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The Padma Multipurpose Bridge: Construction Challenges and Sustainable Management

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ABSTRACT

An iconic building linking Bangladesh's southwest to its northern and eastern areas is the Padma bridge, which spans the third-largest river in the world with a complicated topology. By boosting production, employment, transportation, and the national and regional economy, this multipurpose bridge is projected to boost GDP growth by 1.2%. This study's primary goal is to pinpoint the greatest challenges encountered during Padma Bridge's construction and explain how sustainable management procedures might be put in place to address such difficulties. The most challenging tasks included finding a suitable site, dealing with complex river morphology, overcoming geotechnical barriers, controlling unfavorable environmental conditions, assembling massive construction equipment and materials, maintaining the construction schedule, and dealing with the COVID epidemic. To resolve these construction challenges, massive river training works and a unique pile foundation design that consists of six floating heaps and one center pile with the largest raking pile in the center were both utilized. To get around the difficulties in superstructural design, longer pre-assembled steel truss girders, pre-tensioned Super-T girders in viaducts, seismic isolation devices, and the largest friction pendulum bearings in the world were all made. Only a small number of people experienced COVID-19 without any fatalities or causing delays in the construction schedule since the Project was kept operational during the COVID-19 period by tightly enforcing the COVID laws and limits on people's mobility. The field of construction management would undergo a paradigm shift with this sustainable management of construction-related difficulties, which might later be used to design more intricate bridges.

1. INTRODUCTION

The Padma Bridge, which links Bangladesh's southwest with its northern and eastern areas, is a representation of the country's dignity, honor, and distinction. The greatest mangrove forest in the nation is located in the south and is a designated Cultural UNESCO World Heritage Site. It is currently in danger owing to natural disasters and a lack of connectivity and communication (Mukul *et al.*, 2020). Through her vision and strategic planning, the Honorable Prime Minister of Bangladesh, Sheikh Hasina has made a brave decision to restore the country's dignity and connectedness in this situation (Aditya, 2021).

The third-largest river in the world, the Padma has a complicated morphology that tends to move west. Traveling through the 6.15-km broad river is difficult since there are few and inconsistent boat connections, which limit mobility and economic opportunities (Figure 1).
As a result, the percentage of people living in poverty is around 5% higher than the national average. The government began construction of the Padma Bridge with financial support from the World Bank, JICA, Islamic Development Bank, and Asian Development Bank in order to improve connectivity and increase trade prospects (E. Hossain *et al.*, 2018). But afterwards, the Padma Bridge project was wholly supported by the Bangladeshi government, and both Bangladeshi and foreign construction companies worked on its completion (Du & Weng, 2021).

The bridge would create the gap connecting the Trans Asian Railway and Asian Highway, improving regional communication between the southwest region and the seaports of Mongla and Payra. To facilitate freight movement between India and the container ports at

Chittagong on the south coast of Bangladesh, a multimodal international transportation network would need to be developed. This would help Bangladesh's economy thrive (Islam *et al.*, 2020).

The bridge is expected to boost the nation's GDP by 1.2% and the south-GDP West by 2.3%, which is plagued by poverty (Blankespoor *et al.*, 2022). In total, there were two tiers of the Padma Bridge, which cost about US$2.97 billion and were used for both rail and roads. During the planning and construction phases, the project encountered several obstinate issues, mostly as a result of the Padma River's ingrained characteristics. Significant changes in the riverbed level are brought on by the Padma River's yearly flow variance, endangering the stability of the bridge's foundations. Given that the Padma River transports the most sediment (1×10^9 t/year on average), extensive river training works (RTW) were also necessary to safeguard the bridge against disasters (Islam *et al.*, 2022). With a 100-year return period, the predicted riverbed scour depth is around 62 m. (Wang *et al.*, 2018). Due to Bangladesh's proximity to the Himalayan tectonic plate contact zones, the bridge building location is also vulnerable to seismic activity. Consequently, the pile foundation design was made difficult by deep scour and seismicity.

To design the Main Bridge and RTW, the Bangladesh Bridge Authority (BBA) hired AECOM, Hong Kong, NHS, Canada, and SMEC, Australia. Before carefully considering a variety of bridge shapes, AECOM conducted a thorough evaluation of the prior works designed for the project (Hossain *et al.*, 2018). The COVID pandemic's harsh working circumstances were made easier by the workers' zeal (Figure 3). This project has set four new world records to build the magnificent structure. The design evolved into a two-level steel truss bridge with a concrete top slab operating as a composite element based on the development of a number of workable schemes. This plan, which places the highway on the top deck and the railway on the lower deck, was determined to be the most suitable kind of structure for the project. The detailed design, which was finished in 2010, used this two-level combined railroad bridge scheme. Figure 2 depicts how these multipurpose structure transporting utilities in addition to the highway-railway, such as a gas pipeline and telephone cables (Kabir *et al.*, 2022). The two-level bridge makes it possible to arrange utilities rationally, safely separate the highway from the railroad, and provide easy access for maintenance and inspection (Robin Sham, 2015). The bridge is also provided with emergency access points to facilitate safe and efficient evacuation from a train on the lower deck (Muhaimin *et al.*, 2021). This study critically examined the sustainable management approaches that were applied to resolve the significant construction challenges encountered during the construction of the multipurpose bridge. This project's successful completion demonstrated that any difficulties could be solved by following a strategic process, and it would encourage a nation to carry out more challenging projects in the future.

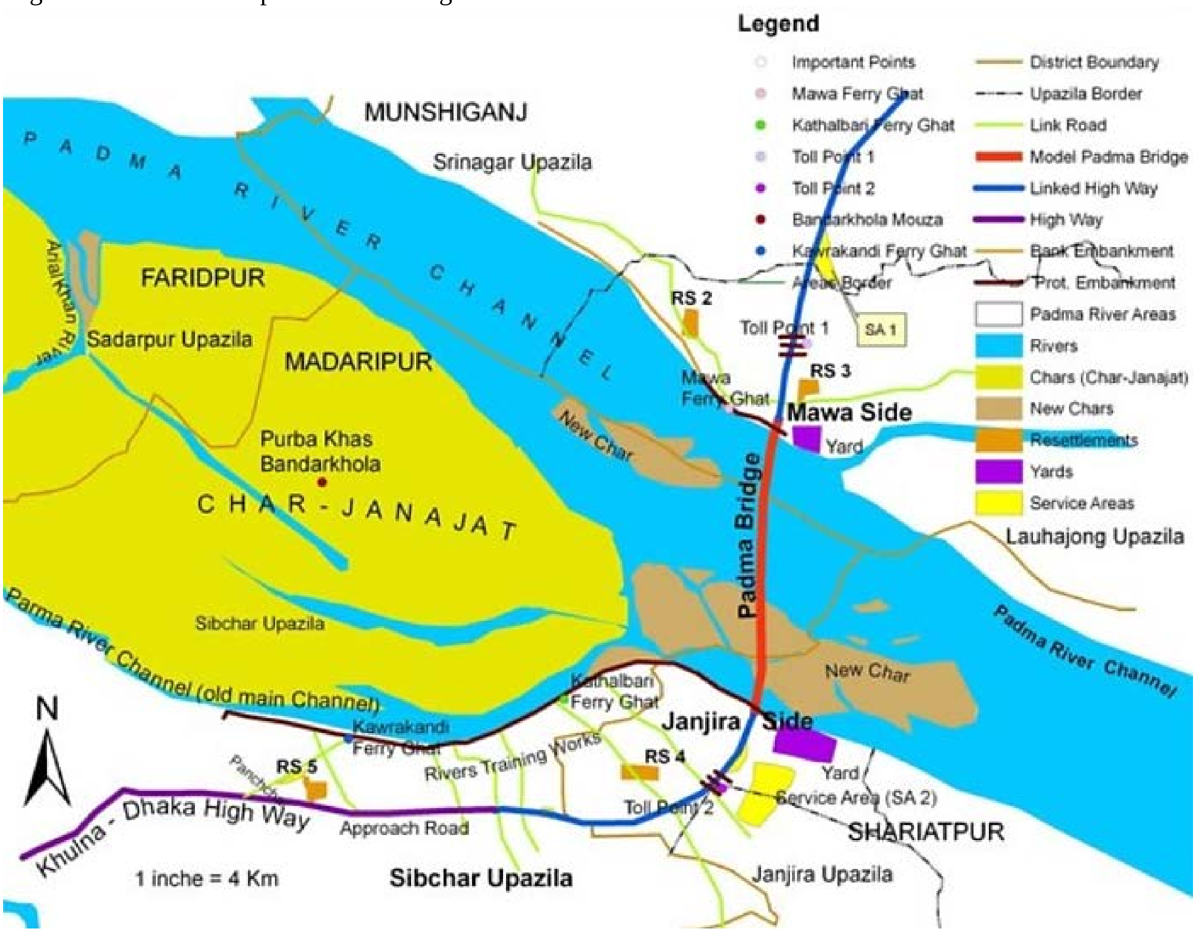

Figure 1: Location of Padma Bridge adopted from Islam *et al.*, (2011)

Figure 2: Gas pipeline and telecommunications cables in Padma Bridge (*Padma multipurpose bridge project*, 2022)

Figure 3: Record-breaking works of Padma Bridge Project (*Padma Multipurpose Bridge Project*, 2022)

2. TECHNICAL DETAILS

With a length of 6.15 kilometres, the Padma Bridge is both the longest railroad and roadway bridge in Bangladesh. The bridge is being built between Janzira in Shariatpur and Mawa in Munshiganj. The construction of the multipurpose bridge, connecting northern and eastern regions to the south-west of the country, created communication between Louhajong in Munshiganj and Shariatpur and Madaripur districts (Blankespoor *et al.*, 2022). There are 42 piers and 41 total spans in the bridge (Figure 4). Of these, two are in approach roads for linking the bridge, and 40 are in the river.

Steel tube driven piles stacked inclined at 1H:1V will be driven beneath the river for each pier. The main bridge has a total of 262 piles, with 6 in each of 18 piers, 7 in each of 11 piers, and 7 in each of 11 piers with skin grouting. Using TAM Duct Technology, Microfine Cement was used to apply the skin grouting (Nur, 2014). The 22-pier structure had to be redone with these unique layouts since TAM Duct technology was being used for the first time in this project.

The Padma Bridge's superstructural loads are supported by 294 piles in total. There are 365 bored piles altogether among the 1.2 m diameter vertical bored piles in viaducts, with 172 in Mawa and 193 in Janjira. The piles are 150 meters long, making them the deepest piles ever used in a bridge (Sham *et al.*, 2010). German engineers employed the largest hydraulic hammer in the world, with a 3,000-kilojoule capacity, to drive those piles (De Silva *et al.*, 2013). The piers are covered with steel spans. In total, the bridge has 41 spans. Upper deck and lower deck are the two decks that make up the spans. The bottom deck features a single-track dual gauge rail, and the upper deck is made up of a 21.65 m wide concrete deck slab with a four-lane roadway. The deck has a 13.6 m height and 18.3 m of clearance was maintained for navigation. The speed restriction for cars on the route is 60 km/h, whereas it will be 160 km/h for trains. The bridge is anticipated to last for about 100 years in total.

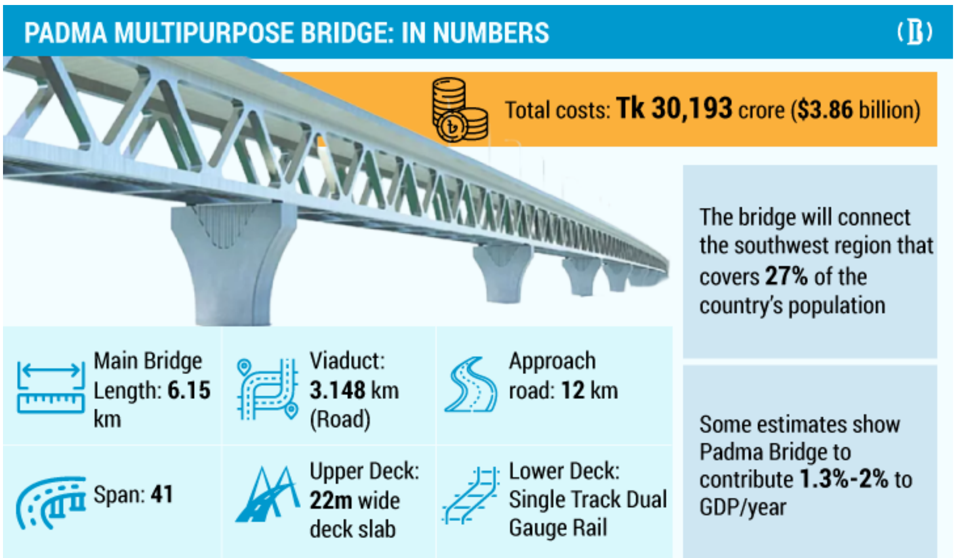

Figure 4: Technical details of Padma Bridge (Business Insider Bangladesh, 2022)

As shown in Figure 5, technical aspects were delegated to a few knowledgeable foreign and domestic organizations through various contract packages. BBA carried out the pre-feasibility study for the Padma Bridge Project between 1998 and 2000. Later, the Japan International Cooperation Agency (JICA) completed the Padma Bridge feasibility study at the request of the Government of Bangladesh (GOB) to the Government of Japan in 2005. The feasibility study proposed that building the bridge will boost regional development through the installation of public services (electric power line, gas pipeline, telecom line), reduce regional poverty, and encourage international trade between neighbouring nations (Zaman *et al.*, 2006).

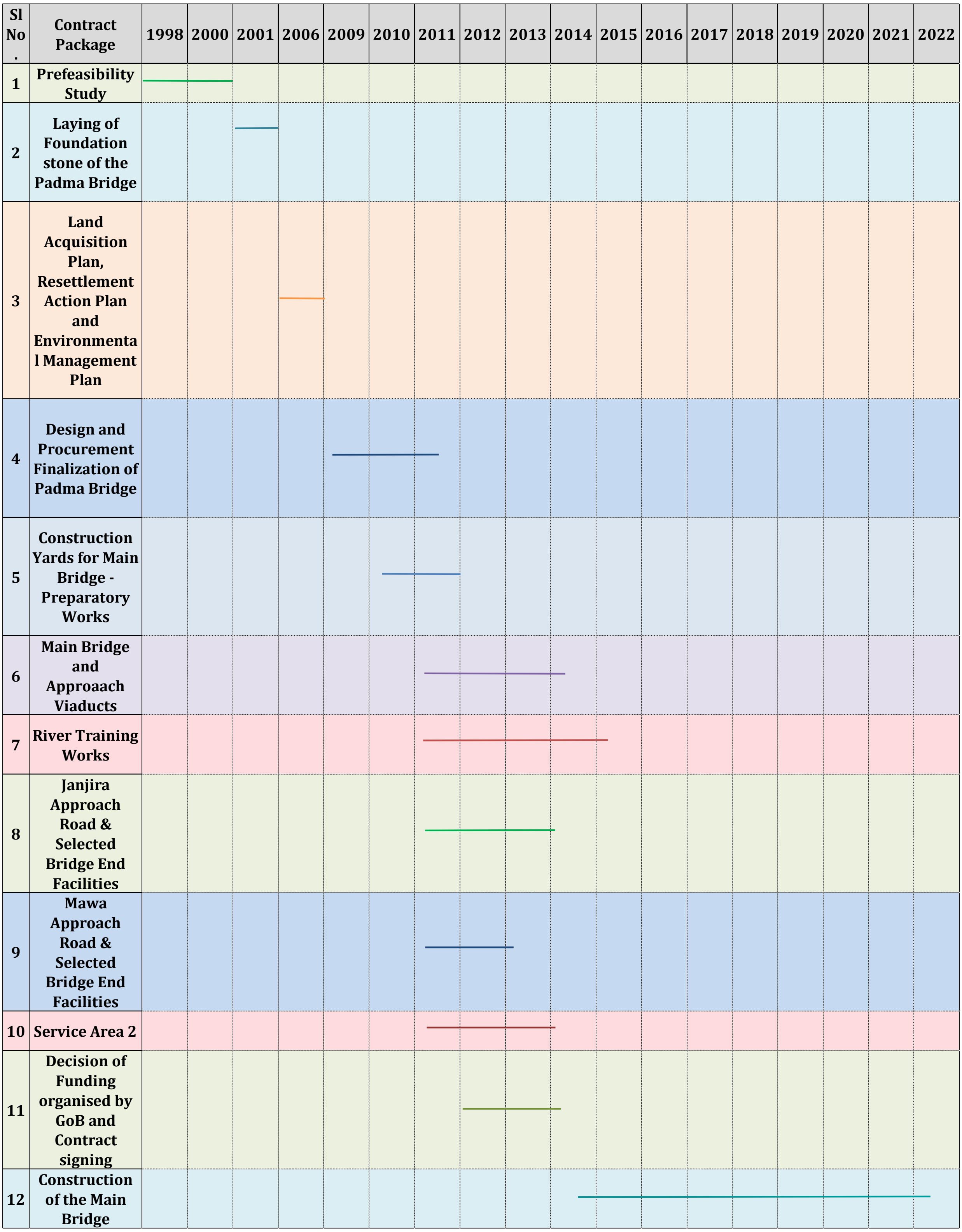

Figure 5: Implementation Schedule of the Padma Bridge Project

3. METHODOLOGY

The Bangladesh Bridge Authority's publications and earlier literature were used to gather secondary data for this study. In order to determine the significant technical originality of Padma Bridge construction, the acquired data were thoroughly examined. The review was carried out by looking into the important conclusions of earlier studies, implementing unique processes in Padma Bridge, and contrasting the benefits and downsides with earlier project management procedures (Campos *et al.*, 2018). Research design, bibliometric data collection, identifying difficulties encountered during the construction of the Padma Bridge, and lastly analysis and interpretation of construction management processes make up the majority of critical review study methods (Qi *et al.*, 2015). The stages for critically examining considerable engineering complexity during the project and management processes of the Padma Bridge are all summarized in Figure 6.

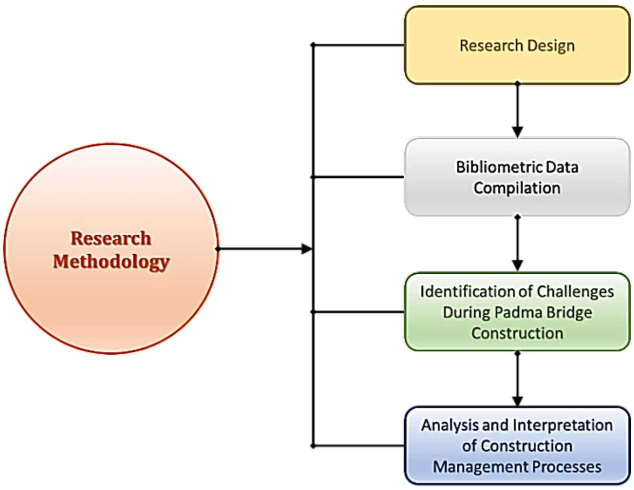

Figure 6: Research methodology of this critical review study

4. MAJOR CONSTRUCTION CHALLENGES

Every work of the Padma Bridge's construction was carried out in accordance with international standards to guarantee that it has a minimum lifespan of 100 years. Additionally, the Bangladeshi government sought to guarantee that the bridge was constructed in accordance with the highest standards (He *et al.*, 2021). During the design and construction phases, a number of critical components of the Main Bridge Contract's works met considerable technical difficulties. The main building obstacles that were faced when putting the bridge's work into actuality are briefly described in the following sections.

A. Site Selection

Four crossing sites—namely, (i) Paturia-Goalundo, (ii) Dohar-Charbhardrasan, (iii) Mawa-Janjira, and (iv) Chandpur-Bhedarganj—were selected for consideration based on a plan-form of the Padma River. After the first assessment of all four sites, two suggested sites, Paturia-Goalundo and Mawa-Janjira, were chosen based on comparison studies from physical, technical, economic, local infrastructural, and social/environmental aspects. However, choosing the ideal location for this historic project was exceedingly challenging.

B. Unfavourable Environmental Condition

The Bridge construction was particularly difficult due to the unfavourable Environmental conditions year-round, which included high sand content in river water, year-round silt in the construction channel, repeated erosion and slips in the construction yard, and frequent tornadoes (wind speeds above strong gale, up to 46 m/s). Due to pile drive, tremendous underwater noise and vibration generated near Hilsa fish sanctuary made the project a challenging one. These conditions have never been seen in conventional bridge construction conditions.

C. Complex River Morphology

For decades, the Padma River has been meandered, twisted, and weaved in different shapes through central Bangladesh. Each zigzag and turn has a geologic story of the region, such as a large flood event or the opening of a nearby dam (Titlee *et al.*, 2020). These events had led to intense erosion along the bank of the river, displacing farms, homes, and even lives. Every year, hundreds and thousands of hectares of land erode and are swallowed by the Padma River (Mondal, 2022). Making a bridge in such a terrible river is a great challenge.

The Padma River, which is thought to have the fastest flow, moves at a speed of 4 to 4.6 meters per second. Approximately 1 billion tons of sediment are transported to the Bay of Bengal annually by the maximum flow, which is 140,000 m3/s (Gani *et al.*, 2022). Since there was so much sediment, the entire construction channel had to be dredged twice a year, which added time and cost to the process. Sometimes the depth of the sedimentation exceeds 10 meters. In 2020 Mawa Construction Yard was the victim of severe river erosion when 125 Roadway slabs and 68 railway stringers were lost into the river and could not be salvaged (Vasquez *et al.*, 2012).

2015 saw considerable erosion on Mawa Construction Yard following the task's award and during the contractor's preparations to begin construction. One batching plant was among the Mawa Construction Yard components lost by the contractor. At the Mawa Construction Yard, the strong river currents during the rainy season of 2020 resulted in significant bank erosion. A sizable portion of the Mawa Construction Yard's eroding area was where slabs for the Roadway Deck, railway stringers, and various items of equipment were piled. A total of 192 railway stringers, 126 roadway deck slabs, and contractor's equipment sank into the riverbed and were no longer retrievable. Rebuilding the deck slabs and importing Railway Stringers from Luxembourg took a lot of time. Projects' work was consequently hampered.

D. Geotechnical Challenges

The construction of steel tubular piles and pile driving posed geotechnical difficulties. Building steel tubular piles with base and skin grouting for the Main Bridge piers to dependable confirm that they can carry the necessary design loads under very deep riverbed scour conditions (up to 62 m depth), as well as very substantial railway loads, wind loads, earthquake loads, and potential ship impact loads (Islam, 2021). The Main Bridge piers' working piles, which are the largest of their kind in the world, measure 3 meters in diameter and up to 125 meters in length. Confirming the construction of RC bored piles for the Janjira and Mawa Approach viaducts, as well as Transition piers P1 and P42, posed a significant problem. On the Mawa side along the Approach Viaducts position, the natural subsoils had a depth of up to 27 m, and they may liquefy after a strong earthquake. Bridge piers. Unexpectedly, as the piling was being completed, the location of the soft soil beneath a few piers was discovered. While bedrock is believed to be located around 6 km downward, the soil at the bottom of the Padma is of the soft mud variety. Flow Slide occurred frequently during precise dredging for the preparation of a slope with just a 250 mm tolerance due to the soil conditions throughout the whole working period, which was a significant difficulty (Oberhagemann *et al.*, 2020). It took a lot of time and money to reconstruct in accordance with the specifications of the design.

E. Funding by own resources

Raising fund for the Padma bridge's construction at that crucial time for the country was a significant task. The World Bank delayed making its decision, therefore the government decided to build the bridge on its own. Prime Minister Sheikh Hasina declared that the Padma Bridge will be built using national funds (Liton & Hasan, 2012). The historic brave choice that was made pushed the construction of the Padma Bridge, which was opened in 2015 (Hossain *et al.*, 2018).

F. Fabrication and Assembly of Structutal Components

In roughly one and a half years, the design and testing work for the new pilings was completed. Steel trusses were still being produced in China at this time. At the Mawa Construction Yard, the steel trusses started to assemble as they came one by one. The steel truss is not being put in any shape because the pile and pier construction there is taking longer than expected. In the event that there is a pressing requirement for storage space, each steel truss is 150 meters long and 3200 tons in weight. The steel truss, which is of the Warren type, is made from steel plates with a thickness range of 40 to 110 mm. After being transported to the Mawa site, the nodes and chords were assembled there using welding to create a whole truss. The nodes and chords were made in China. Each truss has a self-weight of 3200t. The truss had to be moved by a floating crane and put on top of the piers, which was a significant difficulty. The 3600t capacity of the Tyan Yee floating crane was customized (Du & Weng, 2021). The steel truss had to be launched in a certain order for erection since some parts of the bridge are straight and other parts feature horizontal and vertical curves. The nodes and chords of the truss were manufactured in China and put together at Mawa, in accordance with the authorized Program Rev-4B, but pile driving for those piers had to wait a while because the contractor had to wait for the 22 piers' pile working plans to be sent to him. The site's truss storage experienced major issues as a result of the construction delay.

5. SUSTAINABLE MANAGEMENT

A. Site finalization

Based on a plan-form of the Padma River, four crossing sites—namely, Paturia-Goalundo, Dohar-Charbhardrasan, Mawa-Janjira, and Chandpur-Bhedarganj—were chosen for consideration. Two recommended sites, Paturia-Goalundo and Mawa-Janjira, were chosen based on comparison studies from physical, technical, economic, local infrastructural, and social/environmental viewpoints after the initial screening of all four sites. Further comparisons between the two preferred locations were made while taking into account (i) economic viability (economic internal rate of return, benefit/cost ratio, net present value); (ii) economic costs (direct investment costs, operation/maintenance); (iii) regional development (increase in gross regional domestic product)/poverty reduction; and (iv) social/resettlement issues. Last but not least, the Mawa-Janjira site was selected as the best location for the construction of the proposed bridge despite having significantly worse social effects than Paturia-Goalundo due to, among other things, higher bankline stability, higher traffic forecast, lower project construction costs, better EIRR (economic internal rate of return), and other indirect benefits like improved accessibility to the southwest and creation of an international road network. In addition, the government had to spend Tk 4,700 crore on land acquisition, while Tk 3,000 crore in value-added tax was paid on consulting fees.

B. Management for Environmental Protection

According to a study done as a part of the biodiversity baseline survey, the mother Hilsha migrates in deep water. Therefore, it was decided to stop all construction works in the Padma River during Hilsha's breeding and migration season if the depth was greater than 7 meters, and this decision was carefully followed. All activities were prohibited in the Padma River's main channel due to the fast-moving water. Around the bridge, a wildlife sanctuary was developed that comprised a Charland area for the conservation of biodiversity, including the unhindered breeding of turtles. A rise in Hilsha production was observed during the bridge construction phase according to the biodiversity monitoring program.

It was noted that the sound level decreased little as the pile was driven, and the rate at which the sound decreased with distance was very slow. The sound pressure level was less than the injury threshold for fish, which is 206 dB peak, and for pinnipeds, which is 190 dB RMS. The fact that fish were not harmed by the sound of piling was further validated by fishermen who fished within 100 meters of the piling site.

The bridge has a 100-year lifespan. As a result, the design of the bridge takes into account the expected changes in sea level rise, rainfall, temperature, and wind speed in the next 100 years owing to climate change. The bridge is located around 240 kilometers upstream of the Bay of Bengal coast. The maximum range, mid-range, and lower ranges of the expected sea level increase are 0.98 meters, 0.60 meters, and 0.26 meters, respectively, according to

IPCC, where the estimated ice sheet contribution was taken into account. Water levels at the bridge site were predicted to rise by 0.47, 0.42, 0.27, and 0.09 meters, respectively, as a result of the net sea-level rise in the four scenarios: 1.00, 0.88, 0.60, and 0.26 meters.

C. Advanced Materials and Equipment

In addition to purchasing resources from China, such as steel plates and other items, more for the construction of the Padma Bridge, more than 20 new bridge materials from other nations had to be purchased in addition to the steel plates, etc., that were already present in China (Islam *et al.*, 2020). These materials included waterproofing supplies from GCP in the UK, steel stringer beams from Arcelor Mittal in Luxembourg, microfine cement from Singapore, polymer slurry from Australia, skin grouting TAM ducts (customized in China), and American PPG Paints made in as seen in Table 1, anodized aluminum parapet rail is available from V & G in the UK. It gathered more than 100 pieces of cutting-edge equipment, including the largest piling hammer in the world (3500KJ), a self-boring pressure meter from the University of Cambridge, a sonicaliper echo sounder from the United States, and chemgrout grouting equipment (Germany).

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As seen in Table 4, anodized aluminum parapet rail is available from V & G in the UK.

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D. Advanced design of the superstructure

After weighing the benefits and drawbacks of the extradosed concrete truss, concrete girder, and steel truss bridges, the design of the superstructure for the bridge was decided upon. After weighing the benefits and drawbacks of the extradosed concrete truss, concrete girder, and steel truss bridges, the superstructure bridge concept design was decided upon. A two-level structure was suggested in each scenario because it has several advantages over a single-level structure. All welded joints undergo selective non-destructive testing, such as visual inspection, UT testing, and MPI testing, as well as destructive testing, such as tensile and bend tests. In accordance with the terms of the contract, all welded joint surfaces are prepared for painting by grinding and sandblasting. The entire truss is painted using a three-coat method under humidity- and dust-controlled conditions. The trusses were moved from the assembly yard and put onto the piers using a floating crane (Tyan Yi) with a capacity of 4,000 tons (Robin Sham, 2015). Seven continuous structural modules are formed by connecting steel trusses every 150 meters. Each of the six modules has six spans, and one module has five spans. Warren-type two-level continuous steel trusses are used to create composite superstructures that have pre-cast rail slabs on the lower deck and longitudinally post-tensioned deck slabs on the upper deck.The upper deck has a precast concrete deck slab that is 21.65 meters wide and acts as a four-lane roadway with a breakdown lane that is 2.5 meters wide on each side and concrete barriers along the sides and midway (Figure 7). The match-cast portions that made up the deck slab. Each segment is 2 and 2.15 meters long. Segment units are post-tensioned longitudinally and adhered together. The roadway deck slab rises 13.6 meters above the base of the lower chord.

A steel truss bridge with a concrete top slab can have steel weights of up to 3,200t per truss, and when the concrete decks are added, the weight increases to 8,600 t. Nodes and chords of each truss were constructed in China using steel plates that ranged in thickness from 40mm to 120mm (Tian *et al.*, 2021). The nodes and chords were combined and welded into the final 3D shape at the Mawa construction yard.

Figure 7: Provision for a dual gauge double-stack container freight rail line along the lower deck.

At the end of the bridge, the road viaducts are constructed with Super-T girders (Figure 7). A type of pre-cast post-tensioned concrete bridge beam is called a super-T girder. These Super-T girders make up 83 of the bridge's spans, 39 of which are on the Mawa side and 44 of which are on the Janjira side. 438 Super-T Girders in all, comprising 204 on the Mawa side and 234 on the Janjira side, were pre-cast. These five to seven girders, each between 34 and 38 meters long and 1,800 mm deep, make up the single viaduct roadway cross-section (Figure 7). Over the girders is a 180 mm deck slab that has a 50 mm asphalt concrete surface. At each end of the railway approach viaduct, there are seven spans. Six PSC l-girders, each 2200 mm deep, support each span, and the deck slab is 250 mm thick. Three profiled tendons of 29 x 15.7mm dia high-strength and low relaxation steel strands are included with each PSC I-girder. C60 is the concrete grade. The PSC l-girder decks are supported by pot bearings, which also provide seismic protection.

Table 1
Materials used for the construction of Padma Bridge

Major Materials	Quantity	Specification	Source of Supply
Deformed Bar/Rod	108264 tons	It took 92 thousand 286 people for the main bridge. The rest is used for connecting roads.	Domestics
Steel plates	289,000 tons	Pilling and other purposes	China
Steel Span-41	1 lakh 26 thousand tons	steel plates are attached to the spans.	China
Bearing Plate	96 sets	Friction pendulum bearing. The largest bearing weighs about 25 tons. One set of bearings is capable of carrying a load of about 10,000 tons.	
	3556 Sets	Apart from bearings, 3 thousand 556 sets of other types of bearings have been used in Padma Bridge. These bearings help to connect the different parts of the bridge	
	28 Set	All bridges have expansion joints (expansion joints) to accommodate expansion and contraction under heat and pressure. These bearings have been installed in this work.	
Cement	2.25 lakh tonnes 0.25 lakh tonnes	Main Structure Others Structure Padma Rail Link Project	Domestics Domestics Domestics
Microfine Cement	2 thousand tons		Singapore
Sand	64 lakh 58 thousand 115 cubic meters	Sand has been used in the project. 52 lakh 97 thousand 736 cubic meters is taken by river administration.	Coarse sand has been brought from Sylhet and Sunamganj
Stone	15,50,260	Main Structure & Link Road	India & UAE
Bricks	1,22,97,914	Bricks have been used in connection road work. No brick was used in the original bridge.	Domestics
Rock	18,86,000	Used for river management	Jharkhand, India
Concrete Block	8 million	Concrete blocks are needed for river management.	Domestics
Geo Bag	1 crore 90 lakh 90 thousand 521	Geo bags of 125 and 800 kg are used in the river basin of Padma Bridge. 800 kg geo bags and solid rock were thrown into the river to form the foundation in the pile area of the bridge. The sack of 125 kg is thrown to prevent the erosion of the river bank to do the work of river management. Around 24 lakhs of 250 kg geo bags have been installed.	Domestics
Bitumen	2,100 tons		Domestics
Cables	3 Lakh Meter	High-voltage electric line supply	Domestics
Pipe	1 Lakh 20 thousand meter	760 mm dia Gas transmission line through Padma bridge, Fiber optic and Telephone duck which dia is 150 mm	Domestics
	264 each	Pipe-like (hollow inside) steel piles of a three-meter radius are placed on the main bridge i.e., the river section. Their weight was about 1 lakh 62 thousand tons	China
Static load pipe	27	10 steel pipes, 17 board pipe	China
Lamps	415 lamps	328 lampposts have been set up on the main bridge, 46 on the viaduct at the Jajira side, and 41 on the viaduct at the Mawa side. Besides, another 200 electric lights are located on the connecting road on both sides.	Domestics
Diesel	4.15 Crore Litter		Domestics
Waterproof Membrane	560 tons		UK
Rail Girder (Stinger)	9000 tonnes		Luxemburg
Water Disposal Pipe	39000 Meter		Australia
Polymer (For seating Pipe)	249 tonnes		Australia
Hydraulic Hammer	25 thousand Metric tonnes	The world's largest and strongest hammer is being used in the Padma Bridge.	Germany
Floating crane	3,600 metric tonnes	lifting capacity of span carrying crane 3600 tons	China

E. Overcoming Geotechnical challenges

A unique pile foundation design that consists of six floating heaps and one center pile with the largest raking pile in the center were both utilized to resolve the geotechnical challenges. Raking steel tube-driven piles with a 1:6 inclination were used as the Main Bridge Piles. There are 6 piles on 18 piers and 7 piles on 22 piers. Out of 22 piers, 7 piles on 11 piers have skin grouting, and the remaining 7 piles on the other 11 piers don't have that. Pile lengths range from 98 to 125 meters, with the longest-driven tubular pile in the world measuring 125 meters. 124.6MN is the maximum pile capacity (Islam, 2016). The 3m exterior diameter steel tube piles are made from a 60mm thick steel plate (Figure 7). A 70-meter-long bottom part and a roughly 50-meter-long top section were created for each pile by combining 3.2-meter-long pile components. Full penetration welding was used to link each pile segment. After welding, a non-destructive test (NDT) was performed on the pile's inside and exterior. Visual inspection and ultrasound testing were used for NDT testing. Some samples of the welded plates were taken for laboratory tensile tests, bending tests, and impact tests (De Silva *et al.*, 2013). Pile was propelled by MENK hammers with 1,900, 2,400, and 3,500 kJ capabilities. The manufacture of the 262 piles required a total of 155,779 mt of steel plate (Muhaimin *et al.*, 2021).

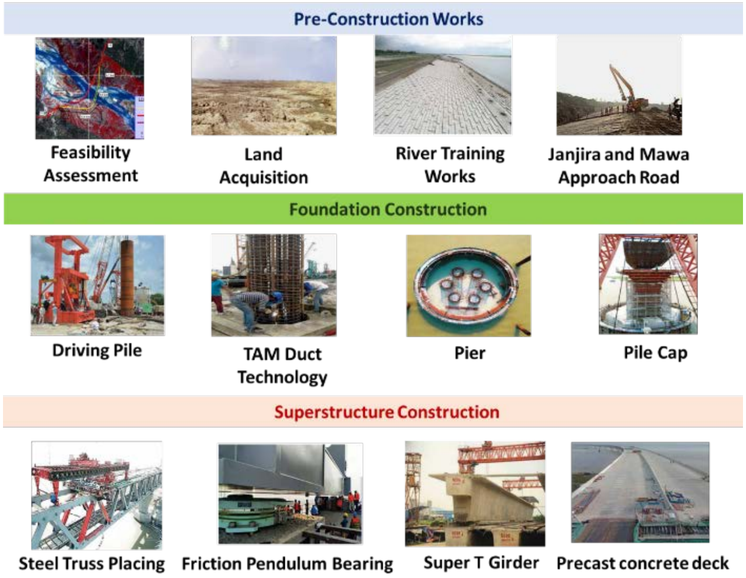

Figure 8: Padma Bridge Project Construction Processes

Through the use of TAM nozzles, microfine cement grout was injected into the skin-grouted pile to fortify the surrounding soil. There are ten 137mm x 130mm TAM ducts that are welded all the way around the pile (Figure 8). On all three of its exterior faces, each TAM duct includes eight 8mm grouting nozzles spaced one meter apart. After the sand was removed from the TAM ducts and before base grouting, the skin grouting operation was completed. "Microfine Cement" grout is poured into the TAM duct from the top with a pressure of up to 3 MPa after driving the pile and cleaning the dirt inside. The skin friction of the pile is considerably increased by the microfine cement grout that travels via the nozzles, penetrates the surrounding soil, and passes through. 11 piers were constructed using skin-grouted piles, with 7 piles under each pier. The TAM duct mechanism is being employed for the first time ever in the world to increase skin friction in the silty sands of the foundation.

F. Overcoming Complex River challenges

Keeping such a turbulent river under control was a big challenge. Since there was so much sediment, the entire construction channel had to be dredged twice a year, which added time and cost to the process. Sometimes the depth of the sedimentation exceeds 10 meters.

The complex river morphological challenges of this bridge project were resolved by introducing massive river training works, employing protection works of lower slope, applying dredging works and placing geobags to treat scour holes and introducing unique pile design along with advanced geotechnical solution including TAM duct mechanism.

(i) ***River training works:*** The river training works were performed to protect the riverbanks from erosion and to ensure that the river will flow under the bridge for its entire lifespan. The river training system consists of a guiding revetment along both banks of the river. Revetment and Slope Protection are layered systems placed on a sloping surface as protection against hydraulic forces and scouring (Figure 9). Revetment constructed by stripping of topsoil with a crest at an elevation of + 9.5m PWD. Dredging was performed from elevation +2.4m to between -12m-25m to develop a uniform slope of 1:6 as per design. The Upper and lower slope maintained at 1:6 (Oberhagemann *et al.*, 2020). This extends from an elevation of +2.5m to +9.0m PWD and is covered by 400 x 400 x 400/300mm CC blocks over the geotextile (Neill *et al.*, 2010). At elevation +5.6m PWD there is a 3m wide berm which is similarly paved. An Anchor Beam has been placed in between the upper slope and the river-side boundary at +2.5m PWD. The Anchor Beam provides a stable reference for the placement of the concrete block pitching. This beam is of 1000mm x 400mm cast in situ reinforced concrete wall (segmental) partially buried in the excavated surface with geotextile material underneath.

(ii) Protection of Lower Slope: The embankment slope protection was covered by placing CC blocks over the geotextile (Figure 8). Blocks were laid parallel to the direction of the river flow over the geotextile filter. Blocks are placed in a manner to have gaps of 10mm that are filled with pea gravel. Geotextiles were required to be provided as an under-layer filter for the various slope protection systems (Kamal *et al.*, 2019). Concrete blocks were laid on a 400 g/m² non-woven geotextile underlayer. 3 layers of 125 kg bags were dumped on the lower slope (Figure 9). 125 kg geobags were transported by barge equipped with an adjustable guiding frame/chute up to 22m long for precision dumping onto the river bed. Geo bags were filled with sand with a size ≥1.0mm. Geo bags were dumped at different stages from -25m/-20m/-15m/-12m up to -2.4m PWD (Hossain & Hasan, 2016). Post-dumping survey conducted by multibeam eco-sounder. Pre-survey and post-survey results were compared to confirm the design thickness of 0.45m or dumping density of 6.27/m².

(iii) Dreging to remove silt and sediment: Developing a suitable method using dredging equipment to build and trim underwater slopes to the tolerances required to allow placement of the revetment bank protection materials (in water depths up to 25 m) (Oberhagemann *et al.*, 2020).

(iv) Protection of Scour with geobags: Creating appropriate methods and specially designed machinery or equipment to reliably and precisely insert geo-bags in water depths of up to 25 meters (on the trimmed underwater slope and in the launching apron). 600 kg of rice bags, 125 kg, and 800 kg of geo-bags were placed within the scour holes (Figure 9).

Figure 9: Dumping of Geobags on the lower slope

G. Construction Scheduling and Contract Management

Under the guidance of the Consultants of Bangladesh Bridge Authority (BBA), the land acquisition, resettlement, and environmental protection projects of the Padma Multipurpose Bridge started in January, 2009, and completed in June, 2022 (Figure 10 and 11). The Jajira Approach Road was started under the supervision of Bangladesh Army, (Construction Supervision Consultant), and it was completed in 2016. Mawa Approach Road construction began in January 2014 and was completed in July 2017 (Jalil & Mia, 2021). China Major Bridge started the main Bridge's construction in November 2014 and completed in June 2022.

River construction was initiated by Sinohydro Corporation Limited and it began in November 2014 and finished in June 2022. The completion of the Padma Bridge was on schedule despite the global COVID 19 pandemic because of the maintenance of the extremely stringent construction timetable and superb management.

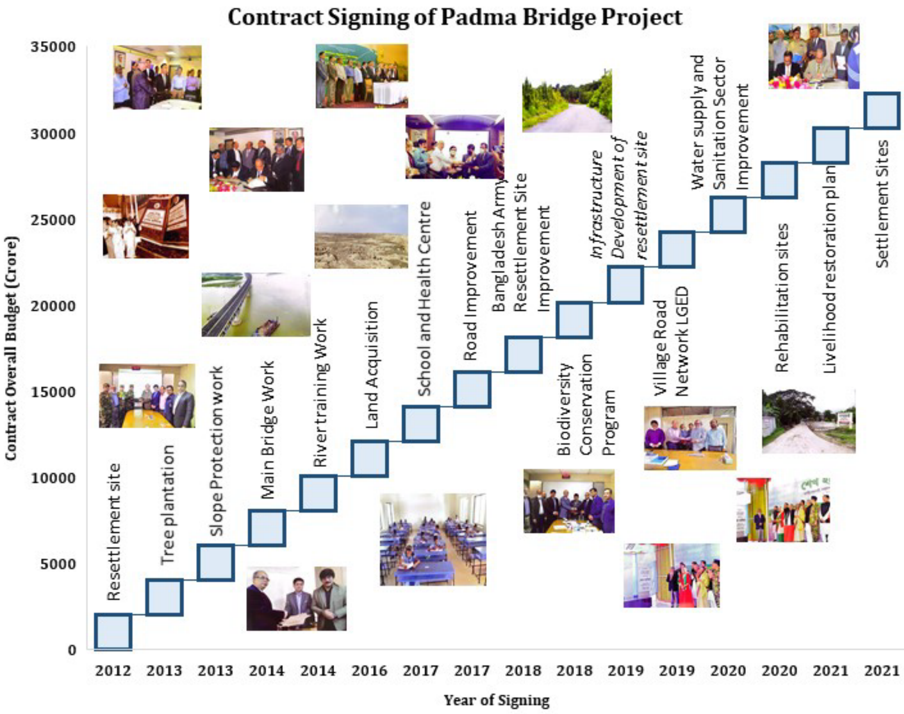

Figure 10: Contract management of Padma Bridge Project

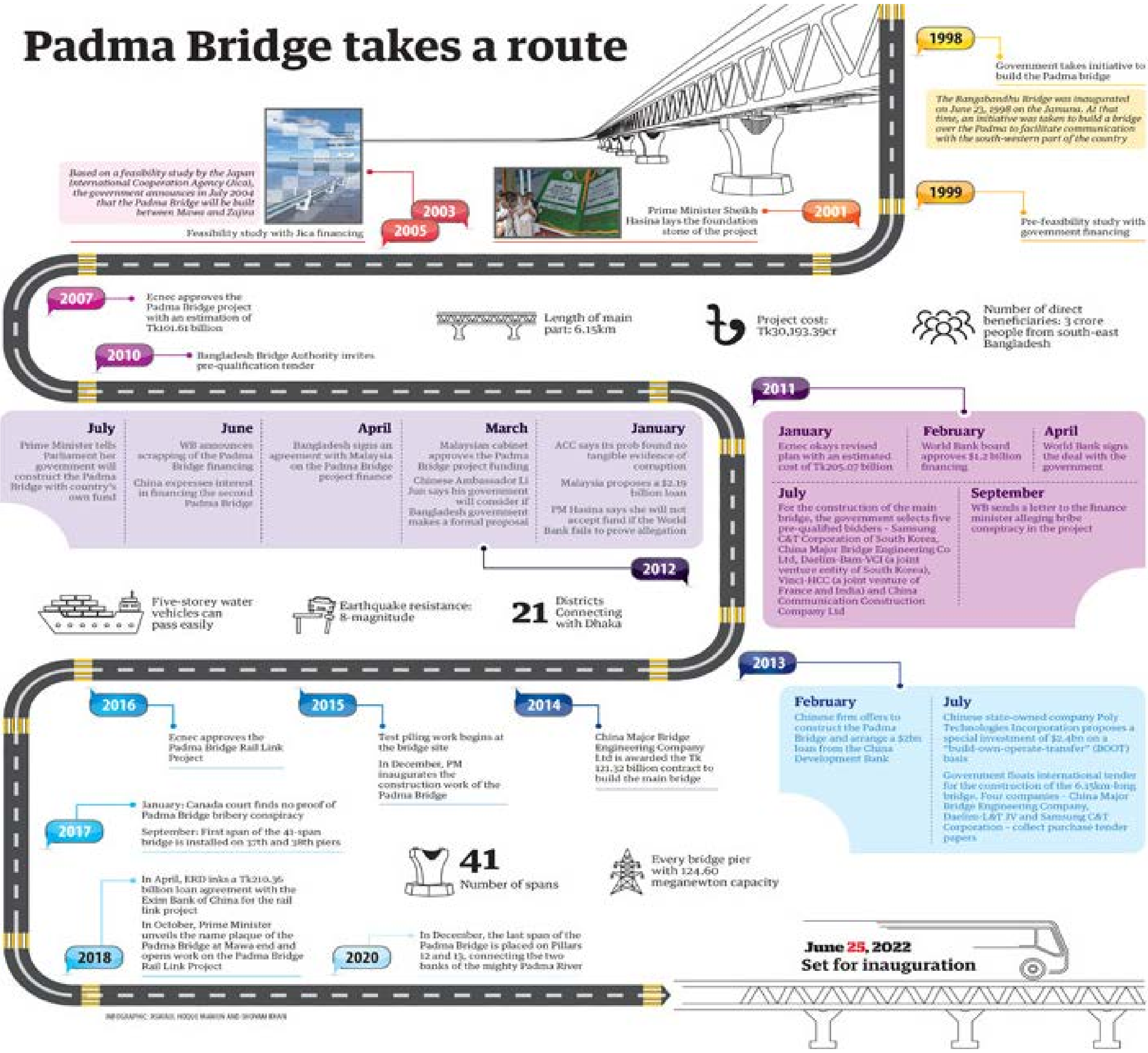

Figure 11: Construction schedule of Padma Bridge Project (Dhaka Tribune, 2022)

Figure 12: A few young members of the ACE engineers working on the bridge project

H. Construction Safety Measures

Local workers have improved their ability to defend themselves at the construction site due to the continuous training on construction safety (Figure 10). The project's vulnerability to extreme weather events like heatwaves, cyclones, and floods was constantly checked by construction safety monitoring team.

I. Management of COVID-19 Pandemic

The project works of the Padma Bridge did not even stop for a single day due to the COVID 19 epidemic. During the epidemic, the bridge contractor from China was severely impacted. BBA declared that the Chinese consultants and Contractors could not return to Wuhan, China, which was thought to be the heart of the COVID-19 pandemic. No one other than the Contractor, Consultant, and BBA is permitted to leave the Project site, and no one is permitted to enter from the outside. In the Project sites Service Areas-1 and 2, a full medical team with the necessary tools and medications was established. Few people were suffered from COVID-19, and there were no injuries because of rigorous adherence to the COVID guidelines and restrictions on people's movement (Lotfi *et al.*, 2022). This made it easier for the project to continue operating. Figure 12 shows specifics of COVID safety precautions taken during Padma Bridge building. However, the project work advanced somewhat slowly since the material supply chain was hampered.

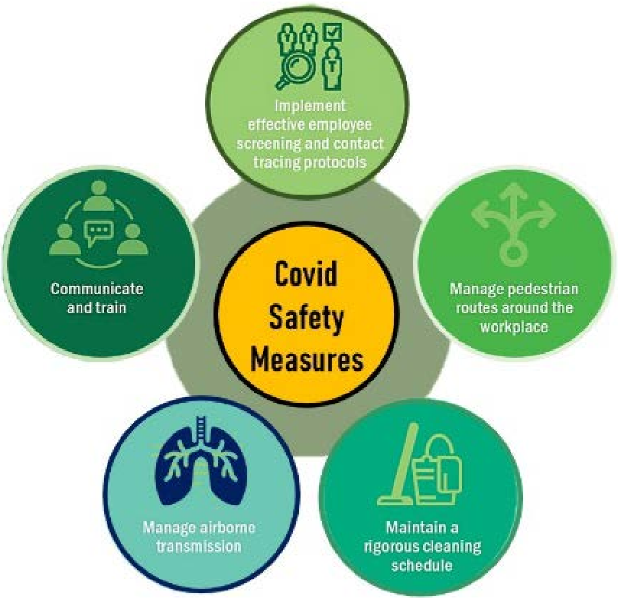

Figure 13: COVID Protocol issued during Padma Bridge Construction

6. CONCLUSION

The Padma Bridge's key construction challenges were examined extensively in this study, as well as the sustainable management strategies used to address them, leading to the establishment of four new world records. Introducing the longest-driven steel tube piling, building the longest steel truss bridge, building the largest double curvature friction pendulum bearing, and building the largest single contract for river training works are the four world records. Only a few people suffered from COVID-19, and there were no injuries since the construction throughout the COVID period was handled by tightly enforcing the COVID rules & limits on the mobility of people. Thus, this sustainable construction management approaches created the groundwork for the completion of the Padma Bridge. Padma Bridge ultimately stands as a miracle above the mighty river Padma, connecting districts and ensuring steady economic growth for the next 100 years, after successfully overcoming a sea of man-made obstacles and engineering difficulties. The building of the Padma Bridge has significantly increased the confidence of the civil engineers of Bangladesh.

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