IABSE-JSCE Joint Conference on Advances in Bridge Engineering-II, August 8-10, 2010, Dhaka, Bangladesh. ISBN: 978-984-33-1893-0
Amin, Okui, Bhuiyan (eds.) www.iabse-bd.org

Detailed design of the Padma Multipurpose Bridge, Bangladesh – An overview

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ABSTRACT: The Padma Multipurpose Bridge Design Project comprises a new fixed crossing of the Padma River in Bangladesh, which will consist of a new bridge approximately 6.15km long across the Padma River, approach viaducts, major river training works and approximately 13.6km of approach roads and bridge end facilities, including toll plazas, service areas and offices. The bridge – the longest in South Asia – will connect the southwest of the country with the capital Dhaka, boosting business and the movement of goods between the country's second seaport, Mongla, and the rest of the country. This paper gives an overview of the project components and describes the design development process from the initial 2005 Feasibility Study to the current design, including the coordination of the multidisciplinary inputs, the extensive site investigations and survey program, determination of the design criteria and the development of harmonised prequalification and bidding documents leading to the tender process. The processes followed in satisfying the essential safeguard compliance requirements are also outlined.

1 INTRODUCTION

1.1 *General*

The three major rivers of Bangladesh - the Padma, Brahmaputra-Jamuna and the Meghna - divide the country into four principal regions of north-west, north central, eastern and south-west regions. The Padma River separates the south-west region from the capital city and requires time-consuming ferry crossings to major destinations. At present, transportation of passengers and freight across the river is by ferries and to a lesser extent by launches and manually-operated boats, but their services are grossly inadequate in both capacity and service level. The existing ferry services involve long and unpredictable waiting times at terminals that lack basic service facilities. Additionally, they are prone to suspension or cancellation due to flood, fog and inclement weather conditions. The proposed Padma Bridge is expected to make cross-Padma transport more reliable and drastically reduce the travel time and cost to cross the river.

The Padma Bridge is a multipurpose bridge designed to carry four lanes of highway traffic, a single freight rail track, a high pressure gas main and various communication facilities.

The Padma Bridge is on the Asian Highway Route A-1 and Trans-Asian Railway Route. When the railway will be effectively connected, the Padma Bridge will contribute to the multimodal international transport network for the Eastern Region of the Indian sub-continent and substantial benefit to the Government of Bangladesh (GoB) for bi-lateral cargo movement between India and Bangladesh.

Figure 1 shows the general layout of the project which comprises a new bridge approximately 6.15km long across the Padma River, approach viaducts, major river training works and approximately 13.6km of approach roads and bridge end facilities, including toll plazas, service areas and offices

The key issues of the Project include:

- Engineering issues such as complex river training works in a river subject to substantial annual flooding, deep pile foundations in loose alluvial deposits subject to extreme scour depths and construction of a major bridge;

- Responsible handling of social and environmental impacts arising from the Project, including land acquisition and resettlement impacts on affected people; and environmental impacts on regional hydrology and ecosystem; and
- Coordination among organisations involved in the Project, including the government agencies and potential financiers.

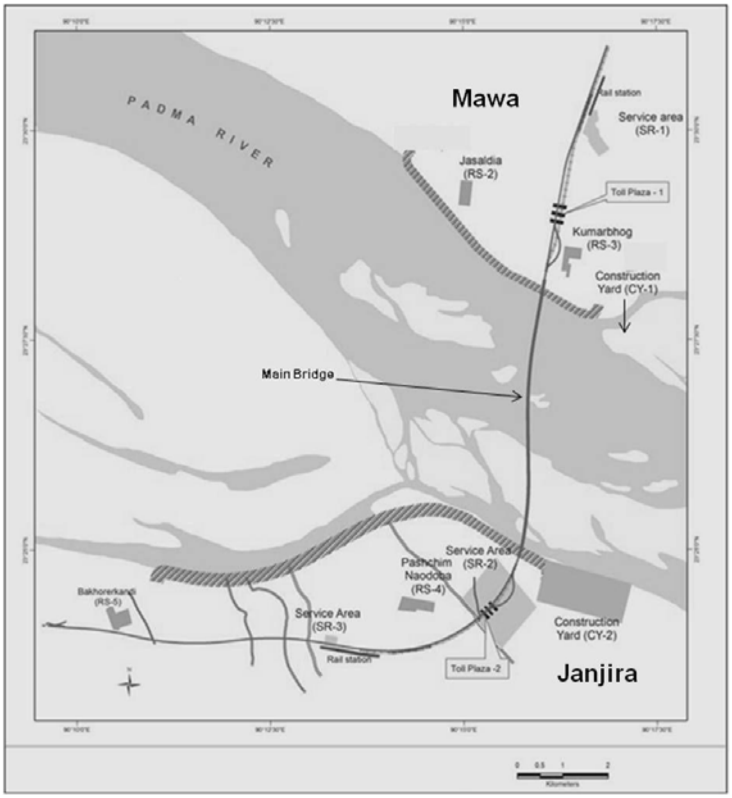

Figure 1. Layout of the Project

This paper gives an overview of the project components and describes the design development process from the initial 2005 Feasibility Study to the current design, including the coordination of the multidisciplinary inputs, the extensive site investigations and survey program, determination of the design criteria and the development of harmonised prequalification and bidding documents leading to the tender process. The processes followed in satisfying the essential safeguard compliance requirements are also outlined.

Separate papers have been prepared which accompany this paper and consider the design of the various elements of the project in more detail – the main bridge river and viaduct spans including the complex foundations, the river training works and the approach road and bridge end facilities structures.

1.2 *Design team*

The detailed design of the Padma Multipurpose Bridge is being delivered by a team of international and national consultants headed by Maunsell AECOM under an Asian Development Bank Technical Assistance loan to the Bangladesh Bridge Authority (BBA). The team comprises Maunsell AECOM, SMEC International, Northwest Hydraulic Consultants and ACE Consultants, with additional assistance from Aas Jakobsen and HR Wallingford.

The Project comprises two phases. Phase 1 of the Project includes the Design Phase leading through procurement action to the award of construction contracts. Phase 2 is the Construction Phase. Phase 1 of the project commenced on the 29 January 2009. A dedicated Project Office was set up in Dhaka in March 2009. Detailed design of the main bridge was carried out in Maunsell AECOM’s Hong Kong office.

All work carried out by the design team was carried out within the framework of Maunsell AECOM’s Quality Management System (QMS) which is independently accredited to AS/NZS ISO 9001. The QMS is designed to control all project work undertaken by the team. A project specific Design Management Plan was established at the outset of the project,

In March 2009, the Government of Bangladesh requested Maunsell AECOM to accelerate the design with a view to ensuring construction could be completed before the end of 2013. This necessitated the mobilisation of additional personnel within the design team.

BBA established an internationally recognised Panel of Experts comprising five national and five international experts to review the design at regular intervals. In addition, an Independent Checking Engineer, Flint & Neill, was engaged to review the design criteria, specification and drawings produced by the design team to ensure the design meets the project requirements and to undertake an independent check of the detailed design of the main bridge and river training works.

Regular meetings were also held during the course of the detailed design with the potential co-financiers for Phase 2 of the project – the World Bank, Asian Development Bank, Japanese International Cooperative Agency and Islamic Development Bank - to assist these agencies in obtaining the necessary approvals within their organisations for loan implementation.

A key feature of the detailed design was the integration of Bangladesh counterparts into the design team, which allowed the successful training of a significant number of Bangladesh personnel in all aspects of the project and the subsequent transfer of the high level of technology involved in this large and complex project.

2 PREVIOUS STUDIES

2.1 *General*

A considerable amount of work had been undertaken on this project, primarily since completion of construction of the Jamuna Bridge in June 1998. At the commencement of the design phase, access was provided to a number of documents. These documents were reviewed for their accuracy, completeness and relevance to the Detailed Design phase of the Project.

The main documents reviewed included:

- *Padma Bridge Study – Prefeasibility Report*, February 2000 prepared by Rendel, Palmer & Tritton, Nedeco and Bangladesh Consultants Ltd
- *The Feasibility Study of the Padma Bridge*, March 2005 prepared by Nippon Koei Co, Ltd in association with Construction Project Consultants, under contract to JICA
- *Land Acquisition Plan*, June 2006 prepared by Bangladesh Consultants Ltd
- *Resettlement Action Plan*, June 2006 prepared by Bangladesh Consultants Ltd
- *Environmental Management Plan*, June 2006 prepared by Bangladesh Consultants Ltd
- *Preparing the Padma Multipurpose Bridge Project*, September 2006 by STUP

2.2 *Main bridge*

With regard to the main bridge, the Prefeasibility Study and Feasibility Study are the most relevant documents. The primary objective of the Prefeasibility Study was to determine the most suitable location for the Padma Bridge and to look at possible configurations for it. Within a period of just under one year, a range of crossing characteristics covering river training, crossing length, depth of foundations and type of bridge superstructure were considered. The study included geotechnical investigations, determination of the site seismicity, assessment of ship impact hazard and requirements for rail loading and clearances.

The most comprehensive document relating to the main bridge is the Feasibility Study (FS). While the rationale behind the recommendations outlined in this study are reasonable, the study did not investigate in depth many of the key factors in determining the most suitable bridge. It was considered necessary to challenge the choice of an extradosed deck superstructure with proposed span length of 180m in particular.

In the FS the functions of the bridge were less clearly defined than in the Terms of Reference (ToR). The FS Report outlined options in respect of the requirement for a railway, although the requirements for the power and gas transmission pipes were not well defined. The ToR is clear in requiring provision for a single track broad gauge railway (with possible future electrification), a 500kV power line and a 30” diameter gas pipe.

The FS recommended a preliminary design comprising a prestressed concrete extradosed bridge with railway provision (labeled as Alternative HR). The bridge had an overall length of 5,580m comprising nine modules of extradosed structures (two modules of 360m and seven modules of 720m with 180m spans), a 180m continuous length of prestressed concrete box girder (3 x 60m spans) at each end of the bridge together with a 60m viaduct (2 x 30m spans) of prestressed concrete T beams at the Mawa end and a 120m viaduct (4 x 30m spans) of prestressed concrete T beams at the Janjira end.

The extradose superstructure comprised a three cell, variable depth concrete box girder supported by two planes of cables. Framed reinforced concrete piers were supported by 3.15m diameter raked steel tubular piles driven to typical depths of 80m through silty sands with a mass concrete toe plug to generate additional end bearing capacity (refer Figure 2). The prestressed concrete box girder and T beam end spans comprised separate superstructures for each carriageway, supported either on a common pilecap or on individual foundation systems. The 180m span extradosed girder type bridge was selected for the main spans on the basis of lower construction cost, aesthetics and minimized constriction of the river by bridge piers.

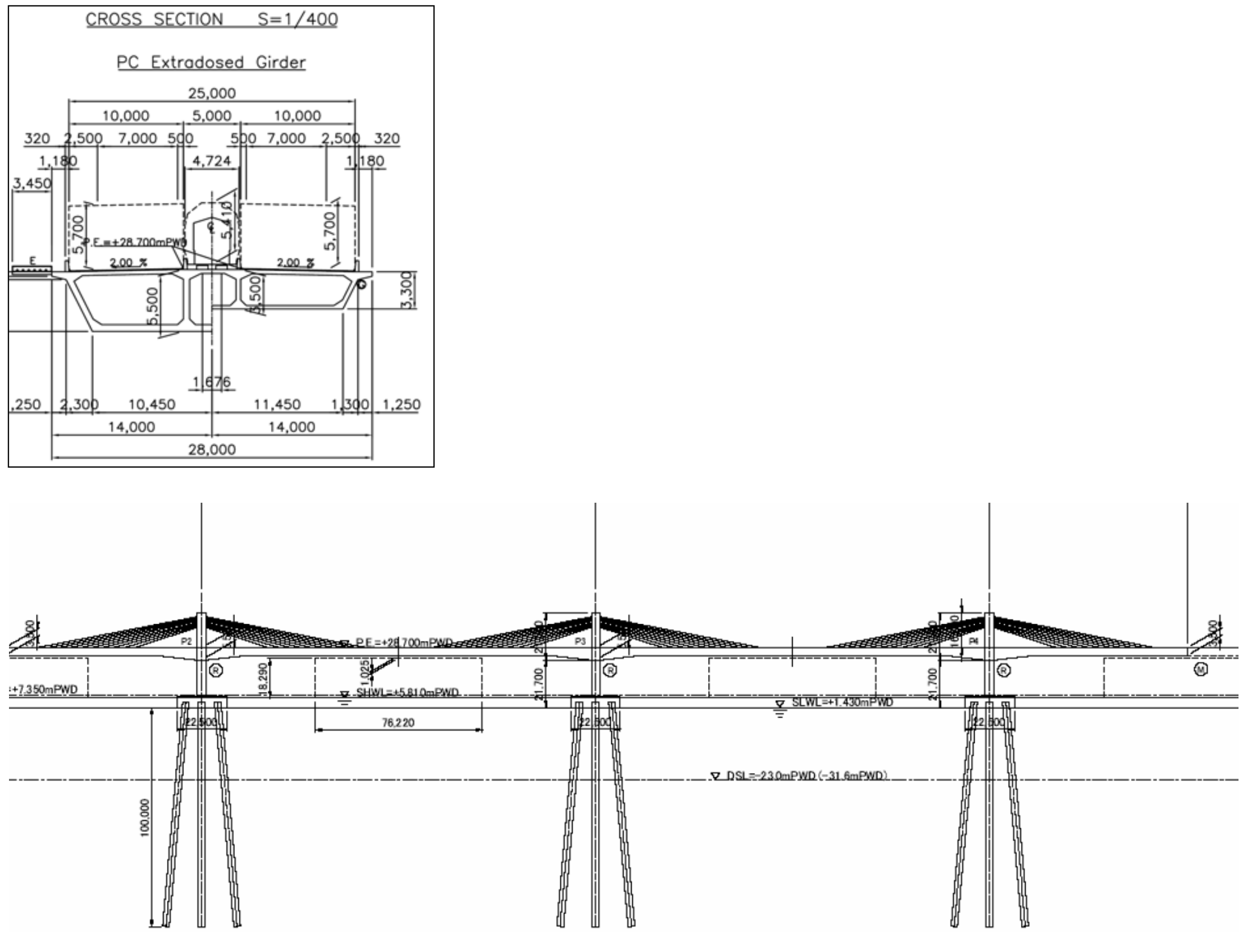

Figure 2. Feasibility Study Preliminary Design for Main Bridge

The FS preliminary design highlighted the horizontal and vertical geometric complexity at the end of the bridge - the railway was restricted to a maximum slope of 1% whereas the roadway was shown with maximum grade of 4%, and the rail corridor was in the centre of the bridge, requiring the rail and road to separate vertically and for the railway to cross over the road. The FS preliminary design, however, did not consider this issue in any further detail. Clearly, a greater length of structure would have been required to carry the rail down to existing ground levels at both ends of the main bridge.

2.3 *River training works*

The Padma Prefeasibility Report provided estimates of discharges and water levels at the Mawa bridge site for a range of flood discharges up to 100-year return period, based on records covering some 20 years. Bankfull (assumed “dominant”) and 100-year peak flows were estimated as approximately 82,000 and 125,000 m^3/sec.

Low-water channel widths over the whole length of the Padma River, based on satellite images of 1992 and 1998, showed a range of 4 to 14km with an average of about 7km. Average erosion rates for the right and left banks upstream of the bridge site were identified as about 120 and 30m/year respectively, but the north bank at the Mawa ferry ghat was found to have been stable for about 30 years.

The river bed material was found to be very fine, slightly silty sand with a median diameter of about 0.1mm. (Such fine material can be mobilised into suspension by relatively weak flow velocities and turbulence, so that suspension becomes the dominant mode of sediment transport at all higher flow conditions.)

The Prefeasibility design for the Mawa site was based on guiding the river flow through an opening having more or less the width of the present main (north) channel. A bridge length of 6km was proposed, with an elliptical guide bund about 3km long at the right (south) end of the bridge only. Maximum scour depths at the guide bund and bridge piers were estimated as roughly 45m below 100-year flood level. (This is almost the same as the maximum scour estimate for Jamuna Bridge, although Padma discharges are considerably larger and the bed material is considerably finer.)

At the left (north) bridge abutment, proposed training works consisted of revetting a length of the existing bank, which has been relatively stable over the years compared to the right (south) bank.

Principal functions of the right guide bund were seen as:

- Protecting the south approach road to the bridge against an outflanking river channel
- Guiding flood flows smoothly into the bridge opening regardless of changes to the upstream river morphology, thereby limiting the potential for large-scale turbulence and deep scour near the bridge piers and abutments.

In the Feasibility Study, the 100-year flood for the bridge site was re-estimated as 136,000m^3/s. Design 100-year maximum water level was set at +7.35m PWD, and corresponding maximum vertically-averaged velocity at 4.8m/s.

Somewhat limited attention was given to the major morphology changes that had occurred in the upstream river channels over the past few decades. Maximum scour depth, as in the Prefeasibility Report, was set at about 43m below 100-year flood level at river banks and training works, and about 48m at the bridge piers. The 5m estimate for local pier scour assumed a foundation geometry consisting of a group of 3m diameter piles.

As in the Prefeasibility Report, a single bridge at the Mawa site spanning the existing channel was proposed. No artificial constriction of the river, as had been done at Jamuna Bridge, was proposed, because of the perceived difficulty of constructing guide bunds (especially on the right side of the river) under water on very fine, loose sand deposited within the last decade or two. The bridge was given a slightly curved alignment with a total length of approximately 5.5km. A cross-section on the alignment, surveyed in July 2004, shows a maximum depth of 18m below design high water level and indicates a cross-sectional average velocity of around 2.6m/s.

The FS training works consisted of:

- Continuous revetment of the relatively stable left (north) bank over a length of about 6km
- Continuous revetment of the unstable right (south) bank over a length of about 4m, and
- A 6km length of additional revetment extending upstream (west) from the south bank along the right bank of the present secondary (or South) channel. This additional South Channel revetment is mostly aligned at roughly 45 degrees to the main right bank revetment, but is merged into the latter by means of a smooth convex curve. All these works were to be built along relatively stable existing banks. There were no traditional guide bunds.

Although the FS layout might well function satisfactorily during the first few years of bridge operation, the high potential for river morphological change over a longer term made it advisable to investigate alternative layouts under the detailed design phase. The hydraulic and morphological effects of selected alternatives were examined and compared with the layout, using both numerical and physical modelling.

The FS appeared to have not obtained borehole information specifically for the design of river training works, but evaluated soil characteristics previously obtained for other purposes.

The FS investigated the substantial mica content of the Padma sands and recommended more study of its effects on shear strength and other parameters. Not simply the percentage of mica, but rather the distribution and arrangement of flaky minerals, is important.

2.4 *Traffic study*

The FS undertook socio-economic and transport studies and resultant patronage and revenue forecast for the project. This work included very useful statistics on:

- Population – sourced from census data
- Economic – sourced from Statistical yearbook and the “The Fifth Five Year Plan, 1997 – 2002”
- Traffic data - sourced from the Bangladesh Road Transport Corporation, Bangladesh Inland Waterways Transport Corporation and the Road & Highways Department. The officially sourced transport statistics were supplemented by additional traffic counts.

The FS conducted traffic surveys between 6 July and 18 August 2003. Based on the survey information, general available statistics and the origin and destination matrices from the pre-feasibility study, a model to forecast future traffic volumes on the Padma Bridge was developed. The FS report provided detailed information on the mechanics and elasticities of the model.

Areas which were identified for further investigation in the detailed design phase included:

- Update and expansion of the surveys undertaken to form the base demand

- Induced demand to be dealt with at the trip generation stage
- Growth rates applied to the various vehicle classes - especially taking into consideration increasing vehicle ownership
- Incorporation of a freight sub-model
- Incorporation of a mode choice model considering coach, rail and boat traffic.

Maunsell AECOM developed a transport model using the Cube modelling platform to forecast traffic volumes and revenues on the Padma Bridge. The traffic surveys conducted during the FS were replicated and expanded, and the data collected was a key source for developing the transport model. The Origin-Destination survey data provided information on travel patterns and the model was calibrated to observed traffic volumes along the river crossings.

Future year travel was forecast by estimating growth in population, car ownership and economic development. The level of traffic on the Padma Bridge was then determined according to the cheapest path based on travel times and costs (distance/fuel, tolls, ferry fares).

The forecast traffic and revenue was then used in an economic and financial evaluation, to test various levels of tolling, gap funding required by the Government of Bangladesh and financing packages offered by the development agencies, keeping in mind that the bridge must be affordable to both the local Bangladeshi users and the Government in repaying their development grants.

3 DESIGN CRITERIA

3.1 *General*

The preliminary bridge design developed in the FS of 2005 was based on a set of design criteria considered appropriate at that time. At the commencement of the detailed design, these design criteria were reviewed. A number of the criteria were updated, based on information available for the site, and a revised Design Criteria for the detailed design phase was developed.

The main design criteria affecting the design of the main bridge included

- Highway design live loading – this was increased from the FS recommendation;
- Railway design live loading – this was increased from the FS recommendation;
- Scour – the depths of scour to be considered in the design were increased substantially from the FS;
- Seismic loading – the recommended level of seismic loading was confirmed;
- Channel and navigational clearances – the section of the river width considered appropriate to satisfy the required vertical navigational clearance was increased markedly;
- Ship impact – a shipping study was undertaken to confirm the loadings nominated in the TOR.

The following sections describe some of these changes in more detail. The consequence of these changes was that the proposed structural form for the main bridge in the Feasibility Study was no longer considered the optimal solution.

3.2 *Highway loading*

The highway loading assumed in the FS of 2005 was the AASHTO HS20-44 loading, as nominated in the Asian Highway and Roads and Highway Department standards. The TOR required the Design Consultant to review this live loading standard in the light of available data relating to current and projected future and traffic types and intensities on Bangladesh’s major roads.

The HS20-44 live loading has been in existence since 1944 and is considered to be too light as a live loading for modern long span bridges. It should also be noted that the AASHTO code had a span limitation of 500 feet, which is approximately the length of the spans being considered. The AASHTO LRFD Code has since increased this loading to the HL93 loading, which includes a heavier design truck loading.

For the design of the main bridge, the British Bridge Code BS5400 was adopted, which has a heavier live loading than the HS20-44 loading and is more consistent with current international and projected future live loadings. BS5400 HA loading was derived through research into the factors affecting loading, the effects of heavy vehicles and a better understanding of the loading patterns on long span bridges. The adoption of the British Code and associated live loading is also consistent with the designs for the Jamuna and Bhairab Bridges in Bangladesh.

3.3 *Rail loading*

The FS of 2005 suggested a proposed design load for the railway across the Padma Bridge using a live load for two locomotives with 20 tonne axle load, followed by a trailing load of 80.9kN/m. This was considered low. The live load for two locomotives is significantly lower than the 22.5tonne axle load for Broad Gauge Main Line Loading (BGML), which has been adopted by Bangladesh Railway for all its broad gauge lines up to 2008, and is also lower than the MBG loading, of 25tonne axle load, which has been adopted by Bangladesh Railway since 2008.

Further, since the FS there had been a number of major changes in the approach to transport infrastructure planning in Bangladesh and the surrounding region, especially in rail transport. The TOR required the Design Consultant to liaise with Bangladesh Railway in determining the railway requirements for design of the Main Bridge. Indian Railways has developed the concept of a Dedicated Freight Corridor (DFC) linking its four major cities of Mumbai, Delhi, Kolkata and Chennai. This corridor will form part of the regional railway and is likely to be part of the Trans-Asia Railway, and hence the standards applied to the DFC will be compatible with those for the Trans-Asia Railway.

For the DFC, freight trains with axle loads up to 32.5tonne will operate at a maximum permissible speed of 125km/h. This is the railway design loading currently nominated by Bangladesh Railway for the Padma Bridge.

From consideration of the highway and railway loadings, the principal design live loading thus became the railway loading. The Padma Bridge changed from being a highway bridge with provision for future rail to a railway bridge with concurrent highway provision.

3.4 *Scour*

The FS concluded that the left bank of the river at Mawa is relatively stable, with average annual erosion rate of about 5m/year, but the right bank at Janjira is much less stable with considerable erosion rates. Since the surveys at the time of the FS, the Janjira bank eroded more than 500m, which has increased the overall length of the main bridge.

The FS made estimates of scour levels using various empirical and analytical methods. The worst scour was assumed to occur adjacent to the bank or at a guide bund. The scour in the main channel was considered to be less severe. For the 100-year return interval, the scoured bed levels are reported as:

Middle of river	-23.63m PWD
Within 300m of river bank	-37.56m PWD

excluding the effects of local pier scour.

Reference to surveys made in the dry season since 1968 indicated the lowest observed bed level in the vicinity of the bridge crossing was -37.0m PWD, which would suggest the FS's 100-year design scour levels may have been under-predicted. A number of instances within this period have recorded bed levels between -21.66m PWD and -31.73m PWD.

A detailed assessment of scour based on satellite images and simple analytical methods was undertaken. The magnitude of the natural scour depends on the flow and channel pattern at the bridge crossing. The river has changed its channel pattern dramatically over the last 40 years. The most severe natural scour occurs when it has an anabranched pattern and a confluence develops just upstream of the crossing. Deep scour can also occur when the river develops a highly meandering pattern and the flow on the outside of the bend impinges against the banks. Based on this work, design scour levels for the 100-year return interval were adopted as follows:

Middle of river	-34.8m PWD
Adjacent to the river bank	-46.7m PWD

excluding the effects of local pier scour.

These values include an allowance for bend scour and some confluence effects, and thus could be considered as conservative. Physical model tests were undertaken on preliminary design arrangements for the pier piles to determine estimates of local scour.

3.5 *Channel and navigational clearances*

The FS identified the following horizontal and vertical navigational clearances for the Padma River:

- Minimum clear horizontal width of navigational channel between any adjacent bridge piers of 76.2m
- Minimum vertical clearance above Standard High Water Level (SHWL) of 18.3m for preferably three adjacent spans and 12.2m for all other spans within a total navigable river width of 4800m.

The FS drawings showed this navigational envelope centred about the middle of the river. It is, however, generally accepted that a principal navigational channel cannot be identified and/or maintained given the braided nature of the river.

The Padma River is part of an important Inland Waterway Network which provides a route to the North Western Region of Bangladesh and a route for vessels travelling from India to the North Eastern border of

Bangladesh. The Padma River is classified as a Class I Waterway and in accordance with the Bangladesh Inland Waterway Transport Authority (BIWTA) standards, the navigational clearance is required to be 60ft (18.3m) vertically and 250ft (76.2m) horizontal.

A shipping study was completed by Maunsell AECOM which found that there are vessels currently plying the river that are up to 16.8m high above the water level. The Least Available Draft (LAD) for a Class 1 Waterway is designated as 3.6m. This limits the size of the vessels plying the river to a draft depth of 3.6m. Therefore, due to the importance of the Padma River as an inland waterway and the limitations on draft depth, the current vertical clearance requirement of 18.3m and the horizontal clearance width of 76.2m were deemed appropriate as a minimum.

BIWTA requested that a minimum of three spans be provided with the minimum vertical clearance – one in roughly the middle of the river and the other two towards the edges of the river where river traffic tends to migrate. Given the braided nature of the Padma River it is not appropriate to assume that a principal navigation channel can be identified and maintained in a particular location for the foreseeable future. The river channel shifts laterally from year-to-year making it impossible to establish a fixed location for the navigational channel. Therefore, it was decided that the number of principal navigational spans should be increased.

Twenty one years of satellite images at the bridge crossing, between the period of 1967 to 2009, were reviewed to assess the effect of channel shifting on the location of the channel. The 2009 bank lines and chars were superimposed on each year's image to illustrate the channel shifting that has occurred. A comparison of these images confirmed that it was not possible to fix the navigation channel at a single location. Furthermore, chars and islands can develop at both the north bank (2001 and 2002) and south side of the river (2005 to 2009), which would obstruct navigation, although the channel has been more persistent on the north side. Therefore, navigation has always been possible near the centre of the channel, and by centreing the raised section of the bridge between the two abutments, this condition will most likely continue. Hence, the following navigational clearances were adopted for the Main Bridge:

- Minimum horizontal clearance of 76.2m
- Minimum vertical clearance above Standard High Water Level (SHWL) of 18.3m
- Provision of 18.3m vertical clearance over 4,800m of the main bridge crossing.

4 ADDITIONAL STUDIES

A total of 37 Additional Studies were identified and undertaken during the detailed design phase of the project at a cost of approximately USD $7.5 million. These studies were required to reduce uncertainty associated with technical, program and commercial aspects of the project.

These studies encompassed a traffic study, topographic and bathymetric surveys, geotechnical investigations, baseline environmental surveys, census surveys, physical model studies for the river training works and river morphology.

An accompanying paper describes in detail the extensive geotechnical investigations being undertaken for the main bridge foundations.

5 MAIN BRIDGE

5.1 *River spans*

Concrete box girder bridges have traditionally been used for major bridges in Bangladesh. With the difficult foundation conditions at the Padma Bridge site, it was preferred to maximise the span length if possible. Cast-in-place concrete box girders allow long spans to be achieved, but are slow to construct and are massive in nature for long spans, which in turn exacerbates design for seismic loadings. Precast segmental construction is much quicker to construct and provides the added advantage of high levels of quality of workmanship associated with precast construction. The maximum span length, however, is limited by the available erection equipment and the maximum segment weight that can be handled. This has led to the superstructure solutions used for the Jamuna, Bhairab and Paksey Bridges with span lengths up to 110m. The extension of this span length is possible through the use of extradosed cables, as proposed in the FS, which comprised multiple 180m spans. This design was developed on the basis of a highway bridge and subsequently modified to include provision for the railway.

For combined road and rail, the structural proportions of the concrete box girder are generally governed by the rail loading to satisfy the serviceability deflection and rotation performance requirements. Review of the FS design at the commencement of the detailed design phase indicated the span length would need to be reduced to satisfy these serviceability requirements. This led to the adoption of a composite steel superstructure solution with greater span lengths.

The resulting main bridge river crossing is in the form of a composite steel truss comprising 41 spans of 150m, with two levels - a single railway track at the lower deck level and two 10.0m wide highway carriageways at the upper deck level (refer Figure 3). Two main truss planes, transversely spaced at 12m, form the major structural component of the superstructure. At the lower deck level, transverse lower cross beams at 18.75m spacing connect the two bottom chords and form a platform for railway track. At the upper deck level, a concrete slab of approximately 22.0m wide is placed on top of the top chords and carries the two 10.0m wide highway carriageways.

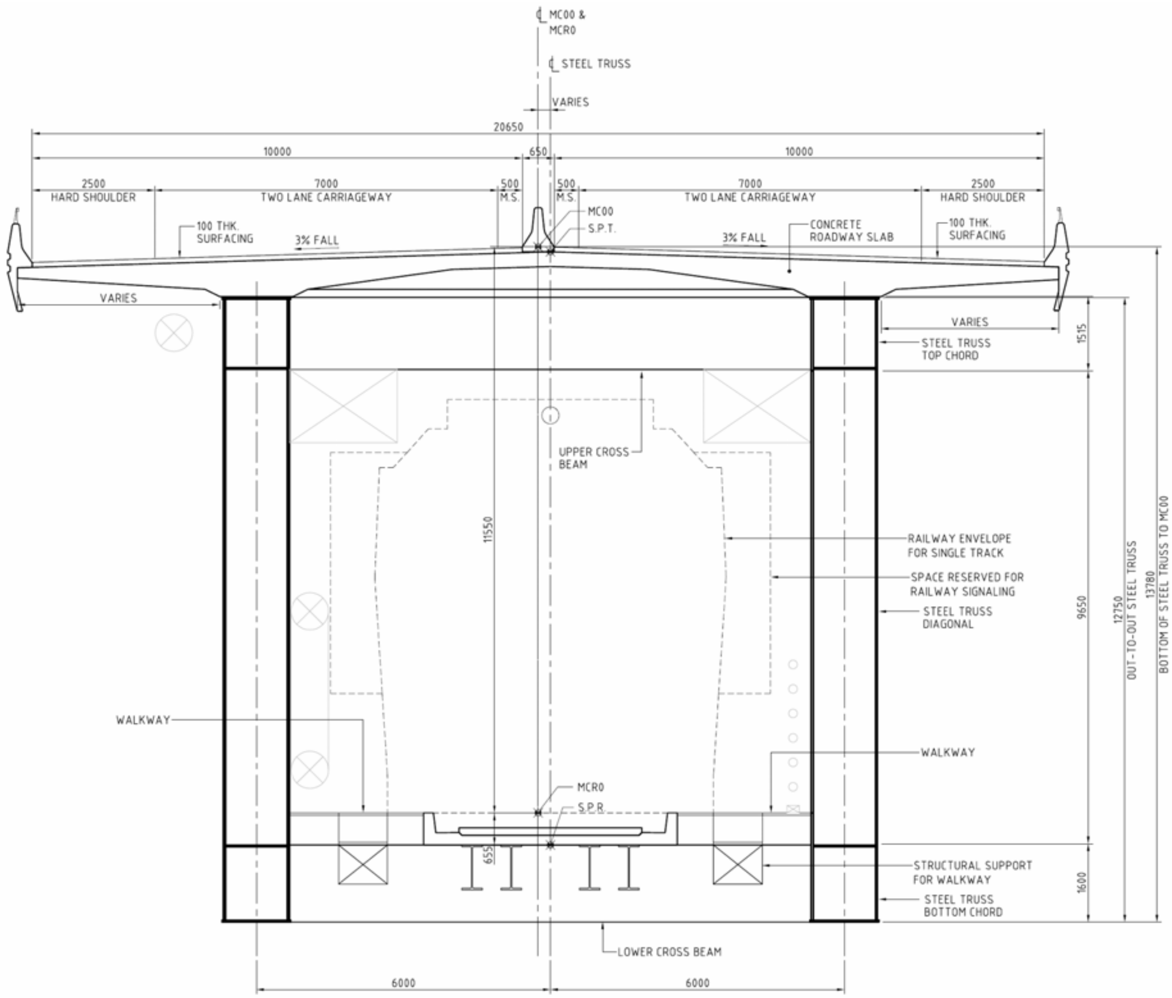

Figure 3. Composite Steel Truss Cross Section

Longitudinally, the main truss is in the form of a Warren truss (refer Figure 4). To further increase the member stiffness, the concrete roadway slab is connected to the top chord by shear stud connections. The railway deck comprises a concrete trough composite with longitudinal steel beams spanning between lower cross beams. Piers comprise reinforced concrete columns supported by a deep pilecap and a group of six, 3.0m diameter steel tubular piles raking in symmetric pattern. The tops of the piles are strengthened by filling with reinforced concrete acting compositely with the steel tube.

An accompanying paper provides an in depth description of the detailed design for the main bridge river spans.

Figure 4. Main Bridge

5.2 *Viaduct spans*

The viaduct spans are separated into the approach road and the railway viaducts. With the main bridge as a two level structure, a complex arrangement of the viaducts was required to separate the railway from the highway. There are a total of four viaducts supporting the highway, two on each side of the river. The approach road viaduct lengths range from 720m to 875m long and comprise 38m spans. The superstructure consists of precast, pre-tensioned concrete Super-T girders. There are two viaducts supporting the railway, one on each side of the river. The railway viaduct lengths range from 2.36km to 2.96km and they also comprise 38m spans similar to the approach road viaducts. The superstructure consists of precast, post-tensioned concrete I-girders. Figure 5 shows the typical cross section and transition arrangement to the river spans.

Another accompanying paper provides an in depth description of the detailed design of the main bridge viaduct spans.

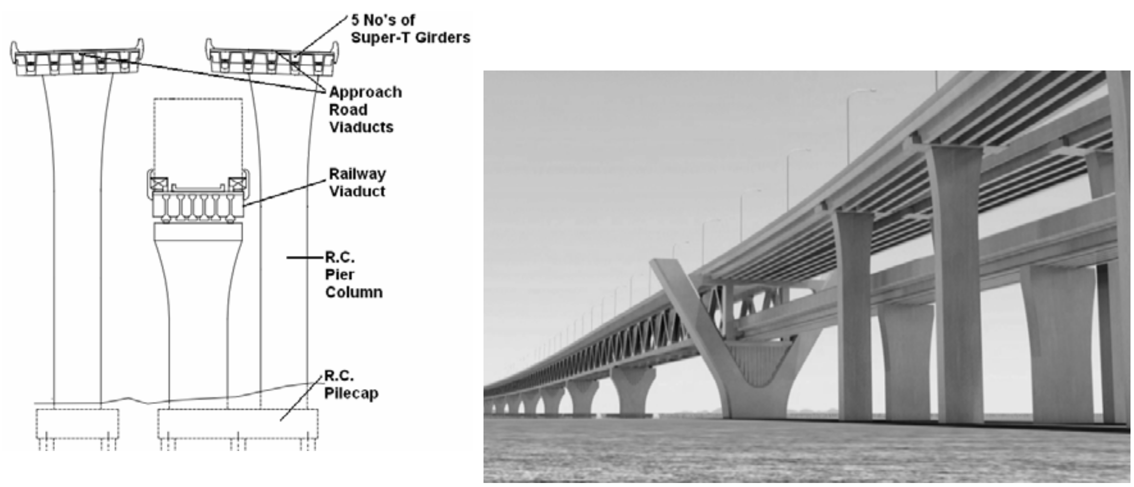

Figure 5. Viaduct Spans

6 RIVER TRAINING WORKS

The river training works (RTW) are intended to protect the main bridge, viaducts, end facilities and the new approach roads. The new approach road on the Janjira side (south bank) parallels the river for a distance of 12km and includes six road bridges, other minor drainage structures and several resettlement villages. In order to ensure these components are not damaged by the river, the river training structures need to protect three areas:

1. the North Bank near the bridge to prevent possible outflanking and erosion of the viaduct and end facilities
2. the South Bank near the bridge and viaduct to prevent outflanking and erosion to critical structures and end facilities
3. the South Bank upstream of the bridge to protect the new approach road, approach road bridges, drainage structures and two river-side resettlement villages.

Options for both the north and south bank RTW were developed in the Scheme Design phase of the project. These options were assessed using morphological and hydraulic methods to arrive at preferred alternatives in each case, which then underwent further detailed assessment.

A 4km long revetment along the north bank (Mawa side) was identified as the only viable scheme for this side of the river. The most critical length of revetment extends over a distance of 500m straddling the bridge centreline. This section consists of riprap slope protection placed on a dredged slope, with a riprap launching apron. The remaining 3,500m length upstream uses a less expensive cross section with concrete blocks above water and geobags below water.

The south bank RTW comprises a continuous revetment which follows the existing bank of the main river and south side channel and integrates the protection of the main bridge, end facilities, viaduct and approach road into a continuous length. At the south abutment and upstream of it, and continuing around the convex bend where the south side channel joins the main river, the revetment alignment in plan has a similar shape to a guide bund. This length is subject to the most severe flow and scour conditions. Figure 6 shows the preferred layout.

An accompanying paper summarises the extensive investigations undertaken to arrive at the proposed options, their assessment and refinement to the final design solutions.

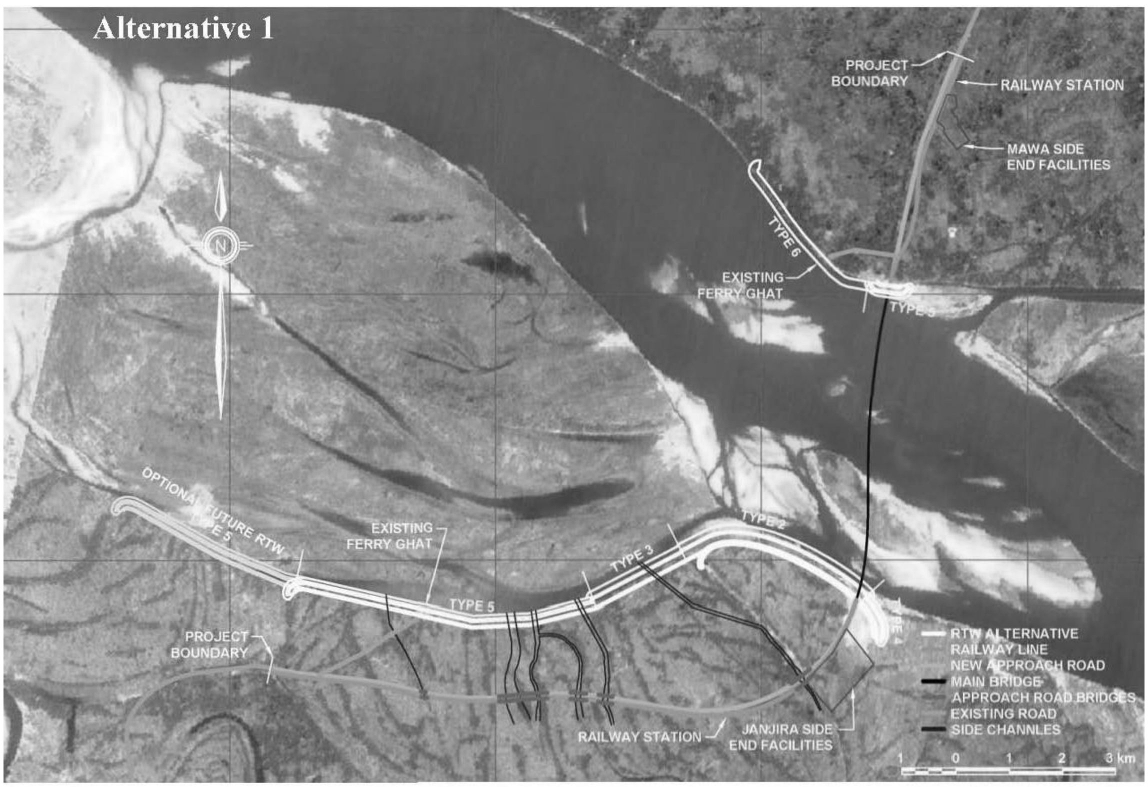

Figure 6. RTW Preferred Scheme

7 FINANCIAL AND ECONOMIC ANALYSES

The estimated project cost prepared in the FS for the extradose bridge with railway provision (Alternative H1R) was USD $1,260 million. This was the estimated project cost at 2004. The project cost estimate was reviewed and updated to April 2009 values using published indices. This updated project cost estimate made allowance for the length of the bridge being increased by approximately 500m due to erosion of the southern (Janjira) riverbank since the FS. The estimated project cost in April 2009 was USD $1,904 million. A Draft Project Cost Estimate was prepared in conjunction with the submission of the Final Scheme Design for the Main Bridge, Approaches and Bridge End Facilities. This estimated project cost was USD $2,384 million and on completion of the detailed design it has been revised to USD $2,418 million.

Economic and financial analyses have been prepared on the basis of these project cost estimates and have also taken into account:

- Regional economic development impacts brought about by the change in transport costs and accessibility as a result of the new link
- The resulting changes in the level of economic activity, population and employment growth that will be generated by Padma Bridge
- The implications on poverty reduction
- Toll harmonisation for both the Padma Bridge and Jamuna Bridge
- The long maturity of several of the loans and a longer period for the financial analysis
- Optimal financing strategy in terms of sequencing the various loans, structuring toll rates and other charges, and incorporating surplus revenues from Jamuna Bridge.

The results of these analyses indicate that the project is economically viable, with a net present value of USD $5,942 million, a benefit-cost ratio (BCR) of 4.4 and an economic internal rate of return (EIRR) of 27%, well in excess of the economic opportunity cost of capital of 12%.

8 SAFEGUARD COMPLIANCE

8.1 *Social action plan*

Padma Bridge is a very large, complex, sensitive and challenging project. Safeguard documentation "packaging" is very important to demonstrate the full coverage of impacts. The social and resettlement safeguards have been packaged under a Social Action Plan (SAP) to provide a comprehensive coverage. This will help easy review and references and fulfils safeguard documentation requirements of all co-financiers. The SAP includes the following:

- Vol. 1 SAP Executive Summary (Technical summary of all SAP documents)
- Vol. 2 Social Assessment (SA)
- Vol. 3 RAP I (Resettlement Site Development)
- Vol. 4 RAP II (Main Bridge and Approach Roads)
- Vol. 5 RAP III (River Training Works)
- Vol. 6 Resettlement Framework (RF)
- Vol. 7 Public Consultation and Participation Plan (PCPP)
- Vol. 8 Gender Action Plan (GAP)
- Vol. 9 Public Health Action Plan (PHAP)
- Vol.10 Char-land Monitoring and Management Framework (CMMF)
- Vol.11 Institutional and Implementation Arrangements

The Project covers three districts – namely, Munshiganj (Mawa/north bank) and Shariatpur and Madaripur (Janjira and Shibchar/south bank). Based on the FS, BBA – the project executing agency – initiated land acquisition and requisition for the project. Additional land acquisition was subsequently identified during the detailed design phase. In summary the impacts are:

- In the three districts, 755ha of land for acquisition for project construction purposes was initially acquired
- Additional area of 235ha will be acquired for Service Area, Approach Roads, Toll Plaza and Construction yard (Mawa side)
- 110ha will be required on a rental basis for the construction yard in Janjira for six years
- An estimated 13,000 households (74,000 persons) will be affected by the project construction.
- Of the total affected households, about 4,000 households will require relocation prior to project construction.
- Four resettlement sites have been identified for relocation of the affected households. Presently, these sites are being developed with all civic amenities for resettlement of the affected families.

8.2 *Environmental considerations*

The direct project boundaries are:

- Longitudinally to the river 15km upstream to cover all project components and Char Janajat and 7km downstream to cover downstream Char Majirkandi
- Laterally 6km from the river bank at Mawa towards Dhaka and 4km from the river bank at the Janjira side
- Indirect boundary zones will broadly cover the associated activities of the Project, like the corridor of the Asian Highway 1, Trans-Asian railway network, transmission and gas lines, etc.

Within these boundaries, consideration has been given to potential changes in ecology, water use and management practices, dredge spoil disposal, agricultural and fishing practices which may occur due to the possible backwater effect, disrupted drainage, navigation, water transport, etc.

The deliverables under the Environmental Action Plan (EAP) of the Project are packaged in the following reports:

- Vol. 0 Executive Summary/Technical Summary of all EAP documents
- Vol. 1A Environmental Assessment for Resettlement Sites
- Vol. 1B Initial Environmental Examination (IEE)
- Vol. 2 Environmental Impact Assessment (EIA) - includes all relevant Environmental Management Plans such as (i) dredge spoil management plan, (ii) plantation or green area development plan, (iii) environmental code of practices, (iv) emergency response plan, etc
- Vol. 3 Environmental Quality Baseline Monitoring Survey Report
- Vol. 4 Ecology
- Vol. 5 Factoring of Climate Change in the Design of the Project

9 PROCUREMENT

For a ‘mega-project’ of very high national importance (which the Padma Multipurpose Bridge Project undoubtedly is) it is critical that contracts are only awarded to contractors who are genuinely capable of undertaking the works to the specified standards and within the agreed contract period. The GoB and co-financiers do not receive any effective return on the massive investment until the critical works components are completed and commissioned. The potential very real economic cost/consequences of unnecessary delays in the awarding of contracts and completion of the works as well as substandard works quality are substantial and ongoing with a project of this type and scale.

A key component of the Design Consultant’s scope of work was therefore assisting with procurement of the civil works contracts including prequalification of contractors, assistance during bid period and bid evaluation. A proposed Procurement Strategy for the Project was initially developed which included a review of contract packaging, methods of procurement, bid processes and prequalification that meet Project requirements and comply with Multilateral Development Bank (MDB) Guidelines. This strategy is constantly being developed and refined to ensure the procurement process meets the project objectives.

The first step was determining appropriate works contract packages which took into account a number of factors, including:

- The magnitude and nature of the works

All of the Project Co-financiers’ Procurement Guidelines require that borrowers carry out due diligence on the technical and financial qualifications of bidders to be assured of their capabilities in relation to the contract(s) being let. The size, scale and complexity of most of the works contracts described above justified a customised approach to the procurement process.

This customisation began with the prequalification of bidders, an essential step in procuring all six works contracts. Key qualification criteria covering an applicant’s eligibility, historical contract non-performance, financial capability and capacity, general and specific construction experience, personnel and equipment were all rigorously assessed and revised to take into account the unique nature of each works contract to ensure that only those firms and consortia capable of constructing and completing the works were prequalified.

The primary advantages of prequalifying contractors before issuing bid documents are as follows:

- Potentially suitable contractors are able to assess the scope of works and key technical evaluation criteria (as described in the PQ document) before deciding whether to apply for prequalification to bid.
- Potentially suitable contractors can form joint ventures and/or conditional subcontracting agreements with greater confidence and enhanced competitiveness.
- Less effort (and cost) is required to prepare and submit an application for prequalification than preparing a bid.

The next step in the procurement process was bidding. In the case of the two largest value contracts, the Main Bridge and River Training Works which together are estimated to cost in excess of USD $1.5 billion, it was agreed that a simplified ‘Two-Stage’ bidding process would be adopted. This process, as shown in Figure 7 below, gives bidders the opportunity to:

- present their technical proposals for the contract, including construction methodologies, plant, equipment and personnel and receive feedback, before pricing their bids; and
- propose limited design alternatives and alternative completion timetables.

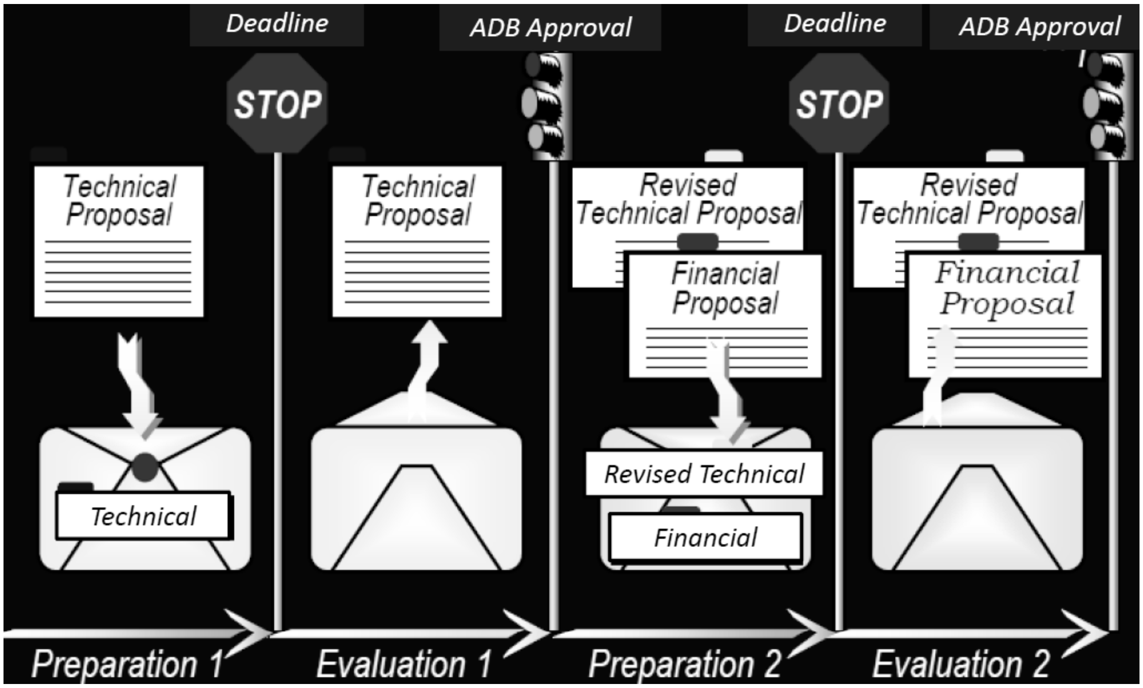

Figure 7. Simplified Two Stage Bidding Process

Although all of the Co-financiers have standard bidding documents for "Two-Stage" procurement, these are intended to be used for the procurement of plant through international competitive bidding when:

- The contract involves the design, supply, installation and commissioning of specially engineered plant and equipment, such as turbines, generators, boilers, switchyards, pumping stations, telecommunication systems, process and treatment plants, and similar projects
- The value of the plant and equipment represents the major part of the estimated contract value
- The nature and complexity of the plant and equipment is such that the facilities cannot safely be taken over by the Employer without comprehensive testing, precommissioning, commissioning and acceptance procedures being followed.

It was therefore necessary to prepare a unique and highly customised set of bidding documents for the two largest contracts to be let under this project. These documents combined the Two-Stage bidding process from the Standard Bidding Documents (SBD) for Plant with the SBD for Works which is based on the FIDIC Conditions of Contract for Construction for Building and Engineering Works designed by the Employer – Multilateral Development Bank Harmonised Edition - the latter only being available either as a 'Single-Stage One-Envelope' or 'Single-Stage Two-Envelope' bid process.

All other contract packages will follow a 'Single-Stage One-Envelope' bidding process following prequalification. The size and complexity of these contracts do not justify the additional time and cost of the 'Two-Stage' bid process.

10 CONCLUSIONS

The new Padma Multipurpose Bridge will provide a vital missing link in the transport network of Bangladesh. The bridge will provide significant travel time savings, particularly between the Dhaka Division to the southeast of Bangladesh and possibly onto India. The operation of the Padma Bridge, with its large step change in transport costs, will result in significant economic changes to the southwest region.

The engineering designs for the main bridge and river training works have been developed to address the complex and challenging site constraints and the tight construction program time nominated by the GoB. In parallel with the engineering issues, the project team has addressed the important social and environmental impacts arising from the project. The stakeholders in the project have been briefed and consulted throughout this design phase to ensure the project meets the overall objectives.