

Concrete highway arch bridges in Bangladesh: Historical development and lessons learnt

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ABSTRACT: Historically the concrete highway arch bridge in Bangladesh dates back to the decade of 1980s, which are of five types: 1. Deck arch type, where the arch runs below the deck; 2. Through arch type, where the deck crosses part of the arches; 3. Tied arch type, where the deck is connected to the elevated arches; 4. Nielsen arch type, where the inclined suspenders cross each other not more than once; and 5. Network Arch Bridge (NWAB), where intersecting suspenders cross each other at least twice. The Author being involved as Team Leader for implementation of most of these bridges, narrates from first hand experiences about the planning, design, construction, material used, the problems faced and their remedial measures. The paper shows out of the above types of bridges NWAB has particular advantages for the medium to long span bridges. In the end, important discussions and recommendations are made.

1 INTRODUCTION

Arches appeared as early as the 2nd millennium BC in Mesopotamia. Romans used arch form in bridges during the 1st millennium BC. In Bangladesh Architect Louis Kahn used the brick masonry arches in the Members of Parliament (MP) Hostel in the Sangshad Bhavan (Parliament House) of Dhaka. The concrete highway arch bridges have appeared late in Bangladesh from the decade of 1980s only. This inhibition was due to the prevailing perception that the arch bridges are not suitable in the alluvial planes of Bangladesh, but is suitable for the hilly regions of the country mainly, where hard strata exist at a reasonable depth, to restrain the horizontal movement of the loaded arches.

More than sixteen concrete highway arch bridges have been constructed in Bangladesh till present, which may be categorized under five types namely; deck arch type, through arch type, tied arch type, Nielsen arch type, and Network Arch Bridge (NWAB) type. The constructed bridges are either of single or multiple spans span length varying between 16.00 and 73.00 meters.

The Author being directly involved, on behalf of Design Planning & Management Consultants Ltd. (DPM) for these bridges, except the bridge on Dhum Ramgarh Highway, mostly as Team Leader, narrates the chronological development of these bridges, and the lessons learnt therefrom.

2 HISTORICAL DEVELOPMENT

2.1 Arch Bridge on Dhum Ramgarh Highway

The first concrete highway arch bridge in Bangladesh has been built by RHD on Dhum-Ramgarh Highway (Z1602) in Chittagong Hill Tracts in the decade of 1980s. The bridge length is 51.20 meters measured at deck level and its carriageway width is 6.80 meters. The size of the arch at deck level is 920 millimeters in transverse direction and 1,220 millimeters in the traffic direction. Figure 1 photograph shows the bridge with its eight vertical concrete hangers monolithically constructed with the deck and the arches. This arch bridge had been designed within RHD's In house capabilities. The Contractor was M/S. Nihar Kanti Das. The restraint to the horizontal movement of the arches due to the dead, live and environmental loads are provided partly by the tie action of the deck, partly by the bending and shear resistance of the abutment foundations, and partly by the passive resistance of the abutment backfill material.

Lessons learnt: It's amazing that in the decade of 1980s, the local engineering professionals with limited capabilities could develop such a panoramic design of the bridge, which is performing well with minimum maintenance till present. This through type arch bridge with vertical hangers matches with the green environment of the Chittagong Hill Tracts. Instead of conventional steel arches, reinforced concrete (RC) arches and hangers have been used, to ensure corrosion protection of the bridge maintenance. It's appreciable that the local con-

tractor with limited equipment and experiences could construct this arch bridge at such a remote location maintaining quality, in the decade of 1980s. The bridge looks fresh till present.



Figure 1. Photograph of arch bridge on Dhum Ramgarh highway

Lessons learnt: The Figure 1 shows the cross girder ends aren't provided with any longitudinal end restraint as a preventive measure against compression buckling, contrary to the normal practice of bridge engineering in the country. This could be done by projecting the main longitudinal girders below the deck either full or part section. The visual inspection showed no cracks or sign of buckling of the cross girders due to this omission.

2.2 Two Dhanmondi Lake Crossing Arch Bridges

There are two identical deck type arch bridges over Dhanmondi Lake in Dhaka city area. The first bridge (Bridge 1) connects Road No. 32 (11/A new) with Road No. 13/A and the second bridge (Bridge 2) connects Road No. 8/A with Road No. 8. These bridges were constructed from April 1999 to April 2000. The two parallel symmetrical reinforced concrete (RC) circular arches with additional eight radial supports to the deck from the arches carry the deck loads. Arches and their radial hangers give the bridge the pleasant look of the petals of the blossomed water lily, which is the national flower of Bangladesh. Bridge 1 & Bridge 2 are 34.00 & 42.00 meters long respectively. The out to out width of the dual carriageway deck is 15.80 meters each. The springing to springing lengths of the arches are 27.734 & 30.811 meters and their rises are 4.724 & 6.818 meters respectively. The Local government Engineering department (LGED) was the Client, DPM-AIA JV was the structural consultants, and Vitti Shapati Brinda Ltd. was the architectural consultant for these two bridges. Their construction was funded by the Government of Bangladesh (GOB). M/S. Jaya Construction (Pvt.) Ltd. was the Contractor for Bridge 1, and its construction cost was BDT 19.10 million, and M/S. Khan Int'l was the Contractor for Bridge 2, and its construction cost was 25.40 million. For further details refer to (Sobhan & Ali, 2001).



Figure 2. Bridge 2: Arch bridge across Dhanmondi lake connecting Road No. 8/A & Road No. 8, Dhaka

Lessons learnt: Architects had been involved in bridge design for the first time in Bangladesh to develop the aesthetically beautiful geometric shape of these arch bridges. The RC arch was used to achieve relatively maintenance free structures.

2.3 Banani Lake Bridge

This 799.00 meters long labyrinth-shaped Banani Lake Bridge Project in Dhaka City, links 18.30 meters wide Banani side Road No. 11 with Gulshan side Road Nos. 41, 43, 35A and 34. Its 90.00 meters long 3-span main bridge with the intermediate 40.50 meters long arch span connects Banani Road No. 11 with Gulshan Road No. 41 at a sharp skew angle of about 40° . Figure 3 photograph shows the bridge. Its arch span contains dual carriageways, each of width 5.70 meters, separated by a 400 mm wide median. Pair of suspenders is provided for each cross girder, comprising high-yield (HY) reinforcing bars encased in 125 millimeter diameter stainless steel pipe in-filled with grout to ensure corrosion protection. LGED was the Client, DPM-Vitti JV was the consultant and AML was the Contractor. Total cost was BDT 145.00 million. For further details refer to (Sobhan & Khan 2009).

Lessons learnt: The challenge arisen due to the sharp skew angle of the main bridge had been solved by designing a 3-span bridge, the middle span containing the elevated tied deck arch; its side spans containing sharp reverse curvatures to address the matching bridge geometry and also enhance its aesthetics. The super elevation has been provided matching with the reverse curvatures to enhance the driving comfort and bridge safety. 1.50 meters wide sidewalks are provided projecting outside the arches on both sides with gaps to view the reflection of the bridge in water. The tied bridge deck joints have been provided over the piers on both sides of the simply-supported arch span. The ties are provided with stainless steel dowel bars and placed near the mid-depth of the deck slab, to distribute to the adjacent spans the horizontal forces due to earthquake and other environmental loading including the effect of differential support settlement. Associated buried joints below the asphaltic concrete wearing course have been provided with replaceable folded aluminum foils to arrest leakage of water through the joints and to stop entry of hard objects in the gap. These tied bridge deck would allow the rotational movement but will restrict the translational movement, and thereby will enable transferring the in-plane movement of the deck of arch spans to the adjacent curved spans.



Figure 3. Photograph of Banani lake bridge

2.4 The Arch Bridges of The Integrated Development of Hatirjheel Area Including Begunbari Khal Project, Dhaka

The multipurpose Hatirjheel project comprises: (i) development of urban flood water retention reservoir-cum-recreational lake for the Dhanmondi-Gulshan-Badda-Tejgaon-Moghobazar area, including cleaning of the sludge below the reservoir. The responsibility of its implementation was entrusted to the Dhaka City Development Authority, named RAJUK; (ii) peripheral ring road development around the Hatirjheel Lake including lake crossing bridges, viaducts, overpasses and other beautification structures, implemented by LGED; (iii) diversion of the surrounding sewage by the large diameter sewerage pipe lines, implemented by Dhaka Water Supply and Sewerage Authority (DWASA); and (iv) landscaping, implemented by RAJUK. Bangladesh University of Engineering & Technology (BUET) was the General Consultant of RAJUK, and also they were the Consultant of Dhaka Sewerage Development Authority (DWASA) components; and Vitti-DPM-AIA JV was the consultant for the LGED components which includes the different types of arch bridges.

2.4.1 Viaduct VD-01

This 100.00 meters long bridge comprises 2 equal arch spans @50.00 meters each, 7.10 meters wide dual car riageways, two 1.80 meters sidewalks on both ends, which gives out to out deck width 10.90 meters.



Figure 4. Photograph of VD-01

Four parallel arches of depth varying between 3,120 millimeters at springing and 1,000 millimeters at crown are provided. Six radial hangers 600 x 600 millimeter size is provided per span. Figure 4 photograph shows one water side view of VD-01. The construction period was between 21 March 2010 and 07 July 2012. Development Consultants Ltd. (DCL) was the Contractor. Total cost was BDT 89.26 million.

2.4.2 BR-01

It's a 180.00 meters long 5-span bridge comprising 3 arch spans of $48.50 + 64.00 + 48.50 = 161.00$ meters, plus 2 side spans of $2 \times 9.50 = 19.00$ meters. The bridge deck comprises 4-lane carriageways of width 13.30 meters and two 2.00 meters wide sidewalks on both sides, giving out to out deck width 17.30 meters. Figure 5 photograph shows one long view of the bridge. The identical abutment pile caps of size 22.20 x 19.80 are provided on both ends, supported on 40 numbers 26.25 meters long 1,200 millimeters diameter cast-in-place bored piles. The hammer-headed pier pile caps are supported on 22 number 1,200 millimeters diameter 26.25 meters long cast-in-place bored piles. The contractor was Mir Akhtar Hossain Ltd. (MAHL). The total construction period was from 05 April 2010 to 15 August 2012. The total cost was BDT 281.74 million.



Figure 5. Photograph of BR-01

Lessons learnt: The several service piles below Tejgaon side abutments (near end in Figure 5), failed in load tests. Fresh Standard Penetration Test (SPT) bore-logs had been taken and also Dutch cone Penetrometer (DCP) tests had been done to re-assess the shaft and end bearing resistance of the piles. The careful review by the geotechnical experts of the consultants and those of Bureau of Research & Testing Consultancy (BRTC) of Bangladesh University of Engineering & Technology (BUET) showed a small depth lens of compressible layer of about 1.00 meter below the pile tip, which escaped detection in SPT boring. Additional piles of larger depth had been constructed, and under-construction abutments had been retrofitted. Different sizes of concrete boxes have been constructed monolithic with the abutments and wing walls, filled some of the boxes with sand to balance the loads on piles. The fixed arches and the continuous decks were re-designed considering the estimated additional differential support settlements. Caution! For important projects adequate care should be taken in the subsurface soil investigations and these should be checked by competent geotechnical experts before using.

2.4.3 BR-02

Figure 6 shows the long view of the 167.24 meters long 3-continuous span arch bridge containing span lengths of $40.50 + 73.00 + 53.74$ meters, and including carriageway and two sidewalks on both sides, its out to out deck width is 17.30 meters. Figure 6 shows the long view of the bridge. The 3 arch spans are designed as con-

tinuous structure. Two identical U-shaped (in plan) abutments are supported on 27 number 1,200 millimeters diameter piles of variable length 25.00 and 21.00 meters for each abutment; and the two identical hammer-headed pier pile caps are supported on 18 number 1,200 millimeters diameter piles of 25.00 meters length for each pier. The contractor was M/S. DCL. The total construction period was between 05 April 2010 and 15 August 2012. The total cost was BDT 219.83 million.



Figure 6. Photograph of BR-02

Lessons learnt: The distance between the C/L piers and the crossing points of the deck with the arch is relatively long, which generates large bending moments on the arch over the piers. The arch section and reinforcement have been designed accordingly. To provide additional redundancy as a precaution, a pair of identical pot bearings designed with adequate factor of safety (FOS) has been provided over each pier. Mageba designed and supervised installation of the bearings.

2.4.4 BR-03 & Dhaka City Corporation (DCC) Bridge Niketan, Dhaka

BR-03 is a 40.00 meters long single span deck type arch bridge under Integrated Hatirjheel Project. The bridge carriageway width is 7.10 meters and with 2 x 2.00 meters walkways on both sides, gives out to out deck width 11.10 meters. Four parallel arches are provided for the bridge. Each abutment pile cap is of size 15.00 x 6.90 meters size and is supported on 18 number 900 millimeter diameter 24.00 meters long cast-in-place bored piles. The contractor was M/S. Monico Ltd. The construction period was between 08 May 2010 and 15 June 2012. The construction cost was BDT 51.59 million.

Another identical bridge has been designed by DPM for Dhaka City Corporation (DCC) South, in the adjacent location of BR-03 to connect Hatirjheel Lake with the Gulshan Lake. M/S. AB-NTL was the contractor. The bridge had been constructed between 08 July 2010 and April 2012. The cost was BDT 68.10 million.

2.4.5 Bridge BR-04

Figure 7 shows the 90.00 meters long 3 simply-supported equal spans triangular tied arch bridge, comprising 2-lane carriageways of width 7.10 meters, on two sides arches of width 0.70 meter each, bridge curbs of width 0.25 meter each, and sidewalks of width 1.75 meters each, have been provided, which gives out to out deck width 12.50 meters. Figure 7 photograph shows the long view of the bridge. A pair of hangers each comprising 19 number 12.7 mm diameter high tensile (HT) strands embedded inside 125 millimeter diameter stainless steel pipe, anchored inside the bottom main longitudinal girders and the triangular arch at its vertex. Anchorage device is similar to the anchorages of the prestressed concrete girders. The contractor was Monico Ltd. The construction was done from 05 April 2010 to 30 November 2012. Total cost was BDT 101.73 million.



Figure 7. Photograph of BR-04

Lessons learnt: This triangular arch type bridge is a new concept for Bangladesh and designed such that its aesthetics matches with the environment. The top tie of the Y-shaped pier showed cracks and review had shown deficiency exists in its main and surface reinforcement. This has been retrofitted with external prestressing using Macaloy bars. The important lessons learnt is that framing and following the necessary Quality Assurance (QA) Scheme should be made mandatory both for design and construction. Further lesson learnt from BR-04 is that although the reinforced elastomeric bearings had been procured after necessary testing from local manufacturers, these failed short time after opening the bridge for traffic. These had been replaced by Hercules brand of bearings procured from Malaysia. It's recommended that, in case of elastomeric bearings, the provision for their easy replacement during the life time of the bridge should be kept in design. It's suggested that well-designed RC corbels in the pier or abutment caps may be kept below the main girders to enable replacing the damaged bearings easily by placing flat jacks below the main girders.

2.4.6 Viaduct VD-03

It's a 92.80 meters long, 6-span deck type arch bridge containing 4 equal arch spans @ 20.00 meters each + 2 side spans @ 6.40 meters on both sides. The deck comprises 2-lane carriageway of width 7.30 meters and two sidewalks of width 1.80 meters each on both sides, which give out to out deck width 10.90 meters. Three parallel arches are provided below deck for each span. Fig. 8 shows the general elevation of the bridge). The continuous span 5 girders supported on transverse diaphragms transfer deck loads on the crown of the arches. The contractor was MAHL. Total cost was BDT 110.06 million.



Figure 8. Photograph of VD-03

Lessons learnt: This deck type arch is the fundamental type of arch for short span bridges where transferring loads from deck through the arch crown will give smaller depths of longitudinal main girders. Its benefit will be that the smaller girder depth will reduce the wind loads and the adverse aerodynamic behavior, and will enable to provide adequate navigational clearances without raising the deck level unnecessarily.

2.5 Elevated Arch Bridge at Dhamalkot, Dhaka Cantonment

It's a 102.00 meters long 3-span bridge with its intermediate span being the arch span. Its deck comprises 7.70 meters wide carriageways, on both sides' two 750 millimeter wide arches/main longitudinal girders and two 3.90 meters wide sidewalks, which gives out to out deck width 17.00 meters. The sidewalks beginning at the abutments run below the deck at a slope joining a 22.00 meters long and 17.00 meters wide platform at bridge center, constructed 2.825 meters below the soffit of the deck giving minimum 2.768 meters clear height below the cross girders. This platform will be used mainly for recreational purposes. The springing to springing length of the two circular arches measured at the top level of the pile cap is 61.77 meters c/c. For each arch, the octagonal-shaped pile cap is supported on 19 number 1,000 millimeters diameter cast-in place bored piles of length 24.30 meters below the bottom of the pile cap level. The rise of the arch at the mid-span measured between top levels of deck to centre line of the arch is 11.30 meters. The depth of the arch varies between 4,500 millimeters at the springing level to 1,500 millimeters at the crown. The deck is supported from each arch by 11 number hangers each comprising 5 number HY reinforcing steel of 32 millimeter diameter embedded inside 167 millimeter outer diameter and 4 millimeter thick noncorrosive stainless steel pipes anchored inside arch and longitudinal main girders. The viewing deck at bottom is also pile-supported. The Client was Military Engineering Services (MES), the architectural consultant was Indigenous Architects and structural consultant was DPM, and the Contractor was Abdul Monem Ltd. (AML). The project period was between 2014 and 2015, and its construction cost was BDT 400.00 million.

Lessons learnt: The original design showed monolithic connections between the deck and the arches and also deck and the abutments. The contractor's adopted staged construction was faulty. They removed the scaffoldings and formworks below one end sidewalk earlier and also not correct. This generated asymmetrical load effects in the adjacent zones of the deck ends, and thereby cracks developed in the vicinity. The retrofit design was made after joint investigations with BRTC, BUET were made. Accordingly, counterforts had been provided behind the abutments and wing walls, fixed end joints have been modified to simply supported joints which required providing reinforced elastomeric bearings below girders. Moment redistribution in the sloping sidewalks due to the above effects had been addressed by providing additional inclined supports from the abutment pile caps to the sloping walkways, and redesigning bridge aesthetics accordingly. Figure 9 shows the finished bridge.



Figure 9. Arch bridge at Dhamalkot, Dhaka Cantonment

2.6 Dhaka North City Corporation (DNCC) Network Arch Bridge at Rayer Bazar Graveyard, Dhaka

This Network Arch Bridge (NWAB) at Rayer Bazar Graveyard in Dhaka city is the first of its type constructed in Bangladesh. It's a 56.50 meters long, 3-span bridge containing intermediate arch span of 40.00 meters, and 2 side spans @ 6.60 meters measured at deck level. The rise of the arch between c/c deck and arch crown is 6.80 meters. The deck contains single carriageway of width 5.50 meters, and with two longitudinal main girders of 1,000 millimeters width and 600 millimeters depth on both sides, gives the out to out deck width 7.50

meters. The 16 intersecting suspenders are placed at 55° angles in a layout wherein each hanger crosses at least twice. The Client was Dhaka City Corporation North (DNCC) and the Contractor was MAHL. The construction cost was 62.10 million. The bridge has been opened to traffic during April 2015. Figure 10 shows the completed bridge.



Figure 10. DNCC network arch bridge at Rayer Bazar graveyard

Lessons learnt: Rayer Bazar Network arch Bridge (NWAB) may be considered as a pilot project for Bangladesh. Several modifications in Per Tveit's concept have been introduced to develop a medium to long bridges in Bangladesh using the locally available material and technology. For further important details refer to (Laila, S.N., et al 2015).

2.7 Arch Bridge over Modhumoti River at Gopalganj

This Nielsen type concrete highway arch bridge is 40.00 meters long measured between springing points. Its deck contains 2-lanes having the carriageway width 7.60 meters, plus 600 millimeters wide girders and 1.80 meters wide walkways on both sides, which gives the out to out deck width 12.40 meters. Its radial hangers comprise 4 numbers. Grade 500 reinforcing steel in accordance with BDS ISO 6935-2-9000, embedded inside 125 millimeters diameter stainless steel pipes with the grout-filled voids.

Vitti-DPM JV was the consultant. M/s. Kamrul & Brothers was the contractor of the bridge. The construction period was between September 2010 and December 2011. Its construction cost was BDT 32.5 million and cost of approach was BDT 15.60 million. The bridge has been completed during 2012 and is in service now.



Figure 11. Arch bridge over Modhumati river at Gopalganj (Nielsen Type)

2.8 Uttara 3rd Phase Bridge No.10

It's a 58.00 meters long single span 3-arch bridge as shown in Figure 10. Its 57.00 meters wide deck contains two dual carriageways each 14.30 meters wide, separated by 3.20 meters wide median, and two 6.50 meters wide service roads separated by two 1.60 meters wide medians with the main carriageways, and two 3.00 meters wide walkways outside the both sides arches separated by 850 millimeters wide curbs. Each arch carries 14 pairs of suspenders for each cross girder. Each suspender comprises 7-12.7 millimeters diameter high tensile (HT) strands anchored inside main longitudinal girders and the arch. Figure 12 photograph shows the completed bridge. The Client was RAJUK, and Monico Ltd. was the contractor. The construction period was between 14 December 2009 and 30 December 2013. The cost was BDT 280.00 11 million.



Figure 12. RAJUK's Uttara 3rd phase – BR-10

Lessons learnt: The construction of this 58.00 meters long and 57.00 meters wide bridge using 3 elevated arches with tied decks in traditional methods was a problem. It could be divided into two bridges with a small gap to facilitate easy construction, which could help phasing out construction by delaying the phase 2 construction of the second bridge till design traffic for the second bridge is generated. The foundation and substructure for both the bridges could be constructed in Phase 1; and Phase 2 construction of the 2nd bridge could be done after adequate traffic is mobilized.

3 CONSTRUCTION METHODOLOGY

The traditional construction methodologies have been adopted for all the above arch bridges. The coffer dams, or sand-filled islands have been made at the start. The cast-in place bored piles had been constructed thereafter placing rigs over the compacted fill material. Bentonite slurry in circulation had been used to protect the pile bore holes from caving. For construction of arch steel scaffolding and formwork had been used. Figure 13 photograph shows typical scaffoldings used for construction of the arches.



Figure 13. Banani bridge construction stage photograph of arch

4 DISCUSSIONS AND RECOMMENDATIONS

The experiences from the construction of the above-mentioned concrete arch bridges show that arch forms enhance aesthetics of the surroundings both for rural and urban environment. With the construction of the 15-16 numbers arch bridges of different types have given scope to test and strengthen the local capabilities in designing and constructing even the complex arch bridges with difficult curvatures using the local materials and technologies by the national contractors maintaining safety at work.

The traditional construction methodologies of insitu construction need to be modernized. The designers need to have the direct experiences of construction to visualize the difficulties of construction in the fields. Similarly vice versa for the contractors, they should have some experiences regarding the basics of arch design to enable them match their construction methodologies with the assumptions of design. The traditional construction methodologies adopted for the above bridges had huge involvement of scaffoldings and formworks which could be optimized by matching the design with the staged construction within the capabilities of the local contractors.

Next important steps will be to undertake one large span NWAB with span length about 150.00 meters, and construct it blending the traditional and modern construction technologies employing the local contractors. For Bangladesh environment the process should be more labor intensive as far as practical to generate more employment opportunities without compromising quality. It will be the challenge for the designers to develop appropriate design matching with the staged construction.

Bangladesh should come up with funding research on these NWAB types of bridges, generating appropriate technology for construction with R & D, combining the academia and the industry. The country's planning commission should come up with broad vision to help the construction industry which in turn will boost our national industries.

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