Design of the Padma Multipurpose Bridge, Bangladesh

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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.

Introduction

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 (refer Figure 1). 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 Padma Bridge is expected to make cross-Padma transport more reliable and drastically reduce the travel time and cost to cross the river.

![Project Location](image)

**Fig. 1. Project Location**

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 2 shows the location and 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 detailed design of the Padma Multipurpose Bridge was delivered by a team of international and national consultants headed by AECOM under an Asian Development Bank Technical Assistance loan to the Bangladesh Bridge Authority (BBA). The team comprises 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 AECOM’s Hong Kong office.

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 organizations for loan implementation.
The key issues of the Project include:

- Engineering issues such as complex river training works in a river subject to substantial annual flooding, high seismicity, and construction of a major bridge with deep pile foundations in loose alluvial deposits subject to extreme scour depths;
- 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 ecosystems;
- Coordination among organizations involved in the Project, including the government agencies and potential financiers.

Previous Studies

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 including the Prefeasibility Study, 2000 and Feasibility Study, 2005 reports. These documents were reviewed for their accuracy, completeness and relevance to the Detailed Design phase of the Project. The Prefeasibility Study and Feasibility Study were the most relevant documents. The objectives of the Prefeasibility Study were to determine the most suitable location for the Padma Bridge and to look at possible configurations for it. The Feasibility Study (FS) recommended a preliminary design comprising a prestressed concrete extradosed bridge with railway provision.

Fig. 3. Feasibility Study Preliminary Design for Main Bridge
The bridge had an overall length of 5,580m comprising nine modules of multiple 180m span extradosed structures with prestressed concrete box and T beam approach viaducts. The extrados superstructure comprised a three cell, variable depth concrete box girder supported by two planes of cables as shown in Figure 3. Framed reinforced concrete piers were supported by 3.15m diameter raked steel tubular piles driven to typical depths of 80m through silty sands. 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 thus considered necessary to challenge the choice of an extradosed deck superstructure with proposed span length of 180m in particular.

**River Training Works**

The river training works (RTW) are required 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. 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.

**Design Criteria**

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.
Three options were considered in determining the most appropriate design code for the main bridge – the British bridge design code BS 5400, the American code AASHTO LRFD Bridge Design Specification and the recently released Eurocodes. BS 5400 was selected as it was considered that the highway loading criteria most closely corresponded to the situation expected in Bangladesh. Trucks are often heavily loaded, matching the load patterns predicted within the British standard. The adoption of BS 5400 was also consistent with the designs for the Jamuna and Bhairab bridges in Bangladesh.

The railway crossing the bridge will connect to the Indian National Railways and hence the railway loading was based on codes adopted on that system. Hence, the bridge was designed to be part of the Dedicated Freight Corridor (DFC), which implies an even heavier loading than usual with a load of 32.5 tonne per axle.

Padma bridge will be constructed in an area of high seismic activity and consequently earthquakes were a critical consideration in the design. Bangladesh University of Engineering and Technology (BUET) carried out a detailed study of the seismic hazard at the site to determine suitable seismic parameters for use in the design. Two levels of seismic hazard were adopted:

- Operating Level Earthquake (OLE) with a return period of 100 years and a 65% probability of being exceeded during that period. In such an earthquake, the bridge will experience a peak ground acceleration of 0.052g and shall remain operational for all traffic after such an event.
- Contingency Level Earthquake (CLE) with a return period of 475 years and a 20% probability of being exceeded during the life of the bridge (100 years). The peak ground acceleration for such an event is 0.144g in the dense sand at a depth of 120m. Any damage sustained from such an earthquake shall be easily detectable and capable of repair without demolition or component replacement.

For such a major river crossing, a step-by-step nonlinear time history analysis was undertaken based on five AASHTO spectrum compatible acceleration time histories representing earthquake loading at a depth of 120m (refer to Figure 4).
The other critical design criterion for the main bridge was 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 increased the overall length of the main bridge.

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 anabranch 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 general 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

To these estimates were added the effects of local scour that occur from the obstruction to the flow caused by the bridge piles. From model test experimentation work carried out in Canada by subconsultant Northwest Hydraulic Consultants, local scour was estimated to deepen the design general scour by a further 15m for the proposed raking pile configuration.

A shipping study was undertaken to confirm the nominated vertical clearances and the design ship impact loading. The Bangladesh Inland Waterway Transport Authority (BIWTA) requested a minimum of three spans be provided with the minimum vertical clearance of 18.3m above Standard High Water Level. 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 to provide the minimum vertical clearance over the central 4.8km of the river.

The load combinations given in BS 5400 Part 2 were generally followed, but this code does not adequately cover how to combine seismic loading, ship impact and scour of the foundations. In particular, the effect of scour has been given special consideration as the nature of the Padma River is unique. Scour can occur over prolonged periods and when infill of scour holes later occurs, the material that fills the holes is loose and remains uncompacted for a long period after the event. The loose material will be susceptible to liquefaction and therefore cannot be relied upon during a seismic event. Hence scour with a 100-year return interval was adopted to be combined with loading from a CLE seismic event. In the case of ship impact, liquefaction of the infill material is not considered a problem and therefore a lesser return period of 10 years for scour was adopted.

**Main Bridge Superstructure**

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 (180m spans).

Review of the FS design at the commencement of the detailed design phase indicated that the FS span length for the river spans, however, needed to be reduced to satisfy the serviceability deflection and rotation performance requirements under the rail loading. 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 typical modules of 6 spans) 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 5). Two main Warren truss planes, transversely spaced at 12m, form the major structural component of the superstructure, with hollow steel box sections for top and bottom chords and for the diagonals. At the lower deck level, transverse lower cross beams at 18.75m spacing connect the two bottom chords and form a platform for the railway track. At the upper deck level, a concrete deck comprising precast sections of approximately 22.0m wide is made composite with the top chords.

The trusses are envisaged to be prefabricated, transported to site in modules, assembled into full span lengths and erected one span at a time, in a similar manner to that shown in Figure 6. Precast deck slab sections are then lifted into placed and prestressed.

Fig. 5. Cross Section for River 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 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 of precast, post-tensioned concrete I-girders. Figure 7 shows the transition arrangement to the river spans.
Main Bridge Substructure

The geology of the Padma River is of Holocene age and comprises mainly river borne alluvial silt, sand and gravels. Stratification within the geological profile are intermixed with depth with mainly silty fine sands to slightly silty fine to medium sands to a depth of about 60m, beyond which the granular strata is increasingly more consolidated with depth to dense sand becoming very dense sand.

Piers for the main bridge comprise reinforced concrete columns supported by a deep pilecap and a group of six 3.0m diameter steel tubular piles raking in symmetric pattern driven to founding levels at 114m depth. Two types of piles were investigated in the design – large diameter raking steel tubular piles and large diameter cast in situ vertical concrete bored piles. The raking piles were found to be more efficient in resisting lateral loads resulting from seismic and ship impact effects.

A 3-dimensional non-linear time history dynamic analysis was performed for the Main Bridge to determine the impact on the structure of seismic action. The behaviour of the bridge is complex due to its unsupported height under scour and the large mass of the superstructure, pile caps and piles. This model was divided into two parts, the structure and the free field soil with interactions between the two simulated by lateral spring links. In order to determine the equivalent shear modulus and effective damping ratio between each layer of the soil, free field analysis was carried out beforehand by the program SHAKE. The ground motions shown in Figure 4 were applied to the model to simulate the earthquake case and loads were generated in the piles and substructure accordingly. Other load combinations were considered such as ship impact and wind, although generally these effects were not found to be critical for the substructure - the seismic load combination dictated the design. A further global model was developed to investigate the global behaviour of the bridge and looked at various combinations of scour on piers to determine the critical axial loads, shear forces and bending moments on the foundations of any particular pier.

Initial studies of the bridge were based on the superstructure being supported off its piers by traditional sliding bearings, with the point fixity being the central pier of the six-span module. To avoid the fixed pier being heavily loaded during a seismic event by a longitudinal translation, shock transmission units (STUs) were provided at the free piers to ensure even load distribution between the piers. The loads applied to the piers were however still large and therefore as part of a value engineering process, alternative forms of articulation were examined, leading to the adoption of friction pendulum isolation bearings. Friction pendulum bearings use the characteristics of a pendulum to lengthen the natural period of the isolated
structure so as to reduce the input of earthquake forces. The damping effect due to sliding mechanism also helps to mitigate the earthquake response. Since earthquake induced displacements occur primarily in the bearings, lateral loads and shaking movements transmitted to the structure were greatly reduced. The reduced seismic loading led to a reduction in section sizes for the truss members.

**Safeguard Compliance**

Padma Bridge is a very large, complex, sensitive and challenging project. The Project covers three districts with an estimated 13,000 households (74,000 persons) affected by the project construction. Of the total affected households, about 4,000 households required relocation prior to project construction. Four resettlement sites were identified for relocation of the affected households and presently, these sites are being developed with all civic amenities for resettlement of the affected families. Safeguard documentation “packaging” was very important to demonstrate the full coverage of impacts. The social and resettlement safeguards were packaged under an eleven volume Social Action Plan (SAP) to provide comprehensive coverage and to assist the review of compliance with the documentation requirements of all co-financers:

- 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 direct project boundaries extend 15km upstream and 7km downstream of the main bridge, laterally 6km from the river bank at Mawa towards Dhaka and 4km from the river bank at the Janjira side. Within these boundaries, consideration was 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 were 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

The Padma Bridge design received the 2010 award for ”Best Safeguard System in Project Planning” by the South Asia Department, Asian Development Bank (ADB).

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 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. In consultation with the co-financiers, it was determined that the Project be packaged into a total of six works contracts as follows:

• The main bridge – river spans and viaduct spans
• River training works
• The Janjira approach road, associated toll plaza and Service Area 3
• The Mawa approach road, associated toll plaza and Service Area 1
• Service Area 2
• Construction yards on both sides of the river.
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 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 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, 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.

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. All other contract packages followed a ‘Single-Stage One-Envelope’ bidding process following prequalification. The size and complexity of these contracts did not justify the additional time and cost of the ‘Two-Stage’ bid process.

**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 south-east of Bangladesh and on to India, with significant economic changes to the southwest region.