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Padma multipurpose bridge: A dream is becoming true

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ABSTRACT: The Padma Multipurpose Bridge is the most difficult bridge on the mighty river Padma, the second largest river of the world next to Amazon in respect of flow. The construction of Padma Multipurpose Bridge is a dream of the people of Bangladesh. The complex project has unique applications of structural, geotechnical, river, environmental, social and construction engineering. A river with such high discharge and unpredictable in nature has not been bridged before. The longest piles ever used in the world for inland river bridge were driven in stratified alluvial riverbed deposition by specially designed world's largest hammer but some the pile clusters needed skin and base grouting by innovative technique to carry loads of the bridge. First time in the world, Largest double curvature pendulum bearings have been used to isolate superstructure in the event of large earthquake. Vary high cost river training works were erected to protect riverbanks and ensure that the river flows through the bridge during its life span of 100 years. Construction of this bridge is a challenge that Bangladesh can construct a complex mega structure of this size using its own professional and financial resources.

1 INTRODUCTION

Bangladesh has been divided in three parts- eastern part, north-western part and south-western part by the mighty Padma and Jamuna rivers. The construction of Bangabandhu bridge connecting north-wester part to eastern part has changed the economic condition of people of north-western part of country. The foundation stone of Padma bridge was laid at Mawa by Hon'able Prime Minister Sheikh Hasina on July 4, 2001at the end of her first tenure (Bhuiyan, M.H.,2020). The event raised hope in the mind of the people of Bangladesh of free movement of people and commodities between eastern and southwestern parts of the country avoiding unusual delay in the ferry. The long delay in the implementation of Padma Multipurpose Bridge for various reasons turned the hope of the people of the Bangladesh into a dream. Finally, the dream is turning into a reality. The Padma Multipurpose Bridge is the longest and most difficult bridge in South-Asia crossing the mighty river Padma, which carries the combined flow of the rivers Ganges and Brahmaputra. The river Padma is the second largest river in the world in respect of discharge. The Padma Multipurpose Bridge Connecting the southwestern part to central parts of the country and the two major ports by rail and road will provide a vital link in the transport network of Bangladesh. The bridge will enhance the use of Mongla Port by connecting it with Chittagong port by road and rail. The bridge will also help rapid distribution of the products of southwestern part to other parts of Bangladesh. In the regional context, the bridge over the river Padma is strategically located on the Asian Highway route A-1 and Trans-Asian Railway Route. It will result in significant economic and social uplift of the country, especially in the south-western part and will function as a catalyst for poverty reduction. The national GDP growth for the construction of Padma Multipurpose Bridge is estimated at 1.23 percent and southwest regional GDP growth at 2.30 percent. The complex project has unique applications of structural, geotechnical, river, environmental, social and construction engineering. The Padma bridge, the dream of the people of Bangladesh, has a long story of hope and disappointment but finally it is near completion.

The Padma Multipurpose Bridge Project (PMBP) has several components such as Main Bridge and viaducts, River Training Works, Approach Roads, Service and Resettlement Areas implemented under different contracts. This paper discusses two main components (1) the Main Bridge and viaducts and (2) River Training Works.

2 THE MAIN BRIDGE AND VIADUCTS

The Padma Multipurpose Bridge is a 6.15 km long main bridge across the Padma river designed to carry 4-lane of highway traffic, a single dual gauge railway line, a 760mm high pressure gas line and a 150mm diameter fibre optical and telephone duct. The 2-level main bridge is a warren type steel truss composite bridge with a concrete upper deck level to accommodate 4-lane roadway plus 2 breakdown lane sand a lower deck level to carry a single dual gauge railway track. Considering the navigational importance of Padma river, the minimum vertical navigation clearance of 18.30m is provided (Wheeler, 2010). The bridge is connected with approach roads and railways by a complex arrangement of viaducts. The total length of the bridge including viaducts is 9.83km.

2.1 *The Foundation*

The river Padma is located in the lower reach of the rivers Ganges and Brahmaputra. The bed material is fine grained soil, which can go into suspension by relatively weak velocities and turbulence to cause scour. The scour depths are further increased by local scour around foundation. In the absence of a solid base for foundation, deep pile foundation was adopted, the load bearing capacity of which is dependent on skin friction and end bearing in non-scoured soil strata. In 100 years return period, the extreme scour depth is estimated to be 62m for the design discharge of 151,000 m^3/sec and a design velocity of 5 m/sec in stratified cohesive and loose to dense sandy bed materials of the river (Figure 1).A very deep foundation, as per original design, consisting of clusters of 6 outward inclined piles driven to a maximum depth of ±120m is required to take the vertical and lateral load in different combinations. This is the deepest pile ever driven in the world to support an inland river bridge. Driving of 3m diameter steel piles to such a depth required huge energy. The world's largest hammer of 2400KJ capacity and later another hammer of 3500 KJ capacity specially designed and manufactured in Germany for this project were in use for driving of pile to the required depths. Another 1900KJ hammer was also mobilized to drive piles up to certain depths. The actual depth of the pile was to be determined by load test on test piles.

Unfortunately, presence of cohesive layers of soil at the end of piles of 22 piers and lower than expected skin friction on test piles created bigger problem in the construction phase of the bridge. The significant reduction of end bearing in cohesive soil made these piers inadequate to carry design load.

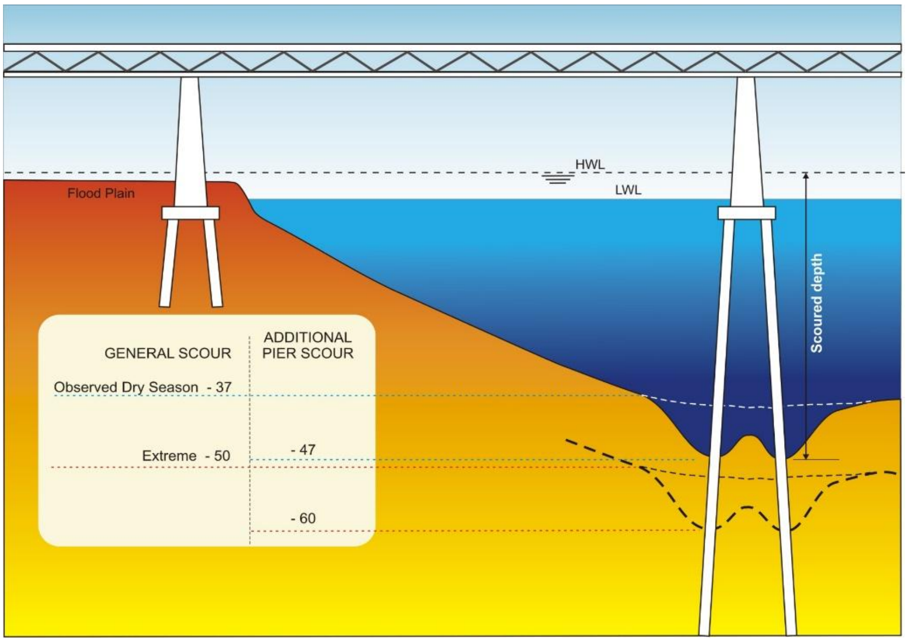


Figure 1. Normal, extreme and calculated additional scour for piers.

Additional test boring showed the layers of cohesive soils were quite thick up to 30m in some locations and the use of the large capacity hammer to penetrate the cohesive layers to reach another non-cohesive sandy layer below to support ends of piles was too risky. The option left was to shorten the pile length to put the pile ends in sandy layer and increase skin friction by skin grouting. Alternatively, the number of piles can be increased but it required redesign of pile clusters, pile cap and also estimation of scour depth under revised pile orientation. The existing pile orientation allowed driving of an extra vertical pile in the centre of cluster without affecting the pile cap. Although vertical pile will not take lateral load, the inclined piles will be relieved of some vertical load. Revised calculations showed that 11 piers with 7 piles were safe for the design load combinations and piles of remaining 11 piers needed further strengthening. An experiment on skin grouting of steel pile was conducted on test pile by fixing perforated TAM ducts on outer surface of the piles and pumping micro fine cement grout in soil strata around piles through TAM duct from top at a pressure upto 3 MPa. The resulting increase of skin friction was highly satisfactory and the cluster of 7 skin grouted piles satisfied the requirements of load carrying capacity of the piers. So the bottom lengths of piles below -50m PWD of 11 piers were grouted by pumping micro fine cement grout through 10 TAM ducts welded on outer surface of each 3m diameter pile having 8mm grouting nozzle on 3 faces of ducts at 1 mc/c distances.

Figure 2. Arrangement of 6-pile cluster.


Figure 3. Arrangement of 7-pile cluster.

In summary, a total of 262 tubular piles, 3m in external diameter were fabricated from 60mm thicksteel plates were used in 40 piers of the bridge. A total of 18 piers have clusters of 6 racked piles, 11piers have 7 piles without skin grouting and remaining 11 piers have 7 skin grouted piles. The arrangements of 6-pile clusters shown in Figure 2, the 7th pile is driven in open space at the centre (Figure 3). The length of the piles varies from 98m to 122m. All the piles except 22 piles in the center of pile caps are raked piles driven with outwards inclination of 1H:6V. The piles were driven by MENK hammers of capacities of 1900 KJ, 2400KJ and 3500 KJ. The materials inside the piles except 5m original soil at the bottom are removed and replaced by 10m concrete plug at the bottom and then by compacted sand upto 15m below the top end of the pile. The remaining 15m is filled with reinforced concrete, which becomes a part of the 5.5m thick hexagonal pile cap. The main piers on pile caps are hammerhead RCC structure with pier size 8.00mx4.800m having 14m to 17m high piers including pier caps. The stems of piers are hollow up to 7.8 to 11 m depending on pier heights. The pier cap is 6m deep heavily reinforced concrete having two solid plinths of size 2.3mx2.3m on top to place bearings.

2.2 *The Main Bridge*

The main bridge has 41 spans, 150m each covered by two 150m long warren type trusses on two sides of the bridge. The total length of the main bridge is divided into 7 modules separated by expansion joints. The 6 modules consist of 6 spans, each module have 6 pairs of trusses welded together to work as continuous one and the last module at one end consists of 5 continuous spans. The roadway of the bridge has been designed adopting the British Bridge Code BS5400, which has the heavier live loading than the HS20-44 loading and is more consistent with current international and projected future live loading. For railway Dedicated Freight Corridor (DFC) loading of 32.5 tonne axle load has been adopted for design, which is higher than the current MBG loading of 25 tonne axel load adopted by Bangladesh Railway in 2008 (Wheeler, 2010). The nodes and chords of the truss are fabricated in China from steel plates of thickness 40mm to 120mm. The nodes and chords are welded to from a 3D complete span consists of two trusses and some lateral members as shown in Figure 6. The truss assembly is tested, polished and provided 3 coats of paint to make it ready for transport and placement on right span. The bridge is slightly curved to match south approach road, hence each truss assembly is unique made for definite span. The upper deck of the bridge is fabricated by precast 2m x 21.65m concrete slabs units resting on upper cord of the truss. The slabs have overhang cantilever parts on both sides extended from truss and two shear stud pockets with slab reinforcement in place just on top cords of the truss having vertical reinforcing bars. The slab segments are post tensioned longitudinally and the holes are filled with post cast concrete to ensure composite behavior of slab and truss beneath. A dual gauge rail line is installed in the lower deck by fixing precast concrete segments on railway stringers which are attached to lower cord cross beam of the truss.

Figure 4. A Fabricated total span of the bridge.

Figure 5. Friction pendulum bearing (cover removed for inspection).

Figure 6. Arrangement viaduct at Mawa end.

Figure 7. Erosion at Naria, few km downstream of Padma Bridge.

Friction Pendulum Bearing (FPB) is provided to support truss on pier. The purpose of FPB is to isolate the superstructure from ground shaking during strong earthquake. The FPB device allows large horizontal displacement and able to restore the structure to original position after seismic event. There are 5 types of FPB used in the main bridge, most of the FPB allows bi-directional displacement during seismic events. The bearings are tested in Wuhan, China and at University of California San Diago, USA. The largest FPB is 2350x2350x507 mm in size, weigh 15 ton with allowable capacity 98725KN, and displacement capacity 330mm. The large FPB bearing as shown in Figure 5used in Padma Bridge is the largest bearing ever used in the world.

2.3 *Viaducts*

The viaducts are needed to connect roadway and railway running side by side to ascend on and descend from the main bridge. Length of total roadway viaduct is 3.148 km, 1.478 km at Mawa end, 1.670 km at Janjira end and the length of railway viaduct is 0.532 km. The roadway viaducts have total 83 spans of which 39 span are on Mawa side and 44 span are on Janjira side. Figure 6 shows the complicated arrangement of the viaducts at Mawa Bridge end. The roadway viaducts at two ends of the bridge were made of 180mm thick R.C. deck slab cast in-situ on pre-cast pre-tensioned pre-stressed Super-T girders. A 50mm asphalt concrete was cast on the slab to finish the road surface of viaducts. The railway approach viaduct has 7 spans at each end of the bridge and each span has 6-2200mm deep prestressed concrete I-girder with 250mm thick deck slab. Considering the soil condition and calculated liquefaction depth during earthquake all bored piles of viaducts at Mawa end were skin grouted. When the borehole was completed, 55mm diameter skin grouting pipes having nozzles of 8mm dia at 1m interval and facing towards bored hole shaft wall were fitted with outer face of the reinforcement case and lowered in the bore hole. The open nozzles were wrapped by rubber sleeves fastened both sides by GI wire. Double packer was used to develop crack for permeation of micro fine cement grout around the pile. This permeation grouting filled the interconnected voids in soil fabric surrounding the pile surface and increased frictional resistance at pile-soil interface.

3 RIVER TRAINING WORKS

The Padma river is known for its fury and ferocity in the monsoon and often termed as *Kirtinasa* (destroyer of landmarks). The river is unpredictable in nature showing both braiding and meandering characteristics. In 2018, during bridge construction, extensive bank erosion took place at Naria in Sariatpur district, a few kilometers downstream of the bridge. The river engulfed a large buildup area including a Bazar having permanent structures including multi-storied buildings. It has been observed that deep scouring takes place beneath the bank of the river and suddenly the bank with all man-made infrastructures and natural resources sink in the river. Figure 7 shows that only the top of an 15m coconut tree is visible after sinking almost vertically in the river. In one case, the curious people observing bank erosion suddenly found themselves in the furious river. Some were rescued and few were reported to be missing.

3.1 *River Morphology*

The study of nature of the river of last 70 years shows that the main flow of the river moves from one bank to other at an interval of about 15 years causing enormous bank erosion. This behavior of the river has been captured in satellite images as shown in Figure 8. The width of the river at bridge crossing point was minimum and both the banks were found relatively stable during the study period. Extensive river training works were required to protects the main bridge, viaducts, bridge end facilities, approach roads and resettlement sites on both sides of the river. A part of the river bank at Mawa having a thick top clay deposit is less susceptible to erosion. The rate of erosion of the south bank has been found to be 50 to 500m per year. The river bank along Mawa side was found relatively stable over the study period.

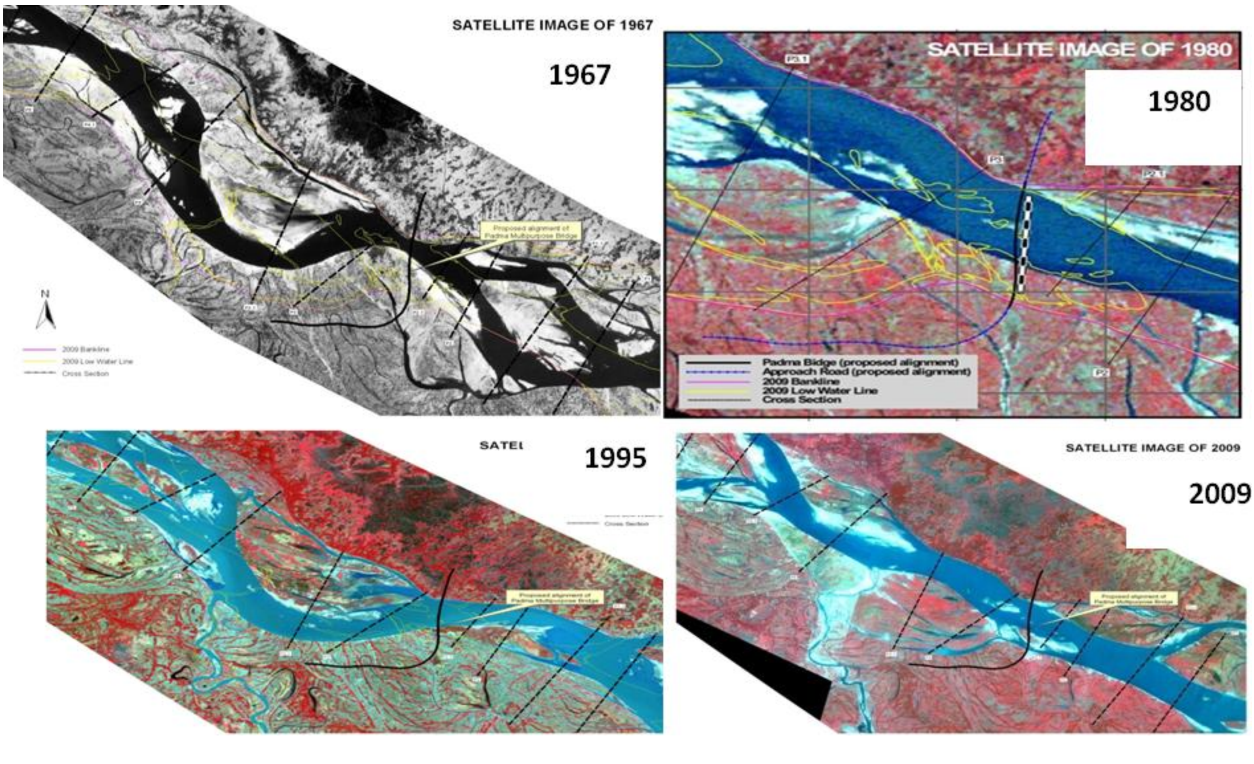
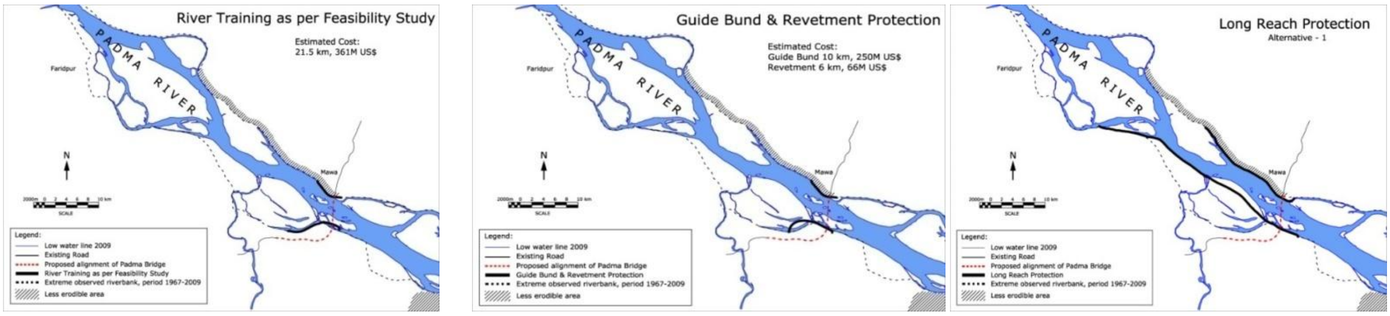


Figure 8. Shifting of riverbank during last 70 years.

3.2 *Selection RTW*

Three alternatives shown in Figure 9 have been considered for river training works for PMBP. Option 1 with a smaller river training work for Mawa end and a long RTW for south bank along the extreme periphery of movement of the river. Option 2 had similar RTW at Mawa end and the guide bund at Janjira end was shifter inside the river to control erosion of south bank. In option 3, extensive river training work from Faridpur to bridge site completely restraining the river to move southwards as shown in Figure 10 was proposed. Long river train work was also proposed at Mawa end to contain the river within certain width required to discharge the flow. The last option was most preferred because it would protect a huge land of Char Janajat, which could be used for new development. But the consultant finally opted for option 1, which is along a relatively stable bank lines allowing the river to continue its usual movement upstream of the bridge.



(a) (b) (c)

Figure 9. The Options of river training works (a) option 1 (b) option 2 (c) option 3.

The major RTW works involved establishment of designed river side slope by precision dredging in 1:6 side slope to a depth of -25m PWD. The upper part of the slope from elevation +2.5 to +9.0m is covered by 400x400x400/300mm CC blocks over a layer of 400gm/m^2 non-woven geotextile. The space between blocks measuring around 10mm is filled with pea gravel. The blocks are aligned with the direction of flow with uneven surface to dissipate energy as shown in a under construction section of slope protection work in Figure 10.Slope protection from elevation +1.5 to +2.5m PWD is done by random CC block dumping on 100mm crushed brick over geotextile (Bangladesh Army). A cast in situ anchor beam 1m deep and 0.4m wide is places at elevation +2.5m PWD partially buried in in excavated surface with geotextile underneath. Then between elevations +1.5 to -2.4m PWD CC blocks are dumped on 100mm crushed brick. The lower part of the slope is protected by placing of 3 layers of 125 kg sand filled geobags and then placing of 25 to 1000 kg stone riprap on geobags and finally a falling apron is establishment at elevation -25mPWD by placing 5 layers of 800kg sand filled geobags (BBA, 2019).The maximum depth of dredging by any dredger available now is limited to elevation -25m PWD but the calculated design scour depth at RTW varies from EL-47m to EL-50m. The falling apron is provided to prevent scour deeper than EL -25m assuming that when deep scour below -25mPWD occurs, the 35 to 65m wide falling apron consisting of 5 layers of 800kg sand filled geobags provided at EL -25m level will fall to prevent such scours. The RTW works for PMBP is the largest single contract river training work in the world.

Figure 10. A slope protection work under construction.

Figure 11. Manufacture of piles of diameter 3m from steel plates being inspected by PoE and BBA.

Figure 12. Driving of Piles at 1:6 slope.

4 CONSTRUCTION TECHNOLOGY

There were many challenges in the construction of the Padma Multipurpose Bridge. Fabrication of 3m diameter piles from 60mm thick steel plates required powerful machine. Figure 11 shows the small sections of 3.2m piles fabricated by precision welding from both sides. The size of the piles can be guessed by comparing with the people standing in front of pile sections. These 3.2 m long pile sections were joined together to form 70m long bottom section and about 50m long top section. Driving of large diameter piles at an inclination of 1H in 6V to required depths needed hammers of very large capacity, not used anywhere in the world. So first a 2400 KJ capacity hammer specially designed and manufactured in Germany was made available for this project. Later a 3500KJ capacity hammer was mobilized for the project. Driving of these piles with inclined guide is shown in figure 12. Again skin grouting of some piles to increase skin friction at such depths required innovative technology. Load testing of large capacity piles in river cannot be done by usual practice of putting dead load on piles. For this Purpose, a number of piles are driven around the test pile. The load is applies on the test pile by hydraulic Jack and upward thrust is transferred to surrounding piles through a strong frame connected to the piles. The upward pull exerted to the surrounding piles is taken by developing negative friction. Fabrication of steel trusses with high accuracy, welding in unfavorable environment and position, then testing of welding from inside and outside by visual inspection and ultrasonic test, polishing and painting in controlled environment are high precision works. Transport and erection of 3088 ton assembled trusses by 4000MT capacity barge mounted floating crane and accurate placing of truss assembly on world's largest double curvature friction pendulum bearings is a gigantic task. Erection and placement of an assembled truss on two piers are shown in Figure 13. The barge mounted crane cannot work when the velocity of river exceeds 1m/s. Geotechnical investigation in flowing river, dredging of bank slope with required precision for RTW and accurate placement of sand filled geobags and stone riprap in water for RTW are challenging tasks of the project. The RTW contractor took a very long time to acquire slope dredging skills in such sensitive work of preparation of side slopes to desired accuracy for placement of protection materials. Several slope failures caused by uncontrolled dredging resulted in undesirable delay of RTW.

Figure 13. Erection of fabricated 3088 metric ton fabricated truss on two adjacent piers by 4000 metric ton capacity barge mounted crane.

5 CONCLUDING REMARKS

Construction of Padma Multipurpose Bridge is a highly complex project. The main problem was faced during construction of the bridge when thick cohesive layers of soil was unexpectedly found at two locations at a depth of around -120m PWD which is the design depth-limit of the piles. The problem was resolved by driving one more vertical pile in centre of cluster and increasing skin friction of some piles adopting innovative technique of skin grouting of the bottom section of piles below -50m PWD by pumping microfine cement grout. Experiments on grouting of test piles was carried out to assess functioning of the grouting process and increased frictional resistance and both were found satisfactory, but it took some time. Skin grouting of pile at such a depth has never been tried anywhere in the world. Some slope slides occurred, but the Chairman and many Members of PoE encountered such problem in the construction of Bangabandhu bridge and could give prompt solution. The problems are addressed and what remaining is routine works and the nation is waiting for completion of the project. The effects of COVID-19 and this year's high and prolonged flood are yet to be assessed.

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