridge structures and its neighboring area.

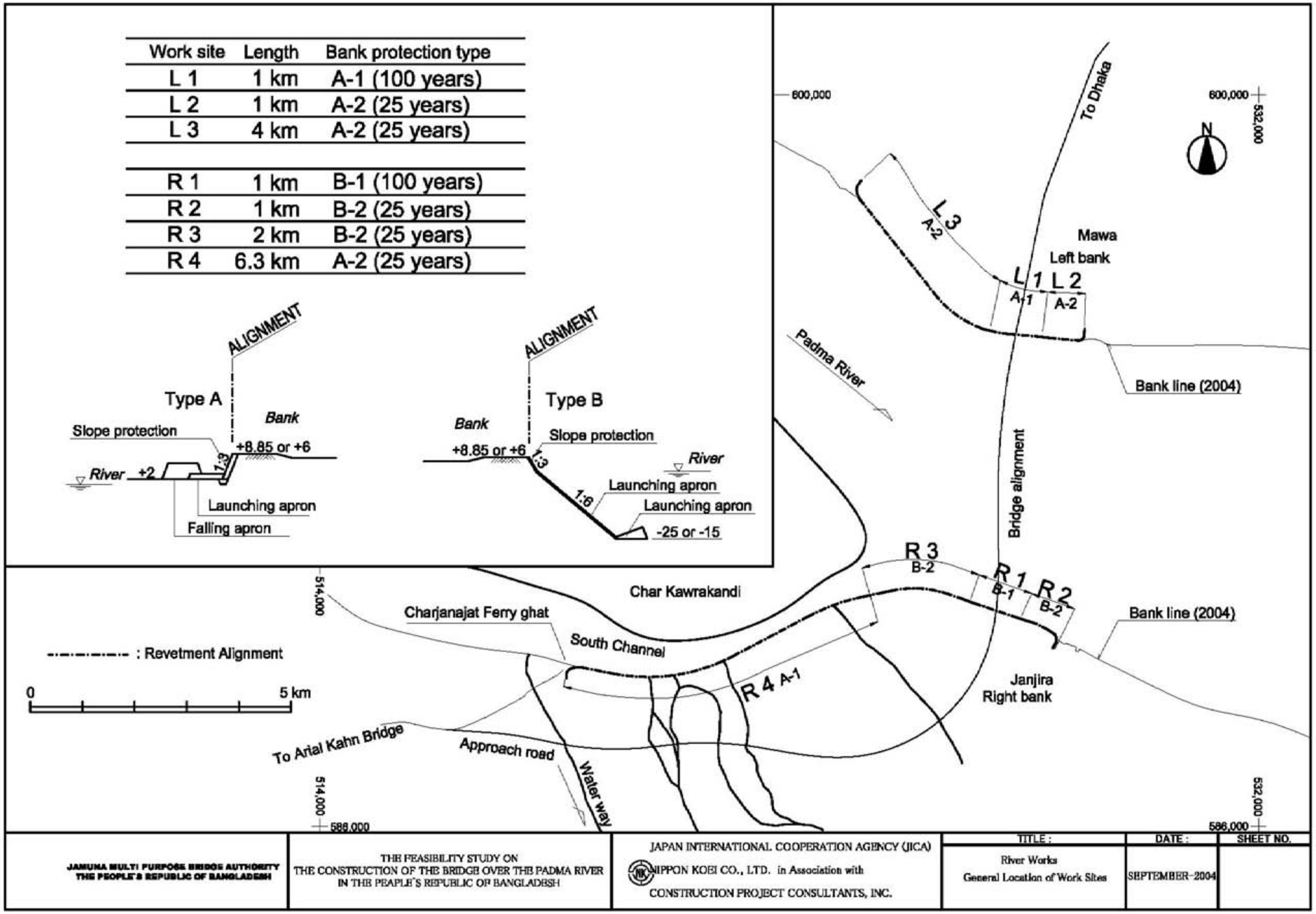


Figure 7.6.3 General Location of Work Site

On the other hand, study results of historical river changes suggest that the stabilization of the South Channel is a crucial measure to attain the stability of river channel around the crossing location and to protect the right approach road from outflanking. In view of this, right bank of the South Channel downstream from Charjanajat Ghat was proposed for protection.

The bank proposed for protection was divided into four (4) work sites depending on their locations and required functions as follows:

Work Site-R1: Site-R1 is located in front of the landing point of proposed bridge along the main Padma River. This is the core facility to protect bridge structures on the right bank in combination with adjoining sites on both ends. The protection length of Site-L1 is determined to be 1 km considering the width of bridge structures and approach road embankment.

Work Site-R2: Site-R2 is located at the downstream end of Site-R1 with a crest length of 1 km. The works at this site serves as downstream termination of Site-R1 works.

Work Site-R3: Site-R3 extending over 2.0 km long including transition to Site-R4 is connected with the upstream end of Site-R1. Site-R3 works function as upstream termination of Site-R1 works along the main Padma and as transition to connect Site-R4 works.

Work Site-R4: Connected with Site-R3, Work Site-R4 extends over a total length of 6.3 km from the Padma river confluence to Charjanajat Ghat along the right bank of the South Channel. Though the erosion of the present South Channel is not active, the South Channel has been the main stream of the Padma River twice in the past 30 years and it may happen in future repeatedly. When the South Channel becomes a main stream of the Padma in future, Site-4 works will play vital roles to check south-word shifting of the South Channel and prevent outflanking of the right approach road. The stretch of protection was proposed, considering the existing bank length exposed to possible current attack, historical movements of right bank, and the location of the right limit of active flood plain.

(5) Types of Revetment Works Applicable to Respective Sites

Structure of Revetment Works: Standardized revetment structure recommended by FAP-21 Manual mainly consists of slope protection, launching apron and falling apron. The slope protection is a main part of the revetment, and the launching and falling aprons are the toe protection works to protect the main part jointly from deep scour at the toe. FAP-21 Manual defines the falling and launching aprons as follows:

1) Falling apron: Toe protection of granular material, such as concrete blocks or boulders, placed directly on the existing subsoil or riverbed without filter.
2) Launching apron: Integrated and articulating toe protection, i.e., mattress systems, placed on prepared slopes and a filter layer above and below water or in a horizontal excavation above Standard Low Water Level.

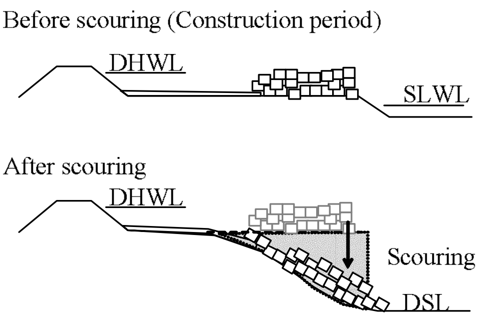
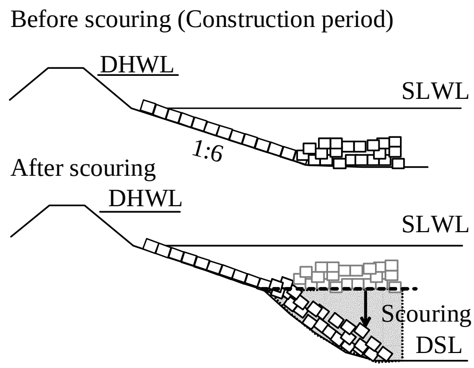
Type-A and Type-B Revetments: Two types of revetment works are proposed depending on the difference of construction method as follows:

1) Type-A Revetment: Launching apron and falling apron are constructed on land above Standard Low Water Level (SLWL).
2) Type-B Revetment: Launching apron and falling apron are constructed under the water. The launching apron is placed on the design slope formed beforehand by dredging.

Principal features of both types of revetment works are shown in Table 7.6.3. The Type-A works enable the sure construction, but the function is not always sure since the slope cover is placed by the natural flow and scour. In order to compensate the risk, excess protection materials should be preserved and successive maintenance would be required more for this type. By the Type-B works, definite function can be realized immediately after the construction. Since the works are executed under the water, uncertainty in construction cannot be avoided to some extent. Careful managements of works are required for the execution of Type-B revetment works.

The Type-A revetment is recommended for ordinary bank protection works by FAP-21 Manual and there is no case yet to be applied to protect important structures as Padma Bridge. On the other hand, Type-B revetment was applied to the guide bunds for Jamuna Bridge and it has functioned well.

Table 7.6.3 Types of Proposed Revetment Works

Types	Type-A	Type-B
Description of works	 *DHWL:Design High Water Level* *SLWL:Standard Low Water Level* *DSL:Design Scour Level* Launching apron and falling apron are constructed on land above SLWL. The falling apron and a part of launching apron fall down and protect the slope coping with the scour at the slope toe.	 Launching apron is placed on the design bank slope formed beforehand by dredging. Coping with the local scour at the slope toe the falling apron falls down and protects the slope.
Construction work	Since the works are executed on dry land, work is easier and sure. Man-power can be employed intensively.	Since the works are executed under the water use of heavy equipment is inevitable. Employment of man-power would be limited.
Cost	Medium	High
Peculiarity	Construction is sure, but the function is not always sure since the slope-covering depends on the natural flow and scour. In order to compensate the risk, excess protection materials should be provided and successive maintenance would be required.	Uncertainty in construction cannot be avoided to some extent; however, once works are constructed thoroughly, definite function can be expected immediately after the construction.
Application	Recommended as ordinary bank protection works for big rivers such as the Jamuna, Ganges and Padma rivers by FAP-21 Manual.	Applicable to bank protection work for protection of important structures such as bridge and weir. The guide bund falls under this category.

Giving conservative design considerations on the achievement of required functions, Type-B works were proposed, for the present study, for the bank protection directly related to the bridge structures and Type-A works for other portions of bank protection as follows:

1) Work sites on the left bank of the Padma River (Sites-L1, L2 and L3): Type-A revetment was proposed as recommended by FAP-21 Manual, since the main objective is to fix the bank-line strengthening the existing less erodible bank.
2) Work sites on the right bank of the Padma River (Sites-R1, R2 and R3): Type-B revetment was proposed, since the right bank is suffering from current attack of the Padma and the river bank is susceptible to erosion, definite protection effects are required immediately.
3) Work site along South Channel (Site-R4): Type-A revetment was proposed as recommended by FAP-21 Manual, since the main objective is to fix the bank-line prepared for current attacks of the main Padma River in future.

Safety Levels of Revetment Structures: The bank protection works are to be designed based on 25 years return period as recommended by FAP-21 Manual for the standardized bank protection structures, except for the banks in front of the bridge structures to be protected firmly. The banks in front of the bridge structures are to be designed based on 100 years return period on the same safety level adopted for bridge design.

Whatever the bank protection works are designed based on 25 year or 100 year floods, the bank would be kept stable, in association with the monitoring and maintenance repairs. The difference among the two would be the recurrence of repair works. The banks in front of the bridge structures should be designed with longer recurrence period of repairs considering the importance of the structures to be protected.

Proposed Revetment Works: As a summary, revetment works proposed for the respective work sites are shown in Table 7.6.4.

Table 7.6.4 Proposed Revetment Works for Respective Work Sites

Work sites	Site descriptions	Revetment type	Design flood
Site-L1	Left bank along the Padma R.(less erodible); protection of bridge/important structure	Type-A	100-yr.
Site-L2	Left bank along the Padma R.(less erodible); downstream termination of Site-L1	Type-A	25-yr.
Site-L3	Left bank along the Padma R.(less erodible); protection of protrusive bank-line	Type-A	25-yr.
Site-R1	Right bank along the Padma R.(highly erodible); protection of bridge/important structure; definite and immediate effects required	Type-B	100-yr.
Site-R2	Right bank along the Padma R.(highly erodible); downstream termination of Site-R1; definite and immediate effects required	Type-B	25-yr.
Site-R3	Right bank along the Padma R.(highly erodible); upstream termination of Site-R1; definite and immediate effects required	Type-B	25-yr.
Site-R4	Right bank along the South Ch.; preparation for future current attack of Padma	Type-A	25-yr.

7.6.2 Design Considerations

(1) General

Standards and References: Revetment Type-A and Type-B were designed for bank protection, mainly referring to the designs of river works for Jamuna Bridge and FAP-21 Manual. The FAP-21 Manual was prepared in 2001 based on the results of studies and pilot works for about 10 years.

Structural Components of Revetment: The proposed revetment mainly consists of slope protection and toe protection. Along the bank-line to be protected earth embankment is constructed, and the embankment slope and the existing bank slope are to be protected. In order to ensure the stability of the slope protection, toe protection is provided. The toe protection is composed of two structural elements, i.e., launching apron and falling apron.

Revetment Types A and B: Two types of revetment were designed depending on the site conditions and functions required as follows:

1) Revetment Type-A:
   - Sites L1, L2 and L3 along the left bank of the Padma River
   - Sites R4 along the right bank of the South Channel

2) Revetment Type-B:
   - Sites R1, R2 and R3 along the right bank of the Padma River

Considerations given to the design of revetments Type-A and Type-B are basically the same except for the structural design of the toe protection. Unless otherwise mentioned, the considerations given in the following subsections were commonly applied to the revetments Type-A and Type-B.

(2) Alignment of Revetment

Alignment of revetment is defined for the present study as an alignment of riverside shoulder of the embankment crest. The alignment which governs the alignment of the slope pavement was set considering the requirements described in the following paragraphs.

Smooth Curvature: The structure alignment should be designed with smooth curvature to reduce turbulence due to flow separation. In this regard, design of terminations and transitions of the works are important, especially for the upstream termination. The FAP-21 Manual recommends the minimum radius for the upstream termination not less than 250m and if possible to be extended 400m, whereas for the downstream termination 100m to 150m. According to the Manual, curvature of upstream termination was designed in combination of 400m and 150m for both banks, while the curvature of downstream termination was designed 100 for left bank and 150m for right bank. The alignment was set as smooth as possible along the existing bank-line so that the present flow conditions would not be changed significantly.

Enough Work Space for Construction: Embankment and slope protection works are executed on land in dry condition. In the case of revetment Type-A, toe protection works are also constructed on land. For these works, enough land space is required above river water level (approx. SLWL+0.5m) on the riverside of the revetment alignment. Total widths of revetment structure on the river-side are 85m for Type-A1 and 72 m for Type-A2. The alignment of revetment Type-B can be set on the existing bank-line.

Less Adverse Impacts to Social and Natural Environment: Since the alignment is a sort of protection line of the neighboring communities, it is preferable to be set out of the settlements protecting the houses and forests around the settlements. The lands used as settlements and forests are in general relatively old and high flood plain and they should be conserved as much as possible.

(3) Embankment and Slope Protection

Function of Embankment: Embankments provided along the bank-lines to be protected were planned mainly for stabilization of slope protection and use as a road for inspection and maintenance activities. Embankments at sites L1 and R1 located in front of the bridge structure are used for inspection activities and emergency repair throughout the year, whereas other embankments are used in a period except for high flood.

Crest Elevation: Crest elevation +6.00 m PWD was proposed, except for sites L1 and R1 in front of bridge structure, considering the existing bank level (approx. +5.00 m PWD for left and right banks, so as not change the over-land flow conditions significantly during flood season) and standard High Water Level (SHWL: +5.81m PWD for the conveniences of use as inspection road). Since the crest elevation is not high, the embankment would be submerged for several days a year during high flood. The dike should be armored for the overtopping flows. As to sites L1 and R1, the crest elevation was proposed at +8.85 m PWD based on Design High Water Level (+7.35 m PWD for 100 year flood) considering a freeboard of 1.50m. Since this part of embankment is designed to protect firmly the bridge structure, the embankment crest should be free from flood water for emergency repair and stockpiling even in case of high floods. Furthermore the embankment should be accessible all the year round connected with the approach road.

Assuming the surface slope of the river flow along the Padma at 1/15,800, crest elevations of respective embankment was determined as shown in Table 7.6.5.

Table 7.6.5 Design Crest Elevation of Embankment

Site	Portion	Length (m)	Total Length (m)	Crest elevation (m PWD)	
				Lower end	Upper end
Left Bank					
L2	Termination	292	1000	5.94	5.94
	Standard	508		5.94	5.96
	Transition	200		5.96	8.85
L1	Standard	1000	1000	8.85	8.85
L3	Transition	200	4000	8.85	6.04
	Standard	3373		6.04	6.21
	Termination	427		6.21	6.21
Right bank					
R2	Termination	331	1000	5.93	5.93
	Standard	469		5.93	5.96
	Transition	200		5.96	8.85
R1	Standard	1000	1000	8.85	8.85
R3	Transition	200	2000	8.85	6.04
	Standard	1400		6.04	6.13
	Transition	400		6.13	6.15
R4	Standard	5855	6300	6.15	6.51
	Termination	445		6.51	6.51

Cross Section: Crest width was proposed at 10m for the use as road for inspection and maintenance and as stockpile yards. Slopes of the embankment were designed in 1V:3H for both the river-side and land-side slopes. The crest and both side slopes are to be paved for traffic and overtopping flows. In order to protect the land behind the embankment, toe protection works and plantation strip were also proposed for land-side slope.

1) Land-side slope protection: Cubical blocks (C-blocks: cubical concrete blocks or equivalent oh which crushing strength ≧ 15 N/mm^2) placed on geo-textiles.
2) Land-side toe protection: 8m in width; wire-mesh mattress filled with bricks placed on geo-textiles.
3) Plantation strip: 20m in width; plants such as tree, shrub, reed, etc. to alleviate the water flow near the embankment. The plantation strip would clearly show the boundary of administrative area of the bank protection facilities

Total land-side width necessary for the embankment and its protection is about 41m from the alignment, except for sites L1 and R1.

Protection of River-Side Slope: Toe elevation of the river-side slope protection was proposed at +2.00 m PWD, considering Standard Low Water Level (+1.43 m PWD) and some allowance, and the work is planned to be executed in dry conditions. The slope protection generally consists of cover-layer and filter layer placed on the embankment slope. For the present study, cubical blocks (C-blocks) were adopted for the cover layer and geo-textiles for the filter layer.

Treatment of Branch Channels: Along the right banks of the South Channel (Site-R4), several branch channels cross the embankment. These branch channels are not perennial and have water flow only in flood season. The embankment and slope protection at the channel crossing are designed as follows:

1) Embankment is cut at the crossing of branch channel to leave the existing waterway section unclosed, while the toe protection works of the revetment are constructed continuously to protect the bank-line.
2) In order to connect the inspection roads at the channel crossing, the waterway section is paved with bed consolidation works providing appropriate slope for traffic. The consolidation works also serve for prevention against enlargement of channel section due to scour.
3) Although the inspection road on the embankment is cut at the channel during flood season, the traffic can be maintained by use of existing rural roads.

(4) Size of Cover Layer Materials

The cover layer must provide protection against current and wave attacks. Characteristic sizes of cover layer materials resistible to these attacks were calculated separately and larger size was adopted for the design. The sizes of cover-layer materials were applied to the slope protections and toe protections. As to C-blocks (C-blocks: cubical concrete blocks or equivalent), a minimum block size Dn = 0.3m is recommended by FAP-21 Manual. The crushing strength of the C-blocks is specified to be equal to or more than 25 N/mm2 for launching apron and 15 N/mm2 for other use.

<u>**Current Attack**</u>

The general formula for the design of characteristic size against current attack is given by the widely used Pilarczyk method (1990).

$$D_n \geq \frac{0.035 \cdot \bar{u}^2}{\Delta_m \cdot 2g} \cdot \frac{\phi_{SC} \cdot K_t \cdot K_h}{K_s \cdot \psi_{cr}}$$

where,

D_n: Characteristic size of the revetment cover layer material (m); Single unit size for loose elements or thickness for mattress systems

$\bar{u}$: Depth averaged flow velocity (m/s); If replaced by u_b= $0.6\bar{u}$, a value of K_h= 1.0 must be applied, where u_b: Theoretical bottom flow velocity for a logarithmic velocity profile.

Δ_m : Relative density of submerged material = $(p_s-p_w)/p_w$

g: Acceleration due to gravity (= 9.81 m/s^2)

ϕ_{SC} : Stability factor for current

ψ_{cr} : Critical shear stress parameter

K_t : Turbulence factor

K_h : Depth factor, dependent on the assumed velocity profile and the water depth to equivalent roughness height ratio:

$K_h = 2 \cdot [\log(12h/k_r)]^{-2}$ *with* K_r = D_n for relatively smooth material

K_s : Bank normal slope factor K_s = [1-(sin α / sin ε_s)^2]$^{0.5}$, in which α: slope angle of bank structure (˚) and ε_s: angle of repose considering the material specific internal friction (˚)

Wave Attack

The minimum characteristic size for the stability of the cover material under wave attack can be determined by the following formula;

$$D_n \geq \frac{H_s \cdot \xi_z^b}{\Delta_m \cdot \psi_u \cdot \phi_{SW} \cdot \cos\alpha}$$

where

D_n: Characteristic size of the revetment cover-layer material (m; Single unit size for loose elements or thickness for mattress systems)

H_s: Significant wave height (m)

Δ_m : Relative density of submerged material = $(p_s-p_w)/p_w$

g: Acceleration due to gravity (= 9.81 m/s^2)

ϕ_{SW} : Stability factor for wave loads

ψ_u : System specific stability upgrading factor

α: Bank normal slope angle (˚)

ξ_z : Wave similarity parameter = tan α · (1.25 $T_m/H_s^{0.5}$), in which T_m: Mean wave period (s)

b: Wave-structure interaction coefficient mainly dependent on roughness and porosity of protective material

Size of Cover Layer Materials Designed

Characteristic size of the cover-layer materials was estimated based on the site conditions and revetment types according to the formulas discussed above. Results of the calculation and design values determined taking larger size/weight are summarized below.

Items	Type-A1	Type-A2	Type-B1	Type-B2
Estimation by Current attack: Size (D_n) Weight	 520 mm 238 kg	 480 mm 219 kg	 340 mm 102 kg	 320 mm 81 kg
Estimation by wave attack: Size (D_n) Weight	 550 mm	 550 mm	 230 mm	 230 mm
Design value	C-blocks 600 mm	C-blocks 600 mm	Riprap 110 kg	Riprap 110 kg

(5) Toe Protection

Toe protection is required to protect the foundation of the slope protection works from the scouring and undermining due to river flow. In case the scour depth is not much, simple riprap works or consolidation works could cope with this. However, where deep scour takes place like the Padma River, special considerations are necessary.

Applicable Measures: Falling apron used for Hardinge Bridge (constructed in 1915) is a conventional measure for toe protection. This measure requires a lot of reserve of apron materials to maintain continuous cover of the bank slope to be naturally formed by scouring. Jamuna Bridge (constructed in 1998) adopted the toe protection consisting of launching apron placed on dredged permanent bank slope up to a certain depth and falling apron below the launching apron. Recently, Flood Action Plan-21 (FAP-21, 2001) recommended a toe protection consisting of launching and falling aprons constructed on land in dry condition as a standardized revetment structure. The revetment structure was developed after the studies and field pilot works for a period of 10 years.

Proposed Toe Protection: The Jamuna-Bridge type revetment was adopted for the present Study as revetment Type-B. Revetment Type-B was applied to erosion susceptible riverbank along the right bank of the Padma River (Sites R1, R2 and R3), expecting definite protection effects immediately after the work. Riprap damping on bamboo mattress is proposed for launching apron and riprap damping for falling apron for this type considering higher flexibility of the riprap. The revetment structures standardized by FAP-21 Study was adopted as revetment Type-A. Revetment Type-A was applied to other riverbanks to be protected. Cable connected concrete block mattress was adopted for launching apron for Type-A revetment and the mixture of several sizes of cubical blocks (cubical concrete blocks or equivalent of which crushing strength ≧ 15 N/mm2) was used for falling apron.

Dimensions of Launching Aprons: The width of the launching apron for revetment Type-A was chosen to be 20m according to the recommendation by FAP-21 Manual. The launching apron units should be placed on a heavy geo-textile. The launching apron was further extended for 10m under the falling apron. Both the geo-textile mats and the interconnected cover units need a sufficient anchoring at the toe of the upper revetment. The launching apron for revetment Type-B is described separately in following sub-section (6).

Dimensions of Falling Aprons: Following the assumptions that the elements of falling apron would cover the scour hole at the slope of 1V:2H with the thickness of 1.5Dn, the required volume (VFA) of a scour protection blanket per meter bank-line can be estimated geometrically as follows:

$$V_{FA} = \text{(thickness) x (slope length) x (safety factor)} = 1.5 \cdot D_n \cdot \sqrt{5} \cdot y_{BL} \cdot C_{FA}$$

where,

V_{FA}: Volume of falling apron per linear meter protected length (m^3/m)

D_n: Block size (m)
y_{BL}: Vertical distance between base level of falling apron at construction and riverbed at design maximum scour (m)
C_{FA}: Flow attack coefficient; 1.50 for moderate flow attack, and 1.75 for strong flow attack. C_{FA} = 1.75 was chosen for the present study

As to the width of the falling apron, FAP-21 Manual recommend to choose to 70 to 100% of the distance y_{BL}, namely;

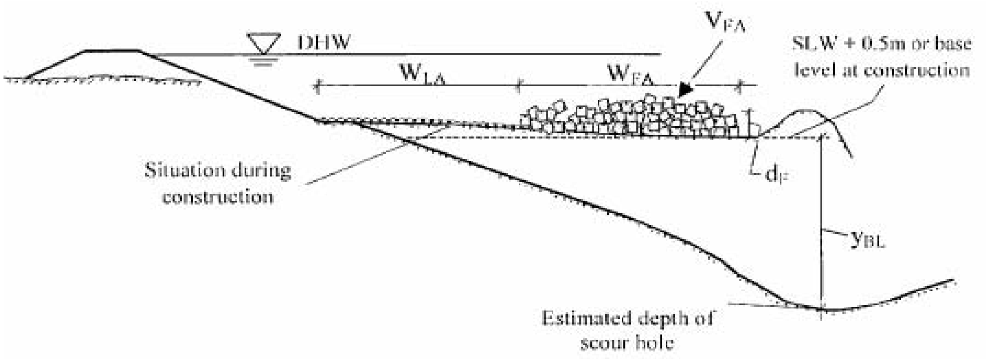
$$W_{FA} = C_W \cdot y_{BL} = 0.7 \text{ to } 1.0 \cdot y_{BL} \quad (C_W = 1.0 \text{ was chosen for the present study})$$

The thickness of the falling apron (d_{FA}: without voids) is theoretically derived approximately;

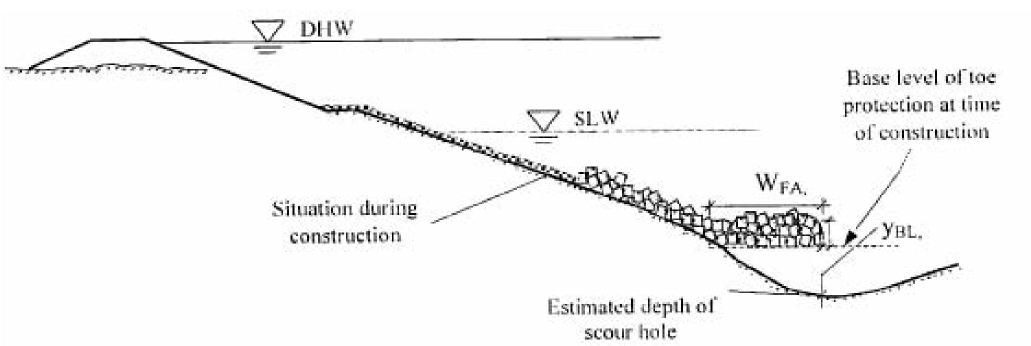
$$d_{FA} = V_{FA} / W_{FA} = C_d \cdot D_n = 5.0 \text{ to } 8.4 \cdot D_n$$

The coefficient C_d varies depending on the coefficients C_{FA} and C_W chosen. For the present design C_d = 5.9 was used for the selected coefficients C_{FA} = 1.75 and C_W = 1.0.

Type-A Revetment



Type-B Revetment



(Reproduced from FAP-21 Manual)

Falling Aprons Designed: Required volume of falling apron was first estimated as mentioned above based on the site conditions and revetment types, and then the width and thickness of the apron were determined. As to the thickness of the apron, river-side 2/3 of apron was thickened reducing the thickness of land-side apron so that the total volume should not less than the required volume. Results of the calculation and design values determined are summarized below.

Items	Type-A1	Type-A2	Type-B1	Type-B2
Estimated values:				
Width of FA (W_{FAe})	40 m	38 m	13 m	21 m
Thickness of FA (d_{FAe})	3.60 m	3.60 m	2.40 m	2.40 m
Volume of FA (V_{FAe})	140 m^3/m	132 m^3/m	30 m^3/m	48 m^3/m
Design values:				
Width of FA (W_{FAd})	45 m	40 m	15 m	25 m
Thickness of FA (d_{FAd})	4.00-2.50 m	4.50-2.50 m	3.00-2.00 m	3.00-1.50 m
Volume of FA (V_{FAd})	146 m^3/m	140 m^3/m	37.5 m^3/m	56.3 m^3/m
Check: $V_{FAd} > V_{FAe}$	OK	OK	OK	OK

(6) Lower Slope of Revetment Type-B

Lower Slope of Type-B Revetment: Type-B revetment is applied to the riverbank along the right bank of the Padma River (sites R1, R2 and R3). For the construction of Type-B revetment, permanent bank slope is formed under the water (lower slope) prior to placing the launching apron. Determination of the lower slope gradient is an important issue, since the gradient definitely governs the dredging volume. For the present study, the lower slope was determined at 1V : 6H, referring to the experience of the Jamuna Bridge works, recent examples of other bridge projects, and suggestion by FAP-21 study as introduced in the following paragraphs.

Experience of Jamuna Bridge: Channel dredging for the West Guide Bund started at the end of December 1995, and five failures had occurred in the permanent slope during the work period of 1.5 month. In order to cope with these failures two measures which markedly reduced the failures in the permanent slope were taken as follows;

1) Modification of Slope Gradient:

Original design		Modified design	
+16.5 to +9.5 m PWD	1:3.5	+ 16.5 to +9.5 m PWD	1:3.5
+ 9.5 to -3.0 m PWD	1:5.0	+ 9.5 to -4.0 m PWD	1:5.0
- 3.0 to -15.0 m PWD	1:3.5	- 4.0 to -15.0 m PWD	1:6.0
(Temporary slope)	1:3.0	(Temporary slope)	1:5.0

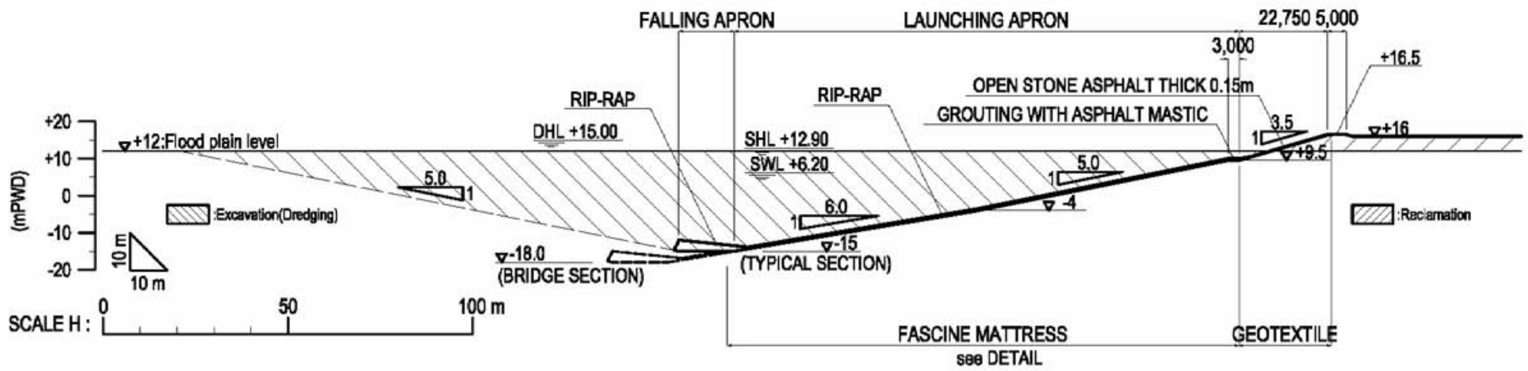
2) Improvement of Dredging Method: Thickness of single cut layer was reduced so that the removal in one cut would not trigger the failure to the adjacent slopes.

Recent Examples: The permanent slopes of guide bank works of the bridges constructed recently were listed below. As an example, guide bund section of Jamuna Bridge is shown in Figure 7.6.4.

Bridge	Upper slope (above water)	Lower slope (under water)
Jamuna Br.	1 : 3.0	1 : 5.0 & 1 : 6.0
Bhairah Br.	1 : 4.0	1 : 6.0
Paksey Br.	1 : 2.5	1 : 50

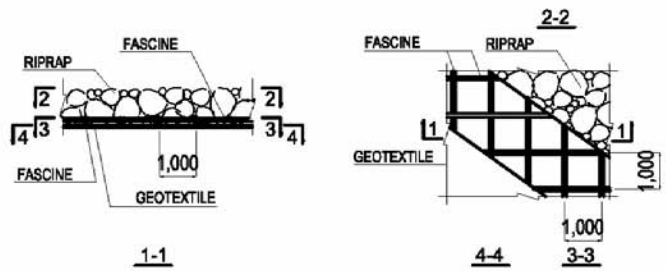
Suggestion by FAP-21/22: With regard to the underwater slope, Evaluation Report of FAP-21/22, Dec. 2001 suggests as follows:

Significant slope slides occurred during dredging of the 1V : 3.5H underwater slopes for the Jamuna Bridge guide bunds and Sirajganj Town Protection. A likely reason for this is the fast excavation of the slope which did not allow the soil to consolidate sufficiently. Therefore, underwater slopes should not be built steeper than about 1V : 6H.



JAMUNA BRIDGE GUIDE BUND SECTION

SECTION	FALLING APRON			LAUNCHING APRON	
	Elevation	Width	Material	Width	Material
TYPICAL	-15 mPWD	15 m	RIP-RAP 1-100kg 35m3/LIN m	184.5 m	RIP-RAP 10-60kg 0.50m THICK
BRIDGE	-18 mPWD	15 m	RIP-RAP 1-115kg 36m3/LIN m	202.5 m	RIP-RAP 10-100kg 1.00 m THICK



DETAIL B1
FASCINE MATTRESS

Source:As built Drawing

Figure 7.6.4 Guide Bund Section of Jamuna Bridge

(7) Construction Method of Revetment Type-B

As to the construction methods of Type-B revetment on the right bank, two methods were considered, i.e., constructions on the bank (Scheme-R1) and in the river (Scheme-R2). General plans of these schemes are shown in Figure 7.6.5.

For the Scheme-R1, design alignment of bank-line should be moved back by about 500 m to provide enough space for revetment work. Awing to this, bridge length becomes longer and wide land area have to be acquired and many village houses to be relocated, while for Scheme-R2, bridge length can be shortened and land and house compensation is minimized, though difficult works in river must be executed during the limited low-water period.

Direct costs were preliminarily estimated and compared each other including other aspects relevant to the schemes as shown in Table 7.6.6. In conclusion Scheme-R2 was selected considering the lower total cost of river and bridge works and less social issues. For the construction of the Scheme-R2, careful arrangement and work time control would be necessary.

Table 7.6.6 Alternative Construction Methods for Right Bank

Alternative scheme	Scheme - R1	Scheme - R2
Description of scheme	Construction on the bank	Construction in the river
Scope of works		
Bank protection	3.5 km along Padma river	3.5 km along Padma river
Temporary works	None	4 km long steel pile coffering
Main Bridge length	5.9 km	5.4 km
Direct work cost		
Bank protection 1)	$107 mil.	$135 mil.
Bridge 2)	$541 mil.	$495 mil.
Total	$648 mil.	$630 mil.
Bank-line	About 500m setback from existing bank-line	On the existing bank-line
Construction	Work is relatively easier and workable period can be taken longer because of on land work.	Work is tight in schedule because the work is affected by river water level and temporary coffering works are required additionally.
Economic and social impacts	More	Less
Evaluation	Scheme-R2 requiring less cost and less land and house relocation was selected. However, much consideration should be given for the execution of work.	

Note: Following unit costs are applied to the direct cost estimation.
1) Bank protection: $30,600/m for Scheme-R1 and $38,600/m for Scheme-R2
2) Bridge: $91,600/m

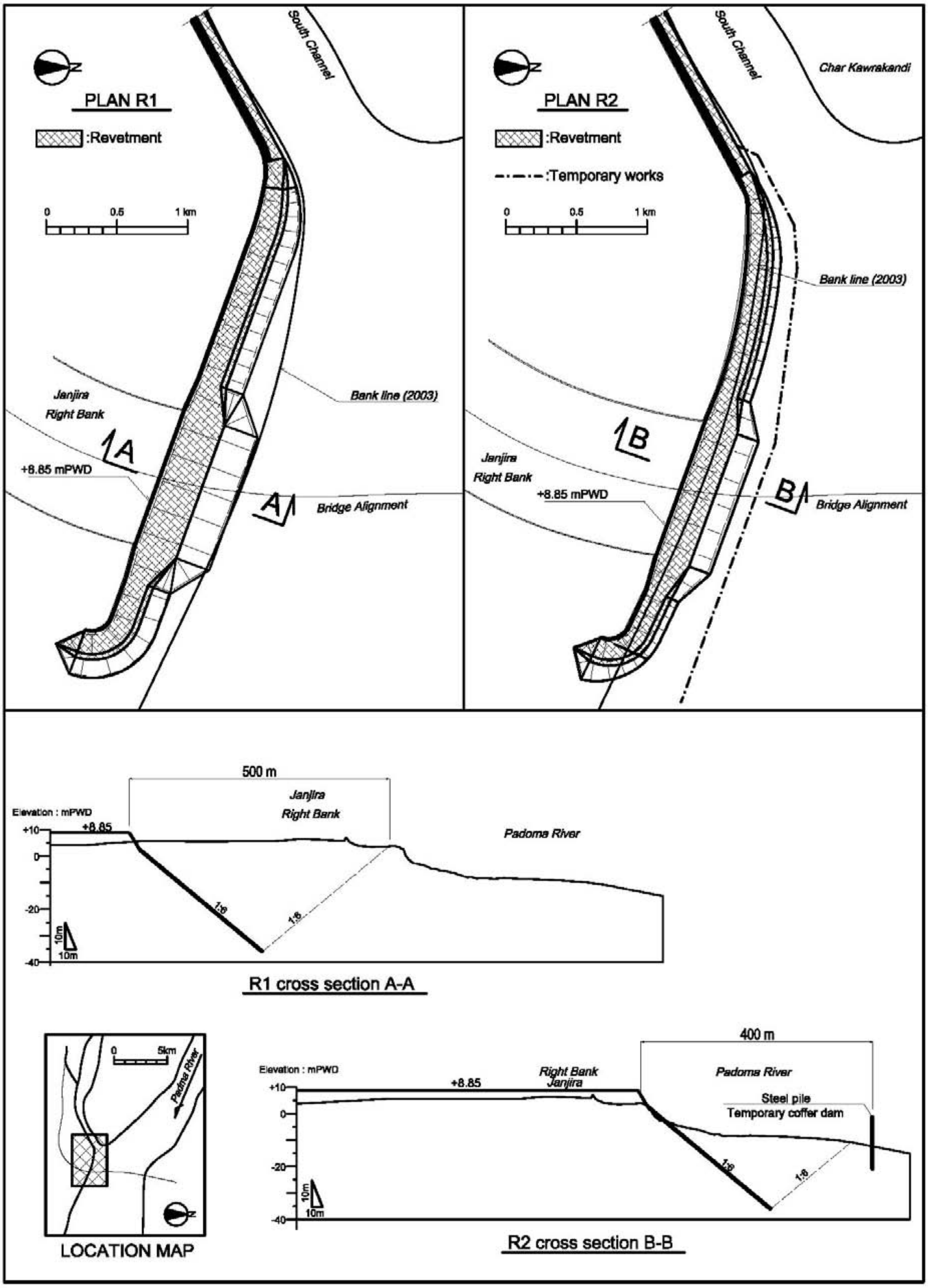


Figure 7.6.5 Alternative Construction Methods for Right Bank Works

(8) Dredging Level of Revetment Type-B

Sites R1, R2 and R3 are located on the right bank facing directly to the main Padma River. For these sites Type-B revetment is proposed, for the riverbank is highly susceptible to erosion and the immediate bank protection effects are required. For Type-B revetment, the launching apron is placed on the design slope prepared beforehand by dredging and falling apron at the foot of the launching apron. These works are executed under the water. According to the earlier study, the slope of the launching apron was determined at 1V : 6H.

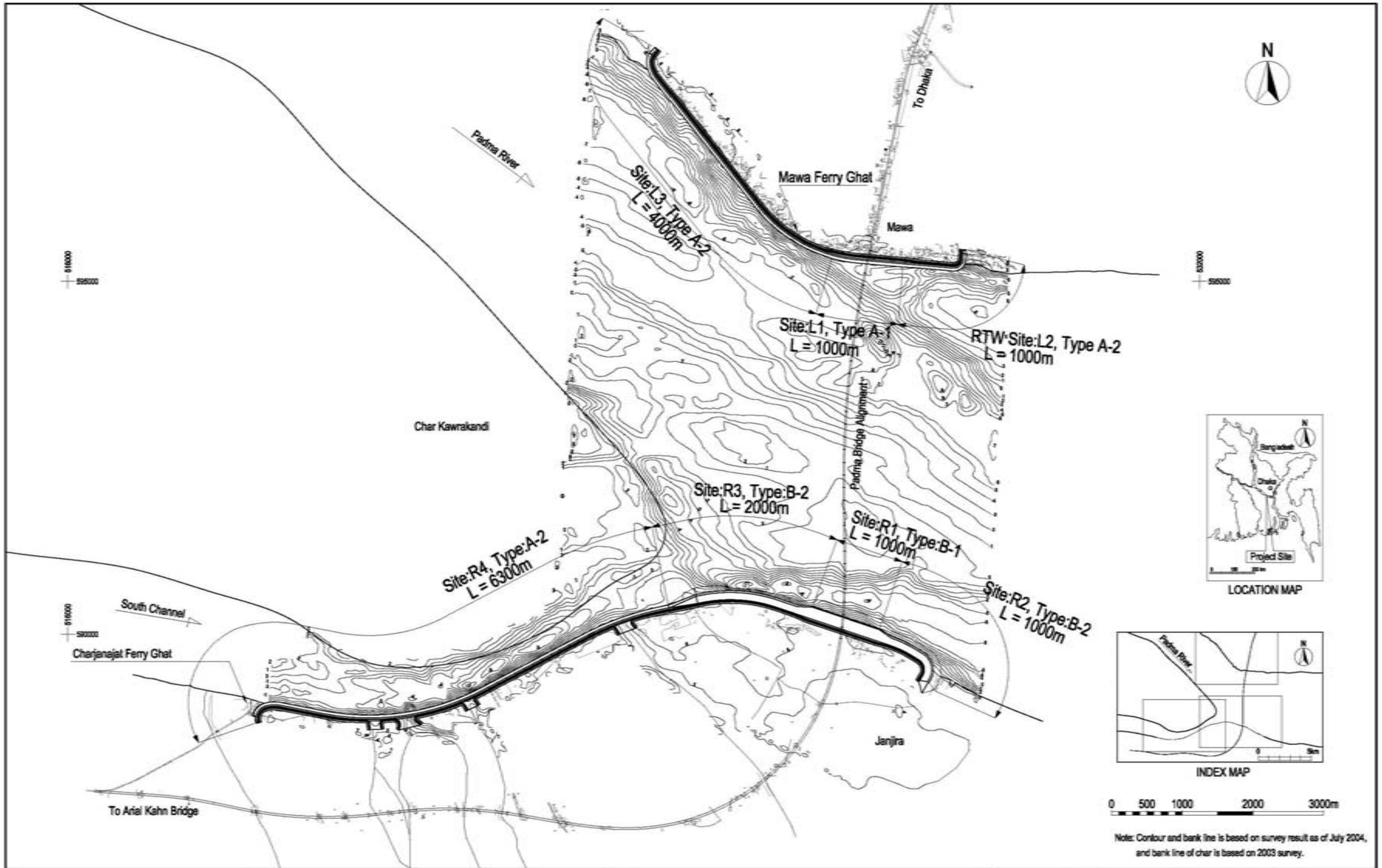
Dredging Level for Site-R1: In order to protect the riverbank thoroughly from the erosion, it is desirable to place the launching apron up to the depth of design maximum scour, dredging the earth in front of the revetment. However, the deep dredging requires much cost and time. For the Type-B revetment at Site-R1 (named as TypeB-1), dredging level was decided at -25 m PWD considering the maximum dredging depth of cutter suction dredger (assumed at 30 m) and the estimated natural scour level. This bed elevation corresponds to about 1.5 m below the riverbed under natural scour condition. With this revetment, the natural scours which would take place in relatively longer stretch is coped with the launching apron placed on the permanent slope and the structure induced scours which would locally occur are protected by the falling apron.

Dredging Level for Sites R2 and R3: As for the revetment at sites R2 and R3 (named as Type B-2), dredging level was set at -15.0 m PWD considering the capacity of dredgers and workable period in a year. The revetment works at sites R1, R2 and R3 must be completed within one dry season.

7.6.3 Design Drawings

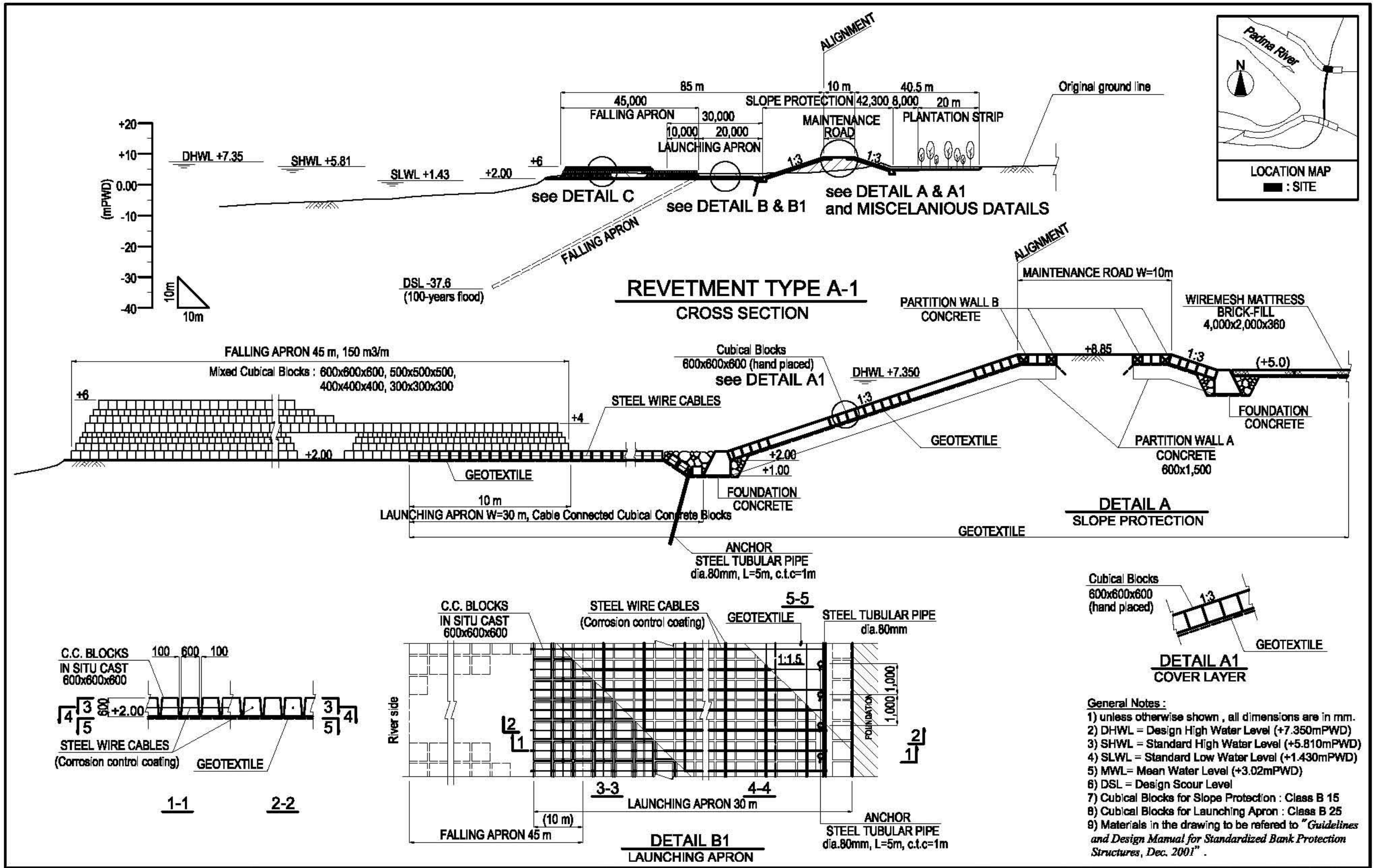
Based on the results of design considerations, river facilities were designed preliminarily. Design drawings of revetment works were prepared for respective sites as listed below.

(Figure No.)	(Title)
7.6.6	General Plan of River Works
7.6.7	Standard Design of Revetment: Type A-1
7.6.8	Standard Design of Revetment: Type A-2
7.6.9	Standard Design of Revetment: Type B-1
7.6.10	Standard Design of Revetment: Type B-2
7.6.11	Miscellaneous Details
7.6.12	Plan of River Works: Left Bank of Padma River (Sites L1, L2 and L3)
7.6.13	Plan of River Works: Right Bank of Padma River (Sites R1, R2 and R3)
7.6.14	Plan of River Works: Right Bank of South Channel (Site R4)



JAMUNA MULTI PURPOSE BRIDGE AUTHORITY THE PEOPLE'S REPUBLIC OF BANGLADESH	THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE BRIDGE OVER THE PADMA RIVER IN THE PEOPLE'S REPUBLIC OF BANGLADESH	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) NIPPON KOEI CO., LTD. in Association with CONSTRUCTION PROJECT CONSULTANTS, INC.	TITLE: River Works General Plan of River Works	DATE: September-2004	SHEET NO.

Figure 7.6.6 General Plan of River Works



			TITLE :	DATE :	SHEET NO.
JAMUNA MULTI PURPOSE BRIDGE AUTHORITY THE PEOPLE'S REPUBLIC OF BANGLADESH	THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE BRIDGE OVER THE PADMA RIVER IN THE PEAPLE'S REPUBLIC OF BANGLADESH	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) NIPPON KOEI CO., LTD. in Association with CONSTRUCTION PROJECT CONSULTANTS, INC.	River Works Standard Design of Revetment Type A-1	SEPTEMBER-2004	

Figure 7.6.7 Standard Design of Revetment: Type A-1

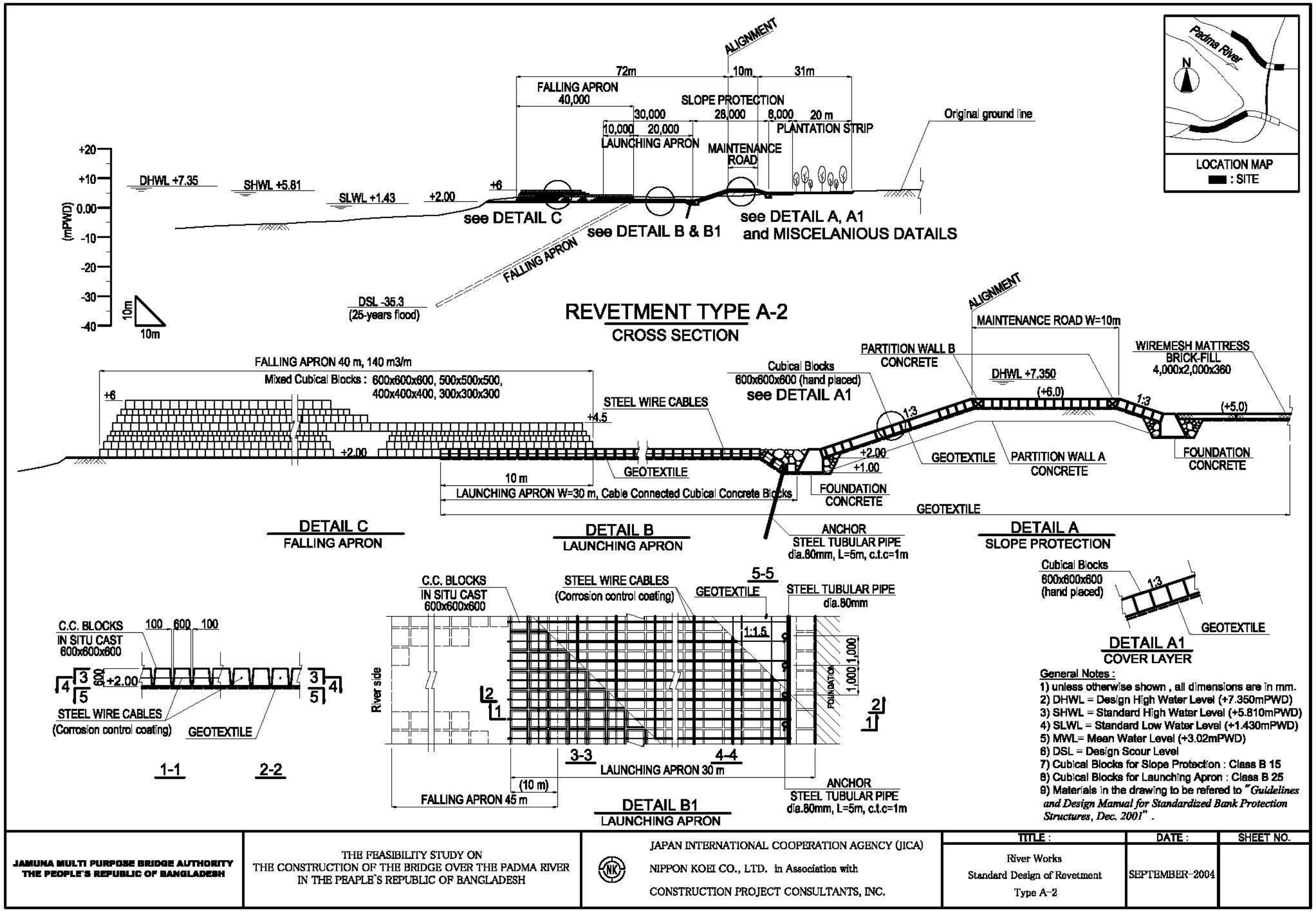
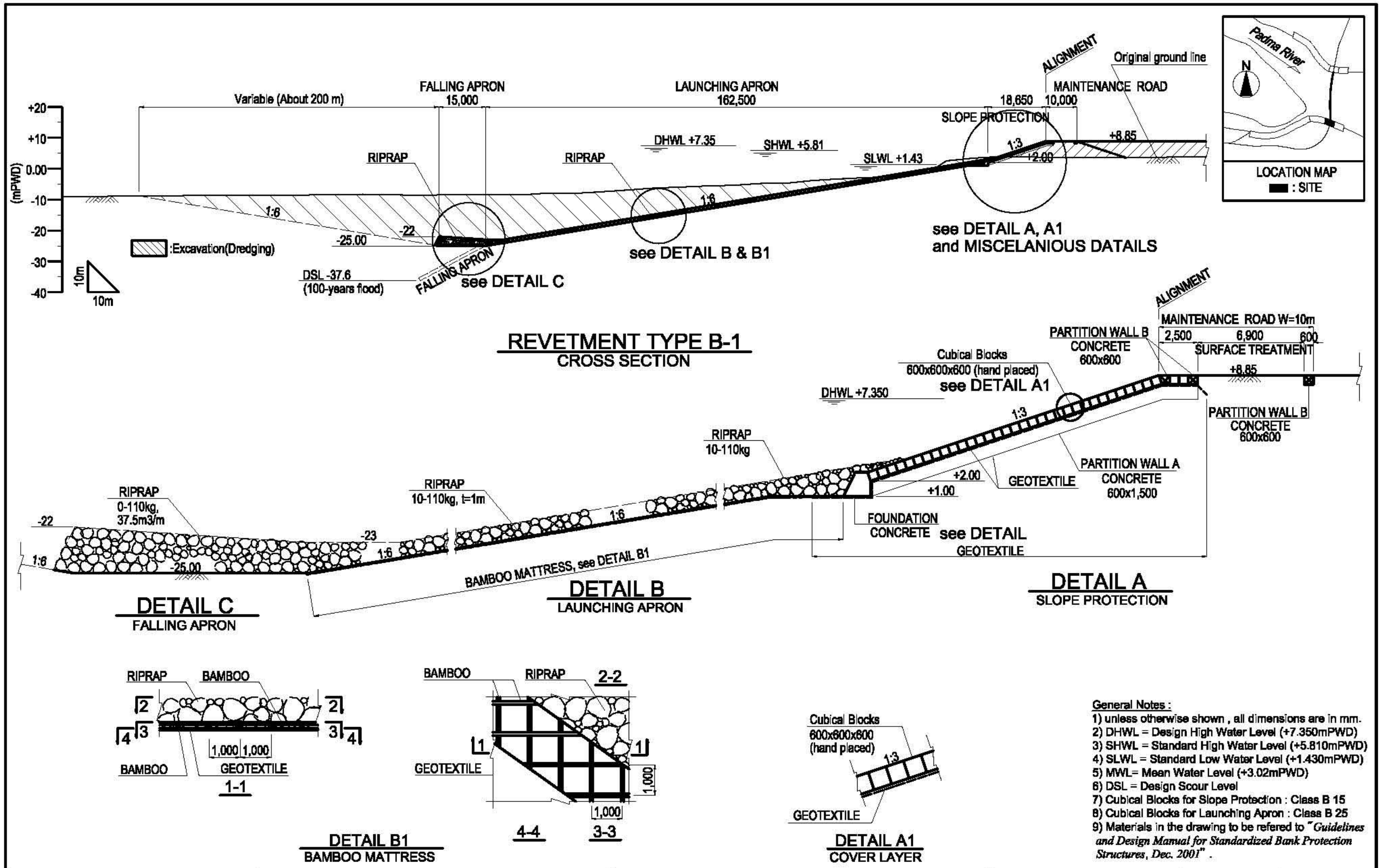


Figure 7.6.8 Standard Design of Revetment: Type A-2



			TITLE :	DATE :	SHEET NO.
JAMUNA MULTI PURPOSE BRIDGE AUTHORITY THE PEOPLE'S REPUBLIC OF BANGLADESH	THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE BRIDGE OVER THE PADMA RIVER IN THE PEAPLE'S REPUBLIC OF BANGLADESH	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) NIPPON KOEI CO., LTD. in Association with CONSTRUCTION PROJECT CONSULTANTS, INC.	River Works Standard Design of Revetment Type B-1	SEPTEMBER-2004	

Figure 7.6.9 Standard Design of Revetment: Type B-1

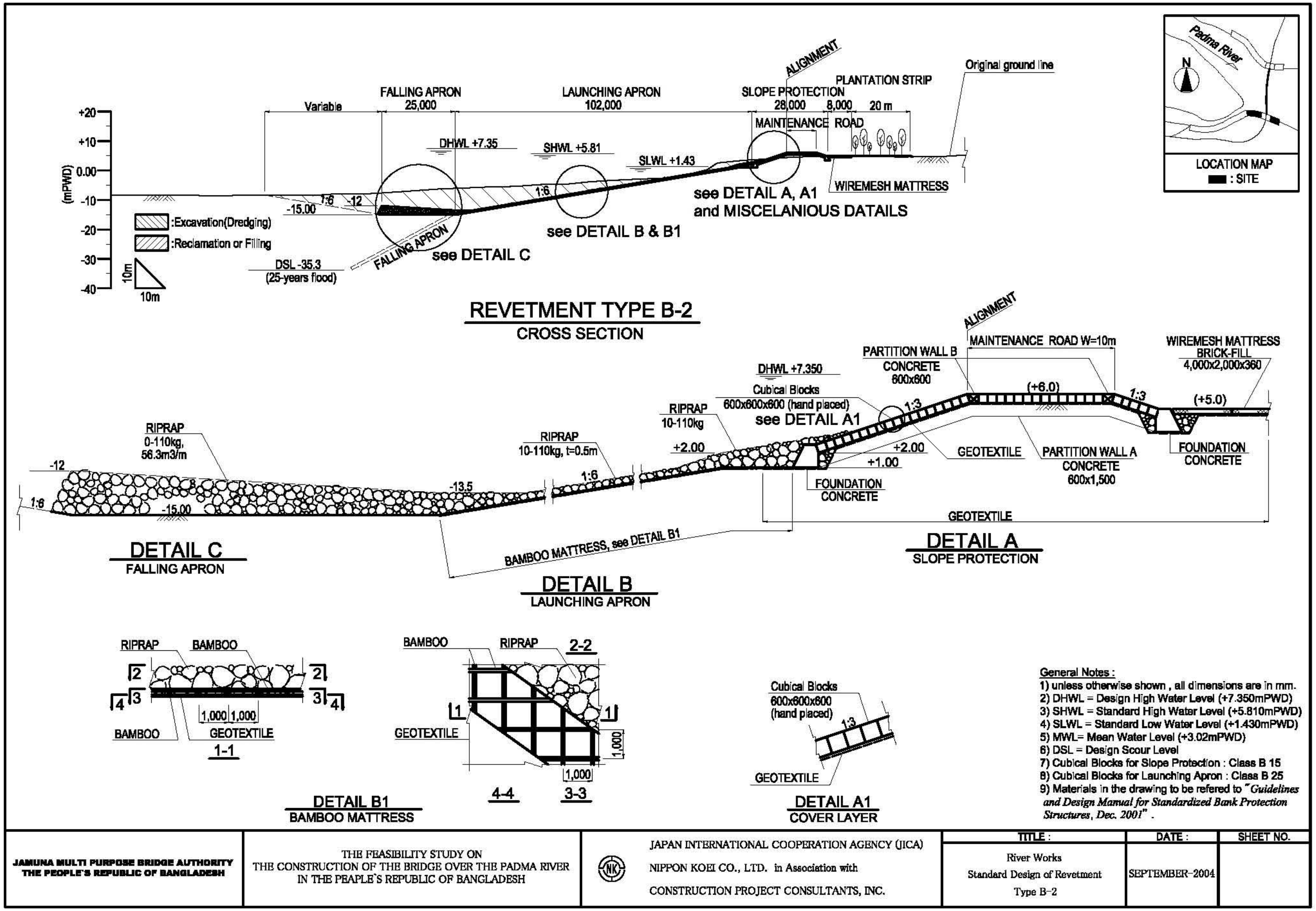
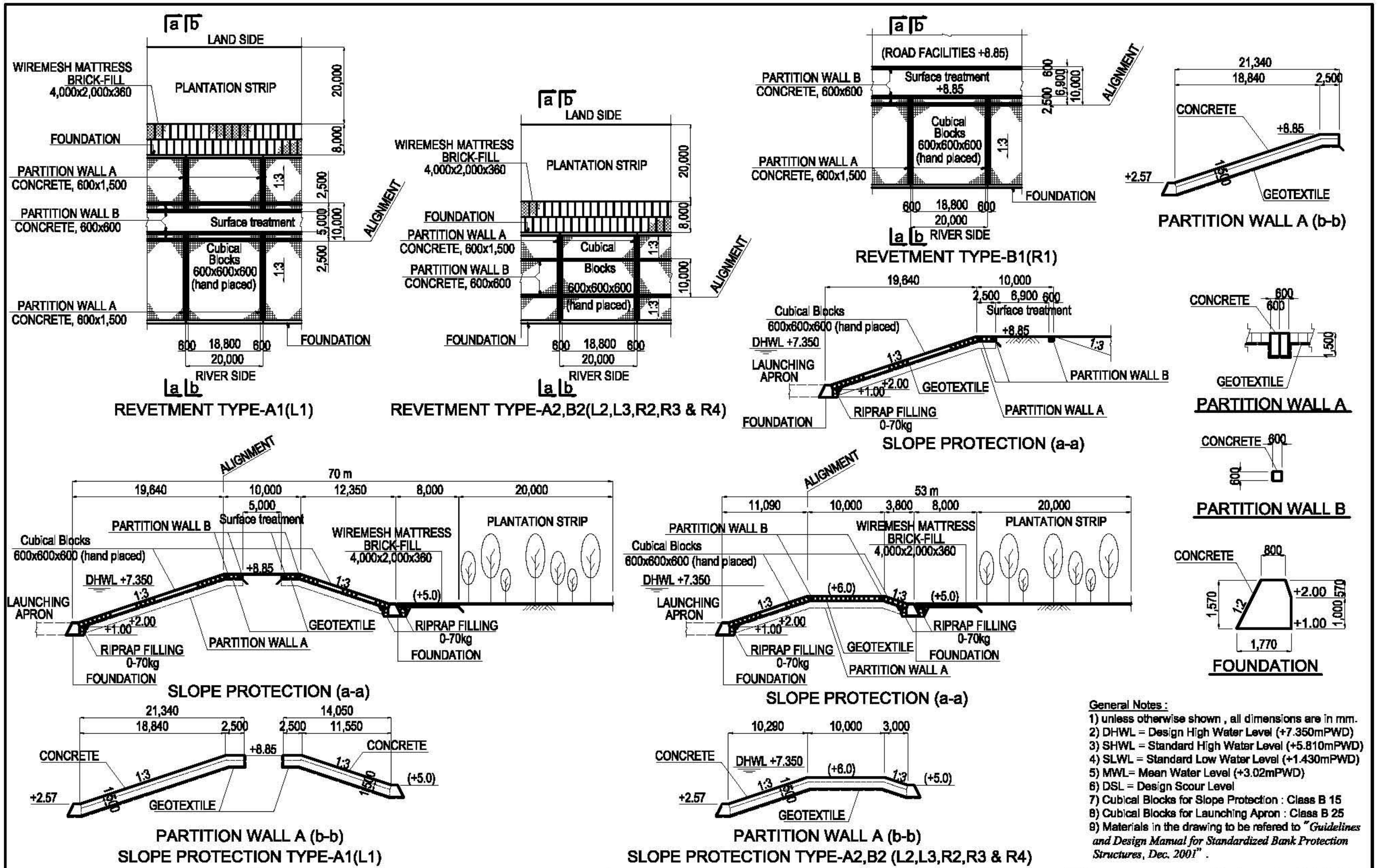


Figure 7.6.10 Standard Design of Revetment: Type B-2



FOUNDATION JAMUNA MULTI PURPOSE BRIDGE AUTHORITY THE PEOPLE'S REPUBLIC OF BANGLADESH	THE FEASIBILITY STUDY ON THE CONSTRUCTION OF THE BRIDGE OVER THE PADMA RIVER IN THE PEAPLE'S REPUBLIC OF BANGLADESH	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) NIPPON KOEI CO., LTD. in Association with CONSTRUCTION PROJECT CONSULTANTS, INC.	TITLE : River Works Standard Design of Revetment Miscelanious Details	DATE : SEPTEMBER-2004	SHEET NO.

Figure 7.6.11 Miscellaneous Details

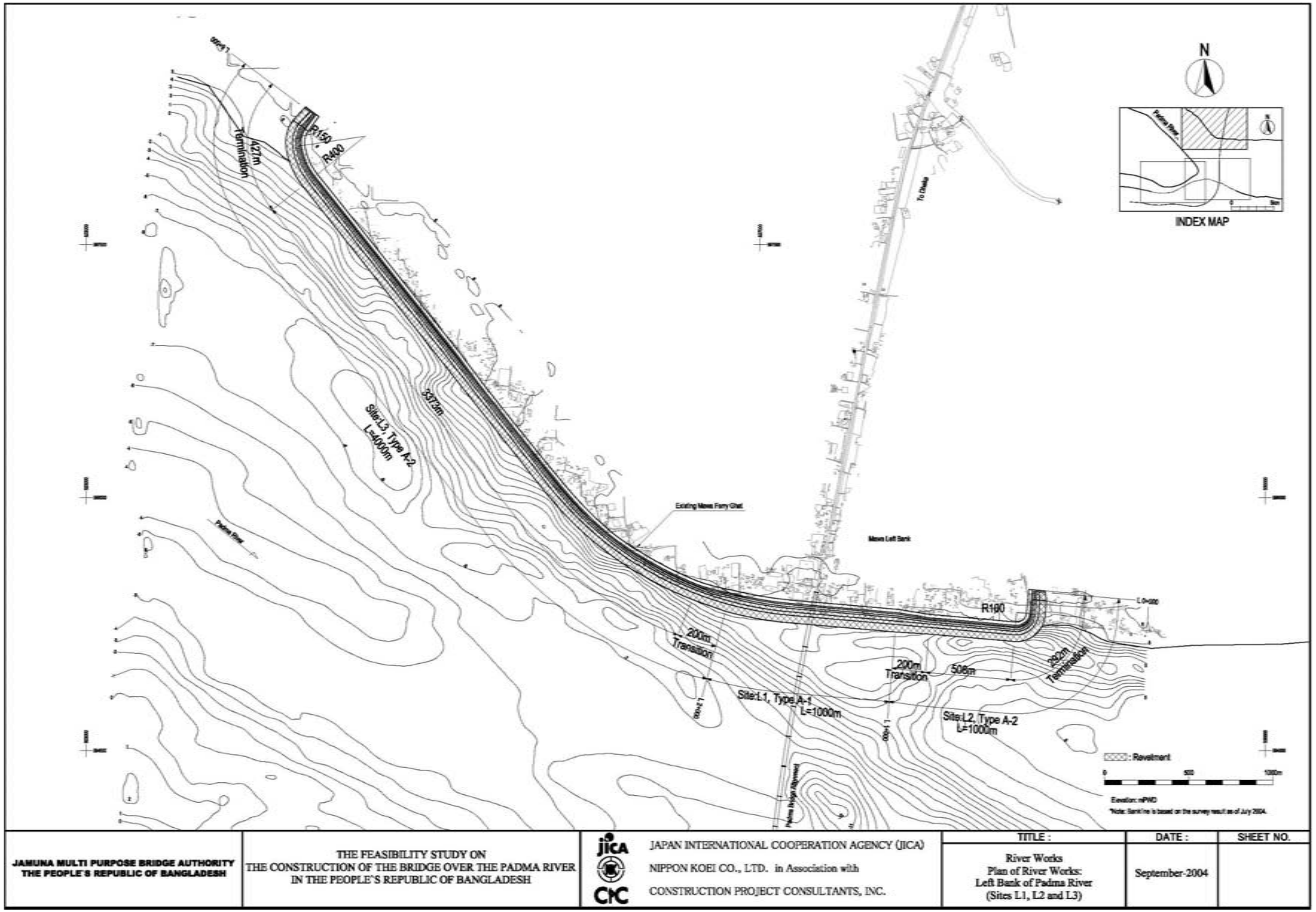


Figure 7.6.12 Plan of River Works: Left Bank of Padma River

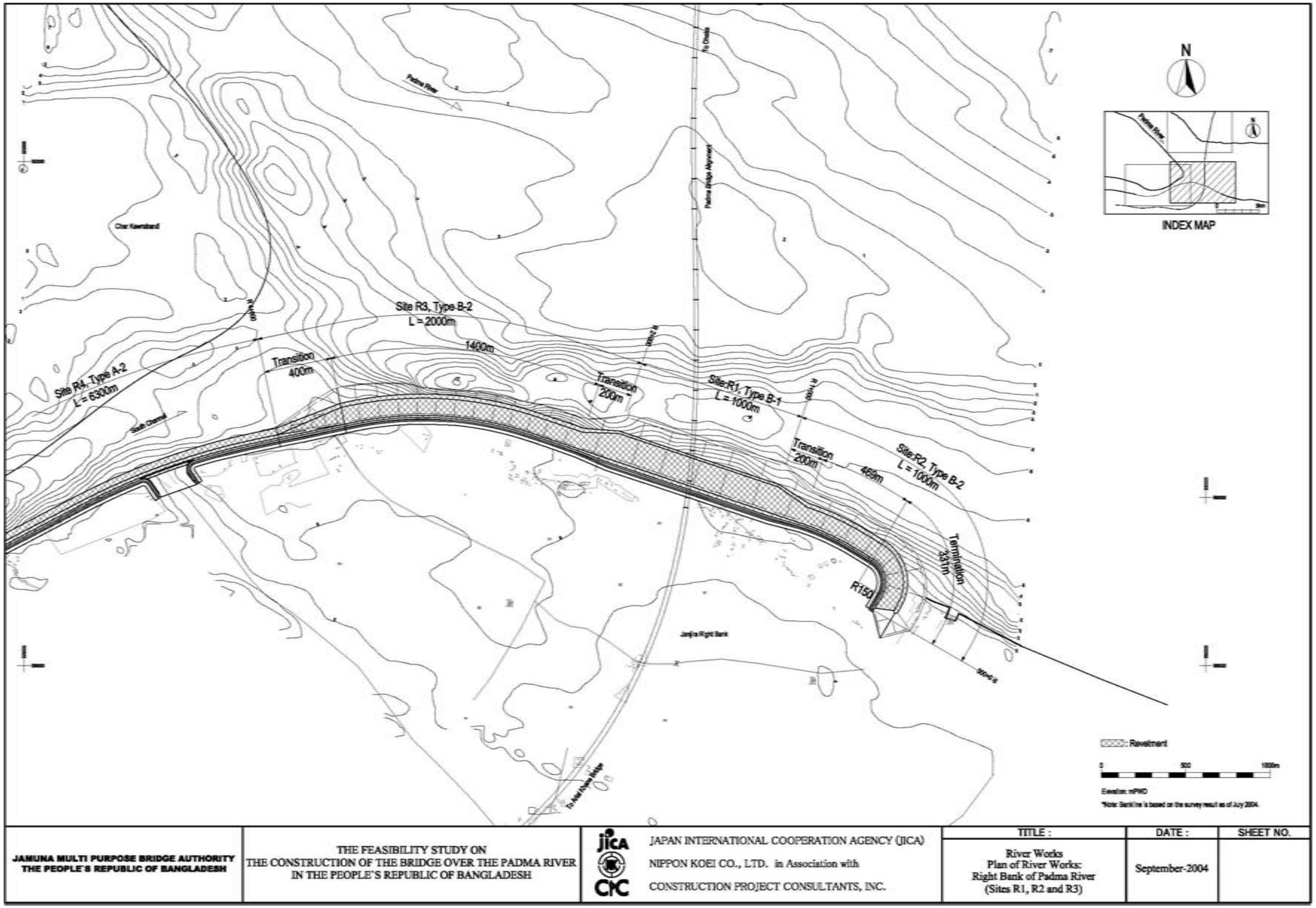


Figure 7.6.13 Plan of River Works: Right Bank of Padma River

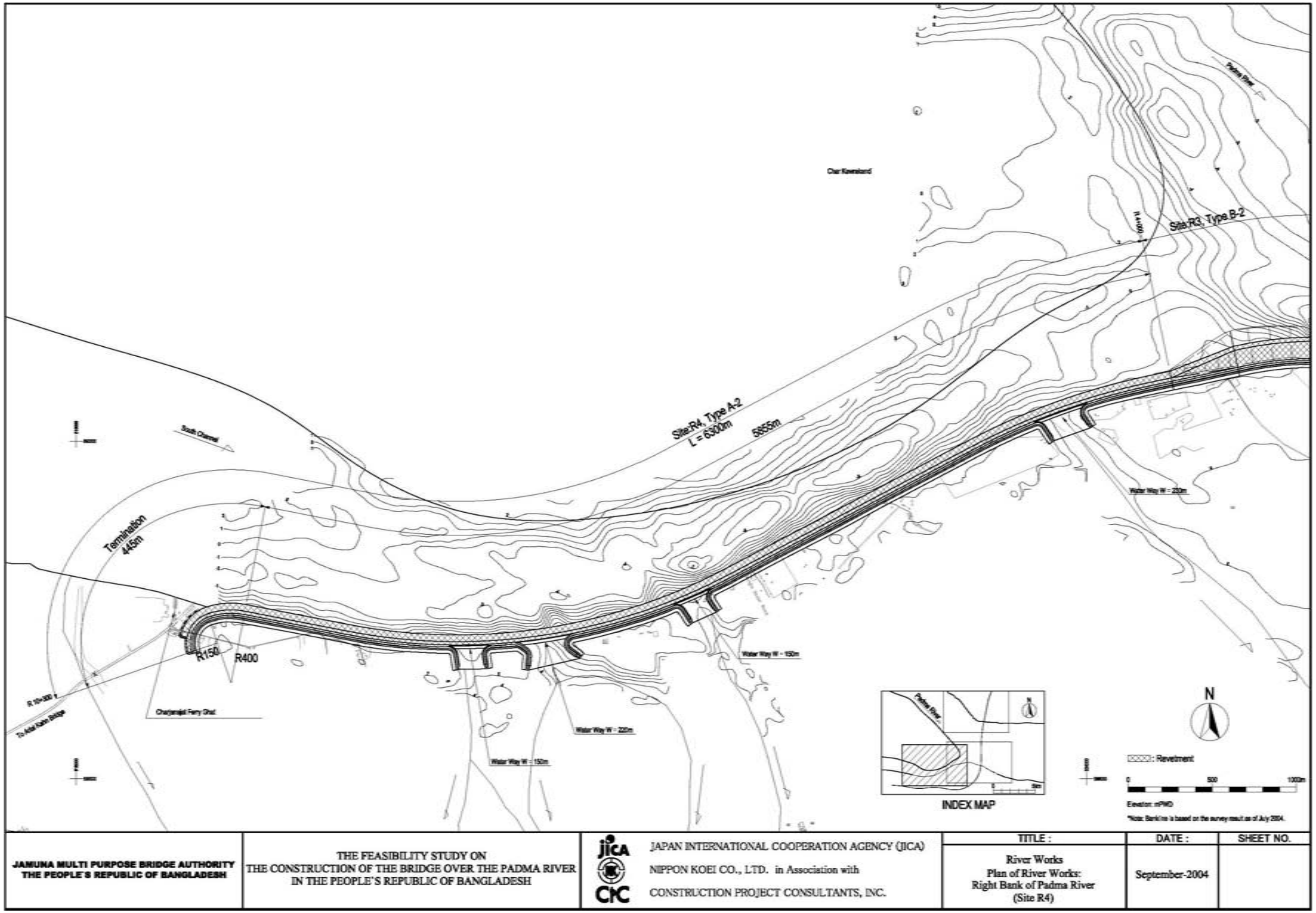


Figure 7.6.14 Plan of River Works: Right Bank of Padma River

7.7 CONSTRUCTION OF RIVER WORKS

7.7.1 Execution Method of River Works

Revetment is adopted as the bank protection works for Padma Bridge. The revetment mainly consists of slope protection, launching apron and falling apron, and is classified into Type-A and Type-B depending on the difference of construction method of launching and falling aprons.

For the revetment Type-A the launching apron and falling apron are constructed on land above Standard Low Water Level (SLWL), while for the revetment Type-B the launching apron is placed on the design bank slope shaped beforehand by dredging. Major work items and execution method for these works are presented below.

(1) Execution Method of Revetment Type-A

1) Site clearing and excavation
2) Embankment
3) Concrete foundation and partition
4) Slope protection: Placing geo-textile filter and concrete blocks on it
5) Launching apron: Placing geo-textile filter and connected concrete blocks on it
6) Falling apron: Placing concrete blocks
7) Surface treatment: For embankment crest as maintenance road and stock pile yards
8) Land side protection: Slope protection, toe protection, etc.

(2) Execution Method of Revetment Type-B

1) Temporary works: Driving steep piles to create still water z one for dredging and revetment works, and extracting steel piles after the work.
2) Dredging and Excavation
3) Site clearing
4) Embankment
5) Concrete foundation and partition
6) Slope protection: Placing geo-textile filter and concrete blocks on it
7) Launching apron: Furnishing and placing bamboo mattress, and riprap work on the mattress
8) Falling apron: Riprap
9) Surface treatment: For embankment crest as maintenance road and stock pile yards
10) Land side protection: Protection of land-side slope, toe protection, etc.

7.7.2 Preliminary Construction Schedule

(1) Review of Jamuna Bridge Works

The experience of the construction of Jamuna Bridge provides us invaluable information. In view of this, monthly reports during the construction period of Jamuna Bridge were reviewed. Figure 7.7.1 shows the construction plan and its actual progress. There are mainly four work groups of river works for Jamuna Bridge, and plan and actual progress of each work group is summariz ed below:

1) Bhuapur Hard Point Works
   - Plan : Dec. 1994 – Jun. 1995
   - Actual : Jan. 1995 – May 1995
2) Work Harbor on East Bank
   - Plan : Oct. 1994 – May 1995
   - Actual : Oct. 1994 – May 1995
3) West Guide Bund
   - Plan : Oct. 1995 – Apr. 1996
   - Actual : Oct. 1995 – Oct 1996
4) East Guide Bund
   - Plan : Oct. 1996 – Apr. 1997
   - Actual : Oct. 1996 – May 1997

(2) Workable Period

Water level is the most dominant factor to determine the workable period for river works at site. According to the water level records at Mawa, workable period above several water levels were estimated as follows:

Water level (m PWD)	Workable months by dependability (months)		
	90 %	50 %	10 %
1) +5.00 (Ground L.)	8.0	9.0	10.0
2) +4.00	6.7	7.5	8.2
3) +3.02 (Mean W.L.)	5.2	5.9	6.8
4) +2.00	2.2	3.4	4.5

Ground level at riverbank is about +5.00 m PWD for both left and right banks.

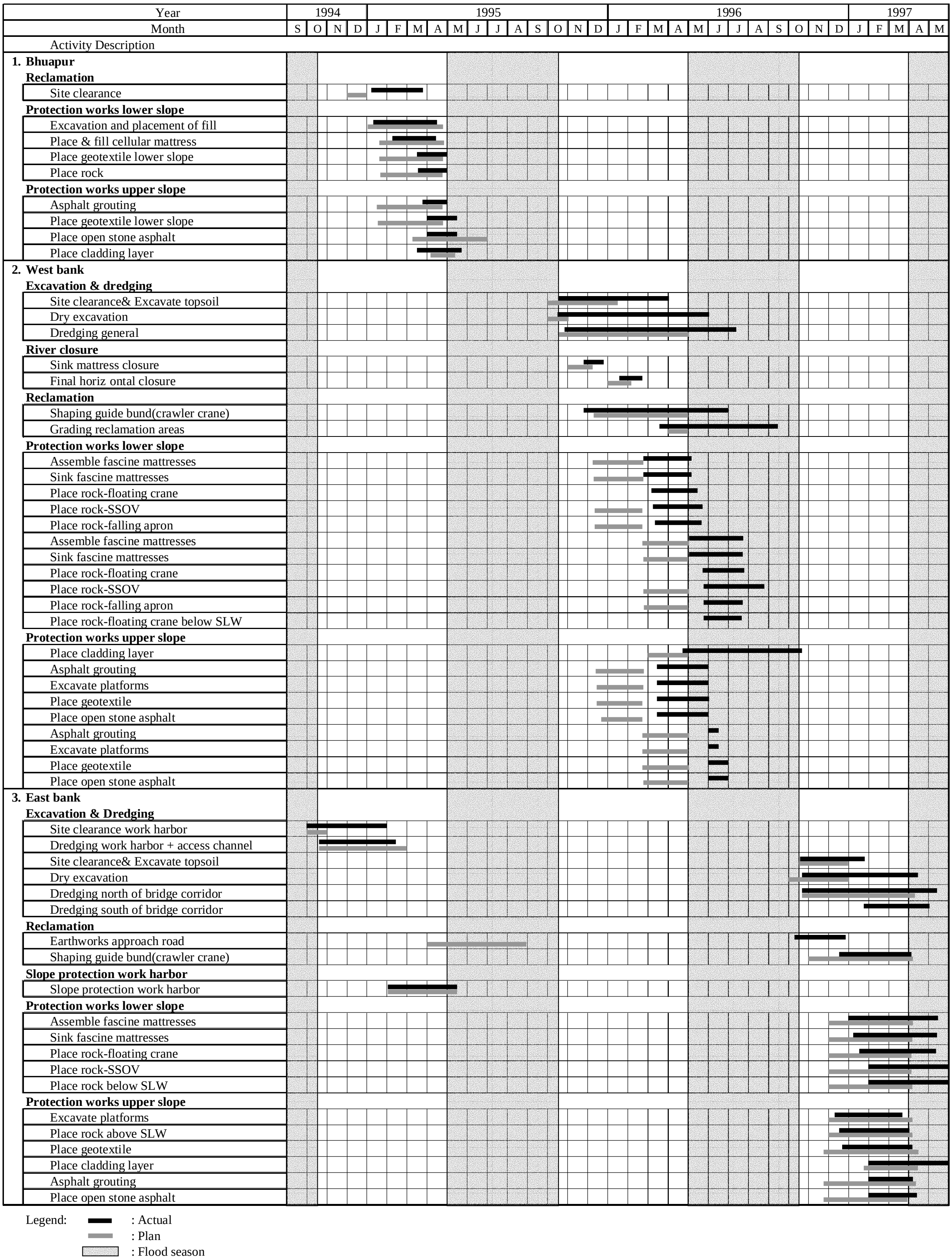


Figure 7.7.1 Construction Plan and Actual Progress of Jamuna Bridge (River Works)

(3) Work Groups

The river works for Padma Bridge can be grouped as follows:

1) **Preparatory Works:** Prior to the bank protection works, several preparatory works are necessary to be executed. The preparatory works may include the following:
   - Preparation of construction base camp, stock yards and work harbor
   - Establishment of field office
   - Land acquisition and relocation
   - Procurement of construction equipment
   - Procurement of construction materials including those procured from abroad

2) **Left Bank Works:** Revetment Type-A is proposed for left bank works of the Padma River covering the work sites of L1, L2 and L3. The work can be started from any sites or simultaneously, since the revetment Type-A is executed on land in principle and the bank is less erodible. Work schedule would not be so tight because of relatively longer workable period on the left bank.

3) **Right Bank Works:** Revetment Type-B is proposed for right bank works of the Padma River covering the work sites of R1, R2 and R3. The revetment Type-B includes temporary works and dredging works prior to the underwater works of launching apron and falling apron. These dredging and underwater works must be executed under still water condition in dry season. If mean water level is assumed, the workable period is about 6 months. In addition all the bank protection works at sites R1 through R3 must be completed in one dry season, since the right bank is erodible. The right bank works would be most tight and critical for construction.

4) **South Channel Works:** Revetment Type-A is proposed for right bank works of the South Channel covering the work site R4. The revetment Type-A is executed on land in principle. The work schedule would not be so tight considering the workable period on the right bank. Although the work can be started at any site of R4, it would be preferable to start from the upper end of the site-R3 where the influence of the Padma River flow is stronger.

(4) Overall Construction Schedule

Taking into account of work groups and their features, sequence of works is proposed as follows:

- 1st year: Preparatory works
- 2nd year: Left bank works
- 3rd year: Right bank works
- 4th year: South channel works

Execution Order of Right and Left Bank Works: As to the execution order of right and left bank works of the Padma River, there is an argument which works should be constructed first. From the river work viewpoint, the program to execute the left bank first in the 2nd year (left-bank-first program) is preferable. However, from the viewpoint of stabiliz ation of site conditions, the program to execute the right bank first in the 2nd year (right-bank-first program) is preferable. This matter should be decided based on the discussion of overall construction schedule including bridge and approach road works. Merits of these schemes are presented below.

1) Program to Execute Left Bank work First: The left bank works are relatively easy and

rather flexible in time schedule, while the right bank works are rather difficult technically and very tight in time schedule. The left bank works are preferable to be executed prior to the right bank works, so that the experience and practice obtained in the left bank works could be effectively applied to the orderly execution of the most critical right bank works.

2) Program to Execute Right Bank work First: The right riverbank is changeable, while the left bank is rather stable. It is preferable to protect the right bank earlier in the 2nd year and fix the location of right bank. Otherwise, the layout design of the related facilities may not be definitely prepared.

Timing for Execution of South Channel Works (Site-R4 Works): Site-R4 works extend over a total length of 6.3 km from the Padma river confluence to Charjanajat Ghat along the right bank of the South Channel. In the present study, the Site-R4 works were proposed to be executed as a component of the present bridge project, since there is no guarantee for financing to implement Site-R4 works in future separately from the present project. The Site-R4 works are duly necessary to check southward shifting of the South Channel and ensure the stability of the bridge structures and the right approach road when the South Channel becomes a main stream of the Padma in future. The South Channel has been the main stream of the Padma River twice in the past 30 years and it is very possible to happen in future repeatedly.

However, erosion of the South Channel is not active now. The present South Channel seems to be in the process of sedimentation and the straight channel along the left bank to be developing. If the past morphological cycle is assumed, the straight channel reaches to the development peak in around 2006, and then the straight channel starts to meander toward west. The meandering will reach to the route of the present South Channel in around 2020. Whatever the accuracy of geomorphologic prediction would be, the Site-R4 works constructed at the same time of bridge construction would be left for a long period without full use. It is reasonable to execute the works when they become necessary based on the monitoring result of the channel behaviors, provided for definite financial guarantee for future execution. By so doing, the latest development of bank protection technology could also be incorporated.

The timing for the execution of South Channel Works (Site-R4 Works) should be finally decided after the discussions on overall project operation program including institutional arrangements for financing the Site-R4 Works.

7.7.3 Maintenance of River Facilities

(1) Maintenance Activities

It is common approach for river facilities to design and construct at a certain safety level and maintain the function after construction by partial repairs during the service period. This approach enables the works economical and effective as a whole project cycle. However, this approach must be supported by well-planned and timely maintenance activities.

The maintenance activities for the river works may include 1) monitoring, 2) study and planning, 3) maintenance works, and 4) administration including budgeting. The activities should be executed according to the maintenance manual which is to be prepared in the detail design stages and to be revised in the course of operation based on the experience.

(2) Monitoring

The conditions of the river and structures should be monitored from wide and local area viewpoints. The monitoring results of wide area would suggest long-term view on the changes of river conditions in future, and the result of local area will give reliable data to decide actions to be taken now. The expected monitoring activities are presented below.

1) Whole Padma River: From the Jamuna-Ganges confluence to the Meghna-Padma confluence. Activity would be mainly collection and integration of following data;
   - Satellite images: yearly
   - Cross section surveyed by BWDB
   - Hydrological observation data
   - Reports and information on bank erosion and river works

2) Riverbank Conditions around Bridge Site: Periodical riverbank survey should be executed every dry season to monitor the changes of bank-lines and their conditions as described below.
   a) To establish and maintain survey stakes for periodical survey: It is important that surveys are conducted at the fixed section periodically so as to quantify the changes.
   b) To conduct riverbank survey: Indicative scopes of works are shown below.

Stretches	Activities
Left bank of the Padma R. from Lohajang to Dohar	• Cross section survey: Length 500m* : Land 200m & river 300m Section interval: 500m • Descriptions on riverbank conditions: (Erosion, sedimentation, river works, etc.)
Right bank of the Padma R. from the opposite bank of Lohajang to confluence of the South Channel	• Cross section survey: Length 800m* : Land 500m & river 300m Section interval: 500m • Descriptions on riverbank conditions (erosion, sedimentation, river works, etc.)
Right bank of the South Channel from the Padma confluence to the Arialkhan R.	• Cross section survey: Length 500m* : Land 200m & river 300m Section interval: 500m • Descriptions on riverbank conditions (erosion, sedimentation, river works etc.)

（NOTE） * Extent of land side survey can be shortened for the sections of bank protection structures.

   c) To conduct bathymetric survey for the following stretches and delineate a contour lines map of riverbed:
      - The Padma River: From Lohajang to Dohar
      - The South Channel: From the Padma River to the Arialkhan River.

3) **Conditions of Bank Protection Works:** Monitoring of the bank protection works are classified into two, i.e., dry season monitoring and flood season monitoring
   a) **Dry season monitoring:** Cross section survey should be carry out for the bank protection works and neighboring riverbed periodically at the ends of dry and flood seasons (in March and November indicatively). In parallel with the cross section survey, intensive inspection of the bank protection works should also be performed to diagnosis the soundness of riverbank against erosion.
   b) **Flood season monitoring:** In order to provide reliable information to decide the actions to be taken in flood season, conditions of bank protection works and neighboring riverbed should be surveyed employing appropriate sounding devices. As to the frequency of monitoring, it should be done at least once a

month during flood months from May to September, and more frequently at high flood times as the occasion demands.

(3) Study and Planning

All the monitoring, study and planning activities intend to formulate measures to maintain the structures and thus the function of the bank protection works to be executed both in dry season and flood season.

1) **Geomorphologic Prediction:** The prediction of geomorphologic features of the Padma River is duly necessary to prepare maintenance program for coming flood season. The satellite images, periodical survey data and other river data as available are used to predict the trend of geomorphologic changes of the Padma River around the bridge site.

2) **Diagnosis of Bank Protection Works:** Based on the intensive inspection, present conditions of the bank protection works, places requiring repairs and works for preparedness, etc. are studied.

3) **Yearly Maintenance Program:** Maintenance program will be prepared yearly based on the study results of geomorphologic prediction and diagnosis of the bank protection works, in consideration of logistic and budgetary arrangement as well.

4) **Design and Procurement:** Works for the maintenance repair and preparedness will be designed and the necessary documents and arrangements for procurement should be prepared in accordance with the yearly maintenance program.

(4) Maintenance works

Dry Season Works: Most of the works for maintenance repair should be carried out during dry season under better working conditions such as low water level, gentle river flow, good land accessibility, etc. These works will be executed based on the maintenance program.

Flood Season Works: In addition to the dry season works, works for emergency repair may become necessary during flood season, according to the monitoring results during high flood times. Most of the sites which may need urgent repair are inaccessible from land, repairs by working vessel should be considered. Equipment and materials for these repairs should be prepared before the flood season and on standby for the operation. A party for the emergency works should also be organiz ed. The party should picket the bank protection works during high flood times.

(5) Administrative Affairs

Maintenance Unit: Maintenance unit for river facilities should be organiz ed as a permanent setup in the maintenance office to be established for Padma Bridge. The unit shall handle all the matters relevant to the river maintenance of Padma Bridge, keeping contact with and in coordination with related agencies such as BWDB, JMBA, etc.

Budgeting: Steady and timely budgetary support is inevitably required for the maintenance activities. Institutional arrangement to allocate maintenance budget from toll would be worthy to be considered.

Training of Relevant Staff: Monitoring and picketing of the bank protection works require thorough understanding on the works and skill for handling monitoring devices and maintenance repair especially for the activities during flood time. Training of the relevant staff is also an important issue.

7.8 FURTHER STUDIES IN SUCCEEDING STAGE

In the present study, designs of river facilities were made preliminarily at the Feasibility Study level. Through the studies made so far, the following studies were recogniz ed necessary further in the succeeding stages before the construction in order to make the project more economical ones accompanied with more definite technical basis:

(1) Implementation of Model Studies:

Mathematical models were prepared within the scope of the present study. The model should be upgraded to meet with the requirements to be expected in the following stages, mainly for river morphologic prediction. In edition to the mathematical modeling, physical model tests would also be required to provide more definite design data for layout of river facilities and structural details.

(2) Risk Analysis:

Since right riverbank is highly movable, the design layout of bridge structures as well as river facilities may need to be revised and their construction program to be adjusted accordingly, considering the latest bank-line location and river features at the time of bridge construction. Therefore, possible risks supposed to encounter should be analyz ed and the measures to reduce and cope with the risks should be studied in the definite design stage.

(3) Development of Low Cost Bank Protection Works:

For the protection of bridge structure, Type-B revetment works were proposed. The Type-B works were applied to the Jamuna Bridge, for which launching and falling aprons were constructed under the water. However, the Type-B works require considerably higher cost comparing to the Type-A works. If the low cost works are developed for the bank protection around the bridge structure, it would contribute much to the reduction of the project cost. Applicability of Type-A works instead of Type-B works should be examined, monitoring the existing Type-A works in the field and enhancing its function for the protection of important structures.