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Design, construction and maintenance of bridges in Bangladesh: In the past, present and future

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ABSTRACT: Bridges are the life lines of not only a country but a region or beyond. This is true for Bangladesh as her geopolitical boundaries place the country in a strategic situation giving ample opportunity to become a hub for a sub-regional to global land transport network. Owning a resilient bridge infrastructure for the Asian region and considering country's location, geomorphological conditions and climatic variations are important for future growth of transportation network. To this end in view, the paper takes a note of the construction of a few land mark bridges those taken place between 1870 AD to present. The major engineering aspects and the performances are being discussed in a broader sense. Finally, the paper presents an outlook identifying the gaps in understanding for achieving an efficient design with the present know-how available elsewhere in the world. The necessity of maintenance aspects is being discussed in short. Salient design, construction and maintenance considerations that the future national design code/ standard for bridges in Bangladesh needs to contain are indicated.

1 INTRODUCTION

The most ancient geographical description of the Ganges delta forming Bangladesh is found in the Claudius Ptolemy's map sketched in 150 AD. The sketched map shows the clear existence of the Himalayan highlands and the river systems those originated from it. The Greek philosopher most likely produced it using the information received from the travellers who extensively visited this part of the land. This surely indicates the ancient importance of this geographical location in the global context. Further the recorded information about its river systems and waterways are known in the sketches found in the Aine-e-Akbari (1582 AD). James Rennell's map of Bengal and Bahar (1778) was the first scientifically prepared map of the Ganges-Brahmaputra (Jamuna)-Meghna basin in a time even before the establishment of the modern prime meridian, based at the Royal Observatory, Greenwich which was established by Sir George Airy only in 1851. Thus, there was no mention about the projection used for the preparation of the maps; and 00 longitude was arbitrarily taken over Kolkata, India; and the scale of the map was British 69.5 miles to a degree. The Statistical Accounts of the Provinces of Bengal and Assam were compiled under the personal supervision of W.W. Hunter, the Director General of the Statistics of the Government of India (1877). Each volume of the Accounts is accompanied with a map in a scale of sixteen miles to an inch. These maps have latitudes and longitudes but there is also no mention about the projection used to make the maps. Nevertheless, in all these cartographic projections, the complex and ever changing river systems of this part of land of world is vividly indicated. The local need to travel from one part of this land to the other was, however, limited in the Mughal era (1526-1857 AD). The dependence on river systems was significant not only for transport but also for the defense of the important forts and townships.

However, in the wake of imperial expansion and increasing interaction with Europe, it became increasingly important to establish fixed links over its great river systems. The geological formation of the country, a low lying delta formed by recent deposits on the flood plains of the Ganges-Brahmapurtra-Meghna river systems, with hundreds of tributaries, distributaries and water bodies, posed a big challenge to the Civil Engineers in design, construction and maintenance of an uninterrupted country wide road-rail network. Establishment of fixed links using bridges required to have deep understanding of the river systems for achieving sustainability in the long run. In the present global context, the geopolitical boundaries also place Bangladesh in a strategic location in between the regional rising economies of India and China together with the ASEAN (Association of Southeast Asian Nations) countries, thereby providing a major hub for the Asian Land Transport Infrastructures. Nevertheless, to develop an efficient transportation infrastructure, the major challenge which Bangladesh faces, needs to have understanding of the local geology, climatic conditions, use of appropriate materials, deep appreciation of the quality of local materials and available construction technology. These are of utmost importance. Special attention is, therefore, being required for strengthening, repair, renovation and maintenance of the bridges for owning a resilient transport infrastructure for not only Bangladesh but also to connect the Asian countries.

In this context, the paper reviews the historic development of bridges in Bangladesh, discusses the challenges offered by the nature and performance of the bridges those are now in service. The limitations in the present understanding and the outlook for future development for a better infrastructure are presented in the later part of this paper.

2 SMALL CANAL CROSSINGS DURING MUGHAL ERA (1526–1857 AD)

Figure 1 depicts one of the known oldest bridges of Bangladesh that still exist today. It is a masonry bridge built in the 17th century during Mughal period over the Mir Kadim Canal (23°32'53.27"N, 90°28'38.05"E), Munshigonj, Dhaka Division (Dani 1961). The bridge has a center arch of 4.3 m span, 8.5 m in height above the bed of the canal with two side arches of 2.2 m span each and 5.2 m high. The piers are 1.8 m wide. The wings are straight back and the whole length of the bridge is 52.7 m. Similar canal crossings existed in different areas of the country but all of those can not be physically traced today. Yet, the choice of four-point arch (a typical ingredient of Mughal architecture), assigned pier widths for the spans and dimension of wing walls of this Mir Kadim Canal 'bridge' shows the concerns of the builders of that era in regard to the soil bearing capacity and its sliding resistance against the flow. During this era, no river crossing was attempted both for technological limitations and strategic reasons.

Figure 1. Bridge over the Mir Kadim Canal, Munshigonj

3 GEOLOGICAL STUDIES ON THE MAJOR RIVER SYSTEMS

The rivers in Bangladesh form the most significant aspects of landscape of the country. Abul Fazal, the historian of 1582 A.D., of the court of Mughal Emperor Akbar, remarked that rivers in Bengal are numerous and these have great influence on the lives of the people of the country. The drainage systems in Bangladesh are very much complex; and such of those are not found anywhere in the world (Alam et al. 1990). These types of drainages were bewildering and surprising for foreign travellers in the past.

Bangladesh is situated in the lower reaches of the Ganges (termed as Padma), the Brahmaputra (termed as Jamuna in Bangladesh) and the Meghna river system. The rivers belonging to these systems have originated from the Himalayan Mountains, the Chotonagpur and the Shillong Plateaus. The three great river systems, the

Ganges, the Brahmaputra and the Meghna comprise about 700 rivers in the country, of which 310 are notable. The river systems pass through a low land between the Rajmahal Hills and the Garo Hills. The total length of these rivers is about 22,155 km. These river systems have formed a catchment area of about 1.5 million sq. km and about 1127 billion cubic meters of water flows through these rivers systems annually. Recently, Bangladesh Water Development Board's reports have estimated the total volume of sediments carried by these big rivers is to be in the order of 2.5 billion tons annually. More than 90% of incoming sediment load is being deposited in the Bengal fan of the Bay of Bengal. A little portion of about 10% the sediment is being deposited in the beds of the rivers. In a study of the river systems in Bangladesh by the Bangladesh Inland Water Transport Authority (BIWTA) suggests that once, the navigable water way of this country was 25,000 km long. Now, it has been reduced only to 1,800 km in lean months due to the deposition of sediments (Alam 2015).

On the other hand, there exists a myth of abnormal ground levels in several places in Bangladesh from the geological observations. In a book named 'Dacca' written by a British physician Taylor has remarked that there are some places in the bed of the Sitalakhya River to be more than 17 m (datum is unknown). A team of geologists of the Geological Survey of Bangladesh measured the depth of water in the Sitalakhya River to be about 30 m in dry season of 1985 (Alam 2015) when water was near to the lowest flow level. Lately, the study by the Padma Bridge Authority has found abnormal ground level in the Padma River bed of about 30 m below the bank full stage (Neil et al. 2010). All these may indicate the presence of scour zones in the river bed to accommodate the main channel flow. Study of the geo-structures (Alam et al. 1990) shows that the river systems are more or less controlled by numerous faults and lineament systems. The complex river systems are the result of the complex structural features and the geological formation in Bangladesh as well as in the adjoining areas. It is beyond doubt the Rangpur Platform (Rajmahal Gap) is a graben between the Indian Shield and Shillong Massif formed by the action of numerous faults. The Ganges-Padma lineament, Old Brahmaputra-Tista lineament, the Dauki Fault and Jamuna lineament criss-crossed this graben. The seismic zones in the area are well defined by the Ganges-Padma-Meghna lineament and the Tista-Brahmaputra lineament. A study on the influence of geo-structural aspects on flood flows in Bangladesh found that all major river systems are controlled by the geological structures, viz., anticlines, synclines, faults and lineaments. Though, it is very difficult to understand the complex nature of structural elements in the surface but the total drainage system reflects the manifestations of the structural actions and their results in the area. The bewildering and surprising drainage systems prevailing in the country are the manifestations of the past tectonic activities in the region in geological history and the changes of drainage system are the result of changes of geo-structural activities. The water of the Ganges-Brahmaputra river systems finds its way through Bangladesh due to geo-structural reasons. So, a change in geological structural aspects has a potential to change the drainage system and will bring changes in the pattern of water flow (Alam 2015). For the development of an effective water management system, it is earnestly needed to delineate the changes of the river courses in the historical past and the present.

4 BRIDGES BUILT IN THE BRITISH INDIA (1857-1947 AD)

The necessity of detailed studies on river morphology was deeply felt when railway system was introduced in 1862 in the undivided British India to connect different sea ports of present Bangladesh, India and Pakistan including Chittagong, Kolkata, Madras, Nagapattinam, Calicut (also known as Kozhikode), Mumbai and Karachi to the other remote production zones. Site specific studies conducted in those times were cardinal to decide about the bridge location, length and optimum span.

While passing by, a few historic events in undivided Great Britain can be noted: Houses of Parliament in London, the capital of Great Britain was re-built during 1837-1860, domestic public telegraph companies formed in Britain from 1838, first operation of British rail network begun by enacting Railway Regulation Act 1840, first underground train service in London was built in 1863, an overland telegraph from Britain to India was first connected in 1866, deep level tube in London was established in 1890, Tower Bridge was constructed over the Thames during 1881-1894 and finally the population in London crossed 4.5 million in 1900.

The geomorphological studies were conducted based on Rennell's map (1778), Aine-e-Akbari (1582 AD) observations and synthesized with the first-hand geophysical surveys conducted at that time. This led to the construction of the 1.64 km Hardinge Bridge (24°4'2.24"N, 89° 1'36.95"E) with 109.5 m river spans, 640 m Bhairab Bridge (24°2'38.38"N, 90°59'41.18"E) with 91.5 m river spans, 650 m Teesta Bridge (25°47'28.55"N, 89°26'13.43"E) with 50 m river spans and 535 m Kalurghat Bridge (22°23'45.29"N, 91°53'19.96"E) with 55 m main span and 12 number of 40 m additional spans. Hardinge and Teesta Bridges connected Darjeeling with Kolkata (both now in India). Bhairab and Kalurghat bridges connected farthest east of Assam (now in India) with Chittagong. 767 m long Rajghat Bridge, inaugurated in 1887 (originally called

The Dufferin Bridge) having 109 m river span over the Ganges at Varanasi (25°19'21.00"N, 83° 2'4.00"E) and 240.9 m single span Lansdowne Bridge Rohri (27°41'37.42"N, 68°53'18.71"E) over the Indus (inaugurated in 1887), 363 m Jubilee Bridge at Hoogly (22°54'26.10"N, 88°24'16.48"E) with 160 m main span were the other bridges constructed in this region during contemporary time. 515 m Gorai Bridge (23°53'10.63"N, 89°10'50.43"E) with 56 m river span were also built contemporarily in the British India. Figures 2-4 depict a few of these historic bridges which are in service till today. However, no attempt was made to construct an East-West link by crossing the Jamuna (Brahmapurtra). Perhaps, engineering feats of that time was not enough to make a judgment for the Jamuna. Not to mention, in this rail link, many bridges were constructed of smaller spans and lengths to cross small rivers and their tributaries.

Figure 2. Hardinge Railway Bridge over the Padma (Ganges) at left hand side. Lalon Shah Bridge constructed later after 1971 is also seen at the right hand side.

Figure 3. Bhairab Railway Bridge at the left hand side. UK-Bangladesh Friendship Bridge constructed later after 1971 is also seen at the right hand side background.


(a)

(b)
Figure 4. Kalurghat Road cum Railway Bridge. (a) Full length from the river, (b) Side view showing the central span.


(a)

(b)
Figure 5. Kalurghat Road cum Railway Bridge. (a) Side view showing the end span, (b) Through view showing the conversion of a rail bridge into a road-cum-rail bridge with signal posts at both ends.


(a)

(b)
Figure 6. Typical composite bridges road bridges 11-13 m span single lane to cross small canals to feed the railway of British India.

Kalurghat Bridge was later transformed into a road-cum rail bridge as shown in Figure 5. Similar modifications were also made to the Teesta railway bridge. Figure 6 shows the remnants of typical narrow steel composite bridges constructed in local roads of that time to feed the passengers and goods to the railway stations. Decks of these bridges were topped with lime concrete placed between the I-joists.

5 BRIDGES BUILT AFTER INDEPENDENCE FROM GREAT BRITAIN (1947– 1971 AD)

After the independence in 1947, a good number of steel composite bridges having about 25 m span were erected under Japanese technical assistance during 1956-58, within about a decade of the end of World War II. This may be identified as one of the first instances of collaboration between this land and Japan. All these bridges were of single lane with a protected side-walk (Figure 7).

In a later time, Professor Dr. Abul Hasnat from the-then East Pakistan University of Engineering and Technology (now BUET) was assigned by the Roads and Highways Department to design and supervise the construction of a river crossing completely with the local technology and know-how. The 493 m long balanced cantilever reinforced concrete cast-in-place hollow box girder bridge with 46.4 m river span was constructed over the Dhaleshwari at Jaigir (23°52'50.22"N, 90°1'32.73"E) in 1962 by a local contractor, the M/S the Engineers Limited. Due to fund constraint, sidewalks were omitted in the design but refuges were put at places for sheltering the walking pedestrians. After construction of this bridge, for a number of times, the bridge was under threat of flood water but finally survived. Nowadays, there is no significant discharge in that river even in the rainy season as seen in Figure 8.

Figure 7. Composite steel bridge fabricated by Miyaji Iron Works Co., Tokyo, Japan in 1958. Photo courtesy: Mr. I.A. Khan, OBE, Formerly Rendel Palmer & Tritton in Dhaka, Bangladesh.

(a)

(b)

Figure 8. Jaigir Bridge, the first box girder bridge in Bangladesh (erstwhile East-Pakistan). (a) Dry season. (b) Rainy season.

Using the financial assistance from United States, a few bridges were constructed over the same highway during 1969-1974 at Tora (23°51'27.45"N, 89°57'29.51"E), Figure 9, Aminbazar (23°47'2.75"N, 90°20'7.91"E) and Noyarhat (23°54'40.19"N, 90°13'46.66"E). The construction of these bridges introduced prestressed concrete (PC) technology in Bangladesh. The bridges were designed by James R. Libby & Associates and constructed by the Joint Venture of Vinnell-Zachry-Perini. The contractor used floating barge to lift the simply supported spans. Subsequently, the local contractor, the Engineers Limited was able to construct the first PC girder bridge in Baghabari (24°7'56.33"N, 89°34'59.82"E) over the Boral river in 1977-78.


Figure 9. Tora Bridge, one of the first PC girder bridges in Bangladesh

6 BRIDGES BUILT AFTER EMERGENCE OF BANGLADESH (1971 AD TO PRESENT)

Bangladesh, a country was born in 1971 after the historic victory in the war of liberation. Losses of lives and properties could never be accounted truly. However, a post-war assessment showed the damage/destruction of 276 bridges all over the country including major damages in the Hardinge Rail Bridge, the Bhairab Rail Bridge and the Keane Bridge, Sylhet. The major emphasis was given by the new government not only to repair/ reconstruct the ill-fated bridges but also to use every possible alternative to achieve fixed link connectivity across the country with new bridges, new roads and also new culverts. Particular emphasis was put on (i) uninterrupted surface connectivity between Dhaka and the Chittagong Port, (ii) to explore the possibilities of establishing east-west connectivity for road, rail, power and natural gas by crossing the mighty Jamuna (Brahmapurtra) river.

In this huge construction activity (immediately after 1971) in an underdeveloped but highly populated country where economic activity as well as financial capacity is low but demand for connectivity is high, the engineers had to depend on the maximum utilization of local materials, technology and often the local contractors. Several type designs were implemented throughout the country for establishing the life links on small rivers and tributaries using simply supported RC bridges, simply supported PC I-girder bridges and some balanced cantilever bridges to meet the immediate connectivity demands (Nuruzzaman 2013).

In addition, the longer bridges were built utilizing helps from international agencies and friendly foreign countries. In those projects, International Consultants and International Contractors worked shoulder to shoulder with local engineers and sub-contractors. This led to a silent transfer of design and construction technology. The first application of traveling form in the Meghna Bridge and the Gumti Bridge (Figure 10) for achieving 87 m span was repeated successfully in many other bridges including the Khan Jahan Ali Bridge, Dapdapia Bridge and the Sultana Kamal Bridge. Use of central hinge was repeated in the Sultana Kamal Bridge. In constructing Bangabandhu Jamuna Bridge, Hyundai, the Contractor had to set up clinker grinding factory for cement production. This nurtured the next growth of cement industry in Bangladesh. The pre-cast segmental PC box technique using gantry cranes were used for construction of Lalon Shah Bridge (Figure 2). The Bhairab Road Bridge (UK-Bangladesh Freindship Bridge) as seen in Figure 3 used pile cap lowering technique to ease under water construction of the pile cap and pier shaft. In such an approach, the design scour depth is lower due to obstruction to flow lesser than the conventional designs having pile caps at the normal flood level. The technique was successfully reproduced by a Bangladesh Contractor in the Dapdapia Bridge construction. United Kingdom funded steel bridge erection technique used in Gorai Road Bridge was repeated in erection of many similar bridges including Sadipur Bridge (Figure 11). The Sunamgonj Bridge and the Patgati Bridge used temporary supports on the river to erect 100 m – 115 m span.

Figure 12 presents the panaromic and side views of the 4.8 km long Bangabandhu Jamuna Bridge, the longest bridge of Bangladesh at present. The span length is 100 m. It is serving as the vital multipurpose road-rail-gas-electricity-telecommunication link for East-West connectivity for Bangladesh, will be discussed more in the later part of this paper for its performances. After the construction of several river crossing rail links in the British India, it is the only link that the Bangladesh Railway obtained after the independences in 1947 and 1971 with a provision for a dual gauge single track rail link. However, Bangladesh Railway could not achieve most benefits for the speed restrictions and a train now takes about 30 minutes to cross the 4.8 km bridge, for several technical difficulties, some of which will be addressed in other sections of this paper, and other papers of this conference. Figure 14 presents a quasi-panoramic view of the Third Karnaphuly Extradosed Bridge that boasts to have the longest 200 m span length in the country. However, it is not in the main Ganges basin but located at the folded flanks of the Arakan-Myanmar range.

(a) (b)

Figure 10. Japan-Bangladesh Friendship Bridges-I &II. (a) Meghna Bridge, (b) Gumti Bridge

Figure 11. Sadipur Bridge

7 FLYOVERS & URBAN BRIDGES IN MAJOR CITIES

Keane Bridge (24°53'15.54"N, 91°52'5.20"E) connecting two parts of Sylhet town built over the Surma river in 1936 is known to be the first urban road bridge in this land. Later on, many magnificent flyovers, viaducts and urban bridges were constructed in different parts of the country including Dhaka and Chittagong, even over small water bodies and canals. Emphasis was given to attain pleasing aesthetic effects even using extraordinary architectural forms and elements. However, the structural design and construction challenges faced in these projects are much different than those faced in river crossings. Application of standard analysis software can be useful to achieve a workable design provided the construction sequence and maintenance aspects are adequately addressed from the very planning stage.

8 PARADIGM SHIFT IN CONSTRUCTION METHODOLOGY

Table 1 summarizes the major river crossings in Bangladesh in order of major span, year of construction and the total length. The paradigm shifts and introduction of new construction methodologies are summarized in Table 2. The tables are of self-explanatory.

9 CHALLENGE FROM THE NATURE IN ACHIEVING LARGE RIVER SPANS

The geological strata of the country is dominated by the recent alluvium and the sediment depositions carried by her river systems. Geotechnical explorations of Gales (1918), Hinch et al. (1984), Chandler et al. (1984) reports the existence of thin-sand sized plates, generally biotite in the soil strata. Grain counting indicated mica contents of 5-10% whereas SPT tests at the site suggested that a relative density of these micaceous sands was between 40% and 60%. It was resolved that the typical presence of mica adversely affects the slope stability and bearing capacity of deep foundations. This has been found particularly affecting the slope stability causing failure of the river training works of the Jamuna river at Sirajganj (Safiullah 2005). The current Padma Multipurpose Bridge Project is also facing similar challenges.

(a) (b) (c)

Figure 12. Bangabandhu Jamuna Bridge. (a)-(b) In rainy season with monsoon flooding, (c) In winter.

(a) (b)

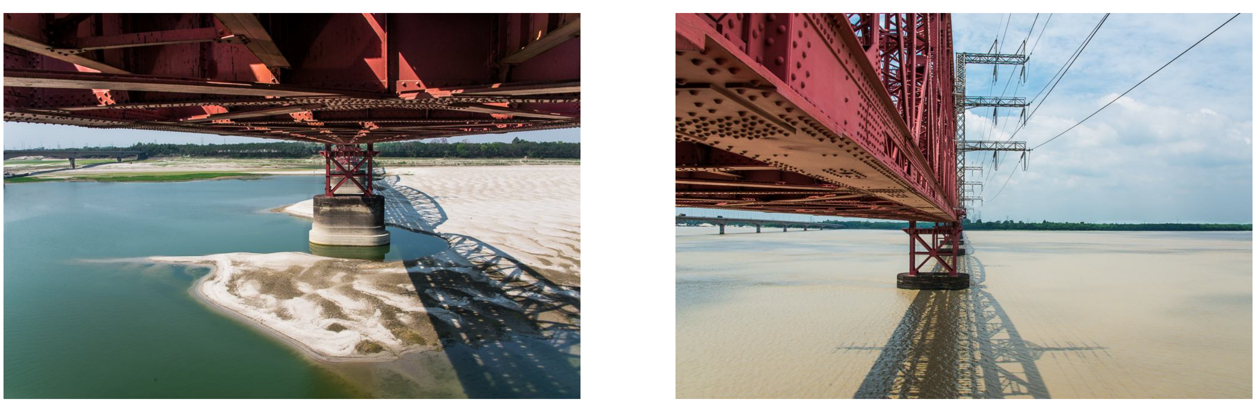
Figure 13. 5th China Bangladesh Friendship Bridge (Gabkhan Bridge).(a) Panaromic view, (b) Multi-cell viaduct

Sobhan and Amin (2010) report of the river system of Bangladesh that carries excessive monsoon sediment-laden discharge and very little dry season flow. The ratio of the maximum and the minimum discharges of the Bangladesh rivers are high; it's generally greater than 10 (Figures 15 and 16). This year round excessive variation of flows charged with excessive sediment load beyond the river's dominant transportation capacity, generates unstable geomorphology of the river giving ample chances to cause general bed scour and local scour in the river bed (Sham 2015).

Furthermore, the country's rivers are generally braided forming shoals, chars, etc. and they shift banks frequently. Thus, determining the regime width of the river and accordingly determining the optimum clear passageway of water for the bridges and locating the bridge abutments require careful hydraulic and geotechnical analyses and judgments by the experienced specialists. Special attention is required to decide about the bridge location and length considering the meandering nature of the river offering deeper channels, usually at the outer bend.

Figure 14. Third Karnaphuly Bridge

Figure 15. Keane Bridge, Sylhet



(a) (b)

Figure 16. Water levels at Hardinge Bridge. (a) Dry season, (b) Rainy season. Local scours are visible around the pier in dry season.

Table 1. Major river crossings in Bangladesh in order of major span, year of construction, total length, superstructure and foundation type.

Geological formation/ Canal	Name of bridge	Major span (m)	Year of completion	Total length (m)	Superstructure for longest span	Foundation
Ganges-Brahmaputra-Meghna	Padma Bridge	150.0	-	6150	Steel-composite	CFT[6]
	Lamakazi Bridge	122.0	1984	226	Steel truss	Bored pile
	Sadipur Bridge	120.0	2000	163	Steel truss	Bored pile
	Sunamgong Bridge	115.0	2015	403	Steel truss	Bored pile
	Bhairab Road Bridge	110.0	2002	1191	PC box girder	Bored pile
	Lalon Shah Bridge	109.5	2004	1640	PC box girder	Bored pile
	Hardinge Bridge	109.5	1915	1640	Steel truss	Caisson
	Moktarpur Bridge	100.0	2008	1514	PC box girder	Bored pile
	Khan Jahan Ali Bridge	100.0	2005	1360	PC box girder	Bored pile
	Bangabandhu Jamuna Bridge	100.0	1998	4800	PC box girder	CFT[6]
	Bhairab Rail Bridge	91.5	1937	640	Steel truss	Caisson
	Sultana Kamal Bridge	90.0	2010	1072	PC box girder	Caisson, bored pile
	Gumti Bridge[1]	87.0	1994	1410	PC box girder	Bored pile
	Meghna Bridge[2]	87.0	1991	930	PC box girder	Bored pile
	Dapdapia Bridge	85.0	2010	1390	PC box girder	Bored pile
	Keane Bridge	75.0	1936	387	Steel truss	Steel pile
	Buriganga-I Bridge[3]	72.0	1989	847	PC girder	Bored pile
	Kachpur Bridge	72.0	1977	397	PC I-girder	Caisson
	Gorai Rail Bridge	56.0	1870	515	Steel truss	Steel pile
	Tora Bridge	54.0	1972	646	PC girder	Caisson
	Teesta Bridge	50.0	1901	650	Steel truss	Caisson
	Aminbazar Bridge	46.4	1972	252	PC girder	Caisson
	Jaigir Bridge	46.4	1962	493	RC box girder	Caisson
	Noyarhat Bridge	42.0	1975	154	PC girder	Caisson
	Baral Bridge, Baghabari	38.1	1978	572	PC I-girder	Caisson
Arakan-Myanmar Folded Flank	Third Karnaphuly Bridge	200.0	2010	830	Extradosed PC box girder	Bored pile
	Shah Amanat Bridge[7]	145.0	1990	919	Steel truss	Steel pile
	Kalurghat Bridge	55.0	1931	535	Steel truss	Steel pile
Man-made canal	Gabkhan Bridge[4]	116.0	2003	918	PC box girder	Bored pile

[1]Japan-Bangladesh Friendship Bridge-II, [2]Japan-Bangladesh Friendship Bridge-II, [3]China-Bangladesh Friendship Bridge-I, [5]China-Bangladesh Friendship Bridge-V, [6]Concrete filled tube, [7]Dismantled

Table 2. Benchmark achievements in construction technique

Construction technique	First known application (probable)
Masonry arch for small crossings	1600
Steel pile for foundation	1870
Steel bridge erection using service truss	1915
Caisson foundation	1915
Falling apron for river training	1915
Steel-composite bridge	1956
RC box girder	1962
PC I-girder	1972
Steel finger expansion joint	1972
Bored RC pile	1984
Neoprene rubber bearing pad	1990
Central hinge with pot bearing and neoprene expansion joints	1990
Cast in situ PC box using traveling formwork	1991
Concrete filled tube for foundation	1998
Segmental pre-cast PC box construction	1998
Base isolation system for earthquake protection	1998
Modular expansion joints	1998
Pile cap lowering to reduce local scour	2002
Multi-cell box system for viaduct	2003
Shock transmission unit	2004
Steel truss with composite deck	2015 (proposed in Padma Bridge)
Single friction pendulum bearing for base isolation	2015 (proposed in Padma Bridge)
High damping rubber bearing for base isolation	2015 (proposed in 2nd Kachpur, Meghna, Gumti Bridges)
Narrow steel box girder with composite concrete deck	2015 (proposed in 2nd Kachpur, Meghna, Gumti Bridges)

Figure 17. Water levels at Bangabandhu Jamuna Bridge over different seasons as seen around the inclined concrete filled steel tubes driven as test piles during construction of the bridge. Local scour around the test piles are visible in dry season photos.

The bridges constructed in the past were mostly located in the Ganges-Brahmaputra-Meghna basin but a few in the folded flanks of Arakan-Myanmar hills. The design and construction were taking place since 1870 to date after giving appropriate attention to the geomorphological features of the country using the knowledge available at the time of those constructions. A careful overview of all the figures and facts (Table 1) indicates that the maximum span, a PC box girder could reach is not more than 110 m. Steel trusses could attain 122 m span while the Padma Bridge with steel truss and composite deck yield the largest 150 m span length as a solution (Sham 2015). Attainment of maximum stiffness to mass ratio is the key to reduce the foundation load. In this way, the authors apprehend the difficulties in making long span bridges in the Ganges-Brahmaputra-Meghna basin but where short and medium span bridges (50 m – 200 m) may evolve as solutions with better efficacies. In passing by, it is worth to note that even before the construction of the Hardinge Bridge, there were technologies available to construct and erect spans longer than that of the Hardinge Bridge, for example, 240.9 m single span Lansdowne Bridge Rohri (27°41'37.42"N, 68°53'18.71"E) over the Indus (inaugurated in 1887), a river system much different than the Ganges basin. 363 m Jubilee Bridge at Hoogly (22°54'26.10"N, 88°24'16.48"E) with 160 m (x 2) main spans was of cantilever steel truss type. The bridge is located at the farthest west of the Ganges basin.

Use of an efficient foundation system providing least flow obstruction should warrant lowest scour depth to come out of a vicious cycle and achieving a design solution. Use of inclined concrete filled tube in the Bangabandhu Jamuna Bridge and the Padma Bridge (under construction) is relied on such approach. This way the bridge construction in this country that started with steel piles for foundation are seeing paradigm shifts from steel piles to caisson, caisson to bored pile and bored pile to concrete filled tubes.

10 PERFORMANCE

Hard paucity in the historic data on local climatic conditions, particularly the earthquake, wind speed, airborne salinity limited the designers to come out with more efficient designs. The engineers were forced towards conservative designs with the projections they conceived from their professional judgments. Bangladesh Meteorological Department has 34 weather stations to monitor temperature, wind speed and humidity all over the country, only since 1993. Before that observations were limited only at a few stations.

During the construction of Hardinge bridge, temperature in England where the girders were manufactured was 18^{0}C and the mean temperature of construction site was taken to be 33^{0}C. It was necessary to make an allowance both for the difference in mean temperature between England and Bengal, and the dimension of

109,423 mm centre to centre of piers for which the girders were designed was increased to 40.386 mm in setting out (Gales 1918).

Tay bridge disaster of 1879 in Great Britain instituted the need for considering wind pressure on rail bridges including the rolling stocks. In Hardinge Bridge, it was originally intended to construct the piers for a double line and to erect at first girders for a single line only. The cyclone of the 17th October, 1909 (Gales 1918), however, demonstrated that the bridge was within the cyclone area. In view of its exposed position, it was then decided, owing to the greater stability which could be obtained with the greater width of span, to design the bridge for a double line in the first instance (Figure 18). This also appeared then to be justified by the traffic prospects. However, all other bridges built in those times and also later in Bangladesh era are of single tracks.

(a)

(b)

Figure 18. Consideration for wind load influenced the engineer to design a double track flatter structural system for Hardinge Bridge and a single track taller structural system with top bracings at three levels for the Bhairab Bridge. (a) Hardinge Bridge (109 m span), (b) Bhairab rail bridge (91.5 m span)

To the knowledge of authors, there is no local weather monitoring station now in operation near the long bridges of the country. Furthermore, the use of weigh-in-motion or weighing in motion (WIM) facilities to control axle load in the major bridges is not so frequent, thus giving enough chance to experience overloading. The gust effects due to wind in river terrains are yet to be characterized and documented in the form of design and operation guidelines. All these provided cumulative problems in the past as narrated in the subsequent sections.

10.1 *Sub-Structure and River-Training Works*

Unknown soil strata with highly unknown characteristics and unavailability of adequate site specific geotechnical investigation data always frighten the foundation designers. This led to conservative foundation design. Problem with foundation settlement is not much known (Safiullah 2005).

However, the lack of geomorphologic history of ever changing river systems substantially restricted the designers to predict the shift of rivers over the design life of a bridge. This caused difficulties in the maintenance of Hardinge Bridge in 1933, Meghna Bridge in 1988, 2005 and 2012 (Noor et al. 2015). The cost of river training component for the Bangabandhu Jamuna Bridge was higher than the cumulative cost of the substructure and the superstructure. Similar problems are being faced in the Padma Bridge project as well.

10.2 *Superstructure*

10.2.1 *Effect of temperature*

The pre-cast segments of the Bangabandhu Jamuna Bridge showed significant cracking before opening of the bridge. The crack was located at the top of the deck in mid-span. The cracks propagated over the years in terms of number. Last two years, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) took onsite temperature measurements in the bridge at different seasons over the year and also conducted laboratory simulations. Figure 19 shows the variation of temperature at the top surface and the bottom surface of the PC box girder of the bridge at winter and at summer. The readings as presented here were taken after incorporation of thermal insulation and stone mastic asphalt pavement in 2013. The general trend indicates a thermal stress reversal between day and night. The intensity of stress reversal is more prominent in summer days (Figure 19d) when a sudden rain cools down the deck giving a temperature gradient of the order of 15^0C. The top surface of the deck was found to be at least 11^0C hotter than the ambient temperature. The situation that bridge experienced during 1998-2012 was even worse because of direct sunlight exposure on bare concrete deck. Furthermore, in Bangladesh, hail storms are common is the wake of early summer. A hail storm may cause rapid cool down of the deck at a hot summer day subjecting the bridge to even worsen situation. During hail storm the ambient temperature dropped by about 12^{0}C that would possibly yield a temperature gradient of around 25^{0}C.

Gabkhan Bridge built in 2003 showed significant lack of allowance for temperature in the expansion joints causing the viaduct girders to slip over the elastomeric bearings because of large expansion of the bridge itself. It is perhaps important and logical to consider the temperature difference in the concrete surface in the design than considering the ambient temperature difference.

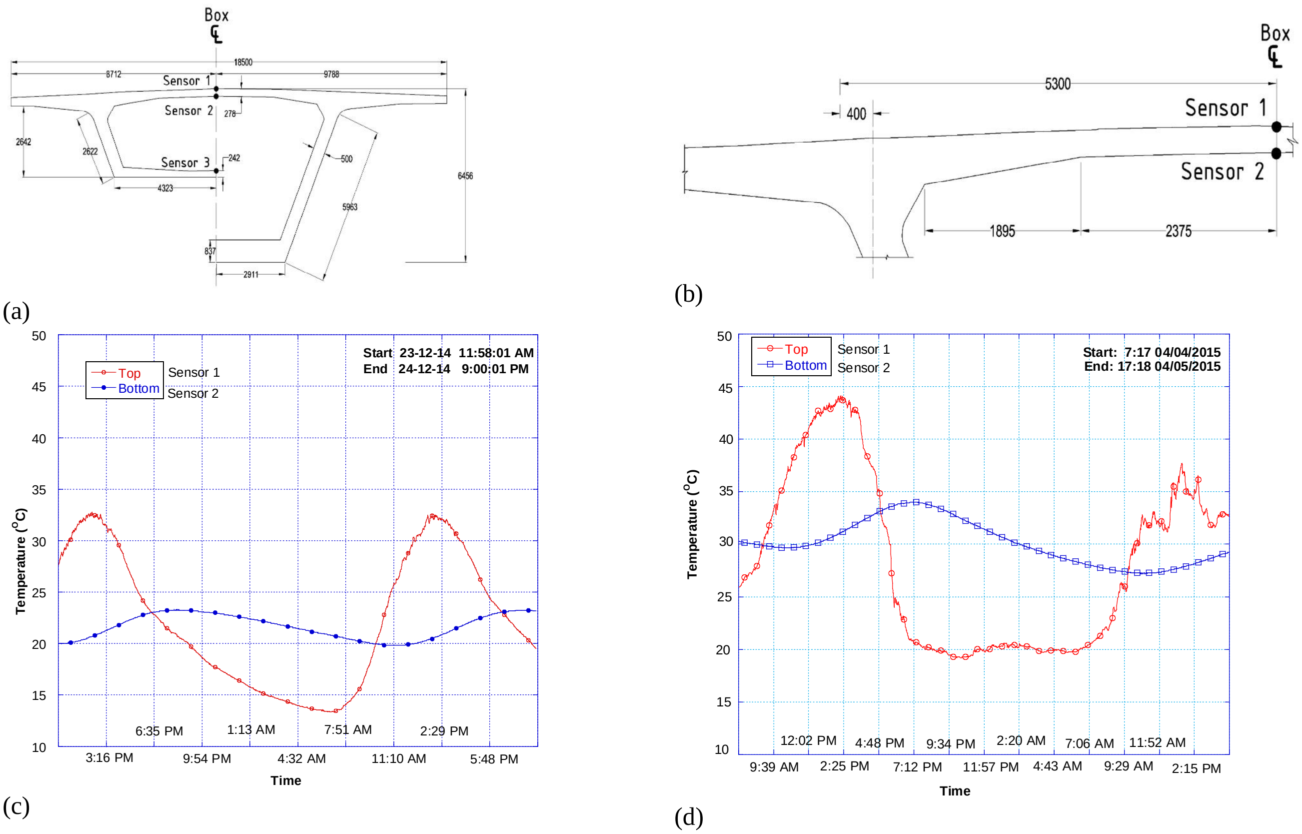


Figure 19. Temperature logging at the deck of Bangabandhu Jamuna Bridge. (a) Temperature gradient measurment locations along a typical transverse span at mid-span, (b) Location of temperature and humidity measurement sensors to measure temperature gradient across the depth at mid-span, (c) Typical measurement taken in winter, (d) Typical measurement taken at summer followed by a mid-day rain. Sensor 3 data were close to Sensor 2 measurements, hence not presented here.

10.2.2 *Overloading and Lack of Monitoring*

The traffic congestion, transport cost and toll prices encourage the transport owners to carry excess cargo than allowed. This excess cargo does have first impact on the bridge deck then on the bearings and expansion joints. Lack of monitoring worsens the situation. Bangladesh is yet to achieve a benchmark in bridge health monitoring through visual and instrumental observations (Amin et al. 2015). Loading the bridges beyond its as-built capacity was assigned as the reason for the appearance of extensive cracks in the Bangabandhu Jamuna Bridge (Amanat et al. 2010). Meghna and Gumti Bridge experienced same problem in 2008 (Amin et al. 2014) and also in 2012 (Choudhury et al. 2015).

10.2.3 *Wind*

The Bangabandhu Jamuna Bridge is the only railway bridge built after British India boasts to have a single track dual gauge lane on the outer curvature of the bridge (Figure 20). The tracks however, do not have any guide rails to prevent derailment that even exist in the Hardinge Bridge (Figure 18a and Figure 20d). On 27 April 2014, a local wind derailed a train while passing on the bridge. The train overturned on the opposite side, making a safe relief for the nation. The train was rescued on 28 April 2014 without any loss of life and damage to the bridge. The absence of local wind monitoring, forecasting and low train speed to cross the bridge are the reasons for such an incidence. It may however, be argued that wind blowing from the opposite direction would not have the same effect as the wind exposure height would have been greatly reduced by the parapet obstruction.

Figure 20. Over-turning of train at the Bangabandhu Jamuna Bridge. Source for (b)-(d): Press/news reports.

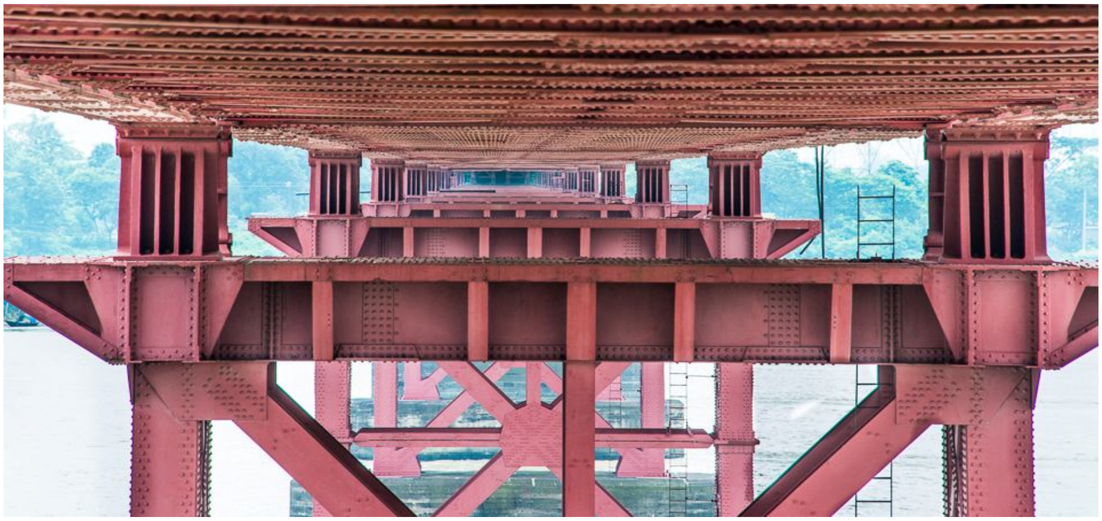
10.3 *Bearings and Joints*

The most worrying effect for the superstructure came from the inadequate performance of bearings and joints coupled with overloading, absence of timely monitoring and maintenance efforts. The railway bridges posses steel bearings (Figure 21) that are better monitored and maintained than those in the road bridges.

Since 1990, Bangladesh started to use elastomer based steel plate laminated rubber bearings having low hysteresis and damping properties in concrete bridges while the earlier bridges used to have metal bearings (Figure 22). Bangabandhu Jamuna Bridge was the first base isolated bridge of the country while the Lalon Shah Bridge was installed with shock transmission units (Figure 23). Amin et al. (2014) reports the problems of rubber expansion joints at the deck in the Meghna Bridge. The problem of replacing pot bearings are discussed in Choudhury et al. (2015). Figure 22(d) shows the pot bearings of the Bangabandhu Bridge that are showing signs of distress due to extruded Polytetrafluoroethylene (PTFE). This is occurring far before reaching the design life certified by the manufacturer.

11 CHOICE OF DESIGN CODE AND LIMITATIONS

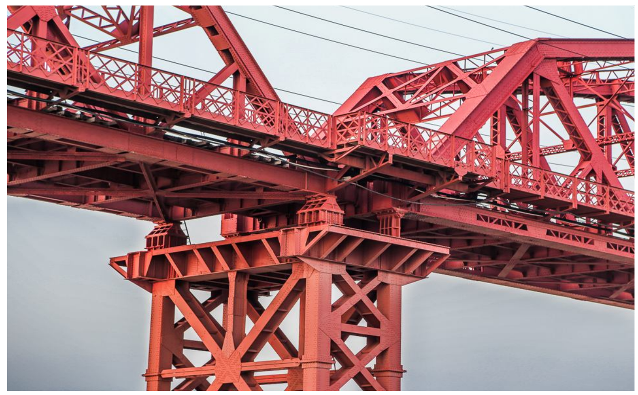
At present, no independent national design code/standard for bridges in Bangladesh exists. The current trend is to use mainly the American Association of States Highway and Transportation Officials (AASHTO) Specifications; in which the different designers use different editions varying between 1992 and 2007. The other specialist literatures are also used. In special cases, the British Standard (BS) 5400 (1978) has been followed, for example, in preparing the Jamuna Design Specification for the Jamuna Multipurpose Bridge (Sobhan and Amin 2010). Indian Roads Congress (IRC) specifications are also often consulted. Design of second Kachpur, Meghna and Gumti bridges followed largely the Japan Road Association (JRA) provisions after consulting the Bangladesh National Building Code 1993 (BNBC 1993) for finding the wind and earthquake loading of bridges. However, BNBC (1993) is meant for buildings while AASHTO, BS and JRA codes do not consider the local conditions.



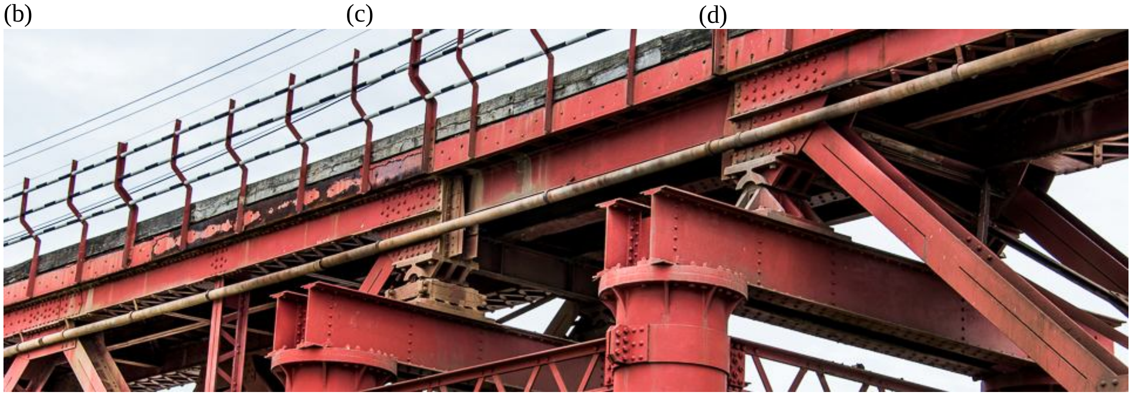
(a)

(b)

(c)

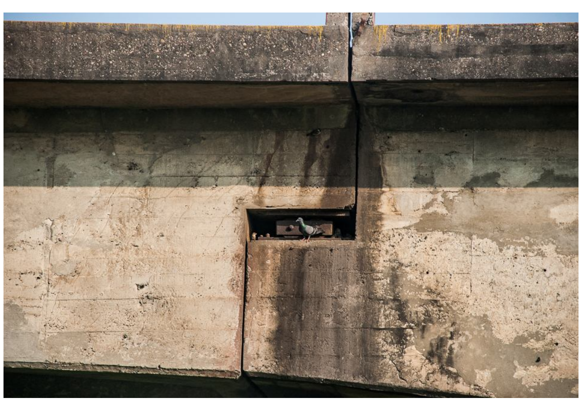


(d)



(e)

Figure 21. Bearings and joints in old railway bridges. (a)-(c) Hardinge Bridge, (d) Hardinge Bridge bearings after restoration of Span 10 as seen in the left, (e) Kalurghat Bridge.



(a)

(b)

Figure 22. Bearings and joints in some of the concrete bridges. (a) Jaigir Bridge, (b) UK-Bangladesh Friendship Bridge (Bhairab Road Bridge).

(a) (b) (c) (d)

Figure 23. Bearings and Joints in (a) Bangabandhu Bridge, (b) Pot bearings of Bangabandhu Bridge, (c) Pintels in Bangabandhu Bridge, (d) Shock Transmission Units in the Lalon Shah Bridge.

11.1 *Geological Information for the River Systems*

The Geological Survey of Bangladesh has been studying the major drainage system of 1778, 1874-77 and 1985 to publish the historical shifts of the River System in a map of Bangladesh in the scale of 1:1,000,000. Along with the study of major fault systems, the drainage systems analysis may indicate the probable causes of floods for geo-structural reasons beside hydrological and climate change considerations. It is expected, the geological aspects mainly related to the development of drainage systems, as studied will be able to identify their nature of influence on the flood flow and the landscape will be available.

11.2 *Earthquake*

Seismic design for bridges usually considers two levels of earthquake, namely Operating Level Earthquake (OLE/ Level I) and Contingency Level Earthquakes (CLE/ Level II) earthquakes. OLE has a return period of 100 years with a 65% probability of being exceeded during that period. CLE has a return period of 475 years with a 20% probability of being exceeded during the design life of the bridge (100 years) as used in the design of the Padma Bridge (Sham 2015). However, in the second Meghna Bridge Project designs, BNBC (1993) response spectra was judged to be close to AASHTO LRFD (2007). Calculations yielded a response spectra for the Meghna site a bit different than that for the Padma Bridge. Furthermore, BNBC (1993) was found to be higher by about 50% in short-periodic region (Tatsumi et al. 2015), compared to Level-1 Type- II soil profile recorded by JRA (2012). However, development of site specific design response spectra for different regions of Bangladesh is needed for efficient designs for all bridges in future. At this moment, in absence of any design code for bridges, there exists no specific guideline to consider for earthquake loading.

11.3 *Wind*

Bangladesh National Building Code was prepared in 1993 based on limited wind speed measurement information. After 1993, thirty four observation stations are in service to record three hourly observations for wind. A synthesis of these data may help in updating the basic wind speed map. However, when bridges are constructed in open areas, the terrain exposure needs to be adequately judged based on local observations or model studies including dynamic effects. Some efforts are needed in these directions.

11.4 *Temperature and Wetness*

Guideline values on the consideration of the effect of daily and annual temperature differences are needed to be prescribed. Recent measurements (Figure 19) show the difference to be much more than what was believed in the past. So reconsideration is warranted, particularly for the design of box girder, setting out requirements and expansion-contraction measures. These measurements are also important to ensure the durability properties of rubber and ageing behavior of rubber, the essential component in all modern bridge bearings and expansion joints.

In addition, in design it is to be considered that more than 60% of time of a year, in Bangladesh, near rivers, the relative humidity stays above 80%. This calls for use of dense concrete and effective measures for corrosion protection.

11.5 *Air Borne and Ground Salinity*

There is no fundamental data available for air borne and ground salinity across the country. This information is important for the viability of steel piles, maintenance requirements for steel bridges and also to check the applicability of new generation weathering steel (paint-less steel) for next generation bridges in Bangladesh.

11.6 *Choice of Materials and Properties of Materials*

The local aggregates used for concrete production is softer and somewhat lighter (Akhteruzzaman and Hasnat 1983, Islam et al. 2015) than those used in other parts of the world. Ishtiaq Ahmad and Roy (2013) reports larger creep in brick aggregate concrete. Similar properties are also expected in stones (other than hard rock) of Bangladesh origin. This needs to be checked for deriving the basic parameters in bridge design and construction.

To reduce the foundation load for achieving longer spans, smaller foundation sizes, smaller design scour depths, it is important to reduce the self weight of the structure. Consideration of efficient structural form and choice of structural steel sections can be a step forward to solve the design catch. However, to reduce the life cycle cost, it is important to reduce the cost required for corrosion protection. Thus, use of weathering steel should be considered thoroughly to reduce the life cycle cost to arrive at an efficient structural form. Measurement of air borne salinity and atmospheric exposure test data on different grades of weathering steel will infer about the applicability of new generation steel for different climatic conditions. The application of such steel in coastal zones for high air borne salinity content may not be suitable as was seen in other countries while prospect in use of this material for rest of the country needs to be immediately explored.

11.7 *Construction Technology and Choice of Bridge Forms*

Cost of a project depends significantly on the availability of construction technology, the time required for completing the project and thereby bringing it to service. Bangladesh is now in a transition towards modernization in pile driving techniques and development of an efficient methodology for erection of longer spans. This will obviously dictate the choice of bridge forms. An achievement is still waiting.

11.8 *Monitoring and Maintenance*

Any bridge project should accompany an operation and maintenance manual, assurance for its execution at field level and a separate but adequate yearly maintenance budget. Conducting an emergency measure is not warranted rather timely regular maintenance scheme is recommended. The bridge design code should encompass these aspects.

11.9 *Appropriate Technology for Strengthening*

Any bridge designed today will deteriorate with time or a requirement may evolve to enhance its performance level. Strengthening for performance enhancement is a world-wide recognized terminology but it needs to be thoroughly customized for local materials and climatic conditions. Fundamental parameters governing the strengthening design needs to be re-determined or re-assured from first-hand experimental measurements.

12 CONCLUSIONS

100 years ago when the Hardinge Bridge was opened, none of us present today was there. About 40 years ago, when Hardinge Bridge was reopened, some of us of that time are present here today. We need to build a bridge tomorrow in this land where people, cars and trains will move at a faster speed for a time longer than 100 years. Perhaps, this is the way to remain in this land beyond our life time but to serve the world. Our sincere thoughts should remain there. Perhaps, we need to look thoroughly at the low maintenance cost, choosing bridge forms matching with the beautiful river setting of the country and owning a resilient infrastructure offering least life cycle cost for the future land transport network not only for Bangladesh but for the Asian region.

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