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The on-going superstructure construction of the 6.2 km 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. Completion 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 on-going technical challenges addressed during the construction of the superstructure as this landmark multipurpose crossing is brought to fruition.

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 broad gauge heavy freight 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 6.15km Main Bridge, extensive River Training Works of 14.0km length, approximately 13.6km 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 also requires 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, connecting to the widened N8 highway.
– 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.

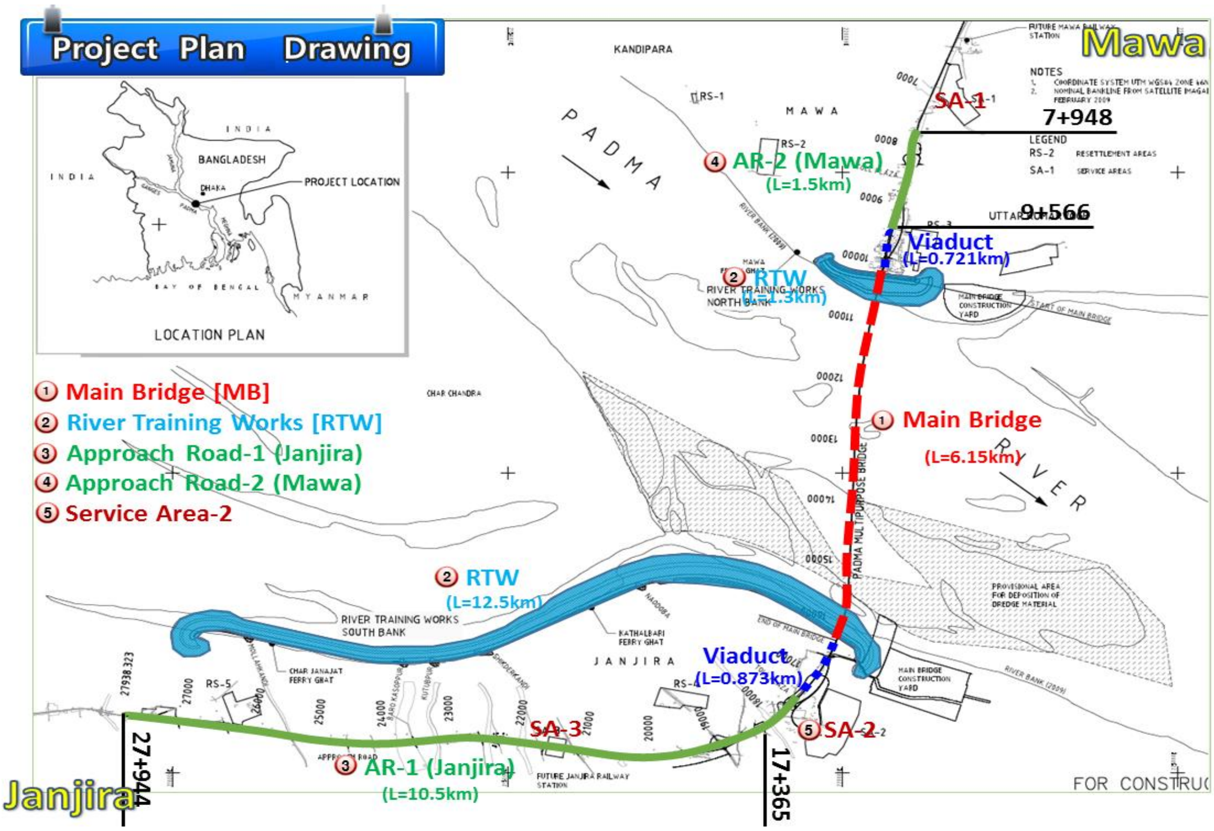

Figure 2. Project components either side of the river Padma.

4 SUPERSTRUCTURE – OVERALL DESCRIPTION

The Main Bridge is comprised of a total of 41 Warren Truss spans each 150m long, 12m wide and 12.75m deep. The truss chords are comprised of generally 1600mm x 1500mm box sections; the diagonal members; 1500mm x 1100mm deep. Plate thicknesses up to 70mm except over the seismic isolation bearings, where they are 100mm thick. These 41 spans are to be erected into 7 complete continuous modules. Six of these modules (Modules 1 to 6) each comprise 6 spans (i.e. they become 900m long modules). One, module 7, is 750m long and comprises just 5 spans.

The truss supports a 4-lane highway at top level, a single-track railway line at low level, a 760mm øgas pipeline and various ancillaries. The steel dead weight of each 150m long truss unit is over 3,000T. With concrete upper (roadway) and lower (railway) concrete decks the total weight of each span is in excess of 8,000T. For this reason, it was considered impractical to design the bridge assuming each span could be erected after completion of the concrete support decks. These concrete decks were therefore designed as pre-cast components to be added after the truss spans in each module had been erected.

The upper level 4-lane dual carriageway roadway is constructed from 20m wide, 2m and 2.15m long match pre-cast concrete units. These pre-cast deck panels are subsequently post-tensioned together and then made composite with the truss upper chords for live loading. This is full HA (normal) loading together with 45 units of HB (exceptional) loading to BS 5400.(the maximum standard UK loading for major highways).

At lower level, the truss carries sets of four stringer beams supported on brackets at each lower cross beams. On these stringer beams are attached pre-cast railway deck panels upon which subsequently will be placed the long sleeper track bed. This railway is designed to the Indian Code DFC loading and equates to 120kN/m.

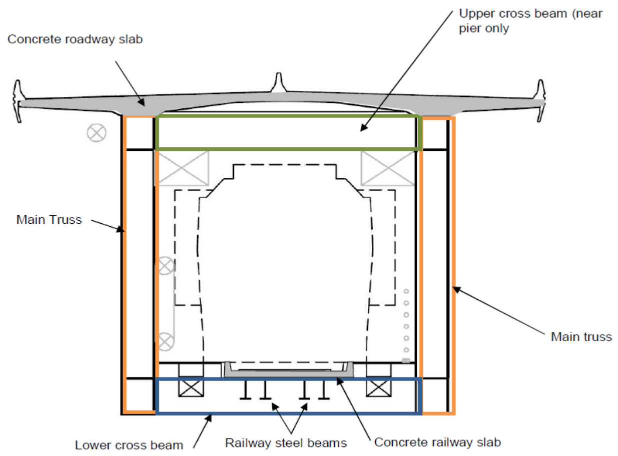

Figure 3. Typical main bridge cross section.

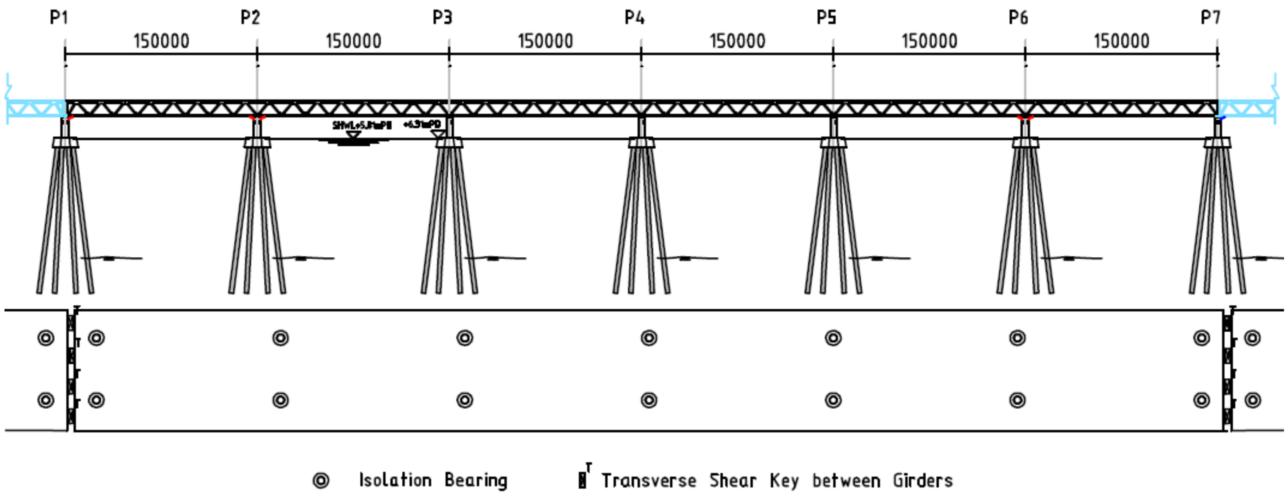

Figure 4. Typical structural arrangement of a complete 6-span module.

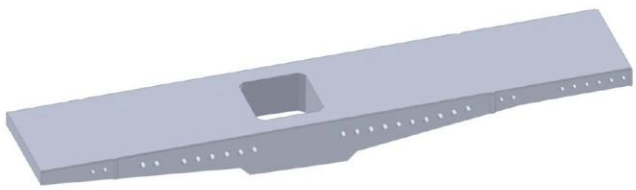

Figure 5. Isometric view of half a deck panel.

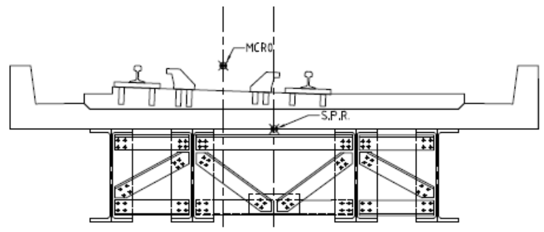

Figure 6. Cross section of railway deck panel supported by 4 beams.

The decision on the direction of erection of the spans of each module was taken by the Contractor prior to prefabrication. From the Contract drawings and in the construction procedure (sketch and photos below),only the first span is initially supported by two piers; thereafter, the subsequent spans to be erected for each module are lifted into position with one end supported by the pier, the other by a lifting frame positioned on the previously erected span.

The decision on direction of erection of each module was made at the commencement of the project construction to allow timeous completion of the fabrication drawings. This necessary programme decision was made before the final detailed Ground Investigation (GI), which formed part of the Contract works, was carried out.

Subsequently the final GI, when completed, identified unforeseen ground conditions which necessitated a re-design of some of the pier foundations. The delays to the construction of the respective supporting piers resulting from this foundation re-design process had a major impact on the sequence of truss span erection.

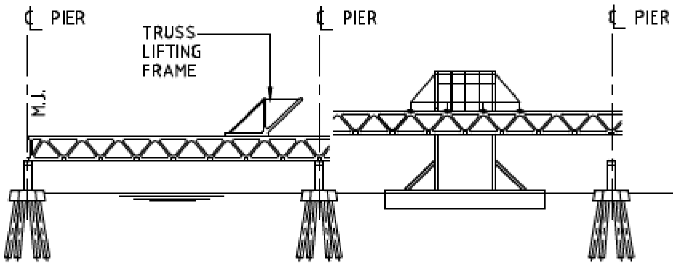

Figure 7. Sequence of erection from contract drawing.

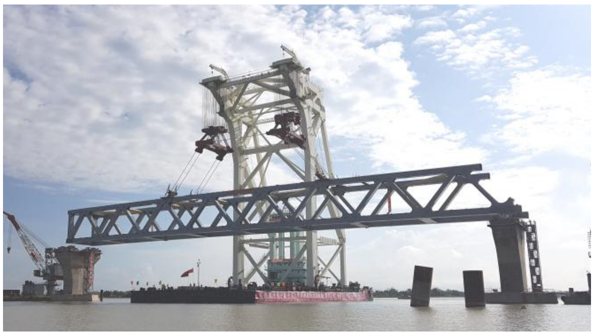

Figure 8. Erection of first spans of module.

Figure 9. Erection of subsequent spans along module.

Figure 10. Truss member fabriation in China.

5 TRUSS FABRICATION AND ASSEMBLY

The truss members are initially prefabricated into units of 50T to 80T by CRSBG (MBEC's sub-contractor) in Shanhaiguanin China. The members are then primed, coated internally and shipped to Bangladesh (generally Mongla) before transshipment to site by a smaller vessel. At Mawa Construction Yard, the units are unloaded at a jetty adjacent to the truss assembly yard. Here, the truss components are assembled into the complete 150m long units each weighing more than 3000T in a series of prepared covered and open yard areas.

(a) (b)

Figure 11. 2D assembly at Mawa CY.

Figure 12. 3D assembly.

Figure 13. Special bogies for moving complete truss assemblies.

Figure 14. Truss in painting shop.

Figure 15. Loading out of truss onto floating crane Tian Yi.

Figure 16. Prefabricated reinforcement cage in casting bed.

Figure 17. Curing of panels in casting bed.

Initially, the units are welded into pairs of prefabricated sub-units, before the complete 2-D assembly of 40m lengths of each truss on a series of prefabricated steel supports. After 2-D assembly the pieces are lifted with tandem gantry cranes and rotated 90^0 into the vertical then placed into the 3-D assembly area.

As part of the 3-D assembly, the cross beams and railway beam support brackets, ancillary brackets for maintenance gantry, gas pipeline installation etc., are added. The complete truss is then moved into the painting shop along special heavy duty multi-wheeled rail bogies. The truss units are now over 3000t in weight and all movement on land is using these special rail bogies.

On leaving the paint shop, the completed truss spans are stored in the yard until loaded out for erection using a special shear legs crane. The assembly and painting of a total of 41 spans of this magnitude, must be carried out in the sequence of proposed erection as the storage of such massive components poses a huge logistical and engineering task.

6 ROADWAY AND RAILWAY DECK UNITSPRE-CASTING

Two pre-cast concrete yards were established for the match pre-casting of the roadway panels on either side of the river. The yard at Mawa, on the northern side, for pre-casting deck panels along Modules 1 to 4 includes 4 beds each holding 10 panels. (In total 1708 panels – almost 100% completed). The yard at Janjira, to the south, for panels along Modules 5 to 7, includes 3 beds of the same size, i.e. each for 10 panels: one earlier match pre-cast segment plus beds for 9 new panels. (In total 1209 panels – all cast). All railway deck panels (2959) have already been cast at Mawa.

Prior to detailing the pre-cast deck panels, the Contractor decided to adopt two different panel lengths, 2.00m and 2.15m to facilitate matching the different types of shear connectors along the 18.75m unit length along the trusses. The 18.75m comprises an 8m panel point region (which utilized hoop shear connectors) and a 10.75m length using stud shear connectors. The distribution of the different panel lengths is shown in the sketch below.

7 RE-DETAILING OF ROADWAY DECK PANELS

During the construction phase in 2016, two concerns were raised with respect to the build ability of the pre-cast roadway deck. The first concern was over the series of ‘blind’ pockets for making the roadway deck integral with the truss upper chord and, secondly, concern over the effectiveness of relatively short shear connectors to satisfactorily provide the necessary transverse moment connections.

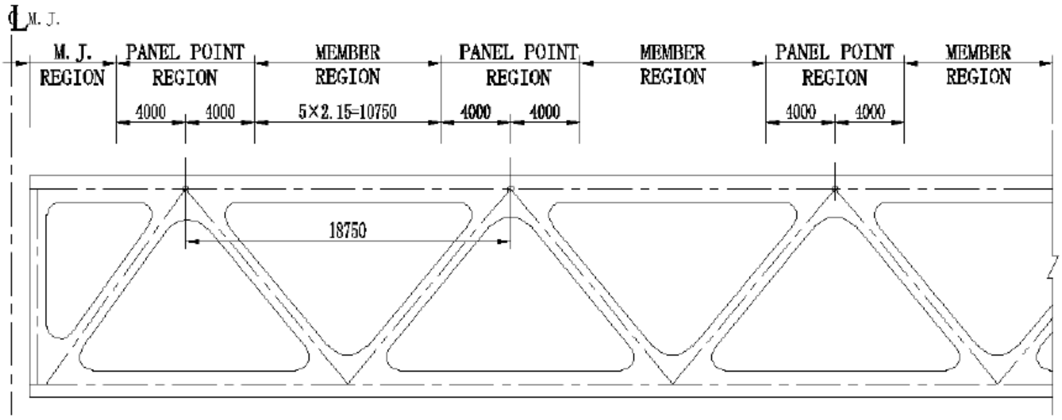

Figure 18. Layout of different panel lengths along the truss.

Figure 19. Lifting panels from casting bed.

Figure 20. Mawa storage yard showing large storage requirements for road and railway panels.

Figure 21. Placing precast railway panels ontoassembled stringer beams.

Subsequently, COWI (the PMBP Independent Design Check Consultants) were appointed to assess and re-detail the pre-cast deck panels. A result of the re-detailing was that, although the longitudinal pre-stress was not reduced in any way, the lateral distribution had to be significantly re-detailed to provide space for the 8 tendons that earlier passed above the blind pockets. Despite the complication this added, there was also a very significant and beneficial reduction of the quantity of transverse reinforcement. This has also greatly reduced the incidence of clashes with shear connectors welded to the truss chord. The introduction of clear visibility of the 'clash-zone' has resulted in the elimination of potentially significant delays from this interference in this area.

8 ERECTION OF ROADWAY DECK PANELS

Following a trial assembly of 4 or 6 panels at ground level within Janjira PC Yard, the erection of deck panels commenced at the Janjira end of the Main Bridge in April 2019. Initially, deck panels were lifted up to deck level and placed using the overhead gantry crane from the approach road construction and with the track extended over the end span of the bridge.

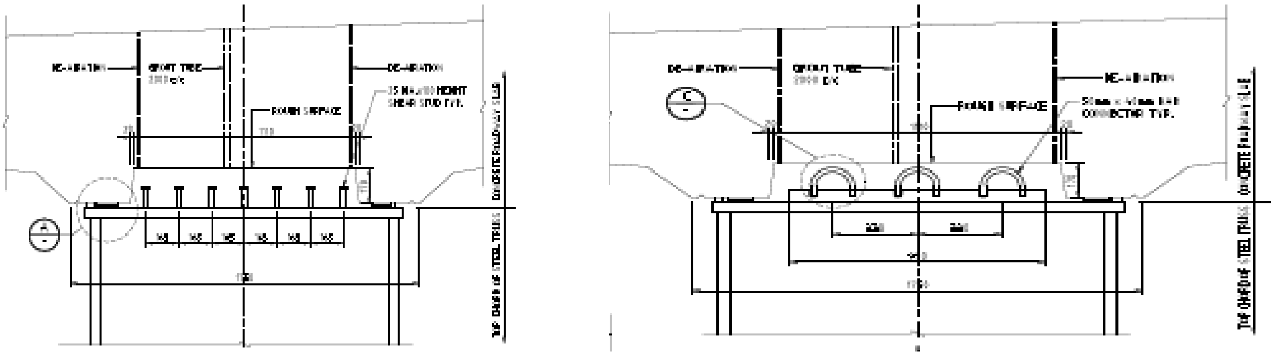

Figure 22. Extract from contract drawing with details of shear connectors in blind pockets.

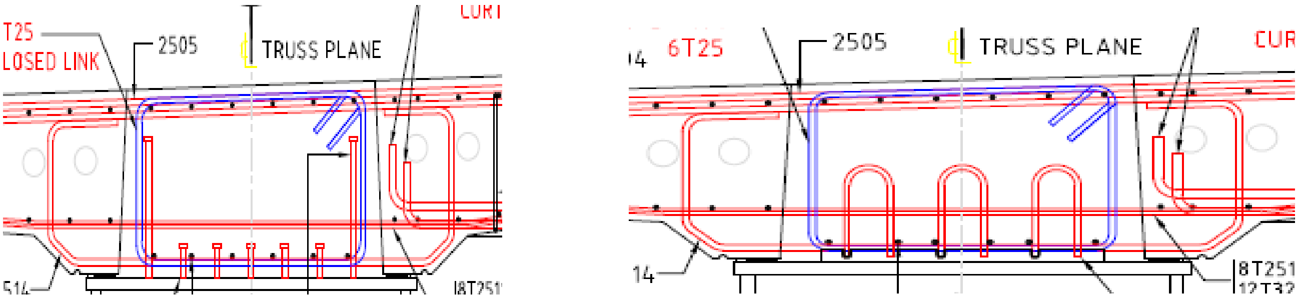

Figure 23. Views after change to pockets and shear connectors.

During this initial deck panel placing, the first launching gantry (LG1) was assembled at ground level before being lifted up onto the crane placed deck panels, in June 2019. After a period of labour skills enhancement, the placing rate of the deck panels increased very significantly and with 3 full shifts per day, a complete span of more than 70 panels can be placed and fully stressed and grouted within one month. A second roadway deck slab erection gantry (LG2) commenced in early 2020 at Pier 13 shown as below.

Figure 24. First deck panels erected by gantry.

Figure 25. Erection of LG1 onto first set of panels.

Figure 26. View of the erection front along Module 7.

Figure 27. View of LG1 progressing along Module.

Figure 28. LG2 commencing along Module 3.

Figure 29. Erection of railway panel assemblies.

Figure 30. View along erected railway slab.

Figure 31. Janjira viaducts view.

Figure 32. View of the Mawa viaducts.

Figure 33. Two truss spans in ‘storage’ on piled supports.

This (Figure 28) shows the first panels erected along span 3A by crane with the second erection gantry (LG2) erected on them. Erection now continues along Module 3, with deck panels being lifted from a barge by floating crane. The introduction of multiple shifts has seen erection rates for roadway deck, a critical activity, improve markedly on this front also.

9 RAILWAY DECK ERECTION

This activity is permitted to commence just before the complete module of truss spans has been erected. The railway deck panels, already assembled onto their supporting stringer beams must be in place before the roadway deck panels are placed over them.

10 CONSTRUCTION OF THE APPROACH VIADUCTS

Throughout the period of works to the Main Bridge, the approach viaducts have been under construction on both banks. The foundation construction, almost exclusively of ø1.5m bored piles, commenced at the southern Janjira side before moving across to the north side at Mawa. Pier construction similarly followed the same sequence. At this time, all piers are complete and pre-cast beam erection has been progressing well, particularly at the Janjira side. In-situ deck slabs are being cast onto both the pre-stressed I-beams forming the railway approaches and onto the ‘super Tee’ beams forming the road viaducts.

11 IMPACT OF UNFORESEEN CLAY LAYER ON DELAYS TO CONSTRUCTION

The Tender design of the Padma Bridge was based upon a Ground Investigation (GI) carried out some years in advance of the contract award. It was identified in the tender that there was very limited GI within the deep channel area and that the available information was to be supplemented by a further GI during the construction contract. This subsequent GI identified significant unforeseen layers of 1_f material, (silts and clays) within the lower region of the pile length or very close to the proposed toe level for up to 14 piers. As a consequence, completion of piling was delayed following the re-design of some pier foundations arising from the existence of these high-level clay layers. The re-designed foundations were issued sequentially in 3 batches. The re-designs for the first batch included the addition of a central 7^{th} (vertical) pile within the original 6 raking pile group. The second batch included the addition of external skin grouting to all piles. The two foundations for piers 6 and 7 proved the most onerous to resolve, as in these locations the bottom section of 3 piles had already been installed by the Contractor, MBEC. It was considered these could not be extracted without damage to the soil strata. This delayed design process necessitated a modification to the sequence of truss erection to match the availability of completed piers along each outstanding module. It is noted that at this stage of the fabrication process, the sequence of truss span erection along each module, could not be varied.

The change to the sequence of erection, caused by the delays to foundation construction, initiated an enormous disruption to the assembly process which was progressing at pace. It became necessary to provide additional storage for trusses (each 150m long and weighing in excess of 3,000T) which had been assembled but were not needed immediately because of the revised erection procedure.

In addition, the sequence of placing the pre-cast deck panels along each module had to follow that assumed when the detailing of stressing anchorages was advanced. Whilst drawings may be revised, once a match cast series of panels are formed, then any revision to the placing sequence requires the affected panels to be recast. The revised erection sequence was extremely problematic, delaying the erection of spans within the section of the bridge in the dredged access channel, until after a further monsoon. Sedimentation levels following the 2019 Monsoon meant that prolonged dredging was necessary to regain access in order to erect the remainder of the modules in this area before the 2020 Monsoon. This was achieved satisfactorily with the final span (5F) erected on 10^{th} June 2020.

12 MAWA CY BANK FAILURE AT THE END OF JULY 2020

On 31^{st} July this year, with high Padma River monsoon levels, there was a major bank failure downstream of the bridge site. Whilst there was no direct threat to the bridge structure itself, the bank failure did result in the loss of approximately 125 pre-cast roadway slabs (equivalent to nearly two complete spans). However, these are all match-cast decks and were from a total of 9 different spans; primarily three within Module 3. This erection front was therefore temporarily halted. In addition, over one module length (900m) of railway support stringer assemblies were also swept away.

Figure 34. Aerial views of Mawa storage yard before slip.

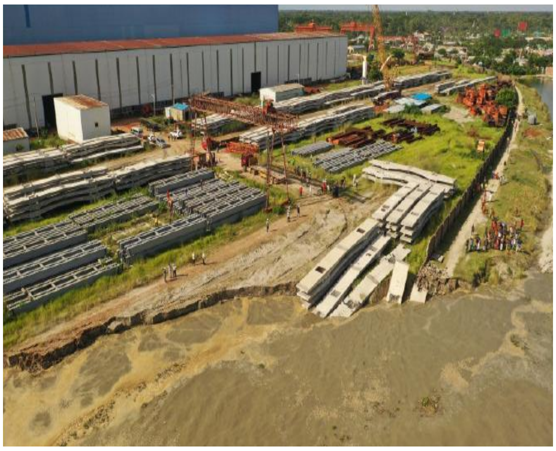

Figure 35. Evening of July 31.

Figure 36. Drone view of area after July 31.

Whilst the Contractor has made immediate proposals to counter the impact of major delays to deck panels erection, by a combination of substitution of match-cast panels from other spans (not yet erected) and re-casting those lost, the impact of delays overall has not yet been quantified.

13 SUMMARY

Despite a number of issues resulting in delays as described above, it is perhaps worth noting the considerable number of ‘unique firsts’ and difficulties the project encompassed.

- Longest road bridge in Bangladesh.
- Longest railway bridge in Bangladesh.
- Longest driven piles in Bangladesh and of this type of piled foundation construction in the world.
- On- going construction during what is reported as the highest monsoon river levels for more than 10 years.
- On-going construction during the world’s first major pandemic for 100 years.

The full impact of the COVID-19 pandemic has yet to be fully determined and may result in further consequences to the delivery of the project. However, all measures possible are being taken by all parties to the Contract to mitigate and minimize any delay. The delays caused by the redesign of the pier foundations have been by definition, unforeseen. It is fortunate for the Project however, that all four key components for success are proving to be resilient, namely; the original design together with Contractor, Supervisor and the Client. Despite setbacks the Padma Multipurpose Bridge Project, for so long seemingly only a pipedream for the people of Bangladesh, is slowly but very surely rising and stretching its way across this majestic river. Bangladesh will not need to wait much longer.