The realisation of the 6.2km long Padma Multipurpose Road and Rail Bridge in Bangladesh

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Abstract

The Padma is one of the world's mightiest rivers, being a distributary of the Ganges and the Jamuna rivers, winding its way through Bangladesh to the Bay of Bengal. It is a major division between the country's south-west region and the capital city and economic centre of Dhaka. During the monsoon season, the Padma River becomes fast flowing and capable of causing deep scour. Crossing the Padma with a 6.2km long steel truss bridge, carrying road and rail, presents technical challenges to the client, consultants and contractors, including significant river training work and deep foundations in an alluvial flood plain, where the rock formation lies several km below the river bed, and in an area subject to considerable seismic activity leading to possible liquefaction of the soil. Other challenges include major vessel traffic and ship impact. Once these technical challenges are overcome, the construction of the bridge will bring considerable social, political and economic advantages to Bangladesh and development to the south-west region, giving greater access to the country's second port at Mongla and to the proposed Payra Port, which is currently under construction. This paper describes some of the technical challenges faced and overcome in bringing this landmark multipurpose crossing to fruition.

Keywords: steel-truss bridge; road; rail; river training; ship impact; seismic; scour.

1 Historical and Geographical Setting

The driving force and aspiration for the implementation of a fixed crossing of the Padma River is the linkage of the South-West quadrant of Bangladesh to the Eastern Region of the country, and to the capital Dhaka. In meeting this aspiration, the Padma Multipurpose Bridge will link Dhaka to the country's second major port, Mongla, allowing diversity from its current primary dependence on Chittagong port. Khulna, the third major city of Bangladesh, and Benapole, the 'inland port' will also thereby be linked to the east of the country. It will also form part of the Asian Highway Network.

Geologically Bangladesh primarily comprises the accretion from the littoral drift up the east coast of India together with the sediment flow down from the Himalayas. This results in a country where 90% of the landmass is within 10 metres of sea level, which is subject to annual fluvial flooding, has numerous unstable rivers and, notwithstanding the level of the riverine traffic, is dependent on the existing fixed crossings over this river system.

The missing link in the primary road network of Bangladesh is that across the Padma River now proposed at Mawa. With the decision made to provide that road link, the incremental capital cost to the bridge structure to additionally carry dual gauge rail loading was determined as comparatively small if incorporated at the outset.

2 Project Inception

Rendel Ltd (formerly HPR) have been involved in the project for an extended period and carried out the Pre-Feasibility Study for the proposed project in 1999 incorporating surveys, studies, preliminary designs, cost estimating, economic and traffic evaluation. The recommendation from that study was to progress to the next stage of the project. A further Feasibility Study in 2003-2005 confirmed the site location and formed the basis for the Government of Bangladesh to proceed with the detailed design and construction of the project.

Figure 1. Project location within Bangladesh

In 2006 the Land Acquisition Plan (LAP), the Resettlement Action Plan (RAP) and the Environmental Management Plan (EMP) were completed. The initial detailed design and procurement by Maunsell / AECOM was commenced under funding from the ADB in 2011, as was the Independent Design Check, by Flint & Neill. (now COWI). However, final procurement and implementation funding (2011 – 2015) of the project has been undertaken by funding directly from the Government of Bangladesh.

Commencement of the construction phase began in November 2014 with MBEC Ltd(China) as the Contractor for the Main Bridge. In December 2014 Sinohydro Ltd (China) commenced work on the River Training Works Contract. Works on the approach roads and ancillary works were already underway, having commenced in January 2014, by the Bangladesh Contractor Abdul Monem Ltd. The Construction Supervision Consultant (CSC-2) is the Korean Expressway Corporation (KEC) with Rendel Ltd (in association with BCL, KEI & PADECO) in the role of the Management Support Consultancy (MSC).

3 Scheme Description

The project comprises a 6.15 km Main Bridge, extensive River Training Works of 14.0 km length, approximately 13.6 km of approach roads and Bridge End Facilities on both banks. The main bridge is in the form of composite steel truss with two levels, a railway at lower deck level and a highway at upper deck level. There will be a number of facilities at the bridge end on the Mawa (north) side including offices, accommodation and a visitor centre. The facilities on the Janjira (south) side will be more extensive and will include the toll facilities and a large office and accommodation compound of a standard to be developed as a major hotel and tourist resort after bridge opening. The project will also require extensive enabling works including the relocation of the ferry ghats, temporary access roads and road diversions, temporary working areas including harbours, and temporary accommodation for site staff.

The 6.15km Main Bridge is comprised of 41 No. 150m long steel truss spans, 12.7m deep with a 22m wide composite upper concrete deck to support the 4-lane highway. The lower level of the truss will support a standard (i.e. broad) gauge heavy freight railway line. The bridge will also carry other major services which will include a 0.76m high-pressure gas pipeline and telecommunication facilities. A separate 400kV power transmission crossing on independent foundations will be provided upstream.

The main bridge comprises very substantial piled foundations consisting of sets of 6 no. 3m diameter raking piles up to 114m long supporting in-situ concrete pile caps, bridge piers and superstructure.

Approach viaducts carrying both road and rail are at each end of the main bridge and comprise 38m spans utilising pre-cast pre-stressed beams with in-situ reinforced concrete slabs. These will provide for the separation of the road and rail alignments. The approach viaducts including the transition piers to the main bridge are supported on bored piles of 1.5 and 3m diameter.

Approach embankments and highways extending many kilometres from the crossing on both banks have been constructed to connect to the existing highway network.

The Bangladesh Bridge Authority awarded construction of the project in 5 principal packages as separate construction contracts. Between them these packages include:

- Main bridge crossing; over 6km of bridge superstructure together with deep large diameter piled foundations.
- Approach viaducts in concrete at both northern and southern ends on piled foundations.
- Approach embankments and associated structures at each end of the bridge
- Approach road works connecting to existing highway network on the North side
- Approach road works connecting to existing N8 Highway on the South side
- Bridge-end facilities on the North (Mawa) side including toll plaza, and service area facilities.
- Bridge-end facilities on the South (Janjira) side including toll plaza, and service area facilities.
- A total of 14km of river training works upstream, principally to the South bank.
- Provision for services to include gas, electricity and telecommunications.

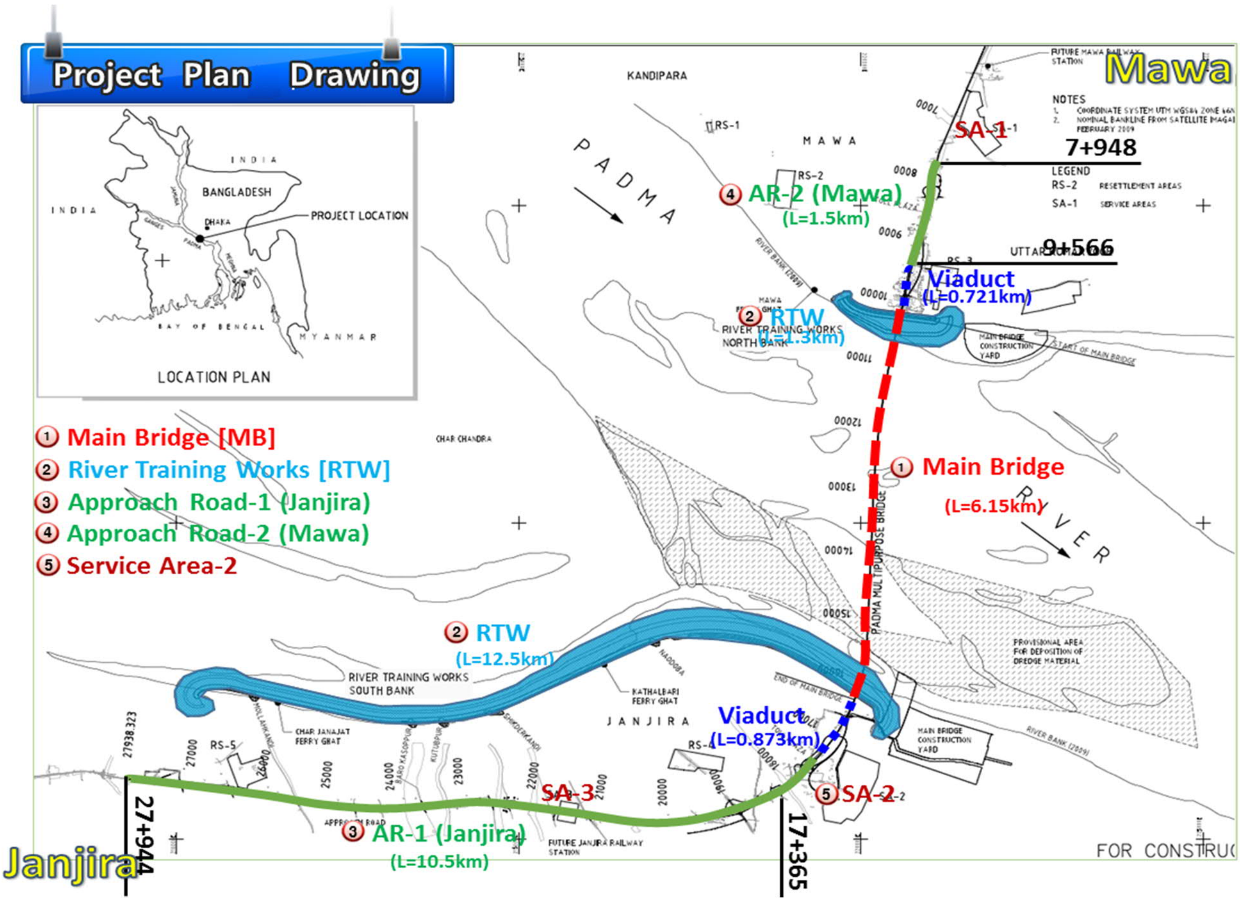


Figure 2. Project components either side of the River Padma

The required river training works comprise, on the North Bank, of a guiding revetment along the river bank on a dredged slope with falling apron at the toe. The total length is around 1.5km along the river bank and with a horizontal projection towards the river of around 170m. Works on the extended falling apron consists of 800kg geo-bags five layers thick dumped on to a dredged surface. This gives way to a dredged slope at 1V:6H protected by 3 layers of 125kg geo-bags and a 90cm thick layer of hard rock up to a level of -2.4m. Between -2.4m and +2.4m the slope is protected by dumped concrete blocks over geotextile layer whilst above +2.4m the concrete blocks are placed, again over geotextile material.

The falling geo-bag apron of around 25m wide is provided at -25m PWD level. Low water level typically is at +2m level, with the highest during the monsoon period at around +6m.

On the South Bank the works are longitudinally much more extensive with a total length of around 12km along the river bank. The revetment is designed with similar cross section as the North bank.

The project works will incorporate extensive enabling works including the relocation of ferry ghats, temporary access roads and road diversions, temporary working areas including harbours, and temporary accommodation for site staff.

4 Design Criteria

4.1 Design Codes – Main Bridge

The Main Bridge was designed primarily in accordance with the British Standard BS 5400: Steel concrete and composite bridges whilst seismic loading and design were according to a combination of Japanese and American codes.

4.1.1 Seismic Criteria

The Padma Bridge is in an area of high seismic activity and Bangladesh University of Engineering and Technology (BUET) carried out site specific seismic hazard assessment with 2 levels of seismic hazard prescribed. These were:

- Operating Level Earthquake (OLE) with a return period of 100 years (65% probability) resulting in peak ground acceleration of 0.051g
- Contingency Level Earthquake (CLE) with a return period of 475 years (20% probability) resulting in a peak ground acceleration of 0.143g at -120m PWD.

Seismic isolation of the superstructure is being provided by friction pendulum bearings manufactured and tested by Wuhan Hirun of China. These bearings, are the largest of their type ever manufactured with capacity up to 10,000 tonnes.

4.1.2 Foundation Scour

The Padma River is the catchment of the Ganges and the Brahmaputra-Jamuna Rivers with 100 year return flows at the bridge site up to 128,000m^3/s. Because of large fluctuations in flow and river level, the potential scour around the piled foundations is a significant concern. Design by AECOM sub-consultants, Northwest Hydraulics (NHC) carried out detailed modelling of the proposed pile foundation group identifying scour depths of up to -70m PWD (50m) on the steel tubular raking pile group. This figure arising as a combination of general (river action) scour and local (bridge pile) scour. The effect of the potential loss of up to 50m of skin friction clearly has a large impact on the pile design.

4.1.3 Ship Impact

A ship impact load, using vessels of up to 4,000 DWT more than adequately covers all vessels on the Padma River ship register and was equivalent to 23MN impact head on and 11.7MN side on to the bridge piers. This conservative 4,000 DWT loading was retained in view of the potential of coal handling ships that may service planned power station requirements.

4.1.4 Road and Rail

The project highway will form part of the national highway system of Bangladesh (NH 8) as well as the Asian Highway Route No. 1 (AH 1). The highway loading is to UK standards; full HA + 45 units HB loading with geometric design to Highway Department of Bangladesh. The railway may form an extension to the Indian Dedicated Freight Corridor so loading for heavy freight accommodates 32.5 tonne axles. Provision is included for overhead electrification.

4.2 River Training Works

The design of the River Training Works was carried out by Maunsell / AECOM in association with Northwest Hydraulic, SMEC and ACE Consultants, resulting in, after several interim design reports, a Final Design report submission in July 2011. The river training structures are designed in accordance with AASHTO bridge standards and HEC-18 (USFHA,2001) standards. The RTW is designed to withstand a check flood (and scour) of a 500-year return period without endangering the integrity of the RTW or resulting in any collapse. The design and check flood levels also include an allowance for climate change.

5 Construction

5.1 Foundations and substructure

After several preconstruction assessments it was determined that a steel tube raking piled option was the most practical and economic solution to the bridge foundations. The prescribed 3m dia. tubular piles are required to accommodate deep river bed scour (+/- 50m), earthquake loads and ship impact loads as well as associated construction dead and live loading from the bridge road and rail traffic. From the river surface level and the 5.5m deep pile cap a 6no. pile group rakes at 1:6 slope to the river bed and through the underlying subsoil with pile lengths of up to 114m.

5.1.1 Piled Foundations

Extensive hydrological river bed modelling was carried out to determine local scour effects around the pile group. Steel tubular piles have been utilised in order to provide a bending resistance in the pile that could not be generated in purely concrete bored piles. The piles require to be designed for a number of load combinations. The 1:6 rake of the pile was utilised in part to resist lateral forces identified under earthquake loading.

A global model was constructed to understand the impact on the six-span modules with differing scenarios of scour at each of the pier locations. In this way the critical axial loads, shear and bending forces were determined in the pile foundation group at any particular pier. The outcome of the analysis resulted in the development of the following pile, pile cap and pier arrangement:

Figure 3. Pier, pile cap and pile arrangement.

The principal activities involved in the installation of each 6no. pile group for each pier are as follows:

1. Positioning and installation of guide frame
2. Lifting and driving of 3m dia. working piles
3. Cofferdam installation to head of pile group
4. Soil removal to inside of piles
5. Installation of centralising frame and base grouting apparatus
6. 10m concrete plug to base of pile
7. Base grouting
8. Sand infill
9. 10m concrete plug to top of pile

The piles are constructed from 60mm flat steel plate and rolled and formed into 3m lengths on site. These 3m sections are progressively welded together to reach 2no. lengths of circa 75m and 45m. The bottom and top sections are transported to the driving platform and driven to length connecting both sections with a final on-site weld after installation of the first 75m length. Soil is then removed from inside the pile leaving a 5m soil plug at the base of the pile. A guide frame is lowered carrying feeder pipes and with manchette tubes fixed to the bottom of the frame. After positioning of reinforcement, concreting of the bottom 10m of the pile is completed. Base grouting of the interface between the concrete plug and the soil plug is then progressed to ensure full end bearing of the pile is mobilised. The tubular pile is then backfilled to within 10m of the top of the pile when a second 10m reinforced concrete plug is installed.

Figure 4. Guide frame and foundation pile driving

Subsequent cofferdam installation, tremie concrete placement and water removal allows the construction of the 5.5m deep pile cap. The 6 steel tubular piles are embedded into the pile cap for 1m, which has a maximum soffit level 2m below the Standard Low Water Level.

Figure 5. Cofferdam and Pile Cap Reinforcement

5.2 Superstructure

5.2.1 Truss Fabrication and Erection

The Main Bridge length of 6,150m is subdivided into 7 modules with each module comprising generally six 150m spans. Within each module the 150m long warren truss spans are initially simply supported under steel self-weight. After erection each span is made continuous with adjacent spans within the module which then becomes structurally continuous for the addition of pre-cast railway and road deck panels.

Longitudinally, the main spans are in the form of a warren truss with the road deck slab connected to the top chord by shear stud connections to provide a composite connection. This form has a relatively high stiffness to mass ratio and has advantages in the control of deflections and seismic performance due to the reduced sprung mass to be carried to the pier and piled foundation should an earthquake occur.

Figure 6. Schematic of deck, truss and pier.

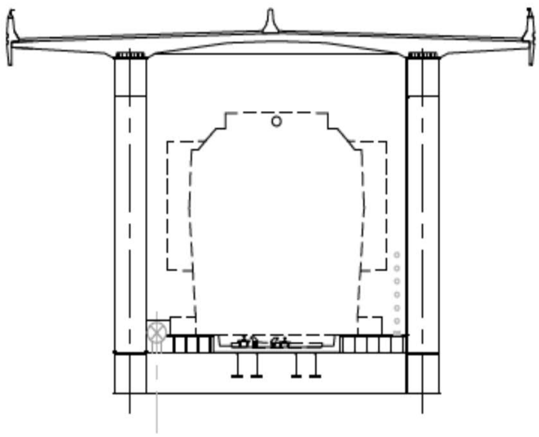


Figure 7. Main bridge truss and deck cross section

MBEC (China) are the Main Bridge contractor for the project. The fabrication and assembly of the 41 steel trusses is carried out in a phased operation as follows:

1. In Shanhaiguan, China, sister company CRSBG, fabricate and paint all truss members; typically, up to ≈60 tonne unit weight comprising nodes, chord members, diagonals, upper and lower cross beams.

Figure 8. Member Fabrication - China

2. Member transportation to the Mawa Assembly Yard, via Mongla Port.
3. At Mawa, in an assembly shed, the components are assembled by CRSBG into larger 2-D part truss modules which are then lifted into the vertical and assembled into complete 3-D assemblies to include railway stringer beam support brackets, maintenance gantry support brackets as well as the gas-line supports before being moved into the paint shop for final painting.

Figure 9. Site pre-assembly at Mawa

Figure 10. Full 3-D assembly at Mawa

Following final painting, completed trusses moved to storage to await load out and erection.

4. Shear legs floating crane transport to pier location, lifting and placing.

Figure 11. Truss Erection

5.2.2 Superstructure Analysis

Figure 7 above shows a typical bridge cross-section. All the main members of the bridge trusses are formed in hollow steel box sections. Sizes of the main members are typically between 1.2 and 2.8m wide and 1.2 to 1.6m deep, with manhole access through all internal diaphragms.

Plate thicknesses vary between 25mm to 70mm with Grade steel S420ML for plate over 40mm thick and S420M for plate less than 40mm. For the railway support girders grade S355M is used.

Analysis, using MIDAS software was carried out identifying three specific models related to different stages of the construction process. These were;

- Simply supported span of the truss without the concrete deck slab;
- Complete continuous module of the bridge (5 or 6 spans) without the continuous concrete deck
- Final stage fully constructed truss incorporating composite action top chord and utilising all appropriate load cases. Fully composite for SDL and all live loading.

A further global model was constructed to understand the impact on the six-span module with differing scenarios of scour at each of the pier locations. In this way the critical axial loads, shear and bending forces were determined in the pile foundation group of any pier.

5.2.3 Railway Deck

The railway is supported by the large section rolled steel beams spanning between the truss lower chord cross beams. Attached compositely to these beams are pre-cast reinforced concrete panels. Following the appointment of China Rail (CREC) to design and construct the rail link across the bridge from Dhaka, the design of these panels was amended at site to accommodate the precast long-sleeper track bed proposed.

All railway deck panels are being pre-cast at the Mawa side and will be placed on the erected trusses before the deck panels are placed above them.

5.2.4 Roadway Deck

On the top of the truss, the road deck is formed from match-cast reinforced concrete panels 2m long which are made composite with the truss upper chords using shear connectors welded to the top chords. These panels are cast in yards on both sides of the river. Following comments and advice from the BBA's Panel of Experts, the detailing of this critical connection was significantly enhanced. Because of this enhancement it was necessary to re-design the deck panels. Work which was carried out by the original checker, now part of COWI group.

After casting and storage, the deck panels are installed from a track mounted launching girder running along the truss and then longitudinally post-tensioned before attaching to the supporting steel trusses by the concreting of the shear connectors within the open pockets of the deck panels. This is followed by installation of movement joint at the ends of each module and the addition of precast and in-situ parapets and barriers.

5.2.5 Dehumidification

The original design includes full corrosion protection inside and out. However, with very limited access internally, the Panel of Experts urged the BBA to consider the provision of de-humidification as this would provide the most cost-effective means to ensure long term internal corrosion protection.

Accordingly, Rendel Ltd as part of their MSC contract carried out a design of the system using 3-D modelling and CFD simulation which permitted the required holing to be added through solid webs and diaphragms before the first span was erected.

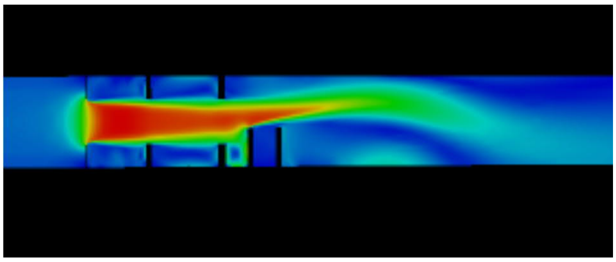
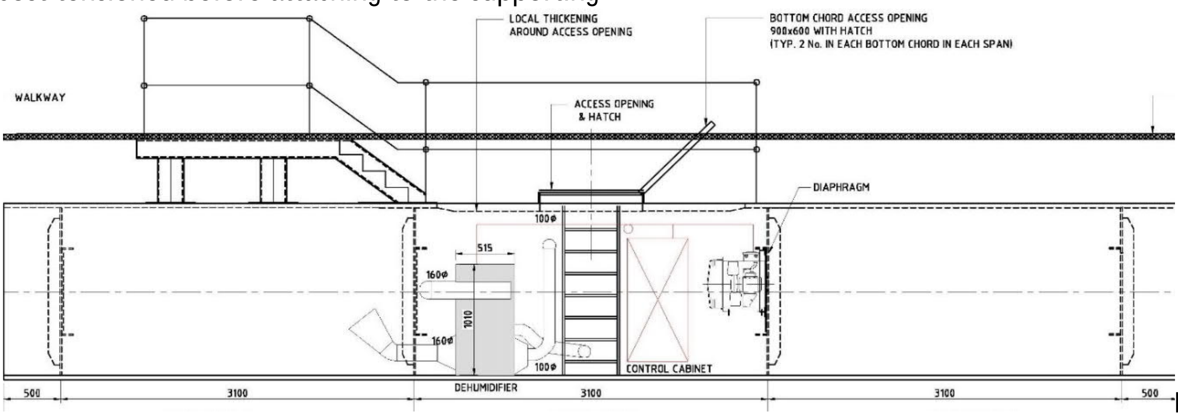


Figure 11. CFD - velocity through lower chord node

The dehumidification design includes two closed circuits within each 6-span module with all required plant installed within chambers in the truss lower chord. The whole installation can be accomplished without any significant steelwork modification.



Figur12. Elevation of dehumidification plant layout in lower chord

6 Summary

The realisation of the Padma Multipurpose Bridge Project has, for Bangladesh, seemed to have been a very long time in coming. Initial financial problems, have been resolved by the Government of Bangladesh, and the project, which is a matter of national pride is now being delivered. The very serious technical issues, including

- a design to accommodate the seismic activity and river conditions of the region,
- installation of pile foundations to unparalleled depths for this type of pile,
- the transportation and installation of superstructure in the constantly changing environment of one of the world's largest deltas;

are all being addressed. Other issues such as refinement of the precast concrete roadway deck slab design, access and maintenance gantries, gas pipeline and services installation together with lighting and dehumidification are all being re-evaluated by the project teams of both the Contractors and Consultants.