People's Republic of Bangladesh
Bangladesh Railway

Supplemental Survey
On
Jamuna Railway Bridge Construction Project
in the People's Republic of Bangladesh

Final Report

November 2015

Japan International Cooperation Agency

Chodai Co., Ltd.

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CR(5)
15-054

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Abbreviations

1989-F/S	Feasibility Study conducted in 1989 for Jamuna Multi-purpose Bridge
AASHTO	American Association of State Highway and Transportation Officials
ADB	Asian Development Bank
ADB-F/S	Feasibility Study conducted by BR under ADB's Loan-2688-BAN(SF)
BBA	Bangladesh Bridge Authority
BG	Broad Gauge
BIMSTEC	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation
BIWTA	Bangladesh Inland Water Transportation Authority
BMD	Bangladesh Meteorological Department
BOQ	Bill of Quantity
BS	British Standards
BR	Bangladesh Railway
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CBD	Central Business District
CEGIS	Center for Environmental and Geographic Information Servic
CFRP	Carbon Fiber Reinforced Plastic
C/S	Construction Supervision
CTC	Centralized Traffic Control
DF/R	Draft Final Report
D/B	Design and Build
D/D	Detailed Design
DDC	Development Design Consultants Limited
DFC	Dedicated Freight Corridor
DPP	Development Project Proposal
DPWH	Department of Public Works and Highways
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMoP	Environmental Monitoring Plan
EOI	Expression of Interest
E/N	Exchange of Note
E/S	Engineering Services
FC	Floating Crane
F/F	Fact Finding
E&M	Electricity and Machinery
F/R	Final Report
F/S	Feasibility Study
GB	Guide Band
GDP	Gross Domestic Product

GOB	Government of Bangladesh
GOJ	Government of Japan
HDR	High Damping Rubber Bearing
HP	Hard Point
HSR	High Speed Railway
IC/R	Inception Report
IABSE	International Association for Bridge and Structural Engineering
ISO	International Organization for Standardization
JBIC	Japan Bank for International Cooperation
JFE	JFE Engineering Corporation
JICA	Japan International Cooperation Agency
JSCE	Japan Society of Civil Engineers
JSJCP	Joint Statement on Japan – Bangladesh Comprehensive Partnership
JV	Joint Venture
KMG	Kanchpur, Meghna, and Gumti Bridge
L/A	Loan Agreement
LA	Land Acquisition
LCC	Life Cycle Cost
LRFD	Load and Resistance Factor Design
LSD	Limit State Design
MG	Meter Gauge
MIC	Middle Income Country
M/M	Man-Month
MOP	Ministry of Planning
MOR	Ministry of Railways
MOS	Ministry of Shipping
MOT	Ministry of Transport
MOU	Minutes of the Understanding
MWR	Ministry of Water Resources
ODA	Official Development Assistance
OECF	Overseas Economic Cooperation Fund
PC	Pre-stressed Concrete
PEC	Project Evaluation Committee
PIU	Project Implementing Unit
P/Q	Pre-qualification
PWD	Public Work Datum
P&Z	Polensky and Zöllner girder erection method
QBS	Quality Based Selection
QCBS	Quality and Cost Based Selection
RAP	Resettlement Action Plan
RC	Reinforced Concrete
RFP	Request for Proposal

RR-2	Ring Road No. 2
RR-3	Ring Road No. 3
RTW	River Training Work
SAARC	South Asian Association for Regional Corporation
SAPI	Special Assistance for Project Implementation
SAPROF	Special Assistance for Project Formation
SHDR	Super-High Damping Rubber Bearing
SHWL	Standard High Water Level
SLWL	Standard Low Water Level
SMA	Stone Mastic Asphalt
SPSP-F	Steel Pipe Sheet Pile Well Foundation
STEP	Special Terms for Economic Partnership
T/A	Tender Assistance
TAPS	Transfer Arc Plasma Spraying
TAR	Trans-Asia Railway
TOR	Terms of Reference
WB	World Bank

Executive Summary

1. Background of Survey

Bangabandhu Bridge was inaugurated in 1998 and constructed with funding from the World Bank, the Asian Development Bank, and Japanese Official Development Assistance. The bridge spans the River Jamuna which divides Bangladesh in two and is now an indispensable part of the country's infrastructure. As a national landmark, it is also pictured on the back of the 100 taka banknote.

The flow of the River Jamuna changes wildly throughout the year and the size and location of the sandbars in the river also keep changing. Although Bangabandhu Bridge was first planned as a road bridge, it was later converted to a road-rail bridge although with restricted load and speed in order to obtain greater economic benefits, and the bridge was finally opened for traffic in 1998 after considerable engineering efforts.

Meanwhile the demand for both road and railway transport is expected to grow due to the economic development in Bangladesh and improved connectivity in the South Asian region. So, in addition to the crack repair work undertaken by BAA, the necessity of a dedicated rail bridge with unrestricted load and speed for double line dual gauge track was felt. In order to cope with this situation, there are plans to construct a new dedicated railway bridge parallel to the existing Bangabandhu Bridge, and Bangladesh's Prime Minister Sheikh Hasina requested yen loan funding for the project when she met Japan's Prime Minister Shinzo Abe in May 2014.

The new railway bridge would be a large-scale railway bridge comparable to Bangabandhu Bridge and would not only be a source of national pride but also a symbol of the friendship between Bangladesh and Japan.

Although Bangladesh Railway carried out a feasibility study on the Jamuna Railway Bridge project, an adequate comparison of the structure type was not made and the application of advanced technology to symbolize the friendship between Bangladesh and Japan was not studied, so it was considered necessary to conduct a supplemental survey. The supplemental survey conducted by JICA showed that the existing feasibility study would have to be reviewed as to the structure type of the bridge and foundation, the convenience of river traffic, the safety of the railway, and the reduction the maintenance burden of the bridge after construction.

2. Major Concerns in the Survey

The supplemental survey emphasizes the following four requirements:

- The structure should be of a standard type widely employed for railway bridges around the world.
- Not only the initial construction cost, but the total life cycle cost including maintenance costs should be considered when the structure type is selected.
- The construction method should guarantee high quality while minimizing the construction period.
- The project should apply advanced technology to symbolize the friendship between Bangladesh and Japan.

3. Structure Type Selection

3.1. Preliminary Selection

Preliminary selection for each of superstructure and substructure is undertaken among candidate structure types listed below in pursuit of the above mentioned major concerns.

- Superstructure
  ① Steel Truss Bridge
  ② Steel Arch Bridge

③ Steel Cable-stayed Bridge
④ PC Box Girder Bridge (ADB-F/S[1] proposal)
⑤ PC Cable-stayed Bridge
⑥ PC Extradosed Bridge

- Substructure
  ① Steel Striking Multi Pile Foundation
  (ADB-F/S proposal is the battered version)
  ② Steel Pipe Steel Pile Foundation (SPSP-F)
  ③ Pneumatic Caisson Foundation

As a result, Steel Truss Through Bridge is selected for the superstructure and SPSP-F for the foundation of substructure as the best candidates for comparison with ADB-F/S proposal.

Regarding the Steel Truss Through Bridge selected for the superstructure, since the dead weight is lighter than concrete bridge, size of substructure can be reduced, therefore substructure cost can be reduced by decreasing number of substructure by extending the span length. On the other hand, unit length price of the superstructure increases when the span length is extended. Therefore, the span length is so determined as to optimize the combination of superstructure cost increase and substructure cost decrease. In the end, the optimum span length is calculated to be 120m.

In this addition, rail level height can be lowered by about 5m without changing navigation clearance height of 12.2m by employing Steel Through Truss Bridge, thus the length of approach section constituting of viaduct and embankment at both sides of the new railway bridge can be shorten by about 2km in total of both sides which contributes total cost reduction.

Qualitatively, it has advantages of shortening construction period and raising construction quality, and consequently it is a de-facto standard type of long span railway bridge.

Regarding the SPSP-F selected for the substructure, in addition to such qualitative advantages of high construction quality, easy construction management, and technology transfer to local engineers of innovative technology, it has engineering advantages such as short construction period, prevention of scouring by reducing river flow disturbance, high seismic performance, and cost cutting by recycling temporary structure for final product. Furthermore, the number of substructure is reduced form 49 of ADB-F/S proposal to 41 of this survey proposal by employing Steel Through Truss Bridge for superstructure.

3.2. Comparison Method with ADB-F/S Proposal

ADB-F/S proposes PC Box Bridge for superstructure and Steel Striking Multi Pile Foundation for foundation of substructure. The cost of ADB-F/S proposal is recalculated by estimating structure volume picking up sizes shown in the drawings in the report and multiplying the volume by unit cost taken from actual construction cost of a comparable project, because the details of the cost breakdown is not available in the report. Unit costs of such as approach section is taken from ADB-F/S and cost comparison is made because such construction works are irrelevant to structure type difference of both proposals of ADB-F/S and this survey. As for such construction works as dredging at sand bar section of which the cost is not possible to be estimated at this stage of the survey due to unpredictable seasonal change of construction condition are not included in the cost estimation of this survey, because the cost is common to both proposals. As such, attention must be paid to the following points in referring cost estimation of this survey.

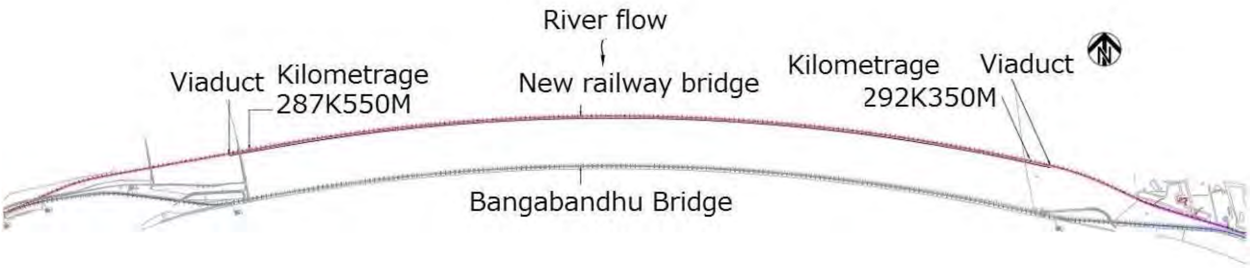
- Cost estimation made in this survey is for the purpose of comparing costs depending on structure type change and not for project cost estimation.
- Unit cost is not standing on the same cost basis among working items but it is standing on the same cost basis between the same working items of different structure types.

[1] The feasibility study conducted by BR in May 2015 having financial assistance from ADB.

- Cost of working items which is irrelevant to structure type change are not included in this cost estimation.

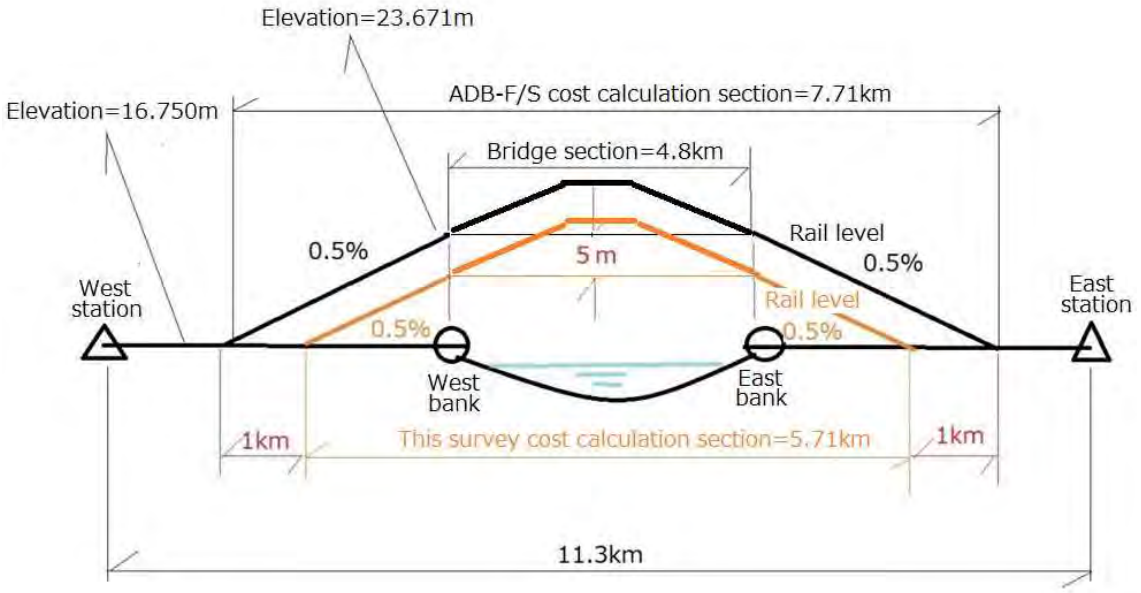
The plane alignment and vertical alignment to compare ADB-F/S proposal and this survey proposal are shown in the figures below.

[Figure 1] shows the plane alignment in which red line represents the new railway bridge and the black line represents the Bangabandhu Bridge. As shown [Figure 1], both of ADB-F/S proposal and this survey proposal employ curved alignment.



[Figure 1] Plane alignment

Vertical alignment of both proposals are shown in [Figure 2] below in which red line represents this survey proposal and black line represents ADB-F/S proposal. As shown in the figure, rail level of this survey proposal is lower than ADB-F/S proposal by about 5m thus total approach section length at both ends of the bridge is shorter in this survey proposal by about 1km.



[Figure 2] Vertical alignment

4. Innovative Technology Application

The criteria to select innovative technologies for the new railway bridge is listed below.

- Technology transfer to local engineers is expected.
- Contributes to quality upgrading.
- Contributes to heighten construction speed.
- Contributes to reduce maintenance dost.
- Accepts modest cost increase.

As a result, the following innovative technologies are selected for the new railway bridge construction.

- SPSP-F for foundation: Expecting upgrading of construction quality, construction speed, seismic performance, etc.
- Weathering steel when Steel Truss Bridge type is employed for superstructure: Expecting reduction of maintenance burden and cost of repainting.
- Curved bridge alignment when Steel Truss Bridge type is employed fot superstructure: Expecting comfortable train operation.
- Direst fastening track: Expecting reduction of maintenance burden and cost and superstructure dead load.
- (Although this is not a kind of innovative technology, but necessary to secure train safety) Three (3) rail configuration track structure coupled by derailment prevention gird.

The followings are the options to be further discussed with BR during the detailed design stage for their application.

- Head hardened rail: Expecting reduction of maintenance burden and cost of rail head ablation and rail replacement.
- Gas pressure rail welding: Expecting long rail performance upgrading and technology transfer.
- Aluminum Magnesium Alloy Plasma Spray Coated Bearings: Expecting reduction of maintenance burden and cost.
- Super-High Damping Rubber Bearing (SHDR): Expecting reduction of maintenance burden and cost.

5. Cost Comparison

Based on the conditions described above, costs of both proposals of ADB-F/S and this survey are compared in [Table 1] below. As shown in the table, the combination of Steel Truss Bridge for the superstructure and SPSP-F for the substructure has cost advantage in the total cost. When the costs of superstructure is compared, PC Box Bridge type looks to has cost advantage, but the weight is as heavy as about three (3) times of Steel Truss Bridge type which increases the volume of substructure by about 1.3 times thus increases the cost. Consequently total cost is larger than the cost of this survey proposal.

[Table 1] Cost comparison

(Unit : Percentage against total cost of ADB-F/S recommendation)

	ADB-F/S Recommendation		This survey proposal	
	Type	Cost	Type	Cost
Superstructure	PCBox	27.7	Steel Truss	38.0
Substructure + Foundation	Battered Pile Foundation	62.5	SPSP-F	42.4
Track -ADB-F/S=7.71km -Survey=5.71km	Bridge: 4 rails slab track Approach: 3 rails	8.2	Bridge: 3 rails direct track Approach: 3 rails	6.4
	Ordinary rail	0	Increase by HH	0.1
	Without derail prevention guard	0	With derail prevention guard	1.8
Approach (Embankment + Viaduct)	Length=2.61km (Total of both sides)	1.6	Length=0.61km (Total of both sides)	0.7
Total		100.0		89.3

6. Construction Quality Control

Since the new railway bridge would be a large-scale railway bridge comparable to Bangabandhu Bridge and would not only be a source of national pride but also a symbol of the friendship between Bangladesh and Japan, the construction work is required to not only be cost advantageous but also line of innovative technologies are applied taking this opportunity. If the innovative technologies are applied on the surface without paying any attention to quality management, it will result in not only to fail extracting performance but also to be dangerous for the structure and railway operation. Therefore, stringent quality assurance measures are needed to be incorporated in the bidding procedure. In this context, the following measures are proposed in this survey.

- Regarding consultant employment, well experienced exclusive consultant is proposed to be employed instead of Design-built contract as it was employed in the Bangabandhu Bridge project.
- Although the number of contract package for the consultancy service is one (1), management consultant function is proposed to be included in addition to F/S review, derailed design, and construction supervision services.
- Regarding procurement of civil work and goods, it is proposed that the number of main component (superstructure and substructure) is two (2) dividing the bridge at the center, the signaling and telecommunication package is separated from the main component, and track work package is reviewed during detailed design stage.
- In case a limited number of bidders for the main component is expected, Multiple Bids One Award System is proposed to be applied.
- In case a limited number of bidders for the main component to comply with the technical specification, the “Single-Stage Two-Envelope Bidding Procedure” in compliance with JICA guideline is proposed to be applied.
- Extended track record is proposed to be applied for the qualification of innovative technology application.
- In case a specific innovative technology of which the performance can be verified by Japanese testing standard only is included in the specification, the equivalent technical qualification criteria is proposed to be specified in the bidding document.

Chapter 1 PREFACE

1.1. Background of the Survey

1.1.1. Overview of Transportation Sector and Development Policy

Bangladesh has experienced strong economic development in recent years and has maintained a GDP growth rate of around 6%. During the thirty (30) year period from 1975 to 2005, the passenger and freight transport volume have increased about 6.5 and 7.7 times respectively, and have since continued to grow at the same pace. The main transport modes in Bangladesh consist of roads, railways and inland waterways, but while road transport has continued to increase its share year by year, railways and inland water transport have seen their shares decrease. As shown in [Tab. 1.1.1], road transport accounted for more than about 80% of both passenger and freight transport volume in 2005.

[Tab. 1.1.1] Modal share of passenger and freight transportation

Year	Passenger				Freight			
	Passenger-km (billion)	Share (%)			Ton-km (billion)	Share (%)		
		Road	Rail	IWT*		Road	Rail	IWT*
1975	17	54	30	16	2.6	35	28	37
1985	35	64	20	16	4.8	48	17	35
1989	57	68	17	15	6.3	53	17	30
1997	90	72	11	17	12.0	65	7	28
2005	112	88	4	8	20.0	80	4	16
2009	155	69	12	19	28.0	74	7	19

Note: "IWT* = Inland Water Transport

Source: Bangladesh Five YearPlan

Such over-reliance on road transport has led to a situation with inadequate transportation infrastructure because new road construction has not been able to keep up with increasing road traffic volume and the existing road network has been deteriorated due to insufficient maintenance. This situation urged the modal shift from road transportation to railway transportation which enables effective transportation for both of passenger and freight.

The Government of Bangladesh (GOB) has established the "Acceleration of economic development and poverty eradication" policy with the goal of attaining middle-income country (MIC) status by 2021. To achieve this goal, the most urgent and important issues include significantly improving the electricity supply infrastructure through increased capacity and improved efficiency, and expanding the transportation and traffic network to support passenger and freight transport.

The policy of the Government of Japan (GOJ) is to support the transportation and traffic network by prioritizing aid for the road sector (including road bridges and trunk roads), which accounts for the largest share of transport volume in Bangladesh.

On the other hand, in order to ease the over-reliance on road transportation and cope with increasing railway freight traffic, GOJ has also expressed its intention to study the diversification of transportation modes and multimodal transport to expand the inland transportation network in Bangladesh.

1.1.2. Expected Role of Railway Sector

The history of Bangladesh Railway goes back to 1862 when the country's first railway, the 53.1km broad gauge line between Darsana and Jagatti, was opened for service. At present, Bangladesh operates a network with a total length of 2,884.7km as shown in [Tab. 1.1.2] and [Fig. 1.1.1]. However, most of the facilities and equipment are from the colonial period and have badly deteriorated, which has led to a drop in service quality and transportation capacity. As a result, railway transportation has seen its modal share decrease every year, and it accounted for 4% of traffic volume in 2005. Meanwhile, although the reason has not been confirmed, the modal share of railway transportation in 2009 has increased to figures by 1997.

[Tab. 1.1.2] Railway network in Bangladesh

Category	Meter gauge (1,000mm)	Broad gauge (1,676mm)	Dual gauge	Total
Operational (km)	1,784.68	507.10	346.15	2,655.93
Closed (km)	53.65	175.09	0	228.74
Total (km)	1,838.33	682.19	364.15	2,884.67

Source: BR Information Book

Although support for the road transport sector has to be prioritized in the short run to cope with increasing transportation demand, the “National Land Transport Policy” established by GOB in 2004 clearly states that railways should be turned into the main mode of freight transport. Railway transport is thus expected to play an important role to ease the over-reliance on road transportation.

In the “Bangladesh Railway Development Master Plan (June 2013)”, the railway transportation sector is assigned the following four (4) roles: (1) Promotion of container-based transport, (2) Development of the urban railway system, (3) Efficiency improvement of bulk freight transportation and improved connectivity with the road network, (4) Play a part of international transportation including trade with India and neighboring countries as a part of the Trans-Asia Railway Corridor. The role of the railway transportation sector is also to support freight transport inside of Bangladesh and to improve connectivity in the South Asian region.

1.1.3. Japanese Aid Policy

The overall objective of Japanese aid to Bangladesh is to “acceleration sustainable and equitable economic development and to eradicate poverty toward the middle income country” according to “GOJ aid policy to Bangladesh (June 2012)”.

GOJ actively participates in the aid coordination meetings, currently chairs the transportation sector meetings, and thus cooperates on issues related to aid coordination within the confines of the framework. Japan’s aid to the railway transportation sector is wide-ranging and includes the provision of loans for the procurement of rolling stock and facilities, improvement of the railway network between Dhaka and Chittagong, loans for the development of the urban railway system in Dhaka, etc.

The existing Bangabandhu Bridge over the River Jamuna in the middle of Bangladesh was co-financed by JICA, WB and ADB, and the opening of the bridge effectively eliminated the traffic bottleneck between the east and west of the country. The bridge has helped correct regional disparity by promoting economic exchange between the two (2) regions and has thus contributed to the economic development of the whole of Bangladesh.

Source: JARTS “World Railway Review”

[Fig. 1.1.1] Railway network in Bangladesh

Aid for the railway transportation sector is part of the transportation sector development policy, which calls for the diversification of transport modes and the development of a multi-modal inland transportation network, and the “Construction Project of Railway Bridge over the River Jamuna” (this

Project) is also in line with this policy.

This project is one of the five (5) projects included in the ”Japan-Bangladesh Comprehensive Partnership” joint statement and was specifically requested by Prime Minister H. E. Sheikh Hasina of Bangladesh during her visit to Japan in May 2014. The Project is therefore considered very important and is expected to significantly boost connectivity in the region.

1.2. Purpose of the Survey

1.2.1. Analysis of the Structural Design in the Proposed F/S

The Feasibility Study (ADB-F/S) for the proposed railway bridge (“the Project”) was conducted in May 2015 with financial assistance from ADB, and a consulting consortium made up of CANARAIL (Canada), SMEC (Australia), DB (Germany), and ACE (Bangladesh) was hired. Eventually, the Project was included as one of five (5) priority projects when the Prime Minister of Bangladesh, Ms. H. E. Sheikh Hasina, requested GOJ for financial assistance during her visit to Japan in May 2014.

The Survey Team identified several items in the ADB-F/S that are not typically used on Japanese railway projects as summarized in [Tab. 1.2.2]. The engineering proposal in the ADB-F/S is summarized in [Tab. 1.2.1]. Since the focus is mainly on the technical aspects of the Project, economic and financial feasibility and associated demand forecasts are not major subjects of this survey.

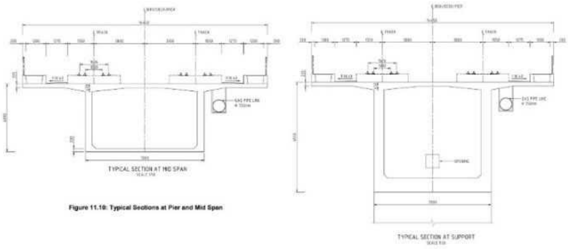
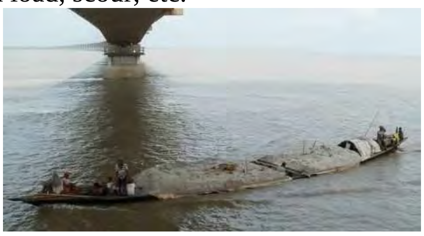
[Tab. 1.2.1] Overview of structural engineering proposal in the ADB-F/S

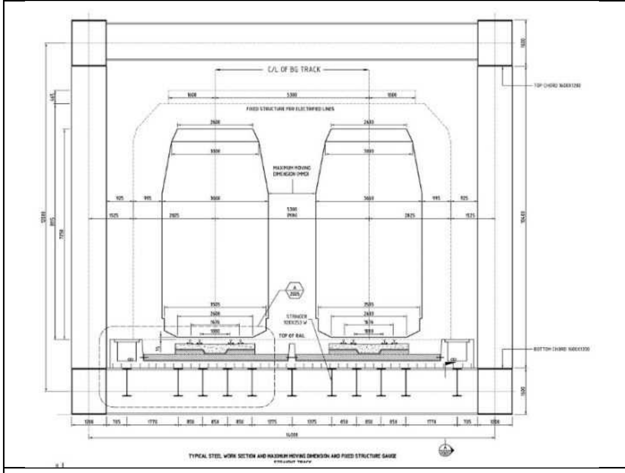
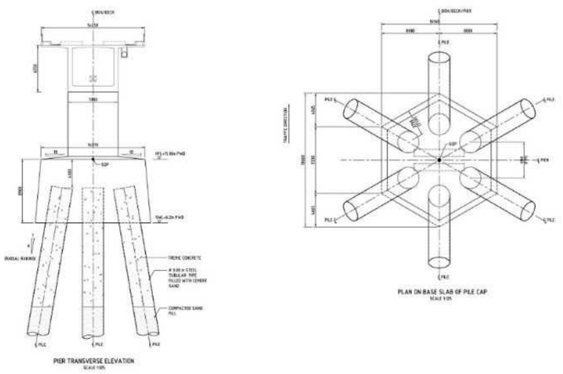
Item	Proposal made in the F/S
Superstructure	Ten (10) PC box girder bridge groups comprised of five (5) spans each with an average span length of 100m.
Superstructure construction method	Balanced cantilever construction method employing precast PC box segments.
Substructure	Concrete piers with three (3) or six (6) steel pipe piles depending on the ground condition with a 3.0m diameter and an 80m length.
Track structure	Dual gauge comprised of four (4) UIC 60kg type rails to allow meter gauge (MG) and broad gauge (BG) to be directly fixed on the concrete slab.
Alignment	Curve radius of 12,000m and longitudinal gradient of 0.5%.
Schedule and cost	Fifty one (51) months for construction work at a total cost of US$1,034.43 million (physical contingencies of 3% and price contingencies of 2%)

Source: ADB-F/S

[Tab. 1.2.2] Sample subjects in the ADB-F/S to be verified

Description in the ADB-F/S	Subject to be verified
Chapter 10: Track Work (Page 10-1) *The track will have a 4-rail configuration with the 2 outer rails for broad gauge (BG) and the 2 inner rails for meter gauge (MG). The MG track rails will serve as guard rails for the BG track and vice versa.*	The 300mm distance specified in the ADB-F/S has been proved to be ineffective for derail action prevention based on consultant’s experience. The Survey Team’s preliminary recommendation is to use three (3) rails equipped with guard rail instead of four (4) rails in order to reduce cost and maintenance burden.

 <The picture is taken on the Bangabandhu Bridge>	 <The guard rail on Harding Bridge>
Chapter 11: River Crossing Studies - Bridge Option (Page 11-14) *A cross-section drawing of a PC box girder on piers is shown. The rail level is about 5.0m higher than that of a steel truss through type girder.* 	Since the dead load is larger for PC box girders compared to steel truss bridges particularly when the rail level of the PC box girder is higher, PC box girders require significantly larger piers compared to steel truss bridges. In addition, steel truss girder contributes to lower the rail level as low as 5.0m compared to PC box girder and shorten approach embankment section length by 2.0km thus reduces total construction cost.
(Page 11-13) *Since the design of the substructure is governed by ship impact load and seismic load, the quantities are equal for the below three options (tied arch bridges, steel truss bridges, and PC box girders).*	It shall be investigated if the size of the substructure can be smaller than the design proposed in the ADB-F/S under actual design conditions including vessel impact, superstructure dead load, scour, etc.  <Typical vessels passing under the bridge>
The construction cost for the superstructure is USD2.5million/m for PC box girders and US$6.5million/m for steel truss bridges (December 2014 version). These figures are significantly altered in the May 2015 version to USD6.25million/m and US$9.63million/m respectively.	Since this price gap between PC box girders and steel truss bridges seems too large based on consultant's experience, it shall be verified.
Drawing No. 5060089-3.1-BR-2004 *Concrete slabs are placed under ballast-less track for steel truss bridges in the drawings.*	It is a standard design for steel truss girder type railway bridges in most of the countries to eliminate concrete slabs under track structure except a site condition where noise and vibration reduction is one of the major concerns. The necessity of the concrete slabs and associated facilities to reduce structure weight will be studied.

	
Drawing No. 5060089-3.1-BR-1004 **Chapter 11: River Crossing Studies-Bridge Option (Page 11-16)** *Foundation piles are comprised of slanted three (3) or six (6) pieces of battered piles with a diameter of 3m and bearing layer of -85m.* 	Considering the design condition that battered piles were employed for the -85m bearing layer, the piles may possibly escape to a softer layer before reaching the bearing layer. Slanted placement of foundation piles with large diameter steel pipe is not only difficult for construction but also less effective for seismic design due to lack of pile bearing capacity management. Furthermore, buttered pile group requires substantial size of pile cap at the boots of a pier which contributes to disturb river water flow and may accelerates scouring.  <The picture is taken at the Bangabandhu Bridge>

Source: Survey Team

1.2.2. Exploration of the Possibility of Incorporating Innovative Technologies in the Project

It is another major subject to study if the Project can incorporate the innovative technology in order for the Project to be successful and effective in terms of not only cost reduction and schedule, but also local capacity building and technology transfer. It shall be noted that cost reduction does not consist of only the initial cost but the Life Cycle Cost (LCC) which includes initial cost, maintenance costs, residual value, and demolishing costs after use.

The Survey Team explored the possibility of applying the following technologies to the Project based on a series of discussions with the survey counterpart agency, Bangladesh Railway (BR).

- Quick superstructure construction work
- Quality control free superstructure construction work
- Maintenance free super structure type
- Less maintenance track structure
- Quality control free foundation piling work

- Quick foundation piling work

It is not enough to only specify the selected innovative technology in the technical specifications of the Project. Performance of the technology to be offered by the bidder must be verified to be sufficient, because many of the above technologies are easy to copy on the surface which means they are not useable due to lack of quality. The application track record must be verified as well because it is not easy to find if past application has been successful or not. The procurement process will play a significant role. So far, no definite methods have been established to detect dubious bidding. However, this is a very important subject since unqualified contractors can create a lot of damage in terms of construction work accident risk, budget availability risk, schedule delay risk, etc. This survey explored how such risks during and after the construction can be minimized in the procurement process for example in the following ways:

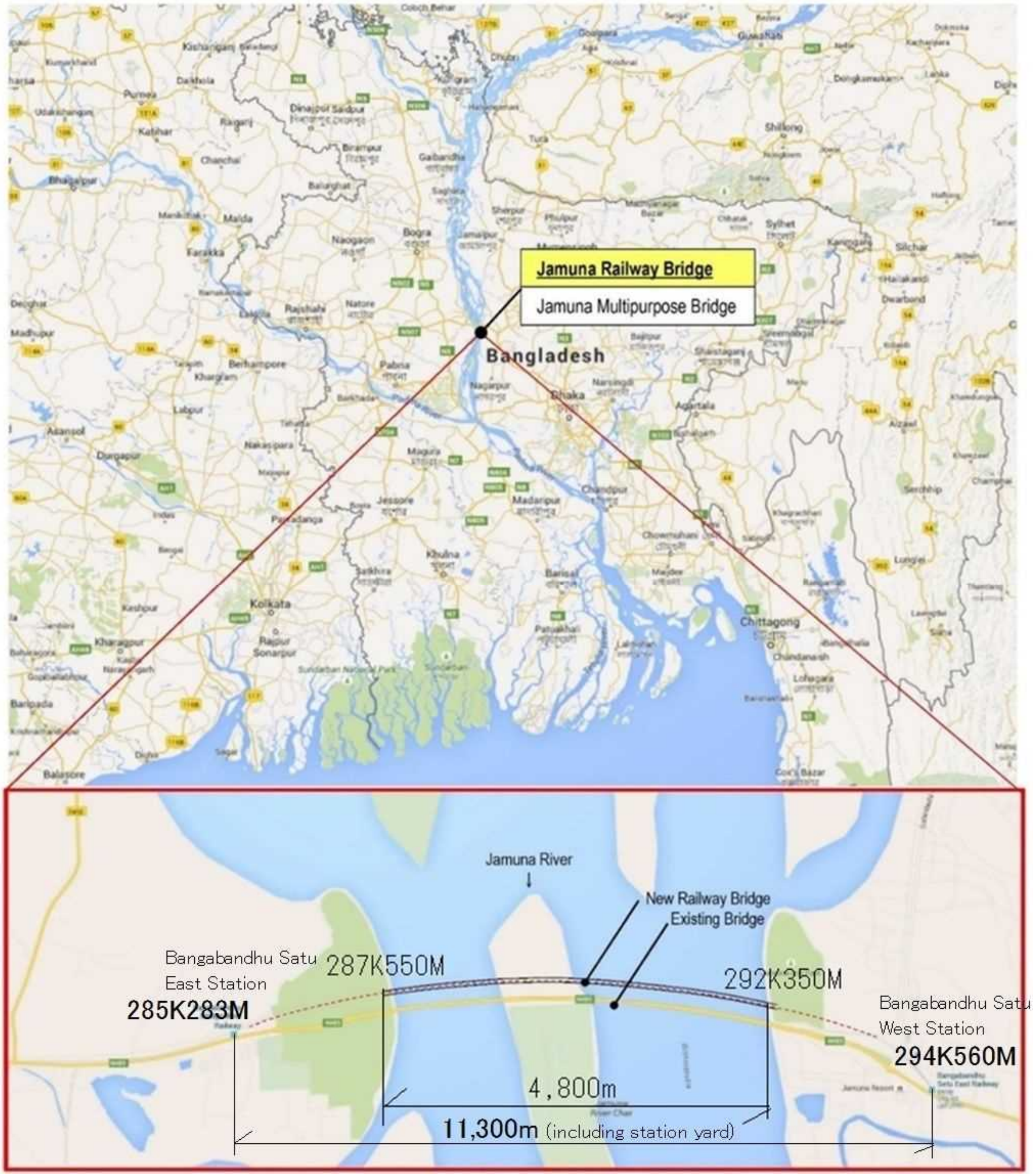
- Effective method to confirm quality guarantee
- Traceability of evidence on successful application record
- Possibility to include maintenance costs in tender price
- Bond presentation to compensate damage due to low quality work
- Insurance to recover damage due to low quality work
- Bid evaluation placing importance on quality

1.3. Survey Area

The proposed site for the new railway bridge construction project is located about 100km north-west of Dhaka as shown in [Fig. 1.3.1]. The bridge is to span the River Jamuna about 300m upstream of the Bangabandhu Bridge opened in 1998 as part of the 170km long line between Joydebpur and Ishurdi. The proposed site is located between the stations of Bangabandhu Setu East and Bangabandhu Setu West. Although the line has great potential for heavy traffic, particularly freight transport between neighboring countries including India and Myanmar, it has limited capacity since it consists of only single track, and both train axle weight and running speed are restricted.

The River Jamuna is also called Rampage River because of its ever-changing width caused by heavy rainfall during the monsoon season. The average river width was 9.74km in 2014 and 14.03km in 2005. The river width at the proposed project site is about 4.8km, and sandbars of various sizes have developed along the river. The largest sandbar at the proposed project site is as wide as 1.7km and farming is practiced on it. The Bangabandhu Bridge crosses over the Jamuna Eco Park but neither land acquisition nor resettlement will be necessary and land simple transfer procedure is necessary as far as the new bridge is concerned.

In addition to the meteorological and geographical conditions, it shall be noted that Bangladesh is an earthquake-prone country and the proposed project site is located in a Category II seismic area.



Source: Google Map modified by the Survey Team

[Fig. 1.3.1] Project site location map

Chapter 2 WORKING FORMATION

2.1. Survey Team Formation

The Survey Team is composed of five (5) members composed of ①Team leader/ Railway plan, ② Deputy team leader/ Superstructure, ③Substructure, ④Procurement and construction work plan, ⑤ Hydrology. For the Survey Team to work in a secure and efficient manner, the Team was supported by other employees of Chodai Co., Ltd. depending on the domain of expertise, supply of information on local conditions, specific engineering skills, safety, etc.

As for the responsibility sharing between the team leader and the deputy, while the deputy team leader leads the engineering tasks regarding bridge construction taking advantage of his extensive experience of large-scale bridge design, the team leader leads the overall coordination among subjects such as survey purpose, engineering matters, innovative technology, ODA project formation, presentation, and dialogue taking advantage if his extensive experience of railway project planning and ODA projects. In this way, maximum synergy was achieved.

An office established in Dhaka acted as the point of contact on behalf of Chodai Co., Ltd during Survey Team's stay in Bangladesh.

2.2. Working Schedule

The prime objective of this survey is to (1) review the proposed bridge structure in the F/S, (2) explore the possibility of incorporating innovative technology in the Project, (3) collect information required for JICA appraisal such as cost, schedule, implementation method (design, procurement, and construction) together with analysis and solution proposal on the new railway bridge requested for JICA finance, and not to make a complete revision of the F/S. Therefore, such survey components as demand forecasting, economic and financial viability verification, socio-environmental verification, etc. are not required, and thus the prescribed implementation period given by JICA is about five (5) months starting at the end of June and continuing until the middle of November 2015. Nevertheless, it is required to collect information such as data on traffic volume, railway operation/ maintenance conditions, and socio-environmental conditions as secondary data when the Survey Team visited the proposed project site, because it is needed for JICA's appraisal work for the coming yen loan. The [Tab. 2.2.1] shows the time schedule of procedural matters.

[Tab. 2.2.1] Procedural schedule of the Survey

Date	Procedure
June 19, 2015	Conclusion of the contract
November 26, 2015	Submission of final report (F/R)
December 18, 2015	Termination of the contract

Source: Survey Team

Since the prescribed time schedule is relatively short, the Survey Team visited the project host country only once for a period of about two (2) weeks between June 26 and July 9, 2015 before the end of Ramadan. The primary mission for the Survey Team during the visit was to get data on site conditions in order to incorporate it into the design planning of the railway bridge. The secondary mission was to collect information relevant to determine design conditions such as traffic volume, railway regulations, design standards, railway operation/ maintenance, procurement practices, commodity and manpower costs, construction technology level, working quality control level, etc.

In order for the work during the visit to be efficient, the Survey Team sent questionnaires beforehand and collected them during the discussions with the counterpart agency of BR (Bangladesh Railways) giving supplemental explanations on the questions. Since the final report of the ADB-F/S was only available just before the start of the field survey, some of the question were changed on the spot during the discussion. Every time before starting discussion with the relevant agencies to the Survey, the Survey Team hold presentation sessions based on the inception report (IC/R) of the Survey in order to articulate the purpose of the Survey. The meeting had to be scheduled with enough allowance time considering extra heavy traffic condition in Dhaka. The [Tab. 2.2.2] shows the working schedule during the field survey.

[Tab. 2.2.2] Field survey schedule

Date	Activity
June 27, 2015 (Sat)	Arrival at Bangladesh
June 28, 2015 (Sun)	DDC meeting, Office setup
June 29, 2015 (Mon)	JICA meeting, Japanese private entity meeting
June 30, 2015 (Tue)	BR meeting, Move (Dahka --> Jamuna)
July 1, 2015 (Wed)	BBA meeting, Site visit
July 2, 2015 (Thu)	Site visit
July 3, 2015 (Fri)	Site visit, Move (Jamuna --> Dahka)
July 4, 2015 (Sat)	- off -
July 5, 2015 (Sun)	Japanese private entity meeting, BUET meeting, BWDB meeting
July 6, 2015 (Mon)	BR meeting, APU meeting
July 7, 2015 (Tue)	BIWTA meeting
July 8, 2015 (Wed)	DDC meeting
July 9, 2015 (Thu)	Arrival at Japan

Note: DDC: Design Development Consultant, JICA: Japan International Cooperation,
BR: Bangladesh Railways, BBA: Bangladesh Bridge Authority, OC: Oriental Consultants,
BUET: Bangladesh University of Engineering and Technology
BWDB: Bangladesh Water Development Board, APU: Asia Pacific University,
BIWTA: Bangladesh Inland Water Transportation Authority

Source: Survey Team

As for the work in Japan side, in order to achieve the mission of the Survey, series of activities were organized by JICA (August 3 and October 30 of 2015) and the Survey Team made presentation on technical aspect of the project.

Another activity is to have a dialogue session with Japanese private entities to know about innovative technologies applicable to the Project available in Japan. It was held two (2) times on August 3, 2015 and October 30, 2015 in which the Survey Team made presentation. The information given by the participants are not disclosed, because they are something to do with intellectual property of private sector.

2.3. Working Plan

The principal component of the Survey is the selection of optimum structure type with regard to super-structure and sub-structure of the new Railway Bridge incorporating innovative technology components. In order for the selection to be more practical, preparation works including information/ data collection and Bangabandhu Bridge site survey were conducted. After the selection of the Optimum structure type, cost comparison between the ADB-F/S proposal and the Survey Team proposal were made. Furthermore, procurement procedure was proposed in order to verify the performance of the innovative technology use proposed in the Survey.

2.3.1. Preparation Work

The preparation work is comprised of the following three (3) kinds of exercises.

(1) Information collection

Additional information supplied by JICA including the M/D (Minutes of Discussion) with BR on the Survey implementation dated May 14, 2015 and updated ADB-F/S dated May 2015 were investigated in the Study Team. Preliminary information collection from Japanese private entities regarding procurement practice, innovative technology application, and local conditions were made. Internal information collection effort within Chodai Co., Ltd. by interviewing those who have working experiences in Bangladesh and by dispatching an engineer to the site in consultant's own account was made as well in order to get familiar with the site condition. In the meantime, local contact point to implement the Survey efficiently were established.

Based on the information collected, specific information necessary for the survey was sorted out, questionnaire was prepared, points of contact were established in accordance with the nature of the information, the questionnaire was sent to the points of contact in advance to the field survey, and the survey implementation plan is finalized in a form of draft Inception Report (IC/R). After the discussion with JICA on the draft IC/R, it was finalized and presentation material based on final version of the IC/R was made.

(2) Dialogue with project relevant agencies

Immediately after the arrival of the Survey Team at Dhaka, supplemental information was provided during JICA office visit and the site visit and meeting plans were modified accordingly.

The dialogue with BR counterpart started from presentation session on the IC/R before starting question and answer session in accordance with the questionnaire. Due to the short of time, the session continued after coming back from site visit. As opposed to the preliminary idea, appointments with project relevant agencies such as BBA, BUET, BIWTA were made not by BR but by the Survey Team.

(3) Site visit and discussion

It took whole three (3) days for the site visit including in-and-out of the Bangabandhu Bridge, river training works of both sides of the river bank, proposed site for the Railway Bridge, and the Harding Bridge. Intensive information was given by the BBA (Bangladesh Bridge Authority) which is responsible for the Bangabandhu Bridge and provides inspection vessel for the Survey Team to conduct ocular inspection. The information supplied by BBA includes construction planning, construction history, engineering difficulties, road/ rail/ water traffic conditions, maintenance management, monitoring work in a form of presentation, discussion, explanation on the site.

Findings of the field survey was reported to JICA immediately after arrival of the Survey Team to Tokyo in which opinions were exchanged by both parties on how to compile the Final Report (F/R).

2.3.2. Optimum Structure Type Selection

The optimum structure type selection work is comprised of the following three (3) steps of exercises. The information collected in the above process of 2.3.1. was supplied in the selection process to verify the applicability of the Survey Team proposal.

(1) 1st screening

The first screening exercise for the selection of bridge structure type was made based on a trade-off table of candidate bridge structure types. The selection was made based on consultant's experience on railway bridge structure types taking local conditions collected during the site survey into consideration. Only inappropriate structure types were eliminated in this exercise without making accurate cost comparison.

(2) 2nd screening

A rough cost estimate for comparison was made to narrow down the structure types selected in the 1st screening above and the best structure type was selected by comparing the cost. The best combination of detailed components of the selected structure type including span length and foundation allocation was selected using a comparison survey on the cost, schedule, and quality upgrading by innovative technology use with reference to the results of dialogue with the Survey counterpart agencies.

A construction plan including rough design calculations, design drawings (frame, plane, side, cross-section), member volume estimation, construction method, cost evaluation, and scheduling was made for the structure selected. The result of the cost estimation for the selected structure type was summarized in line with the cost estimation kit used in JICA appraisal work.

(3) Comparison

A comprehensive comparison survey including cost, construction schedule, quality control-ability, maintenance-ability, and improvement by incorporation of innovative technology was made between the ADB-F/S proposal and the proposed plan made by 2nd screening above. Here, the LCC (Life Cycle Cost) shall be used instead of the initial cost, and the applicability of innovative technology taking local technology transfer and capacity building into consideration were important factors when conducting the comparison. The comparison results were summarized in a table.

2.3.3. Ensure Innovative Technology Application Workable

This work is comprised of the following three (3) aspects.

(1) Applicability of Innovative Technology

Candidate innovative technologies including devices/ construction methods for the Project and the interest of their suppliers/ contractors were listed by series of hearings with them.

As opposed to initial idea of discussing on the applicability of specific innovative technologies, the conceptual function of the innovative technologies were discussed with the Survey counterpart agencies and the applicability of the specific technologies are proposed in the F/R.

(2) Procurement Procedure

The prime objective of proposing the procurement procedure is to preclude unexperienced bidders and thus secure working quality of the Project. This process is particularly important when it comes to the innovative technology application to exert its expected performance. The procurement procedure was proposed based on JICA's "Guidelines for the Employment of Consultants and Procurement under Japanese ODA Loans" which requires P/Q (Pre-Qualification) process before bidding in this Survey.

Lastly, construction plan for the selected engineering solution including administrative and procurement schedule including the governmental approval procedure of the Project (Environment Impact Assessment (EIA), Development Project Proposal (DPP), implementation body establishment, etc.), consultant selection, and construction contract procurement procedure was proposed.

2.4. Information Collection Counterparts

Although the counterpart agency of the Survey is BR, the Survey required wide range of information relevant to the Project formation, such as maintenance management standard of the Bangabandhu Bridge, Maintenance record and current condition of the bridge, local design standard, navigational requirements, environmental condition, local procurement practice, and local construction market. They include the followings.

- APU (Asia Pacific University): Responsible for technical aspect including construction and maintenance of the Bangabandhu Bridge
- BBA (Bangladesh Bridge Authority): Responsible for construction and maintenance of the Bangabandhu Bridge
- BIWTA (Bangladesh Inland Water Transportation Authority): Responsible for water transportation of the Jamuna River
- BR (Bangladesh Railways): Project implementing agency of the new railway bridge
- BUET (Bangladesh University of Engineering and Technology): Responsible for technical aspect including construction and maintenance of the Bangabandhu Bridge
- BWDA (Bangladesh Water Development Board): Responsible for river management
- DDC (Development Design Consultants Limited): Consulting firm engaged in relevant projects to the new railway bridge project
- JBCA (Japan Bridge Construction Association): Bridge project contractors association in Japan
- MWR (Ministry of Water Resources): Supervising public entity for river management agencies

Chapter 3 SITE CONDITIONS

3.1. Natural Conditions

The Project area belongs to tropical monsoon climate zone with four (4) seasons namely: dry or winter season (December-February); pre-monsoon hot season (March-May); monsoon or rainy season (June-September) and post–monsoon or autumn season (October-November). The Project area is not suffered by flooding (even by the latest heaviest flood event occurred in 2004).

The Project area falls in Zone II of the north and east regions of Bangladesh, which are seismically the most active area. During the last 150 years, seven (7) major earthquakes (with Magnitude>7) have hit Bangladesh. Among them two (2) earthquakes had their epicenters within Bangladesh.

3.1.1. Meteorological Conditions

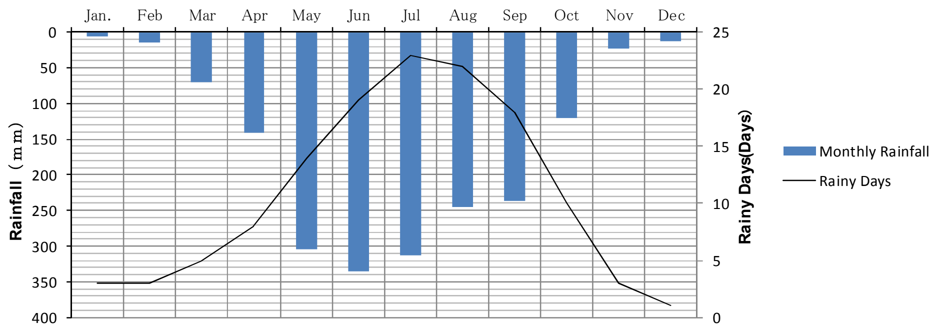
Tangail meteorological substation controlled by BMD (Bangladesh Meteorological Department) is the nearest from the Project area and is located at southern-east of 20km (shown in [Fig. 3.1.1]). Monthly meteorological pattern is shown in [Fig. 3.1.2].

Source: Survey Team

[Fig. 3.1.1] Location of Tangail meteorological substation

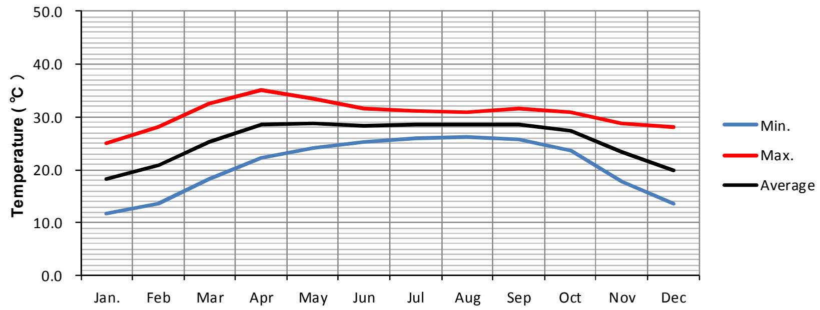
Rainfall is considerably varied from month-to-month (5-335 mm/month) and yearly rainfall is 1,872mm. Majority of rainfalls concentrate in monsoon and rainfall amount is over 300mm/month between the month of May and July.

Average annual temperature is 25.5°C (19.3-28.8°C), average of maximum temperature is 30.6°C (25.0-35.0°C), and average of minimum temperature is 20.7°C (11.7-25.9°C). The maximum temperature between March and May is as hot as 32.5 to 35.0°C.



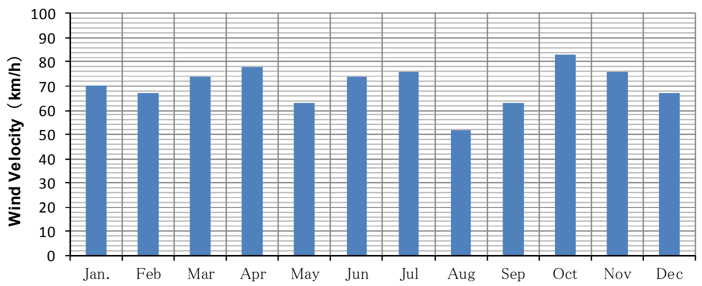
	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	6	14	70	141	305	335	313	246	237	120	24	12	1823
Rainy Days	3	3	5	8	14	19	23	22	18	10	3	1	129

Rainfall (unit：mm)



	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Min.	11.7	13.6	18.2	22.3	24.2	25.3	25.9	26.1	25.8	23.6	17.9	13.6	20.7
Max.	25.0	28.1	32.5	35.0	33.5	31.6	31.1	31.0	31.5	31.0	28.7	28.2	30.6
Mean	18.3	20.8	25.3	28.6	28.8	28.4	28.5	28.5	28.6	27.3	23.3	19.9	25.5

Air Temperature (unit：℃)



	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max. Wind Velocity	70	67	74	78	63	74	76	52	63	83	76	67	70.3

Max. Wind Velocity (unit：km/h)

Source: http://www.myweather2.com/City-Town/Bangladesh/Tangail/climate-profile.aspx

[Fig. 3.1.2] Monthly meteorology at Tangail

The maximum wind speed is around 70km/h (19.4m/s) throughout a year with the dominant direction of south-east. The relative humidity is considerably high except dry (winter) season.

3.1.2. River Conditions

The River Jamuna is large braided river with its width of 12-15km, but is narrowed to 4.8km by the Bangabandhu Bridge. Annual mean and annual maximum discharge are estimated at 20,000m^3/s and 100,000m^3/s respectively (ADB-F/S, vol.3). The slope of flood water surface is 7.5cm/km. Medium size of bed materials (D_{50}) is 0.20mm and particle size distribution is very fine (Performance review of

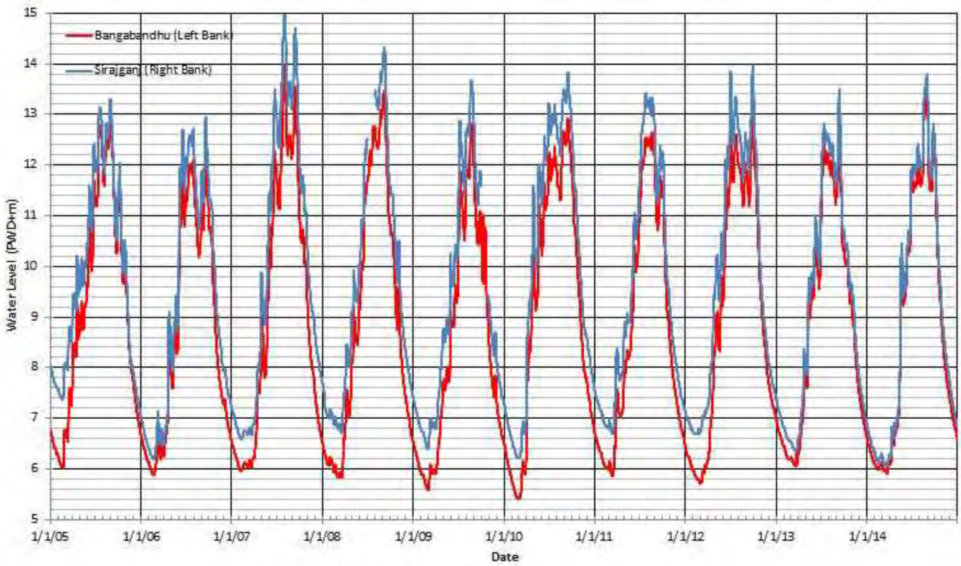
Jamuna Bridge River Training Works 1997-2009, CEGIS[1], 2009). Fine-grained sand is difficult to compact and is erosional by flood flow.

There is an existing bridge 300m downstream from the new railway bridge. Bangabandhu water level gauge/staff gauge (SW-49.3) which is controlled by BBA (Bangladesh Bridge Authority) is located at a pier on the left bank site (shown in [Fig. 3.1.3]) and the water level data from 2003 to 2014 is available. Judging from the conditions of staff gauge and available data, this staff gauge is well operated.

Source: Survey Team

[Fig. 3.1.3] Bangabandhu water level gauge

The water level data at Sirajganj station (SW-49) is used in ADB-F/S. This station is controlled by BWDB and is located 9km upstream from the new bridge. The water level data at Sirajganj station and Bangabandhu station are collected and decade (2005-2014) water level data of both stations are compared hereunder (shown in [Fig. 3.1.4]).



Source: Survey Team

[Fig. 3.1.4] Comparison of water level at Bangabandhu and Sirajganj

Annual minimum water level at Bangabandhu Station is stable as PWD[2]+5.41m -+6.06m and annual minimum water level at Sirajganj station varies widely from PWD+6.0m to PWD+7.4m in recent decade.

From the hydrological point of view, yearly fluctuation of the annual minimum water level falls

[1] CEGIS: Abbreviation for "Center for Environmental and Geographic Information Service" and is under "Ministry of Water Resources, Bangladesh".
[2] PWD: Abbreviation for "the Public Work Datum" and is standard zero level. This is 0.457 m under the mean sea level.

within narrow range when the river bed elevation is not so much fluctuated. Therefore, water level data at Bangabandhu seems to have higher reliability than that of Sirajganj[3]. But, data period of 13 years (2003-2015) is not enough to use the probability analysis.

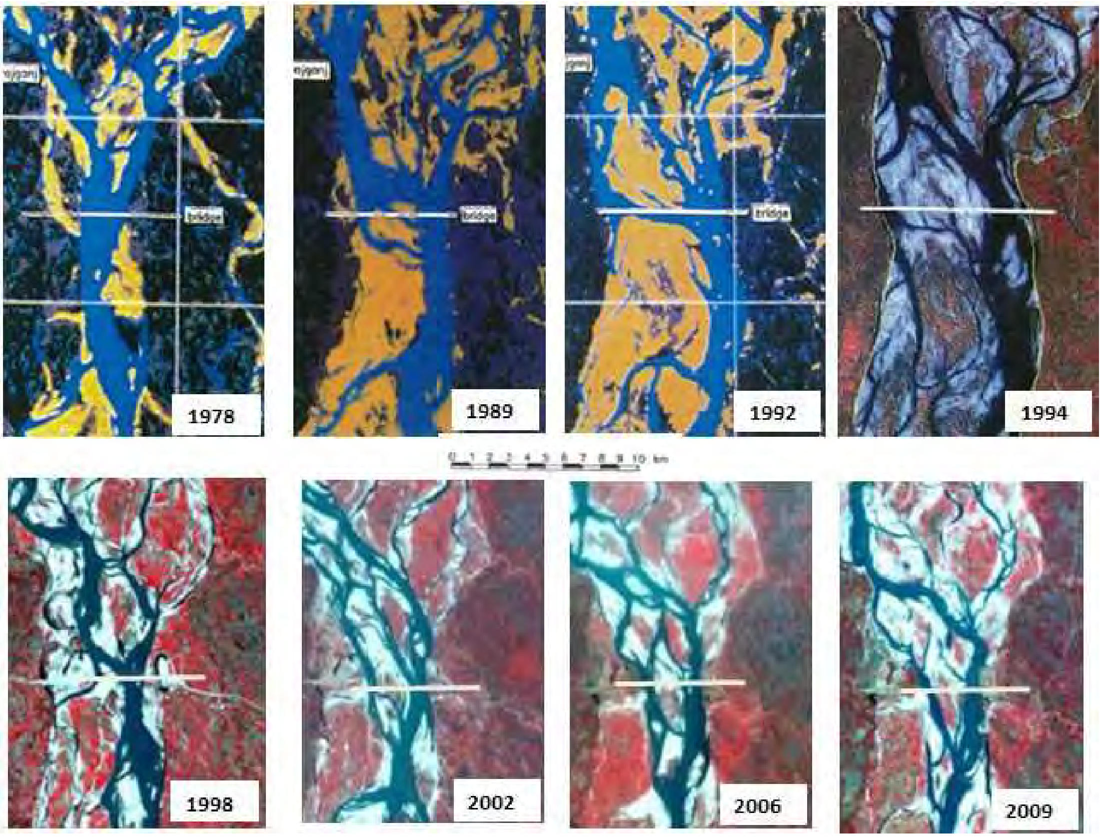
Water depths were measured during the field survey conducted on 1st of July, 2015. Water depth was measured at 13.1m around the left bank side and was 10.1m around the river center.

The new railway bridge is located about 500km upstream from the sea (river mouth), and it is assumed that there is no effect by the sea level rise due to climate change (Preliminary Survey Report of the Western Bangladesh Bridges, JICA, 2015).

3.1.3. Transition of River Course

Present general location of the River Jamuna dates back from1787. Before 1787, the River Jamuna flowed in southern east from the north of Mymensingh (80km north east from the Project area) and flow into the Meghna River. The cause of river course change is considered as the large flood in 1787, but there is a hypothetic (Large scale river bank erosion at Sirajganj, 21st Convention of Hydrological & Water Resources in Japan, 2008) that the channel shift was derived by a faulting of the earthquake.

Judging from [Fig. 3.1.5] (upper) that indicates the river course transition in 1978 to 1994, river width around the bridge crossing had varied from 5 to 10km before bridge construction in 1998. Considering the geological and geomorphological evidence, in combination with the topographical features of Bangladesh at present, it seems that major changes in the River Jamuna are unlikely for the next century according to ADB-F/S.



Note; White bold line indicates Bridge.

Source: Jamuna Multipurpose Bridge, Construction of river training works, delft hydraulics, July 1994
Performance review of Jamuna Bridge River Training Works 1997-2009, CEGIS, 2009

[Fig. 3.1.5] Satellite image around Bangabandhu Bridge (1978 – 2009)

[3] The minimum water level is corresponding to the minimum discharge. The minimum discharge is not depended on the flood event (rainfall →discharge transfer) but is mainly depended on the base flow event (ground water). The base flow of long-term trend has no yearly difference and the fluctuation of the annual minimum water level is not so much (especially in a large basin). The annual minimum water level at Sirajganj has highly varied, so the reliability of this data is doubtfully. There will be a possibility of the water level rising by the riverbed rising.

In the report of "Large scale river bank erosion at Sirajganj", the river course is shifting toward west in the long run and a part of river channel is assumed to shift to west more at the upstream site of Sirajganj. This scenario may be possible in a long term period but is not a current problem. When the river course change happens to occur, the river training works (HP, etc.) should be considered in actual.

Judging from [Fig. 3.1.5] (lower) that indicates the river course transition between 1998 and 2009, there are two (2) major flow courses around the new railway bridge crossing. One is left side and another is right side, and there were no major changes in this period.

3.2. Navigational Condition

3.2.1. Navigation Management

BIWTA (Bangladesh Inland Water Transportation Authority) is a government entity in charge of management of the inland water navigation. The following information was supplied by the Director of BIWTA. The rivers of Bangladesh is classified as follows.

[Table 3.2.1] Necessary Width and Height for Navigation

Navigation Class	Width (m)	Clearance above SHWL (m)
Class I	76.22	18.30
Class II	76.22	12.20
Class III	30.48	7.62
Class IV	20.00	5.00

Note：This table is the same as [Table 3.4.1]

Source：Bridge Design Standards for Roads & Highways Department, BIWTA, 1991

The River Jamuna is classified as Class II with the overhead clearance of 12.2m. The Bangabandhu Bridge has the clearance of 15.5m complying this regulation. The navigational width is 76.22m. Usually only small vessels are passing under the bridge but salvage ships pass under the bridge in seldom occasions which require 12.2m height due to the crane height of the ships. Other larger vessels are a type of ship towed by a tug boat having barges on both sides fully loaded with construction materials coming from India. The tug boat has a mast with the width of about 40m, the length of about 150 to 200ft, i.e. 45 to 60m, and the height of 40ft or 12m. The navigation width of 250ft (76.22m) is specified to allow the passage of this kind of ships. At present, there are neither commercial based ferries nor ships that violate this navigational clearance. But the ferry service may be expected as future possibility so that this clearance must be secured. There are no ship collision records either. BIWTA prefers to secure the navigational clearance all along the new railway bridge, because sand bar location developed inside of the Jamuna River is unpredictable and they incidentally appear and disappear annually.

The Padma Bridge which is located at downstream of the Bangbandhu Bridge is currently under construction and this bridge is classified as Class I (18.3m high). This fact is important for construction material transportation planning via river from the sea to the new bridge construction site.

Source：Survey Team

[Fig. 3.2.1] Typical vessels observed near the Bangabandhu Bridge

3.2.2. Hydrological Characteristic

Hydraulic characteristics of Bangabandhu Station in the past decade are as follows.

[Tab. 3.2.2] Water level condition in recent 10 years

(unit: PWD+m)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Ave.
Annual Max.	13.16	12.33	13.97	13.48	12.81	12.91	12.65	13.35	13.08	13.43	13.12
Annual Min.	6.01	5.88	5.96	5.83	5.58	5.41	5.86	5.70	6.06	5.92	5.82
Annual Ave.	9.21	8.67	9.05	8.95	8.40	9.17	8.72	9.01	8.83	8.76	8.88

Source: Survey Team

- Maximum water level was PWD+13.97m on the 2nd of Aug., 2007 and minimum water level was PWD+5.410 m on the 1st of Mar., 2010.
- Decade mean water level was PWD+5.827m and annual mean water levels had a range of 0.630m.
- The fluctuation range of water level was 7.30m (PWD+5.82m to 13.12m).

3.2.3. River Channel Condition

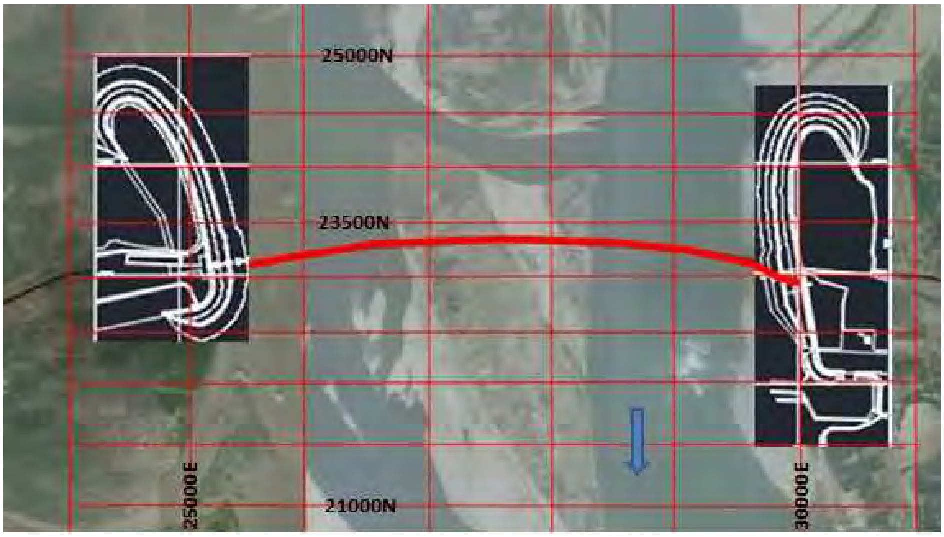
Minimum water level was PWD+5.41m and average river bed level was around PWD+ 4m in the past decade. Main streams with elevation of lower than PWD-3m has been existed constantly, but the locations were not constant. Large vessels (e.g. crane barge) are able to run because the vessel draft can be secured. But the locations of deep section will be determined only after flood event.

(1) Cross Profile

Cross sectional data is collected to understand the stream course change. Cross survey is executed around the Bangabandhu Bridge crossing four (4) or five (5) times a year since 1998 by BBA. Since bathymetric survey (sonar survey) is not possible to be executed on the sandbar, there is no cross sectional data on this section. The extent of bathymetric survey is from 21000N to 25000N[4] with interval of 500m and total survey lines are nine (9) (shown in [Fig. 3.2.2]).

Since survey line of 24000N is close to the alignment of the new railway bridge, the survey data at the line is selected to represent the site condition. The cross profile is shown in [Fig. 3.2.3]. The cross profile of 28th of July, 1998 when the Bangabandhu Bridge was completed is shown by red fat line in [Fig. 3.2.3]. The cross sections are typically irregular with two (2) main streams and a wide shallow part (shown in [Fig. 3.2.3]). The bottom elevations of the two (2) main streams are PWD-4.0m on the left side and PWD-7.5m on the right side A wide shallow part (sandbar) exists with the width of 2.8km (5700E～8500E) and the elevation of PWD+8.0m.

[4] Longitudinal distance from the survey datum line in Bangladesh and unit is meter.



Source: Survey Team

[Fig. 3.2.2] Traverse lines (21000N ~ 25000N, 500m interval, 9 lines)

The trend change of the main streams in the period of 1998 to 2015 is summarized as follows.

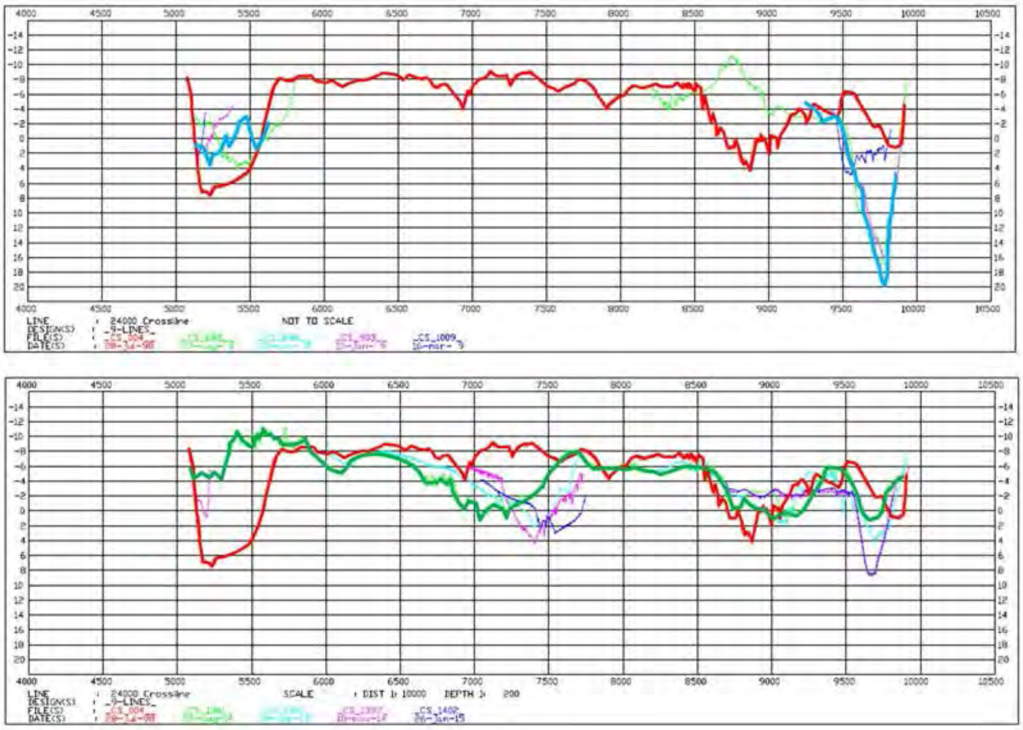
- Riverbed elevation of a main stream around the right bank varies between PWD-7m and PWD+0m and tends to be getting shallower.
- Riverbed elevation of a main stream around the left bank varies between PWD-4m and PWD-20m and tends to be getting deeper.
- Since, it is not possible to execute the bathymetric survey around the river center due to the sandbar, there is no survey data around the river center before Feb., 2012. But, there has been existing a main stream of PWD-3m around the river center since Nov., 2013.

(2) Conditions of Sandbars

Period of field survey between 1st and 3rd of July, 2015 was a monsoon season and water level was relatively high. Almost all of sandbars around the new railway bridge alignment were submerged and green grass rarely appeared over the water surface.

Small sandbar was confirmed at the downstream (a little right side from the bridge center) of the Bangabandhu Bridge (refer [Fig. 3.2.4]). There was small bush on this sandbar, so it is assumed that this sandbar has existed for several years.

Riverbed of middle channel (5700E ~ 8500E) had height of over PWD+6.0m in the period of between 1998 and 2012. Average minimum water level was PWD+5.8m and this section was over the river surface. The condition of sandbar (location and height) has been irregularly fluctuating year by year.



Source: Survey Team

[Fig. 3.2.3] Cross profile (line: N25000)

Source: Survey Team

[Fig. 3.2.4] Sandbar around downstream of Bangabandhu Bridge

3.3. Present Condition of the Bangabandhu Bridge

To confirm the present condition of the Bangabandhu Bridge, BBA (Bangladesh Bridge Authority) was interviewed at the bridge site followed by site inspection from outside as well as inside of the box girder. In Dhaka, Professor A.F.M. Saiful Amin of BUET, Bangladesh University of Engineering and Technology and his academic supervisor, Professor Jamilur Reza Choudhury, who are key figures in Bangladesh Bridge Industry, were interviewed to investigate the bridge. Also BIWTA (Bangladesh Inland Water Transportation Authority) was interviewed to investigate the navigational clearances. The results are summarized in [Tab. 3.3.1].

When this bridge was planned, only the road bridge was not economically feasible so that other facilities such as gas pipes, electric lines and railways, were added. This is the reason why this bridge is called the Multipurpose Bridge.

[Tab. 3.3.1] Present condition of the Bangabandhu Bridge

1. Horizontal alignment  4.8km length and R=12,000m curve. Curve is introduced to avoid monotonous driving, aesthetics, longer facing time of train front light. Increase of bridge length is about 32m.	2. Girder end sections  Many Span Continuous PC Box Girder Bridge. At about 1/4 span point, girder ends meet. Not at center of span. There are no settlement problems. To repair settlements, PC cables can be installed.
3. Expansion joint of gas pipe 	4. Bearings and seismic resistance device 
5. Electric power line 	6. Longitudinal cracks under box girder.  Cracks appeared during construction and repaired by Hyundai.

7. West side approach viaduct

RC Slab Bridge. Many cracks are developed on the bottom slab.

8. Repaired slab bridge

Narrow steel strips in longitudinal direction are attached. Cracks may have appeared in lateral direction.

9. Cracks and repair

10. Bee hive at girder end

11. Bridge surface

End section of four (4) lane road is occupied by train track and lanes became narrower. Beyond left concrete barrier, a rail track exists.

12. Passing train

When a train is running, bridge reportedly vibrates considerably. Though this was not detected from the inside of the running car.

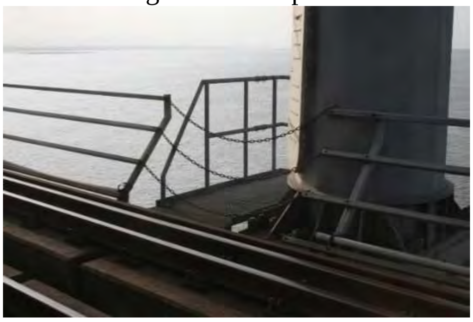
13. Track structure

On approach sections three (3) rail track is placed. Only on the bridge section, four (4) rail track is placed. About 300m gap between outer rail and inner rail, which is too large to prevent derailment.

14. No. 26 Power line pole(P26)

No.26 power line pole is placed exactly above No.26 pier. Poles are also spaced 100m interval.

15. Clearance height at No.26 pier



Height from water surface to bridge deck at No.26 pier was 22m. In rainy seasons of July to August, water level rises 2m more. If girder height is about 4m at 1/4 span, then clearance is 22-2-4=16m. This coincide with story of Mr. Azad of BBA that 15.5m navigation clearance is secured at center.

According to Mr. Hossain of BIWTA, Jamuna River belongs to Class Ⅱ, and 76m (=250ft) wide×12.2m high navigation clearance needs to be secured. Present bridge reportedly secures 76m×15.5m clearance at bridge center and descends down with 5‰ gradient. Thus bridge does not secure clearance all along bridge.

Mr. Hossain requested to secure navigation clearance all along new bridge.

Water depth was measured 10m at one point. According to depth gauge of ship, 20m was recorded as the deepest point.

16. Side of experimentally cast segment

17. Section of segment

Rail track is on the left wing. On upper haunches inside of the girder, cracks are observed. As this was design-build project by JV of Hyundai and T.Y.Lin (which was already sold by Mr.T.Y.Lin at that time). Then responsibility of cracks were attributed to Hyundai. It looks that the construction was fine but design by T.Y.Lin was inadequate. Rigidity seems to be inadequate.

18. Passing train over bridge

Train speed is limited to 20km/h on bridge but the actual train speed is around 10km/h because it takes about 30 minutes to pass bridge. Hence only 26 trains can pass bridge.

19. Inspection entrance for PC Box Girder

20. Inside of Box Girder

White lines on haunch indicate cracks.

21. Pipes inside of girder

22. Trial repair of cracks

Repair of cracks on corner haunches is examined. Carbon fiber reinforcement is tested. But this may conceal cracks and cracks cannot be confirmed by eye inspection.

23. Bearing

Needles prevent bird approach and protect weathering steel plates under exposure test.

24. Lateral movement stopper

Protrusion from girder bottom hits stopper on pier when girder moves sideway due to earthquake.

25. Lateral movement stopper and bearing

26. Seismic resistance device

These steel bars may be deformed during earthquakes.

27. Japanese weathering steel plates under exposure test

Joint experiment of JFE, Saitama Univ. and BUET.

28. Night light up of piers

29. Lighting device of pier

Four (4) lights are on one pier. Two (2) are on both sides of a pier in bridge axis direction. Two (2) are on downstream side and upstream side. This shows one on bridge axis direction and lights navigation channel.

30. Lighting device of pier

This lights up downstream. Due to these lights, there have been no records of ship collision on piers.

31. Construction of pile cap

Pile Cap is constructed by 250tFC (Floating Crane). At present, FC cannot be brought to site because of navigation clearance of existing bridge.

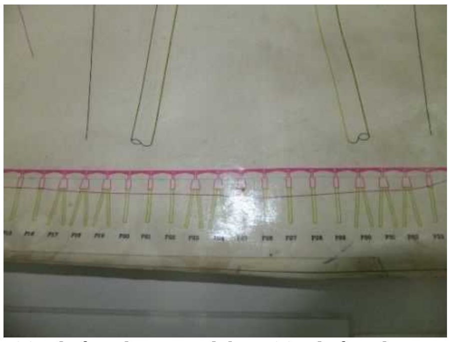
32. Construction of pile foundation

Substructures were constructed by ships after dredging sand bars.

33. Foundation Construction

Foundation construction by dredging sand bars

34. Pile foundations



Two (2) pile foundations and three (3) pile foundations

35. Piling of battered pile

36. Girder Construction by P&Z method

37. Sand carrying ship passing under the bridge

Typical size of vessel passing under the bridge.

38. Slightly larger sand carrying ship

39. Sand carrying ship passing under the bridge

40. East hard point

Due to river width reduction at the Bangabandhu Bridge site, some places upstream are attacked by river flow harder. BBA protects such places by sinking sandbags.

41. East hard point and river revetment

Revetment is here. Sand deposits in front began to be eroded.

42. Sand bag sinking at East Hard Point

Manual sand bag sinking

43. Erosion upstream of East hard point and houses on sand deposit

44. Sand bar downstream of existing bridge

Submerging sand bar. With 2m more increase of water height, this sand bar will be completely submerged.

45. Almost submerged sand bar

Submerged sand bar upstream of the Bangabandhu Bridge and near planned new railway bridge site

46. West Hard Point Area

47. Sand carrying boat on west hard point

Sand is pumped up from ship to bank.

48. Tug boat on west hard point

This tug boat may be the largest ship.

49. River Revetment on west hard point

This year no damages on revetment. Last year there were small damages and they were repaired.

50. Prepared stones for bank protection

Stones are domestic product of Bangladesh.

51. Sand boat on West Hard Point

52. Concrete blocks on west hard point

53. Train leaving East Station

54. Train near East Station

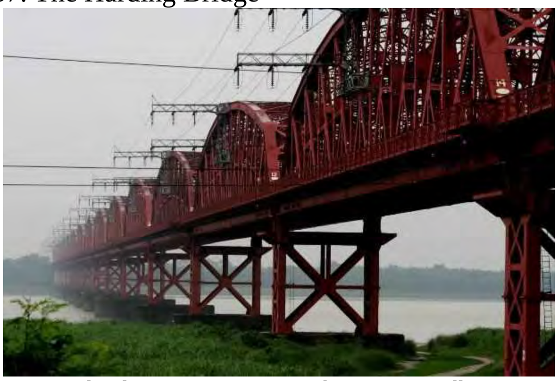
55. Track is transferred from three (3) rails configuration track t0 four (4) at this point after East Station

Four (4) rail configuration track is on the bridge.

56. Buildings on east side

If the new railway bridge alignment is planned slightly more to the north, the train track may interfere with these buildings.

57. The Harding Bridge



Completed in 1915. One span is about 110m. Well-maintained and last painted in 2012. About 280m downstream, there is the Lalon Shah Bridge which has almost identical span lengths as the Harding Bridge.

58. Train passing the Harding Bridge

This bridge was constructed as double track bridge. But connecting approach tracks are only single. As wind speed of this area is large, the double track structure was adopted to increase wind load resistance.

59. Derailment Prevention Guard

Although the Bangabandhu Bridge is not equipped with derailment prevention guards, this bridge is equipped with derailment prevention guards.

60. Inspection way between tracks

61.Adjacent Lalon Shah Bridge

Road surface level of PC Box Girder Bridge, deck bridge, is higher than trough bridge.

Pedestrian deck was opened to public but recently it was closed due to security reason.

62. Plan of Ganges Barrage

About 50km downstream of the Harding Bridge, Ganges Barrage is planned. If completed, ponding area may reach to Indian border and Indian Government minds this fact. But Indian Government has a barrage near the border, too. Over Ganges Barrage, a highway is also planned.

3.3.1. Superstructure

From the result of site survey, it was found that the Bangabandhu Bridge is well maintained. From the interview with Professor Amin and Professor Choudhury, the history of the bridge and its present situation became clear.

(1) History of the Bangabandhu Bridge

Professor Choudhury joined F/S of the Bangabandhu Bridge in around 1985. At that time, World Bank (WB) opposed the addition of the railway because they thought it would further weaken financial health of Bangladesh Rail (BR). On the other hand a person in charge of ADB promoted the railway addition. Then before the final decision of the railway plan, it was allowed to proceed to the construction. The Design-build Scheme was adopted and the design was done by T.Y.Lin Consulting Company, at that time the company was already sold to some other company from Mr. T.Y.Lin, and the technical ability was unknown. First the bridge with the Design-build Scheme was bidden as a road only bridge and the winning bid price was 248 Million US$. The Contractor, Hyundai Construction Company, assured that with another 2 Million US$, the railway could be added. Then it was decided to add the railway. The railway should have been placed at the center of the bridge. But if the railway was placed at the center, the road must have overpassed the railway in the approach section, which would have pushed up the cost and WB opposed. Consequently it was decided to place the railway on the cantilever of the Box Girder Bridge, which is the only one example of railway bridges in the world.

As the design-build scheme was adopted, the contractor was responsible for the design too. After the completion of the bridge, crack development at concrete decks progressed and BBA requested the repair works. But Hyundai rejected the works (if the design was wrong, the design consultant's responsibility would have been pursued, but this was a Design-build Project and the responsibility of the main contractor was pursued).

The railway design first assumed the meter gauge and the axle weight of trains of 11.9t. But later, four (4) rail configuration, the combination of the wider gauge and the meter gauge, was adopted.

Indian railway standard adopts the axle weight of 25t and to accommodate Indian trains, the bridge should have been designed for 25t axle load. Because of this constraint, the international trains from India cannot pass the Bangabandhu Bridge. Only one (1) international passenger train (the axle weight was not clear but the weight is below the design axle weight according to BBA) passes through this bridge once a day with the speed below 20km/h which is specified as the limit of the speed. But the actual train speed may be about 10km/h because it takes about 30 minutes for trains to pass through this bridge. Hence even though the wind speed is observed, the wind speed changes and increases during the train is on the bridge and an accident that the train fell down sideway actually happened.

At present, there are, in total, only 26 trains a day in both directions. It is difficult to accommodate more trains and this bridge forms a bottleneck of the railway network in Bangladesh. There is one (1) fuel tank train a week. The weight of one oil tank car is 30t consisting of two (2) sets bogies of two (2) axles so that one (1) axle load is 7.5t. As the weight of this fuel tank train is so large, there is large vibrations of the bridge when this train passes. To secure the safety of the bridge and to increase the transportation capacity, the construction of the new railway bridge with double tracks is urgently needed.

There are three (3) reasons why the Bangabandhu Bridge introduced the curved horizontal alignment, which becomes clear by this survey. If the straight alignment is adopted, the driving becomes tedious and could make the drivers sleepy. The train track is on the bridge (the track was planned to be at the center in the beginning but later changed to be on the north side of the bridge), if cars are facing the train front lights, it would last for a long time. But if the bridge is curved, the length of time to face the train lights is comparatively shorter and it is safer for driving. If the bridge is curved, it is aesthetically better. But everybody may question why this bridge has a curved alignment, there were many requests to clarify the reasons of this curvature when the website of the Bangabandhu Bridge was opened.

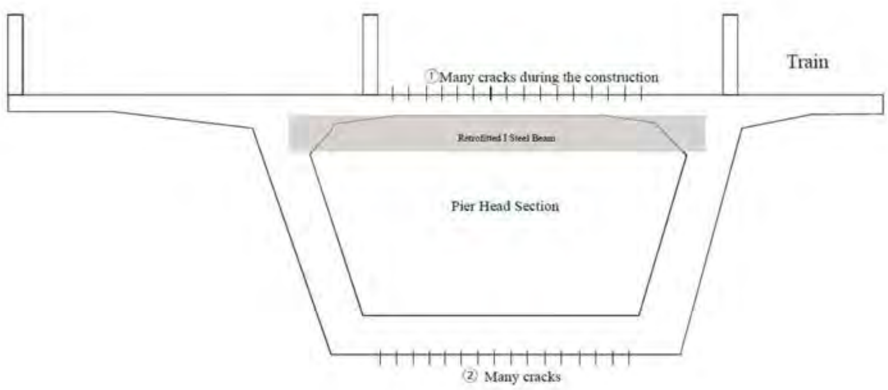
According to this survey, the straight length of the bridge is 4,768m instead of 4,800m with the radius of R=12,000m. This means 32m shorter than the present bridge. For the new railway bridge, as the existing guide bunds are not parallel, even if the straight alignment is adopted, the length of the bridge and that of the curved bridge parallel to the Bangabandhu Bridge are almost the same so that it would be better to adopt the curved alignment for the new railway bridge. Also this coincides with the intention of BR, as they prefer the curved alignment because of its aesthetic appearance.

The width of the Bangabandhu Bridge is 18.5m and 3.1m is utilized for the railway. The rest of the width is utilized for the four (4) lane road. There is a center barrier and the lane width cannot keep one (1) lane width of 3.66m (=12ft) specified by AASHTO but is only 3.1m wide. There are not enough shoulders, either. Many trucks are running on the bridge but sometimes the springs of some trucks are broken and these trucks are tilted considerably with the loadings, which makes the taking over, very dangerous.

(2) Damages of Superstructure

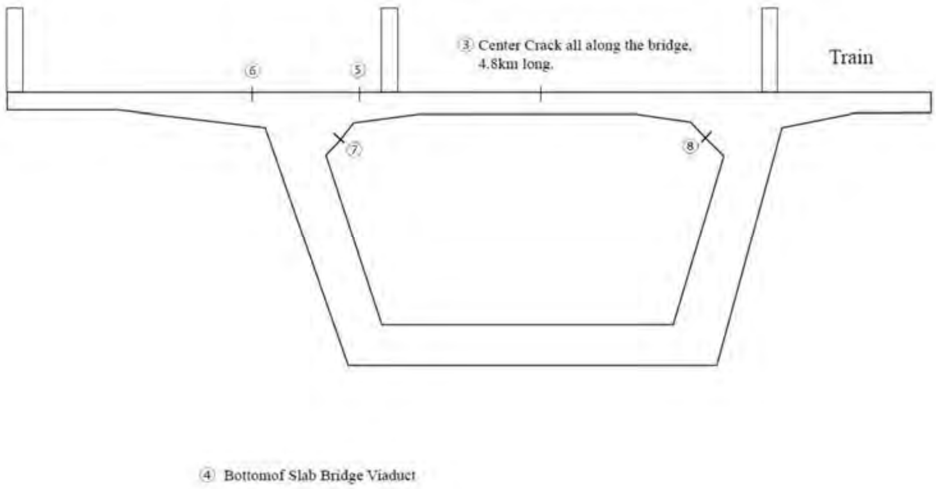
Professor Amin is investigating the condition of the present bridge and advising BBA for the repair method. He also presented the paper of the damages of the present bridge to IABSE (International Association for Bridge and Structural Engineering). The following information was obtained from him.

The concrete cracks are investigated from 2005. There are twenty two (22) kinds of cracks and eight (8) of them are active and may advance further. The eight (8) kinds of cracks are shown in [Fig. 3.3.1] to [Fig. 3.3.2].



Source: Presentation of Prof. Amin modified by Survey Team

[Fig. 3.3.1] Crack types of ① and ② of PC Box Girder,



Source: Presentation of Prof. Amin modified by Survey Team

[Fig. 3.3.2] Crack types of ③ to ⑧of PC Box Girder

The crack type ① appeared when four (4) or five (5) segments of the east side were cast, these cracks were observed all over the deck surface and in the longitudinal direction. Afterwards the design was changed and I section steels were added. Therefore there were no more cracks for the later segments. But these cracks developed further during 2005 to 2006. The cause was unknown.

The crack type ② appeared on the bottom of the box girder during the construction. The contractor, Hyundai repaired the cracks with the epoxy resin during the construction, which the study team confirmed at the site.

The cracks types ① and ② were already repaired and cannot be confirmed by eyesight. The crack type ③ is still widening. This crack appeared at the center of the upper slab plate along the whole length of 4.8km. This crack was sealed by epoxy resin, by Hyundai. But the epoxy resin was not pressured into the crack so that it did not reach the deeper areas. This crack appeared on the segments shown in the park, too, so that this crack was not due to the loading after the erection.

The cracks type ④ appeared on the bottom of the approach slab viaducts, during the construction. Steel strips were attached to the bottom surface and the viaducts were repaired.

The crack type ⑤ began to appear since around the year 2005. This type of crack is observed on the slab, in the longitudinal direction, above the opposite side web from the rail track and on the center side.

The crack type ⑥ appeared after crack type ⑤, on the slab, in the longitudinal direction, above the opposite side web from the rail track and on the outer side.

Both crack types of ⑤ and ⑥ appeared due to the existence of one lane on the cantilever section and the bending of the cantilever section downward.

The crack type ⑦ appeared on the haunch section between the top slab and the web opposite to the train track and in the longitudinal direction. Later the crack type ⑧ appeared on the haunch section between the top slab and the web near the train track and in the longitudinal direction. The crack types of ⑦ and ⑧ are still growing and the counter measures are being studied.

Out of these cracks, to prevent the extension of the crack types of ③, ⑤, and ⑥, a Chinese contractor repaired the bridge. About 25cm wide thin CFRP (Carbon Fiber Reinforced Plastic) plates with the interval of about 25cm, were attached on the slab surface in the perpendicular direction from the bridge axis all over the entire bridge section, i.e. 4.8km. Afterwards, the top slab was painted with the epoxy resin coating and paved by SMA (Stone Mastic Asphalt).

In the beginning, BBA tried to let Hyundai repair the cracks as a compensation work but Hyundai refused. Then BBA contracted out the work. After the above repair, the vibration of the girder in the perpendicular direction from the bridge axis was measured. It was observed that the frequencies were raised and the stiffness was increased, which proved the effect of the repair. As for the train running over the bridge, the vibration by the meter gauge trains was larger than that of the broad gauge train. This was observed by Prof. Choudhury. On the contrary to their expectation, the vibration by the meter gauge train was larger because the meter gauge trains were more unstable than the broad gauge trains.

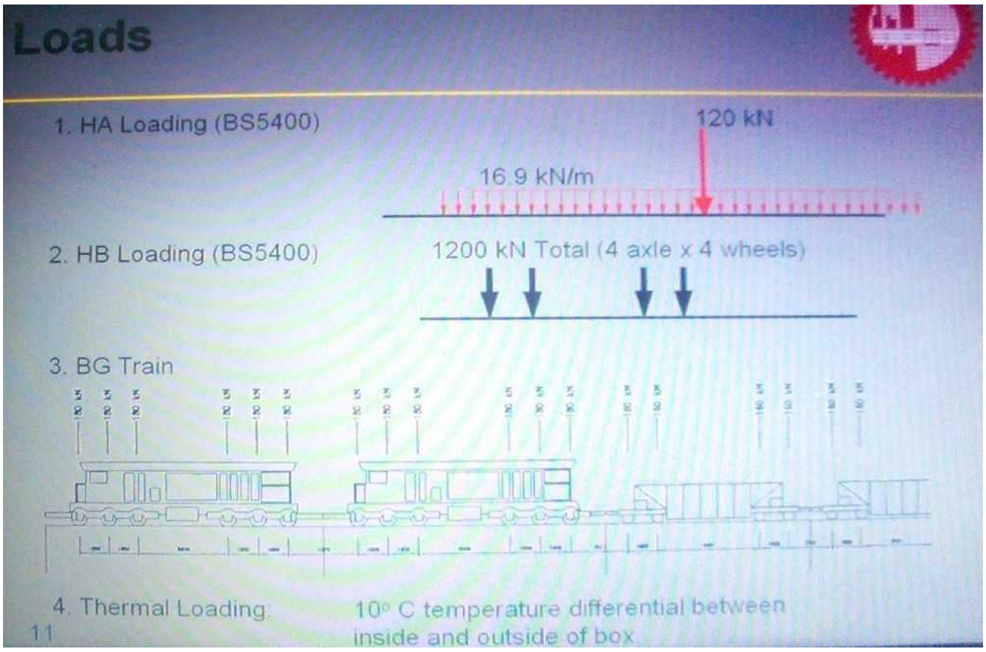
The Bangabandhu Bridge was opened in 1998, at that time, the concrete slab was not paved and the concrete surface was exposed. Thus it was quite easy to confirm the cracks. In 2011, the slab was covered with the asphalt pavement, which was planned from the beginning and it was recommended to pave the surface after the creep deformation was finished, which was explained by BBA. But this seemed to be a little strange, because the asphalt pavement could follow the creep deformation of concrete easily and it was not necessary to wait for the end of the creep deformation. The construction supervision consultant was RPT of UK.

The design thickness of pavement is 50mm. Over the glued CFRP plates and the epoxy resin coating, 50mm thickness asphalt pavement was applied and the thickness became 8mm thicker than the original design. But this was within the allowable error of the design. According to the study of Prof. Amin, the reasons for these cracks are as follows; the cracks are mainly concentrated on the top slab, which symbolizes the damages of this bridge. The reason should be the inadequacy of the lateral reinforcing bars of the top slab. Many pages of calculation documents were used for the bridge axis direction calculation. But the bearing strength of the lateral direction of the box girder was not designed properly or hardly investigated. The pre-stressed tendons in the lateral direction are inadequate.

The temperature of the surface of the top slab sometimes reaches 55℃ under the sunlight. While the temperature of the inside surface under the top slab is about 27℃. If it rains or in the extreme case, the hail storms come, which actually occur 4 or 5 times a year, the temperature of the top surface drops suddenly whereas the inside temperature keeps almost the constant degree. In the design calculation, the temperature difference of 10℃ only was adopted and this seemed to be too small.

Due to this temperature difference, the lateral tension stress to pull apart the top slab at the center occurs. The connections of lateral reinforcing bars are concentrated at the center of the top slab and these connections form a weaker point against the tension and consequently many cracks appear. This may be the theory behind the occurrence of cracks. The north side cantilever section is thicker, about 50cm thick compared to the 30cm thickness of the road side cantilever section, because this section supports the railway track. Because of this thickness, the temperature difference effect is smaller and there are no cracks on this north side cantilever section.

Another reasons are, the inadequate design study of the loading combinations and the overloaded trucks. In Bangladesh, three (3) types of train loading are considered for the bridge design, namely ① HA Loading, for private sector and based on BS5400, 16.9kN/m distributed load and 120kN concentrated load, ② HB Loading for military based on BS5400 in total of 1200kN, two (2) axle (2) bogie freight car, and ③BG Train.



Source: Presentation of Prof. Amin

[Fig. 3.3.3] Live loads of Bangladesh railway bridges

With these three (3) loading types, eight (8) variety of combination of loading modes need to be studied, with or without the train loading, with or without train loading with one (1) directional train loading or with two (2) directional train loading, etc. But this eight (8) combination was not studied for the Bangabandhu Bridge. The reason is unknown.

(3) Information of Bridge Maintenance from BBA

The Bangabandhu Bridge consists of seven (7) sets of seven (7) span continuous PC Box Girder Bridge. Therefore there are eight (8) expansion joints and six (6) hinges. (Refer to 2. in [Tab. 3.3.1]). A 50mm settlement is allowed for hinges between piers but at present, there are no settlement for the last eighteen (18) years. If the settlement occurs, PC cables will be applied and tensioned. But this has never been done.

Axles of all of passing trucks are measured and if the axle load is below 16t, it is allowed to pass the bridge. If the axle load is more than 16t, even 100kg more, it is not allowed. But the axle load of 16t is too large. Generally speaking, the axle load up to 10t should be allowed. The bridge is monitored in real-time basis and the scene of the strong earthquake motion on April 25th, 2015 is also recorded.

3.3.2 Substructure

Substructures were inspected from the boat by the survey team. It seemed there were no problems (Refer to 3. of [Tab. 3.3.1]). There were inspection corridors around the piers. The bearings and the seismic resistant devices could be eye-inspected from there and they were well-maintained. There were no information of damages of the piers from BBA, Prof. Amin nor Prof. Choudhury.

From BBA, the following information was obtained. The scouring once reached the depth of -33m near one (1) guide bund because the flow speed becomes larger near the guide bunds. This slightly surpassed the design scouring depth, which is assumed to be -30m. The water depth of each pier is measured periodically and one record showed the depth of -9.5m. But the design scouring depth is -27m. Generally speaking, the water depth around the pier is about -4m. Then the scouring effect is not so severe.

There are no larger ships on the river. According to BIWTA, there is a possibility that the inland passenger boat service could begin in the future. But according to the information of the local engineering consultant, in Bangladesh, the passenger boat service was well-developed during the English Colony era because the road network was not well-developed. Recently the road network is being improved and much more developed than ever. Passengers prefer bus services because of their faster speed. Hence the number of passengers who use boat services is declining. From this tendency, there is a very low possibility that the passenger boat service which utilizes the navigation route under the Bangabandhu Bridge, will begin in the near future.

For the past eighteen (18) years, there were no ship collision accidents against the piers. This may be due to the fact that the piers are lighted during the night so that they are visible from the passing ships (Refer to 28.to 30. [Tab. 3.3.1]).

The settlements of piers are also recorded by BBA. The maximum measured settlement is 24mm which is within the allowable maximum settlement of 50mm. Then the bridge is judged to be safe.

For pile foundations, large diameter of φ2.5m to 3.15m steel driving piles were adopted. One pile foundation consisted of two (2) or three (3) battered piles. Number of piles varied according to the ground condition. The deepest pile reached the depth of -72m. In total 121 piles were used. A 250t Floating Crane was used to place pile caps on the top of the piles to form piers (Refer to 31. [Tab. 3.3.1]). The floating crane was brought to the site from Korea. At that time there were no bridges downstream and it was possible to bring in the floating crane. But at present, there is the existing bridge and the new railway bridge is planned upstream, so that it is almost impossible to utilize floating cranes.

3.3.3 River Training Works（RTW）

The River Jamuna was narrowed from 10km to 4.8km by the construction of the Bangabandhu Bridge and flood risk at river banks seems to be increased.

RTWs were constructed for the purpose of mitigating flood disasters. RTW consists of two (2) guide bunds (GB) at each end of the Bangabandhu Bridge and two (2) hard points (HP) about 10km upstream; at Bhuapur on the left bank and at Sirajganj on the right bank. GBs are the measures to protect abutments and approach roads. HPs are located upstream of about 10km of both river sides of the Bangabandhu Bridge for protecting river banks and stabilizing river flow course.

Source: Survey Team

[Fig. 3.3.4] Locations of guide bunds and hard points

(1) Scouring Conditions

Scouring is caused by flood flows and scour depth is maximized at the time of flood peak. The scouring pit is backfilled during the flood recession time, therefore actual maximum scour depth is difficult to measure.

Maximum scouring is observed in 2006 at around the right GB with scouring elevation of PWD-34m which is a bit deeper than the design scour level of PWD-30m.

The scouring elevation of PWD-9.5m at the pier was measured by BBA. The scouring level is normally PWD-4.0m, but design scouring level is estimated at PWD-27.0m. The course of main stream was changed by floods year by year and the location of the main stream changed irregularly. Design scouring level at the pier is PWD-27m, and the maximum scouring level of PWD-34m was observed at GB. Considering the maximum scouring level of PWD-34m, the design scouring level of pier should be PWD-34m for safety, though the design scouring level is PWD-27m. The detailed simulation and/or model test should be validated during D/D (Detailed Design) stage.

(2) Guide Bunds

GBs were settled in 1997 around the existing bridge ends for the protection of banks and approach roads. Details of GBs are as follows.

- GBs are maintained by BBA (entrusted to private sector).
- Scouring level of PWD-34m was measured at upstream side of right GB in 2006.
- Upstream side of right GB was damaged in 2014, but was repaired already.
- In the field survey, it is confirmed that GBs are maintained well.


Right bank, upstream view


Left bank, upstream view

Source: Survey Team

[Fig. 3.3.5] Conditions of guide bunds

(3) Hard Points

HPs were built on the both riverbanks at around10km upstream from the Bangabandhu Bridge. The function of HPs is to protect bank against erosion by flood flow and to stabilize river course. Details of HPs are as follows.

- Bhuapur HP on the left bank (built in 1995) is maintained by BBA.
- Sirajganj HP on the right bank is maintained by BWDB.
- Revetment of Sirajganj HP is often damaged by the flood (no detailed information).
- Both of HPs were damaged in 2007 (already repaired).
- It was confirmed during the field survey that HPs are well maintained.

Following points were confirmed during the field survey.


Right bank, upstream view


Left bank, sandbags for protection

Source: Survey Team

[Fig. 3.3.6] Conditions of hard points

- Rubbles (soft stone produced in Bangladesh) and concrete blocks are prepared for bank protection at Sirajganj HP.
- The river bank of Bhuapur HP was found to be eroded by flood flow during the field survey. BBA prepared many sandbags for protection measures and residents set them along the river side.
- There is an embankment 150m inside from a shoreline and surface of embankment is covered by ballast with asphalt at Bhuapur HP. There are quick-built houses in the floodplain.
- From the interview to the residents at Bhuapur HP, flood water level rises between 1 to 2 m over the flood plain in monsoon season. But, there is about 2m allowance to the bank crest.

During the field survey, it was confirmed that the maintenance of RTWs have been adequately executed. Existing RTWs were well functioned, and additional RTWs are not necessary (mentioned in ADB-F/S).

3.4. Design Condition

Based on ADB-F/S and the site investigation results, the design conditions of the new railway bridge are proposed as follows.

3.4.1 Horizontal Alignment

When the Bangabandhu Bridge was constructed, the east and the west guide bunds[5] (GB hereinafter) were constructed by the Dutch construction company. There are no major damages which need the repair work, after the completion.

The same GB will be utilized to construct the new railway bridge. The bridge will be constructed inside of GB and upstream or downstream of the existing bridge. In ADB-F/S, the new railway bridge is planned 300m upstream of the Bangabandhu Bridge. According to “Ministry Ordinance for Structural Standard for River Administration Facilities” in Japan, it is specified that “If the distance between an upstream bridge and a downstream bridge is more than the river width or 200m, the rules for the adjacent bridges do not need to be applied”. But this may be applicable for smaller rivers in Japan and may not be applicable for larger rivers in Bangladesh. ADB-F/S shows the influence of existing piers to the downstream and that of the new piers to the existing downstream piers as shown in [Fig. 3.4.1] and [Fig. 3.4.2].

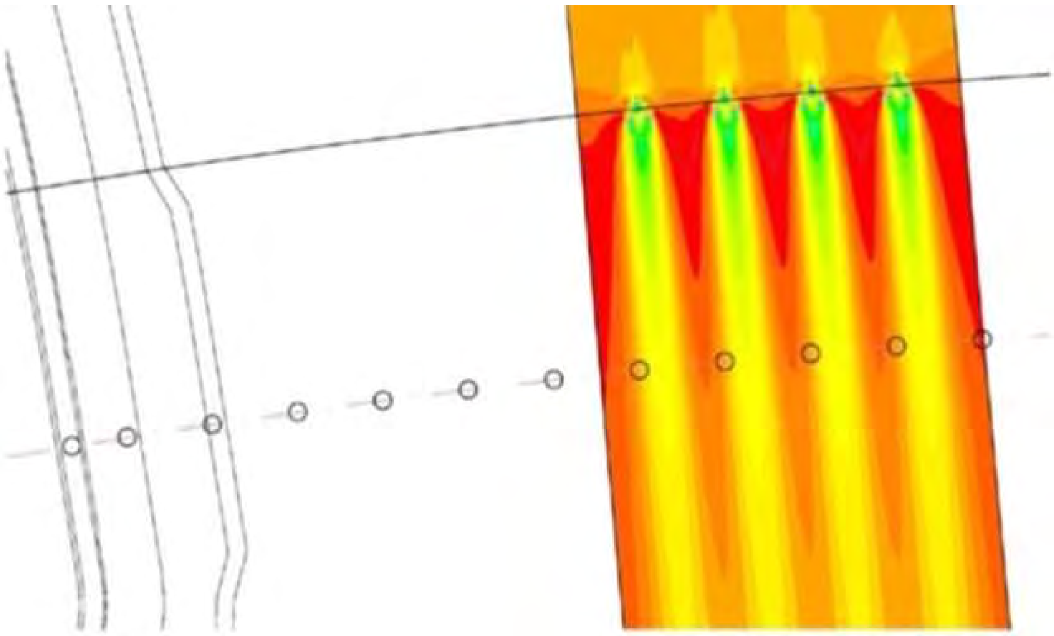
But in ADB-F/S, it showed that a new bridge 300m upstream of the Bangabandhu Bridge would not influence largely on the existing piers. Therefore in this study, too, the location of the new railway bridge should be whether 300m upstream or 300m downstream of the existing bridge. In ADB-F/S, the positions of new piers are exactly upstream of the locations of the existing piers and two (2) bridges have the same spans, although the flow directions vary depending on the locations of sand bars. But if the pier locations of the new railway bridge are different from ADB-F/S, another detailed study of

[5] A guide bund is one kind of embankment developed especially in Bangladesh, which is designed to protect bridge abutments with its curved arms to prevent scouring behind abutments.

influences on the existing piers may be needed.

Source: ADB-F/S

[Fig. 3.4.1] Influence on downstream by piers of the Bangabandhu Bridge



Source: ADB-F/S

[Fig. 3.4.2] Influence of 300m upstream piers of new railway bridge on existing piers

Although this is not the case of the Jamuna River, on the Padma River, which flows from west to east of the country and merges to the Jamuna River at the downstream of the Bangabandhu Bridge, there is the Harding Bridge which was constructed about 100 years ago and upstream of the confluence of the Jamuna River. Recently the Lalon Shah Bridge was constructed about 300m downstream (between 270m to 292m) of the Harding Bridge. The piers of this bridge is quite healthy at present and no bad influences are observed.

Source: Google earth

[Fig. 3.4.3] The Harding Bridge and the Lalon Shah Bridge

The location of the new railway bridge, upstream or downstream of the Bangabandhu Bridge, is studied. The satellite image of the Bangabandhu Bridge is shown in [Fig. 3.4.4]. As shown in the figure, the Bangabandhu Bridge is an R=12,000m curved bridge. The west side GB ends soon downstream of the Bangabandhu Bridge, which makes it difficult to plan a new railway bridge downstream of the Bangabandhu Bridge.

But as shown in [Fig. 3.4.3], the Lalon Shah Bridge is constructed just outside of the existing GB, it may be possible to construct a new railway bridge downstream of the Bangabandhu Bridge without the addition of GB. But if the new railway bridge is constructed downstream, rail tracks will cross the roads on both banks and rail overpass bridges are needed which pushes up the construction cost. There are no merits to construct the new railway bridge downstream. Instead three (3) alternatives 300m upstream of the Bangabandhu Bridge are compared. They are shown in [Fig. 3.4.4].

Alternative 1 has the same alignment as ADB-F/S and is parallel to the Bangabandhu Bridge (R=12,000m). This alternative has a curvature of R=12,300m and a length of 4,810m.

Alternative 2 has straight alignment and 300m upstream of the Bangabandhu Bridge at its center. The reasons for the curved alignment of the Bangabandhu Bridge is from the interview investigation, as follows;

(1) If the straight alignment is adopted, the driving becomes tedious and could make the drivers sleepy.

(2) The train track is on the bridge, if cars are facing the train front lights, it would last for a long time. But if the bridge is curved, the length of time to face the train lights is comparatively shorter and it is safer for driving.

(3) If the bridge is curved, it is aesthetically better.

From these reasons, the new railway bridge does not need to adopt the curved alignment. Alternative 2 adopts the straight alignment, but the total bridge length is 4,810m and cannot be shortened from Alternative 1 which is also 4,810m long, because GBs are not exactly parallel.

For Alternative 2, there are no problems to connect to the existing railway on the right bank shown in the left in [Fig. 3.4.4]. But on the left bank shown in the right in [Fig. 3.4.4], there is a military facility, it is difficult to cross this facility and the precise design of rail track alignment is needed to connect to the existing railway based on the land survey.

Alternative 3 adopts the straight alignment, too. To avoid the military facility, the starting point on the left bank is the same as that of Alternative 1. The straight line is extended to the opposite GB in the west. The bridge length, 5,210m, is longer than the other alternatives.

Note：(1) Curved bridge, (2) Straight bridge, (3) Straight bridge with same starting point on east bank as (1)

Source: Google earth

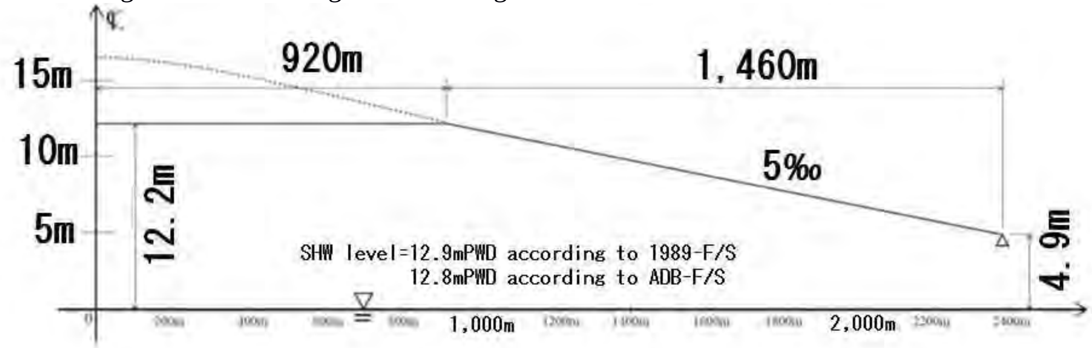
[Fig. 3.4.4] Horizontal alignment alternatives of the new railway bridge

These three (3) alternatives are compared. Alternative 3 is longer and more expensive. Alternative 1 and 2 have the same bridge length and they cost almost the same. For Alternative 2, the rail track alignment on the east bank needs to be studied carefully to avoid the military facility. But Alternative 1 does not need such a consideration. Alternative 1 has a curved alignment and is parallel to the Bangabandhu Bridge and aesthetically better. Bangladesh side also prefers the curved alignment and Alternative 1 should be selected as the best horizontal alignment.

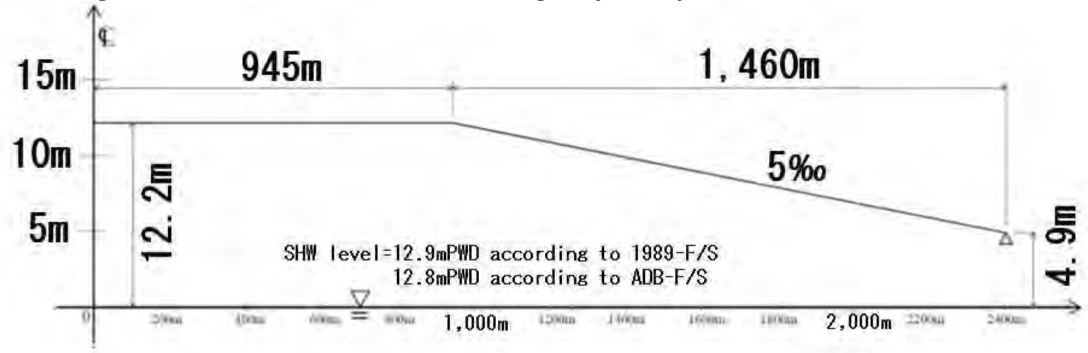
3.4.2. Vertical Alignment

The vertical alignment of the Bangabandhu Bridge is investigated based on F/S report in 1989. The vertical alignment of 1989-F/S and that proposed in this study based on ADB-F/S are compared in [Fig. 3.4.5]. In ADB-F/S, a vertical curve alignment is proposed at the center section (945m section in the figure) in a same manner as the Bangabandhu Bridge. But as explained later, this vertical curve should be eliminated from the new railway bridge and the straight horizontal alignment replaces the vertical curve. Then the vertical alignment of this study is explained as “Vertical alignment based on ADB-F/S and rearranged by Study Team”.

(1) Vertical alignment of the Bangabandhu Bridge



(2) Vertical alignment based on ADB-F/S and rearranged by survey team



Source: F/S of the Bangabandhu Bridge and ADB-F/S modified by Survey Team

[Fig. 3.4.5] Comparison of vertical alignments between the Bangabandhu Bridge and the new railway bridge

The Jamuna River is classified as Category II (refer [Tab. 3.4.1]) in which navigational width of 76.22m (=250ft) and the height of 12.20m (=40ft) need to be secured. On the upper side of [Fig. 3.4.5], the clearance of the Bangabandhu Bridge is shown based on 1989-F/S. The 12.20m height is secured for the center 920m×2=1,840m section. From there, the vertical alignment descends down to 4.90m height at the banks with the gradient of 5‰(＝0.5%). The dotted line in the upper side figure shows the curved vertical alignment for the 1,840m section instead of the straight line. In 1989-F/S and on page E.1-4, it is written that "In 1.8km center section, the horizontal line was planned but later the curved vertical alignment was introduced."

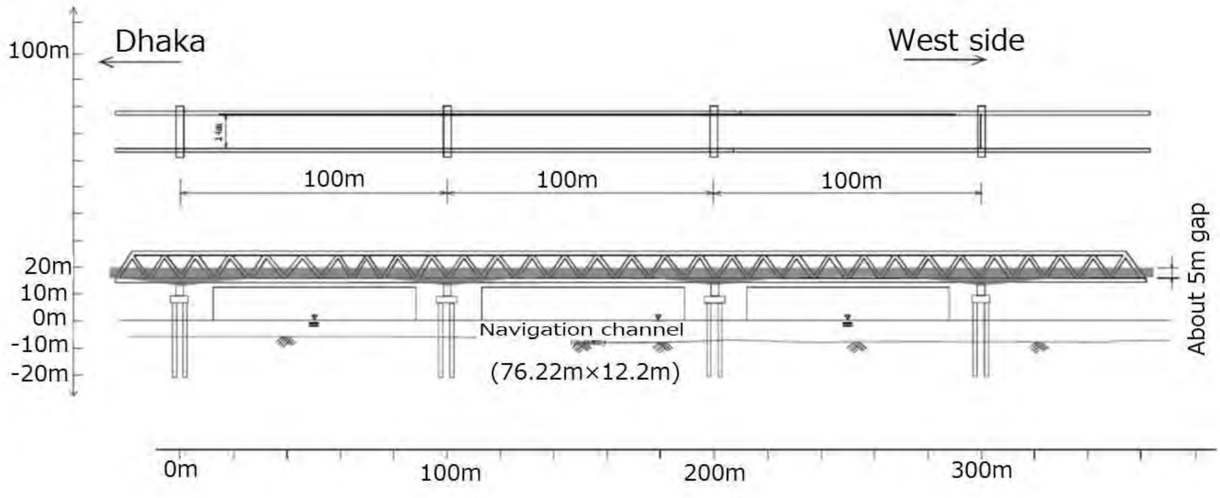
From the as built drawings of the Bangabandhu Bridge, a circular vertical curve (R=188,002.35m) is introduce for the center 1880m (=940m×2) section. This circular curve has 5‰ gradient at its both ends. Due to this vertical curve, the center of the bridge is 2.35m higher than 12.20m, the clearance height of Class II. This coincides with the fact that BBA told us "At the center of the bridge, 15.5m×76m navigation clearance is secured."

For the new railway bridge, it is not necessary to secure the navigation clearance of 15.5m at the center of the bridge, instead 12.2m high navigation clearance (Class II) needs to be secured. When the new railway bridge is designed, it is better to avoid the long ascending gradient as far as possible. Therefore the center curved vertical alignment should be eliminated. The vertical alignment of ADB-F/S adopted the same vertical alignment of the Bangabandhu Bridge. The vertical alignment of this study has a horizontal straight line as shown in the lower side of [Fig. 3.4.5]. As shown in the figure, both 5‰ gradient sections are identical to the Bangabandhu Bridge. As the new railway bridge total length is slightly longer than the Bangabandhu Bridge, the horizontal section at the center is 1,890m which is slightly longer than 1,880m of the Bangabandhu Bridge.

The center 1.8km section of both the Bangabandhu Bridge and the new railway bridge, can be within the sand bars during the dry seasons and larger ships which are barely within the Class II height, may not be able to pass the bridges. But at present, larger ships are not passing and during the dry seasons, the lower clearance height sections near GBs can be used for navigation. BIWTA which controls the inland navigation, requested us to secure the Class II height all along the bridge as far as possible for the future navigation (Refer to Sec.3.2.1).

The vertical alignment in the lower side of [Fig. 3.4.5] consists of one (1) horizontal line and 5‰ gradient line. Between these two (2) lines, R=10,000m curve needs to be inserted as the transition of railway.

If the structure types are different, the center horizontal straight line section can be elongated by reducing the height from the top of the navigation clearance to the rail level. In ADB-F/S, a PC Box Girder Bridge Alternative is adopted and the height from the navigation clearance to the rail level is about 5m. If a Steel Through Truss Bridge Alternative is adopted, the height is about 1m. Then if the rail surface level is the same for both Alternatives, the center horizontal section of the Steel Through Truss Bridge Alternative can be elongated more.



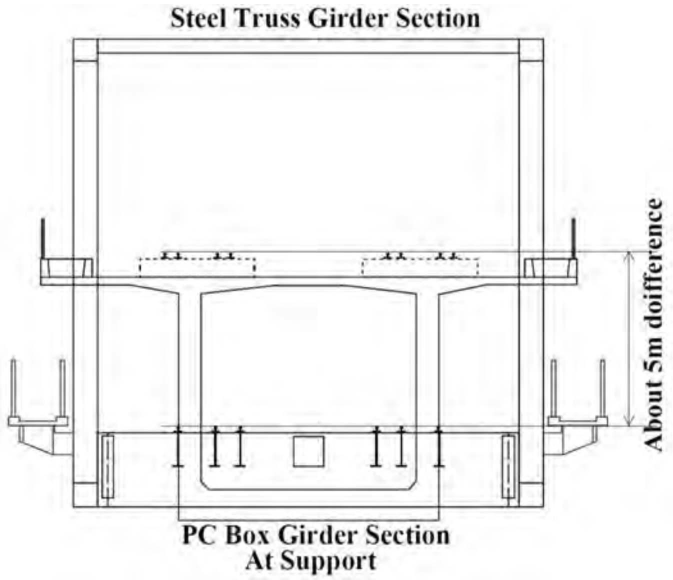
Source: Survey Team

[Fig. 3.4.6] Difference of height from navigation clearance to road surface

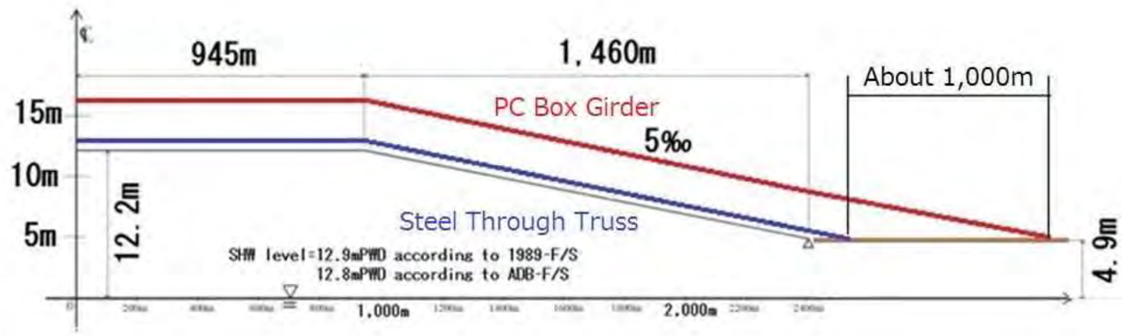
But the Bangabandhu Bridge keeps the navigation width of about 1.8km. It is meaningless for the new railway bridge to have a longer navigation width than 1.8km. Then regardless to the bridge types, the navigation width should adopt the length of 1,890m as explained above.

If the Trough Truss Bridge is adopted, the abutment height difference of PC Box Girder Bridge Alternative of ADB-F/S and the Through Truss Alternative is about 5m. This means that the length of the approach viaduct and the embankment becomes about 1,000m shorter for one bank side and in total 2,000m shorter for both banks. This reduces the cost (Refer to [Fig. 3.4.7]).

1. Cross Section



2. Profile



Source: Survey Team

[Fig. 3.4.7] Rail Level Difference according to bridge types

3.4.3 Hydraulic Conditions

(1) Hydraulic Factors

As the new railway bridge is located about 300m upstream of Bangabandhu Bridge, the hydraulic design parameters of Bangabandhu Bridge (commissioned in 1998) will be applicable. Details are listed as follows according to ADB-F/S.

- Design Discharge (100 year return period) 91,000m^3/s
- Design High Water Level (100 year return period) PWD+15.50m
- SHWL (Standard High Water Level) PWD+12.80m
- SLWL (Standard Low Water Level) PWD+6.30m
- Maximum Scour Depth PWD -32.0m
- Maximum Flow Velocity 3.3m/s

If the distance between an existing bridge and a new bridge is 200m or more, these bridges are not defined as "adjacent bridge" according to "Cabinet Order concerning Structural Standards for River Management Facilities, Japan River Association" which means that the new railway bridge does not hydraulically affect the Bangabandhu Bridge.

However, further hydraulic investigation should be needed to confirm whether the new bridge hydraulically affects the Bangabandhu Bridge or not, because hydraulic conditions of the River Jamuna must be very be different from Japanese rivers.

(2) Navigation Clearance

The soffit level of bridge is determined by considering design high water level for no navigational river channel and is determined by considering navigation clearance for navigational river channel.

BIWTA classifies the River Jamuna upstream of the port Baghabari as a Class II route (refer [Tab. 3.4.1]). At least one (1) span of a bridge must comply with the navigation requirement for the river traffic. The base level for measuring the vertical clearance is Standard High Water Level (SHWL).

The new railway bridge requires 12.20 m vertical air clearance above SHWL and 76.22m horizontal width according to [Tab. 3.4.1].

[Tab. 3.4.1] Navigation clearance requirement

Navigation Class	Min. Horizontal Clearance (m)	Min. Vertical Clearance above SHWL (m)
Class- I	76.22	18.30
Class- II	76.22	12.20
Class- III	30.48	7.62
Class- IV	20.00	5.00

Note: This table is the same as [Tab. 3.2.1].

Source: Bridge Design Standards for Roads & Highways Department、BIWTA, 1991

The navigation course is difficult to identify because the location, height and extent of sandbar had changed irregularly. The Bangabandhue Bridge is located 300m downstream from the new railway bridge, therefore the consistency for navigation between the two (2) bridges should be maintained, which means that soffit level of the new railway bridge for navigation should be kept at 12.2m or more above SHWL.

Concerning the relationship between the pier locations of the new railway bridge and the Bangabandhu Bridge, it is recommended that there is no pier (of both bridges) in the horizontal (cross sectional) extent of 76.22m, because skewed directional navigation to the flow direction is not recommended. The maintenance including dredging and/or placement of navigation course are the responsibility of BIWTA.

(3) Clearance for RTWs

Design height level of the RTW should be PWD+16.5m, which is corresponding to the 100-year high water level[6] of PWD+15.5m plus freeboard of 1m.

3.4.4 Design System

(1) Design Concept

Allowable Stress Design Method had been used for railway bridge design in Japan, but it was shifted to Limit State Design Method in 1983 and it evolved into Performance Verification Design method based on the Limit State Design Method in 1999. In the latest design method, the Limit States are classified as Ultimate Limit States (sectional failure limit state, rigidity stability limit state, deformation limit state, and mechanism failure limit state), Serviceability Limit States, and Fatigue Limit States in which the safety of the structure is verified by comparing design stress against each limit state by using Safety Factors (Structure Factor, Load Factor, Material Factor, Member Factor, Structural Analysis Factor) and Adjustment Factors (Load Adjustment Factor and Material Adjustment Factor). Seismic performance is verified by special provision separately based on Dynamic Analysis Method or Static Analysis (Non-linear Response Spectrum Method).

On the other hand, AASHTO which is commonly used in Bangladesh is based on Load and Resistance Factor Design Method (LRFD). This is conceptually equivalent to the design method applied for railway bridge design in Japan, but it must be noted that AASHTO is a design standard compiled for the road bridge structure and some provisions peculiar to railway bridges are required to be supplemented to the standard when it is applied for railway bridge design.

(2) Load System

Loads lineup used for railway bridge design in Japan are Dead load, Train load, Impact, Centrifugal load, Train lateral load, Wheel lateral load, Breaking load, Traction load, Maintenance vehicle load, Crowd load, Long rail longitudinal load, (Pre-stressed load, Dry shrinkage effect, and Creep effect in case of concrete structure), Temperature fluctuation effect, Soil force, Water flow, Wave force, Wind load, Snow load, Earthquake effect, Ground displacement effect, Supporting point displacement effect, Construction load, and other loads.

Load lineup of AASHTO used in Bangladesh is Dead load, Live load, Breaking load, Train centrifugal load, Train collision load, Vessel collision load, Crowd load, Water flow, Wind load, and Earthquake effect. Since these loads are the ones relevant to automobile, the standard requires designer to prepare other set of loads peculiar to railway if the bridge is served for railway too. The new railway bridge is served only for railway without having automobile run so that the design requires to take account of railway loads set defined in Bangladesh.

(3) Live Load

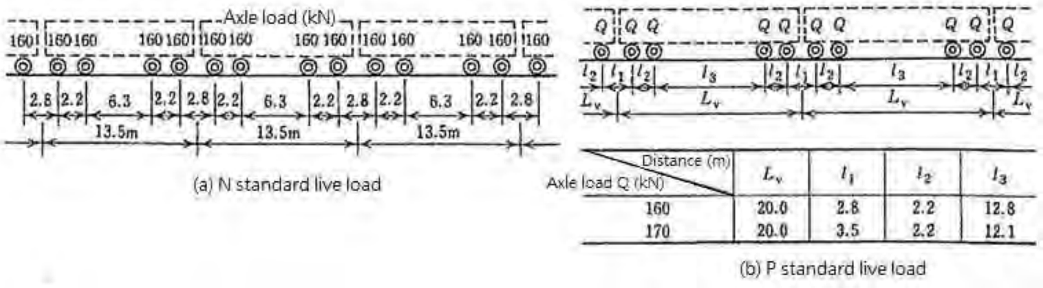
Live load is one of the load used for structure design and it corresponds to train load in case of railway structure7.

Live load for railway structure used in Japan depends on limit states for verification. The standard trainloads are shown in [Fig. 3.4.8].

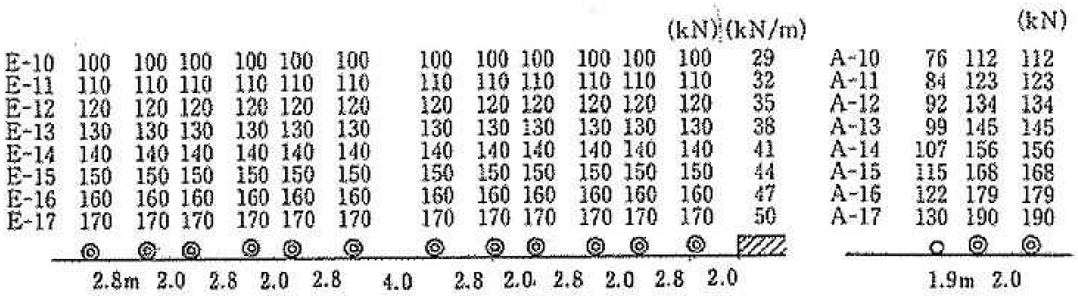
[6] DHW: Design High Water Level is estimated by the exceedance probability analysis for the identified return period (100-year, 500-year, etc.). SHWL for the rivers with non-tidal effects is calculated at SHWL = FML 5%, where FML5% is the fortnightly mean water level with 5% exceedance probability. It can be said that SHWL will be exceeded for about 18 days in a year on the long-term average.

[7] Source: ：Railway technical term dictionary（(Railway Technic Research Institute）

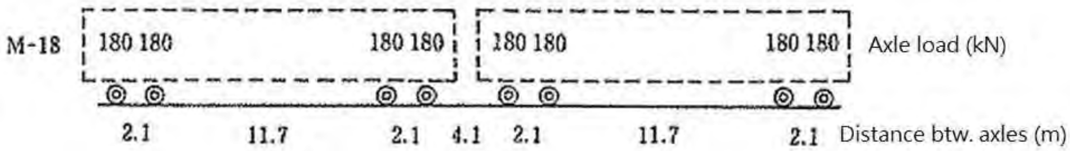
(1) NP Load (for HSR)



(2) EA Load (for Locomotive)



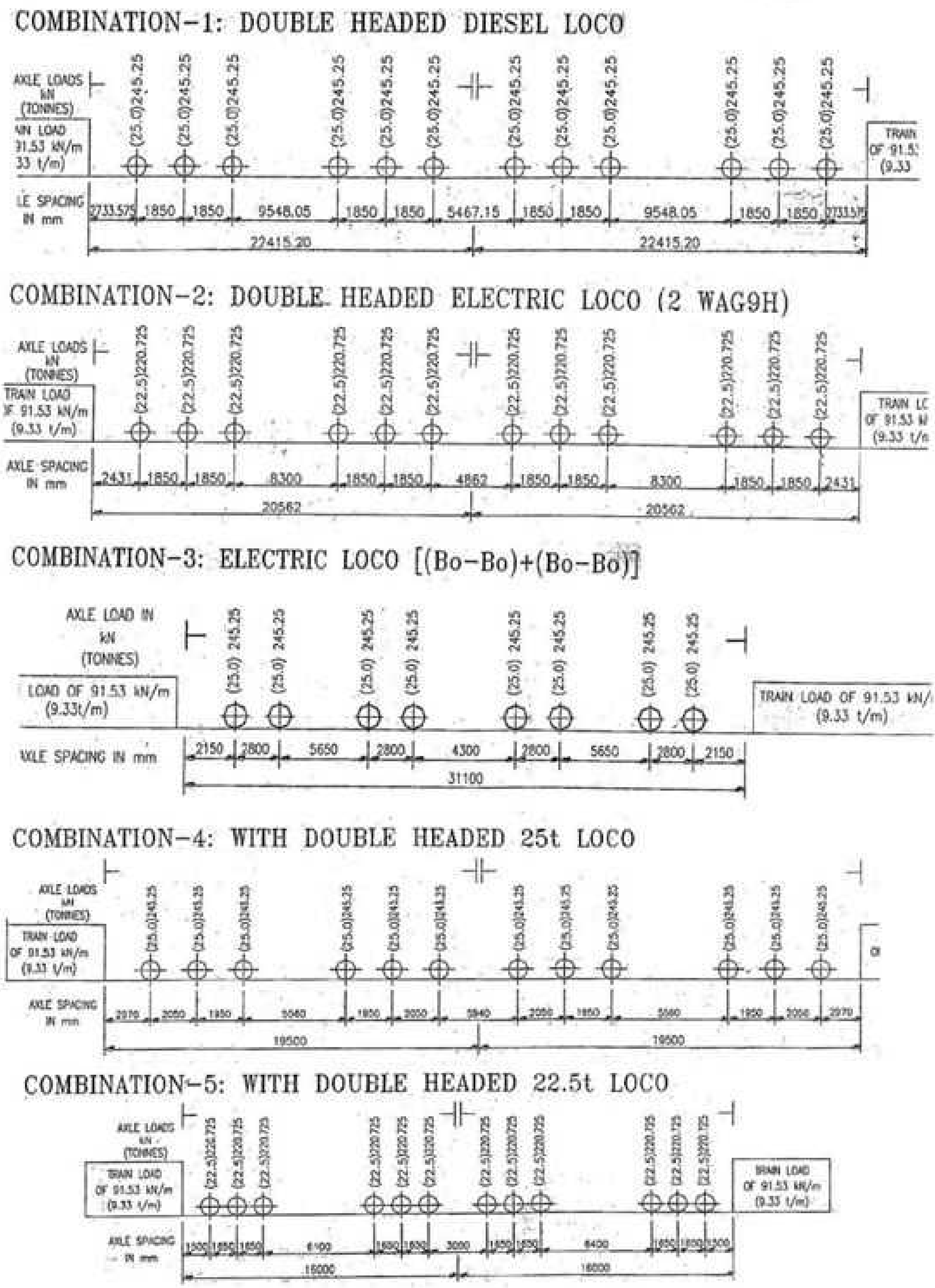
(3) M Load(for electric car and diesel car)



Source: Structure design standard (Railway Technical Research Institute)

[Fig. 3.4.8] Train live load system in Japan (NP load)

Indian standard train loads are basically used in Bangladesh as they are shown in [Fig. 3.4.9].



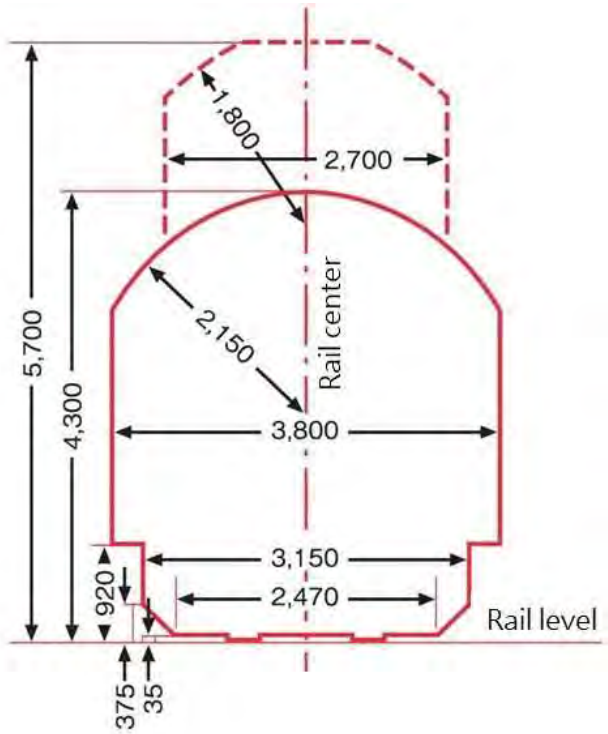
Source: BR

[Fig. 3.4.9] Train load system in Bangladesh

(4) Construction clearance

Construction clearance is a space boarder line secured above track in which any parts of the structure must not encroach so that trains will not touch any parts of the structure in order for the safety of train running. It is an inflated space of maximum measurement of train body cross section placed on straight track section in static condition with enough tolerance space for displacement of body due to spring and electrical shock safety in case of electrified section. In curved sections, the construction clearance must be enlarged considering lateral displacement of train body toward inside of the curve and track cant at the curve.

The construction clearance used for railway structure design in Japan can be defined by railway operator as long as it complies with regulation set by MLIT (Ministry of Land, Infrastructure, Transport, and Tourism). [Fig. 3.4.10] shows the construction clearance used in JR for ordinary railway sections and this is different from that of Shinkansen (HSR) section.

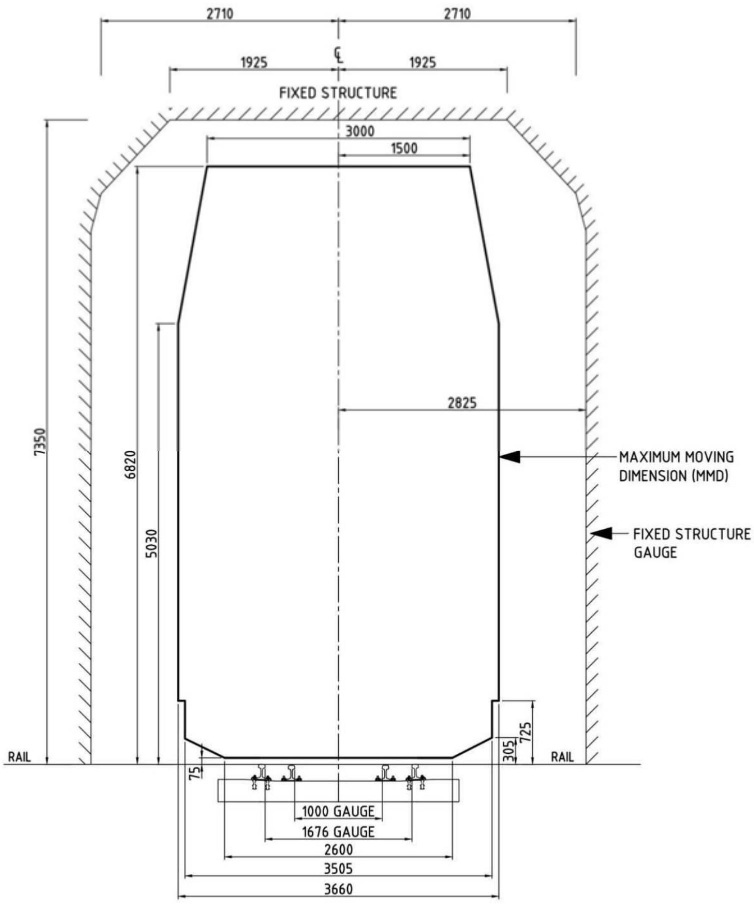


Note: The solid line represents basic construction clearance and the dotted line represents construction clearance for electrified section considering power supply facilities such as suspension line and insulation devices.

Source: Website of Shinsei Technos

[Fig. 3.4.10] Construction clearance of JR lines (ordinary line)

[Fig. 3.4.11] shows the construction clearance based on Indian Railway Standard used in Bangladesh. Although this construction clearance is used in this survey, it must be reviewed during detailed design stage considering the future mode of railway service of the new railway bridge such as electrification and service for double decker container freight train for DFC (Dedicated Freight Corridor of India).



Source: ADB-F/S

[Fig. 3.4.11] Construction clearance of railway structure in Bangladesh

3.5. Cost Estimating Condition

3.5.1. Construction Conditions

(1) Transportation Route for Construction Equipment

The proposed construction site for the new railway bridge is located approximately 300km from the coast. Since the site is also located around 100km by road from Dhaka, the transportation of materials and equipment involves considerable difficulties. Padma Bridge, which is currently under construction downstream, is classified as a Category I bridge by BIWTA, and will therefore have a navigational clearance of 18.3m. Bangabandhu Bridge, on the other hand, is located on a Category II section of the river and thus has a navigational clearance of only 12.2m.

Since Padma Bridge did not yet exist when Bangabandhu Bridge was being constructed and there were also no other bridges over the river at the time, it was possible to tow large floating cranes and other equipment upriver from the sea. For this reason, 250 ton floating cranes could be used to construct the pile caps for the foundation of Bangabandhu Bridge. However, the new railway bridge is located upstream from both Bangabandhu Bridge and Padma Bridge which makes it almost impossible to tow high floating cranes to the site. To be able to use large (500 ton etc.) crawler cranes for construction, they will therefore first have to be disassembled and transported by barge to the site, where they will then be reassembled using 25 ton truck cranes.

(2) Procurement of Construction Material

It is problematic to procure aggregate for the construction of concrete structures in Bangladesh. As Bangladesh does not seem to produce good quality (high-strength) coarse aggregate, and it is generally imported from neighboring countries such as India and Myanmar. Since it is not easy to import crushed stone, it is necessary to investigate how this issue is dealt with on other large-scale construction projects.

The difficulty of procuring coarse aggregate in Bangladesh pushes up the unit price of concrete.

Since Bangladesh is a country which has largely been formed by soil and sand carried by its rivers, it would seem easy to obtain fine aggregate. However, care needs to be taken since the soil usually contains silt, and it may therefore be necessary to remove the silt in order to obtain good quality fine aggregate.

(3) Fabrication Yard

The construction site of the new railway bridge is located in a suburban area, and there are vast sites on both river banks which remain after construction of the guide bands. It appears that these sites were used to store construction materials and equipment and to house the workers during the construction of Bangabandhu Bridge. At present, part of the sites have been turned into parks and are also used for the offices and dormitories of BBA which is responsible for the management of the bridge. It is possible to use the sites near the guide bands to store construction materials and equipment and as a temporary assembly yard for steel members.

(4) Construction Workers

Bangladesh has a large population and many construction workers were also employed during construction of Bangabandhu Bridge. According to BBA, there have been no particular problems related to the employment of construction workers, so this should not be an issue for the construction of the new railway bridge.

According to interviews conducted with Japanese contractors active in Bangladesh, the accuracy of geological surveys and measurements carried out by local Bangladeshi companies can unfortunately not be relied on. Qualified local engineers tend to move to other countries to work, and most of those who remain in Bangladesh are either young and inexperienced or old, and it is therefore difficult to find skilled but experienced engineers.

3.5.2. Conditions of Similar Construction Projects

The construction of three (3) new bridges—Kachpur Bridge, Meghna Bridge, and Gumti Bridge (the so-called KMG project)—is currently about to begin on the outskirts of Dhaka. The KMG project can be used as a reference for the procurement of materials and equipment for the new railway bridge. Since Padma Bridge is now also under construction, it is possible to study the construction method to be used on the new railway bridge construction project as well as the transportation method for the steel superstructure and the erection method to be employed. However, specific details could not be included in this survey since both projects are yet to enter the construction stage.

As was the case for Bangabandhu Bridge, large-diameter batter piles will be used for the substructure of Padma Bridge, and a Chinese contractor has also been selected to carry out the construction work. As pointed out in Chaper 4 of this survey, there were problems related to the bearing capacity of the batter piles used for Bangabandhu Bridge, and it will therefore be necessary to confirm whether the bearing capacity will be verified during the construction of Padma Bridge.

Since Padma Bridge will have a superstructure consisting of a double-deck steel truss, the construction method employed for Padma Bridge can be used as a reference when preparing the construction plan for the new railway bridge in case the latter will also employ a steel truss structure. However, since there are no bridges which impose height limits downstream of the Padma Bridge construction site, it is possible to use large floating cranes for its construction.

Since SPSP-F are employed for the three (3) bridges on the KMG project, this can also be used as a reference when preparing the construction plan if SPSP-F is also to be used for the new railway bridge. However, the KMG project uses SPSP-F as reinforcement for the existing bridges, and strict construction restrictions such as height limits are the main reason for the increased construction costs.

3.5.3. Construction Prices

The construction prices used for the construction cost estimate in Chapter 6 in this survey have been taken from a list of construction material unit prices (see [Tab. 3.5.1]) obtained from BR which is used for cost estimation in Bangladesh. [Tab. 3.5.1] shows typical labor and material unit prices in Bangladesh.

[Tab. 3.5.1] Comparison of typical construction material unit prices in Bangladesh and corresponding unit prices in Japan

Price in Bangladesh				Price in Japan (Construction Prices (September 2015, Tokyo))		
Type	Unit	Unit price (taka)	Unit price (yen equivalent)	Type	Unit	Unit price (yen)
Foreman/Supervisor	Man-days	567	907	Foreman	Man-days	32,800
Painter	Man-days	423	677	Painter	Man-days	35,700
Welder	Man-days	423	677	Welder	Man-days	38,200
Heavy Machine operator	Man-days	423	677	Driver (Special)	Man-days	30,400
Portland Cement	50kg bags	470	752	Portland Cement	25kg bag×2	880
19mm Downgraded Crashed stone chips	m^3	5,370	8,593	5-20mm crashed stone	m^3	4,150
12mm Downgraded Crashed stone chips	m^3	5,000	8,000			

Note: The exchange rate used is 1.6 yen / taka.

Source: BR

As shown in [Tab. 3.5.1], the labor costs in Bangladesh are considerably lower than in Japan, but the price of cement is almost the same, and the price of aggregate is approximately double that in Japan. It is therefore evident that procuring high quality concrete is very expensive in Bangladesh.

Based on the above considerations, the unit prices shown in [Tab. 3.5.2] have been used for the construction cost estimate in this survey. The basis for the calculations is presented in Section 6.1 and 6.2.

[Tab. 3.5.2] Unit prices used for construction cost estimate

	Unit	Unit price (million yen)
PC Box-girder Bridge	Million Yen/m	3.8940
Battered Steel Pipe Pile Foundation	Million Yen/Unit	879.0000
Steel Truss Bridge	Million Yen/m	5.3357
SPSP-F	Million Yen/Unit	698.0000

Source: Survey Team

Chapter 4 SELECTION OF BRIDGE TYPE (Step 1)

4.1. Selection of Superstructure

The most important factor to decide the superstructure type is the span length. The most suitable span length is influenced by various factors such as the ground condition, the type of foundations, etc. and it is difficult to simply decide the most suitable spans. But from the experiences and preceding examples, roughly the following equation is established.

Most suitable span：$L= (1.0\sim2.0)\times H$ ………………………………………………[Eq. 4.1.1]
Where H=Pier Height+1/3(Embedded depth of foundation)

If this equation is applied to the new railway bridge, the pier height of SPSP-F is 31m and the foundation embedded depth is about 30 to 50m long for the case of SPSP-F or caisson foundation, then roughly the following equation is acquired.

L = (1.0~2.0)×H
= (1.0~2.0)×(Pier Height+1/3(Embedded depth of foundation))
= (1.0~2.0)×(31m+1/3(30~50m))=Roughly 50m to 100m

As the next step, the suitable span is adjusted based on the condition of navigation clearance, scouring, etc. When the scouring occurs, the pier height becomes about 55m and the foundation length is about 5 to 25m. If 1/3 of this foundation length is assumed to be the embedded depth, or about 10m long, then the most suitable span length is,

L =(1.0~2.0)×(Pier Height+1/3(Embedded depth of foundation))
=(1.0~2.0)×(55m+10m)=Roughly 65 to 130m

From the above two (2) cases, one with scouring and one without scouring, the most suitable span length is between 50m and 130m. With this span length in mind, the most suitable structure type is selected based on the following items.

(1) Best combination of superstructure and substructure: If the superstructure is lighter, the substructure becomes smaller. If the span becomes longer, the superstructure becomes heavier and more expensive. But the number of piers decreases.

(2) LCC (Life Cycle Cost), which includes both the initial cost and the maintenance cost, needs to be considered.

(3) Easiness of quality control of construction works

(4) Construction period and its influence on the economy

(5) Natural condition constraint, i.e. rainy season, dry season, river condition, etc.

(6) Easiness of maintenance of rail tracks.

Whether the number of applications of the bridge type for the railway bridges is large or scarce, is also considered, because if there are more examples of application, it should be judged that the bridge type is more suitable or may have less problems for the application. The single track over the Bangabandhu Bridge limits the axle weight up to 16t and the train speed is limited to 10 to 20 km/h. This bridge forms a bottleneck of the railway network and the earlier completion of the new railway bridge is really expected. The shorter construction period is another important criteria to select a bridge type.

4.1.1. Superstructure Types

Superstructure types which are often adopted for railway bridges in Japan are listed in [Tab. 4.1.1].

[Tab. 4.1.1] Applicable superstructure types

Girder		Types	Outline & Reasons of Evaluation	Evaluation
Superstructure	Steel	Truss Bridge	• Most economical for Railway Bridge with main span over 50 m long, considering whole configuration including substructure type.	Best
		Arch Bridge	• Good in the aesthetic aspect. • Costs more than truss bridge.	Good
		Cable-Stayed Bridge	• Applicable for long span bridge. • Construction cost rises up. • Difficult to determine right location of Cable-stayed Bridge. • Hard to find out any appropriate reason to choose this type, given at many deep points on Jamuna River.	Poor
	Concrete	PC Box Girder Bridge	• Most economical for long span bridge, only considering superstructure construction cost. • Applicable for bridge with span length of app. 100m. • Need to estimate total cost including substructure construction.	Best
		Cable-Stayed Bridge	• Applicable for long span bridge by making span longer where Jamuna River is deep. • Construction cost rises up. • Difficult to determine right location of Cable-stayed Bridge because of many deep points on Jamuna River. • Hard to find out any appropriate reason to choose this type, given at such deep points on the river. • Less record as a type for Railway Bridge.	Poor
		Extradosed Bridge	• Mixed structure type with Cable-stayed Bridge and PC Girder Bridge. • Possible for more rigid stiffening girder, lower tower, and more resistance against vertical deflection, compared to Cable-stayed Bridge. • Longer span is achievable, compared to PC Girder Bridge, but not economical. • Less record as a type for Railway Bridge.	Normal

Source: Survey Team

In Japan, almost all of the long span railway bridges were steel truss bridges. But from the time when Sanyo Shinkansen (HSR) Line was constructed, PC Box Girder Bridges began to be adopted to cope with the noise and vibration problems. In Japan steel truss bridges are generally adopted when there are noise/vibration problems. Steel members of old truss bridges can be utilized again after the service life has elapsed, thus the residual value is larger than concrete bridges. Also the demolition cost when the bridge needs to be replaced is small. As selected in [Tab. 4.1.1], in the following section, the Steel Truss Bridge and the PC Box Girder Bridge are compared. The PC Box Girder Bridge, whose dimensions are decided in ADB-F/S, is compared with the Steel Truss Bridge designed in this study. In the following section, a Steel Cable-stayed Bridge alternative is also compared just for the reference.

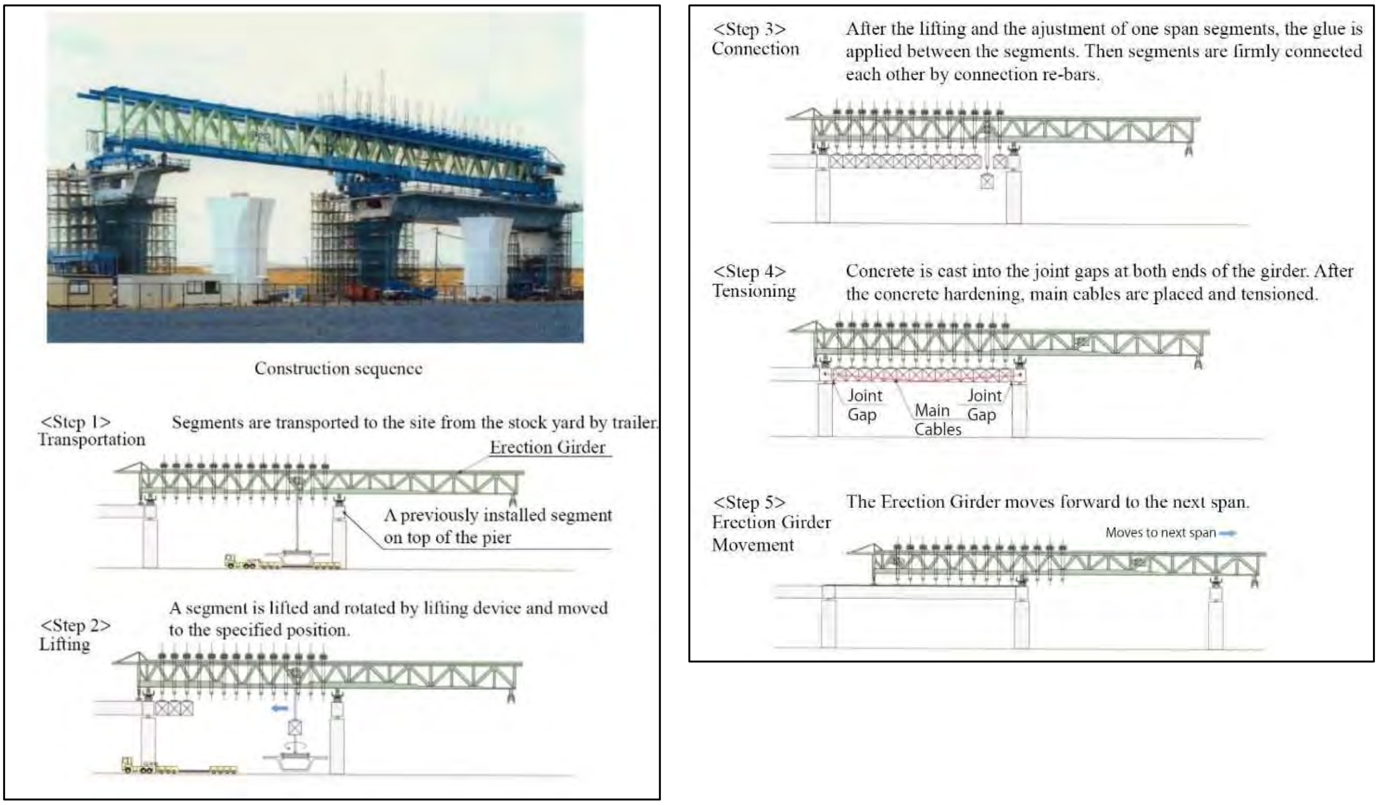
(1) PC Box Girder Bridge

The typical methods to construct PC Box Girder Bridges are, the balanced cantilever method, the span by span method using the erection girder and P&Z (Polensky & Zöllner) method. The balanced cantilever method is shown in [Fig. 4.1.1].

Source: Web site of Shimizu Corporation

[Fig. 4.1.1] Balanced cantilever method

About 4.5m long girder segment is cast at the site using the moving scaffolding (Wagen). After the concrete is hardened, PC Cables are tensioned and the moving scaffolding is forwarded to continue to construct next segment. The scaffolding can be utilized repeatedly, the temporary facilities are less but the construction period may become slightly longer. The construction cycle of the span by span method is shown in [Fig. 4.1.2]. Precast segments are transported from the stockyard to the site by trailer. The segments are lift up from the erection girder, placed in the position and connected. The photo shows the construction of Nagashima Viaduct by the span by span method.



Source: http://www.nipponps.co.jp/kasetsukouhou-supanbai.htm , modified by Study Team

[Fig. 4.1.2] Construction cycle of span by span method

Precast segments can be prepared beforehand in separated places from the construction site and they are transported to the site segment by segment. Therefore the construction speed at the site is higher. To construct one (1) span, it takes about eight (8) days (gross) and twelve (12) days (net) (8days÷0.7（rate of operation）≒12). The demerit of this method is the maximum span length. As the erection girder supports all of one (1) span girder weight, the maximum applicable span is up to about 60m long. If the span becomes longer, the other method, the P&Z method needs to be adopted. In this method, segments are extended from the pier in both direction in the same manner as the balanced cantilever method. Instead of cast-in-place concrete, the P&Z method employs precast segments. By the P&Z method, each segment is fixed by PC cables soon after the erection. Then it takes about one (1) month to complete one (1) span of the bridge. The Bangabandhu Bridge was constructed by this method which is shown in [Fig. 4.1.3]. For this bridge, segments were transported over the already constructed girders and the transportation of segments may have had formed the critical path of the construction.

Source：http://www.panoramio.com/user/703267?comment_page=1&photo_page=3&show=best

[Fig. 4.1.3] Construction of the Bangabandhu Bridge by the P&Z method

In the report of ADB-F/S, the balanced cantilever method is selected and the construction period should be calculated based on this method. The more the number of moving construction scaffoldings (Wagens), the shorter the construction period of the balanced cantilever method. Therefore the decision of number of moving scaffoldings becomes very important, as the too many scaffoldings will push up the total construction cost.

(2) Steel Truss Bridge

Typical construction methods of continuous Steel Truss Bridges are, the launching erection method (refer to [Fig. 4.1.4]), the piece by piece erection method (refer to [Fig. 4.1.5]) and the large block erection method (refer to [Fig. 4.1.6]).

If the 4.8km bridge is constructed by the launching erection method from both banks, then 4.8km/2=2.4km length of girder needs to be launched. It is not impossible to launch 2.4km but when the girder is launched, the girder needs to be supported in a higher position than the bearing on each pier, consequently many temporary supporting devices are needed and it becomes uneconomical.

If the piece by piece erection method is adopted, the number of temporary facilities are less and immediately after the completion of piers, the erection work can be commenced. If piers are constructed from both banks to the center of the river, the erection of the girder can follow the completion of the piers and proceed to the center of the river. By this manner, the construction period can be minimized.

Source : http://www.oxjack.co.jp/modules/example/index.php?op=productview&product_id=5

[Fig. 4.1.4] Truss girder launching erection method

Source : Web site of Yokogawa Bridge

[Fig. 4.1.5] Piece by piece erection of Yoshima Bridge

The large block erection method is as follows. One (1) large block girder of one (1) span length is transported to the site on the barge. At the site, this block is lifted by floating crane and set to the final position. Instead of floating cranes, if the construction site is near the sea, the tidal difference is sometimes utilized.

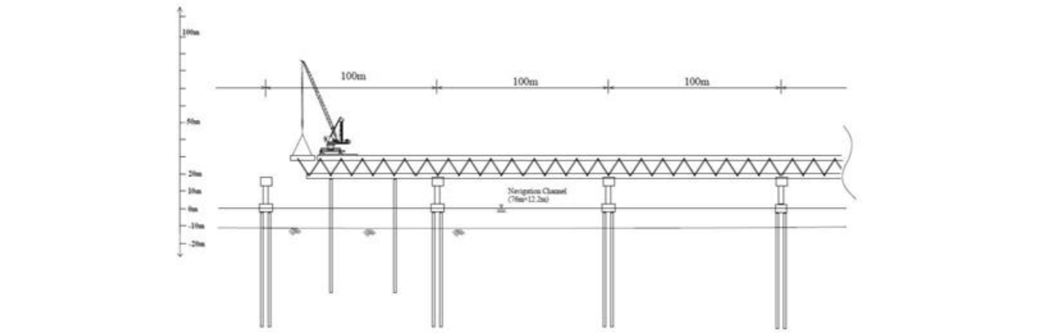
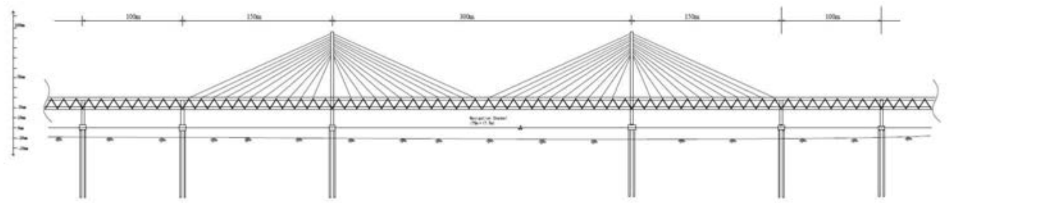
Source：http://www.takadakiko.com/products/bridge/09.html

[Fig. 4.1.6] Large block erection method by floating crane, Kansai Airport Access Bridge

But downstream of the new railway bridge, there is the Bangabandhu Bridge and the Padma Bridge is under construction. Therefore it is impossible to bring floating cranes to the site. There is no tidal difference either and the adoption of the large block erection method is impossible. From the above investigation, the piece by piece erection method together with the temporary bents is selected as the construction method. The result of comparison is shown in [Tab. 4.1.2].

[Tab. 4.1.2] Applicable Bridge Alternatives

PC Box Girder Bridge by balanced cantilever construction method		
	Features	100m span PC Box Girder Bridge. The same type of bridge as the Bangabandhu Bridge. About 100m span is close to the maximum. Girder weight is large and substructures may become larger consequently.
	Const. method	Balance cantilever construction method. 12m Pier head Section: 80 days, installation of Wagen 20days, 10blocks×10days=100days, Installation of Wagen to end of one span construction=120days.
	Const.cost	Generally speaking, this superstructure is less expensive than Steel Truss, but the size and the number of substructures are larger and more expensive.
	Const. period	Depending on the number of Wagens employed.
	Evaluation	From the view point of only cost, this may be the most economical alternative.

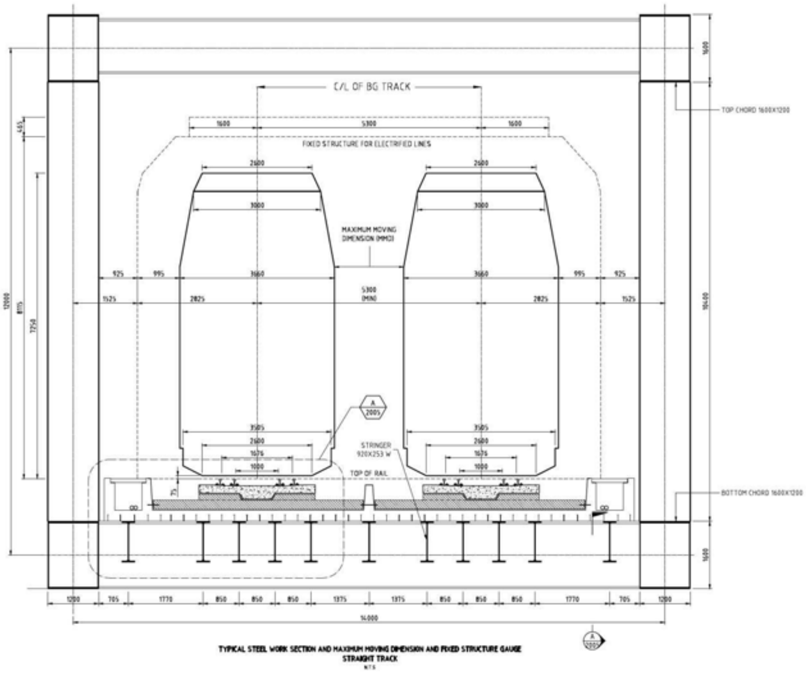
Steel Truss Bridge by piece by piece erection method on traveler crane		
	Features	Span can be extended up to about 150m. If span is longer, number of piers can be reduced. Therefore the most economic span needs to be selected. If Through Truss Bridge is adopted, rail level becomes lower and approach bridge becomes shorter. If Weathering Steel or Fluoro Resin Polymer Coating is adopted, Maintenance free bridge can be constructed.
	Const. method	After completion of substructures, immediately construction of superstructure can be commenced. If substructures are constructed from both banks to river center, superstructures can follow the construction of substructures in the same direction. As shop-fabricated members are assembled at site, construction speed is fast. If temporary bents are utilized between spans, this will alleviate extra stresses of girders. Temporary bents can be reused for other spans.
	Const. cost	Steel Truss Bridge is generally a little more expensive than PC Box Girder Bridge. But Truss Bridge is lighter and size and number of substructures and smaller and more economical.
	Const. period	If 100m span consists of seven (7) sets of 15m-panels, then one (1) span can be constructed within about 30days.
	Evaluation	If construction cost only is compared, Steel Truss Bridge may be slightly more expensive. But shorter construction period is taken into account, Steel Truss Bridge may be the most feasible alternative.
Steel Truss Bridge ＋ Steel Cable-Stayed Bridge		
	Features	Steel Cable-Stayed Bridge is planned over the deepest waters. But the deepest points of Jamuna River are unstable and unpredictable. Therefore it is difficult to find a proper positions of long spans.
	Const. Method	Girders are extended from towers.
	Const. Cost	As spans become longer, the construction cost becomes increasingly more expensive. Therefore this is not a feasible solution for the Jamuna River.
	Const. Period	Balanced Cantilever Erection of Steel Girders and installation of cables take longer time.
	Evaluation	Expensive and longer construction Period.

Source: Survey Team

As the Step 1 screening, the Steel Truss Bridge is selected as the steel bridge alternative and the PC Box Girder Bridge of ADB-F/S is adopted as the concrete bridge alternative. These two (2) alternatives will be compared further. The best combination of superstructure and substructure is investigated. The total aspects of the two (2) alternatives will be compared including not only the superstructure construction cost but also the construction period, easiness of quality control of construction works, easiness of maintenance works, etc.

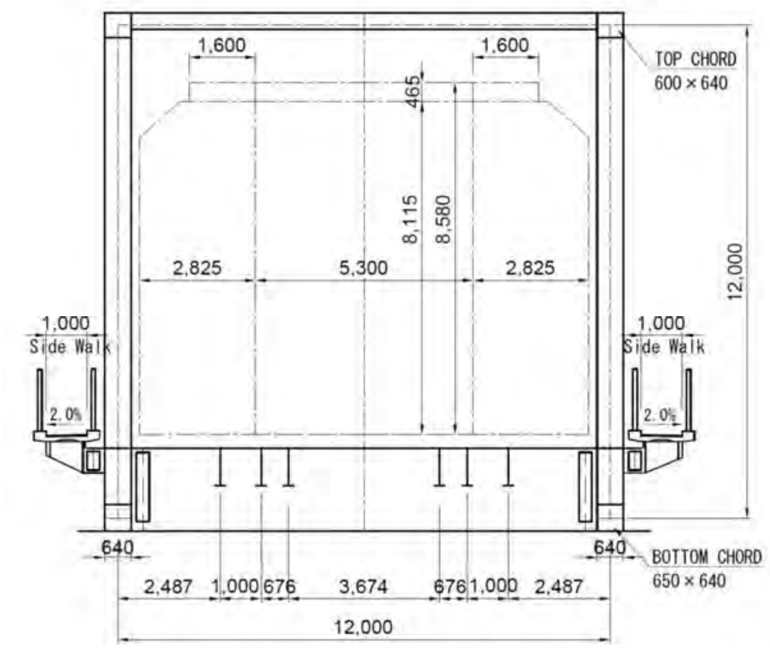
4.1.2. Optimization of the Steel Through Truss Girder Bridge

In ADB-F/S, the cross section of the truss bridge shown in [Fig. 4.1.7] is assumed. In this section, a concrete bridge deck is placed and two (2) inspection ways are placed beside the tracks. This widens the cross section of the bridge. To minimize the cross section, inspection ways are placed outside of the truss girder and the concrete deck is eliminated. Afterwards the structural calculation of the Truss Girder Bridge is performed and the girder weight is calculated. The new cross section is shown in [Fig. 4.1.8].



Source: ADB-F/S

[Fig. 4.1.7] Truss Girder cross section of ADB-F/S



Note：Construction gauge is exactly the same as ADB-F/S

Source: Survey Team

[Fig. 4.1.8] Truss Girder cross section proposed in this survey

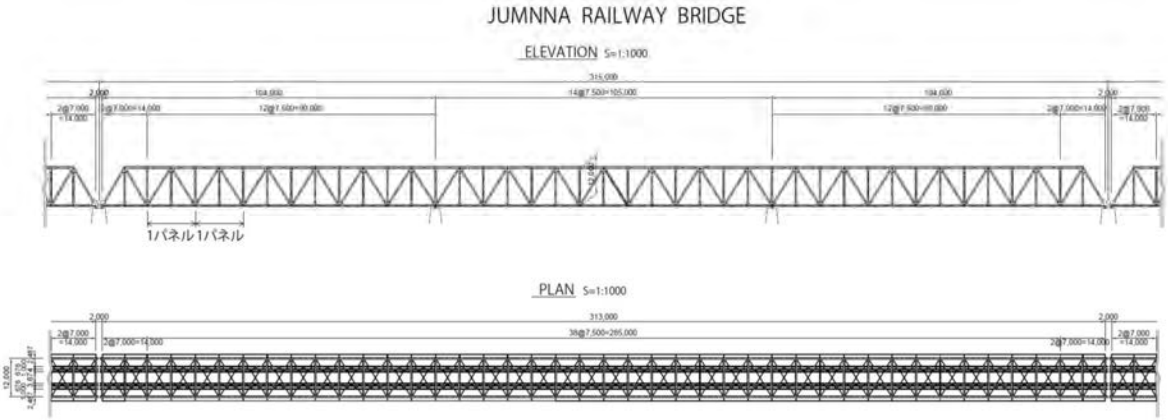
4.1.3. Optimization of Span Lengths of Steel Truss Bridge

From the investigation in Sec.4.1.1, the suitable span length is between 50m to 130m. The Bangabandhu Bridge is a PC Box Girder Bridge and the span length is 100m. The new railway bridge will be constructed upstream of this bridge and to avoid the bad influence on the existing piers, the span length should be equal to or more than 100m. Theoretically the steel truss bridges can span longer than the PC Box Girder Bridges. Therefore the longer spans than 100m are studied for the steel through truss bridge.

One (1) panel length of steel truss bridge is assumed to be 15m (Definition of one (1) panel is shown in below [Fig. 4.1.9]). Three (3) alternatives of spans are compared. They are 105m (=15m×7panels), 120m (=15m×8panels), and 135m (=15m×9panels). For these alternatives, structural calculations are executed and the steel weights are calculated. If the steel weights of other spans are needed, they will be calculated according to the proportion.

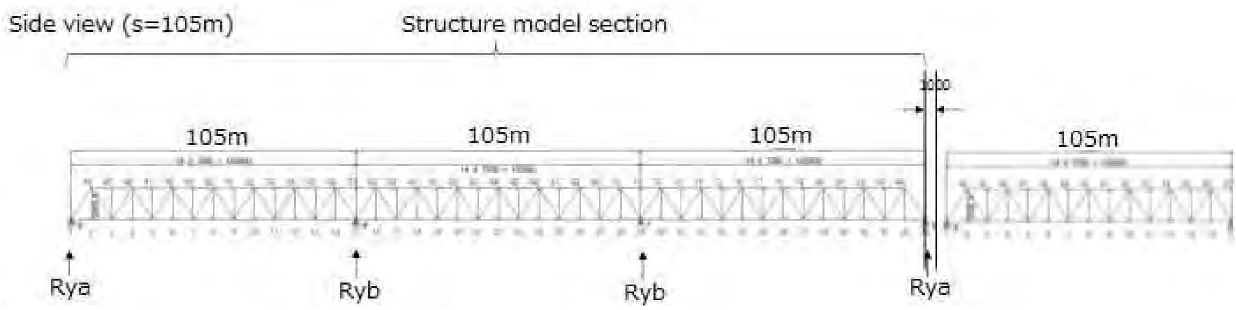
As for number of span of one (1) unit of bridge, three (3) span Continuous Bridge is adopted to avoid the large concentration of the earthquake force on one pier and to avoid the influence of uneven settlements of piers. Train running condition of railway bridges is not affected by the expansion joints unlike road bridges thanks to the track.

The most suitable continuous span number should be studied by the detailed design. But even if the number of continuous spans becomes larger, the unit weight of steel girder per length may not vary largely. The three (3) span Continuous Through Truss Bridge is shown in [Fig. 4.1.9].



Source: Survey Team

[Fig. 4.1.9] Three Span Continuous Steel Through Truss Bridge



Source: Survey Team

[Fig. 4.1.10] Framework model of Trough Truss Bridge

The modelled framework of three (3) span continuous Steel Through Truss Bridge is shown in [Fig. 4.1.10]. After the structural calculation, the steel weight is obtained and the result is shown in [Tab. 4.1.3]. As the span becomes longer from 105m to 135m, the superstructure weight becomes heavier. But the number of piers are reduced. When the substructure cost is calculated, the best combination of superstructure and substructure can be found. In Sec.4.2, the substructures are compared and the best alternative is selected. In the table below, the substructure costs are not listed.

[Table 4.1.3] Calculated steel weight of Truss Bridge

	Span (m)	105 7.5m@14=105m	120 7.5m@16=120m	135 7.5m@18=135m
①	Bridge length (3 spans) (m)	315	360	405
②	Steel weight (t)	2,500	3,055	3,711
③	Steel weight/m (t/m)=②/①	7.937	8.486	9.162
④	Total bridge length (m)	4,810	4,810	4,810
⑤	Total steel weight, 4,810m (t)=③×④	38,177	40,817	44,070
⑥	Unit price of superstructure (fabrication + erection) (1,000Yen/t)	600	600	600
⑦	Superstructure cost (Million Yen)	22,906	24,490	26,442
⑧	Bearing cost (Million Yen)	1,131	1,175	1,296
⑨	Superstructure total cost (Million Yen)	24,037	25,665	27,738
⑩	Substructure+Foundation(Million Yen)	27,507	25,076	23,571
⑪	Total cost (Million Yen)	51,544	50,741	51,309
	Ratio of total cost (Cost of 120m span is set as 1.0)	1.016	1.00	1.011
	Steel weight/㎡ (t/㎡)	0.661	0.707	0.764
	Truss height (m)	12	12	14 (Note)

Note: For 135m span, to satisfy deflection limit of L/1000, truss height is increased.

Source: Survey Team

4.1.4. Bearing Cost

The calculation method of the bearing cost is described in this chapter. The reaction forces of bearings are calculated from the structural calculation and shown below.

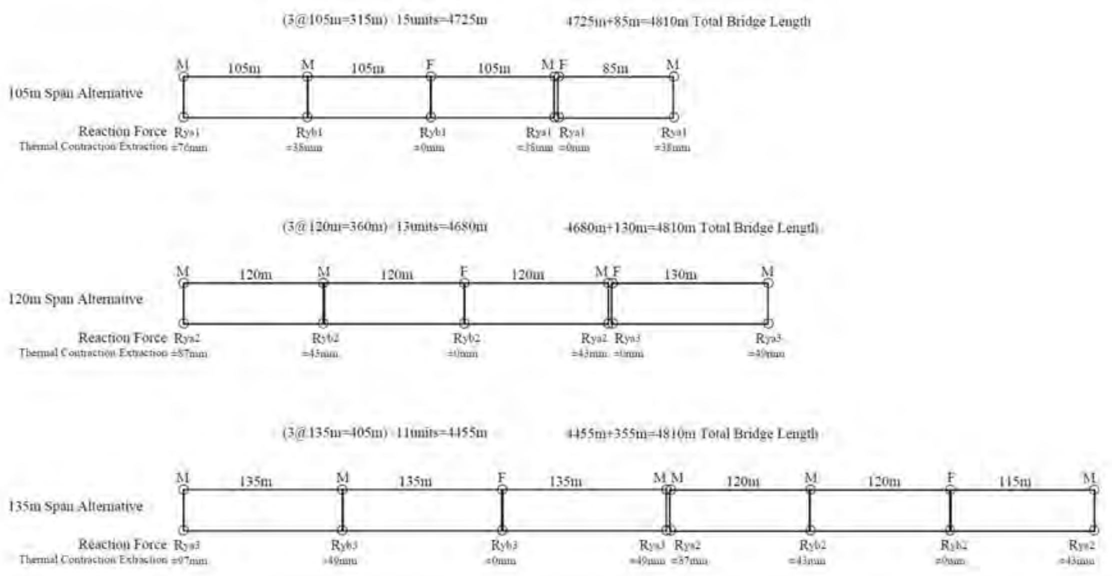
[Table 4.1.4] Reaction forces of bearings

Reaction Force	Span (m)	105	120	135
Vertical Reaction Force of End Support Rya=RyaD+RyaL+RyaI (KN/Bearing)	Dead Load (RyaD (KN/Bearing))	2,255	2,704	3,201
	Live Load (RyaL (KN/Bearing))	3,845	4,388	4,932
	Impact Load (RyaI (KN/Bearing))	833	911	986
	Total	6,933	8,003	9,118
		Rya1	Rya2	Rya3
Vertical Reaction Force of Intermediate Support Ryb=RybD+RybL+RybI (KN/Bearing)	Dead Load (RybD (KN/Bearing))	6,200	7,447	8,828
	Live Load (RybL (KN/Bearing))	10,571	12,087	13,602
	Impact Load (RybI (KN/Bearing))	2,289	2,509	2720
	Total	19,060	22,043	25,151
		Ryb1	Ryb2	Ryb3

Note: For Rya、Ryb, refer to [Fig. 4.1.15].

Source: Survey Team

As the next step, 105m to 135m span Truss Bridges are placed over 4,810m section appropriately and the number of bearings is counted. The arrangement of three (3) span Continuous Truss Bridges is shown in [Fig. 4.1.11]. These arrangements are used to count the number of bearings only. The real arrangements of bridges will be studied in the detailed design.



Source: Survey Team

[Fig. 4.1.11] Arrangement of three (3) span Continuous Through Truss Bridges

Based on the bridge arrangement of [Fig. 4.1.11], the number of bearing is counted and shown in [Table 4.1.5].

[Table 4.1.5] Number of bearings of the Steel Through Truss Bridges by spans

(1) 105m Span Alternative

	3 span Continuous Truss Bridge×15sets＋85m Truss Bridge				
Fix (F) or Movable (M)	M	M	M	F	F
Reaction Force (KN)	6,933	19,060	6,933	19,060	6,933
	Rya1	Ryb1	Rya1	Ryb1	Rya1
Expansion (±mm)	76	38	38	0	0
Number of Bearings	30	30	32	30	2

(2) 120m Span Alternative

	3 span Continuous Truss Bridge×13sets＋130m Truss Bridge					
Fix (F) or Movable (M)	M	M	F	M	F	M
Reaction Force (KN)	8,003	22,043	2,2043	8,003	9,118	9,118
	Rya2	Ryb2	Ryb2	Rya2	Rya3	Rya3
Expansion (±mm)	87	43	0	43	0	49
Number of Bearings	26	26	26	26	2	2

(3) 135m Span Alternative

	3 span Continuous Truss Bridge×11sets＋(120+120+115m) Truss Bridge							
Fix (F) or Movable (M)	M	M	F	M	M	M	F	M
Reaction Force (KN)	9,118	25,151	25,151	9,118	8,003	22,043	22,043	8,003
	Rya3	Ryb3	Ryb3	Rya3	Rya2	Ryb2	Ryb2	Rya2
Expansion (±mm)	97	49	0	49	87	43	0	43
Number of Bearings	22	22	22	22	2	2	2	2

Source: Survey Team

From this table, the unit prices of bearings are acquired, the cost of bearings can be calculated in [Table 4.1.3] .

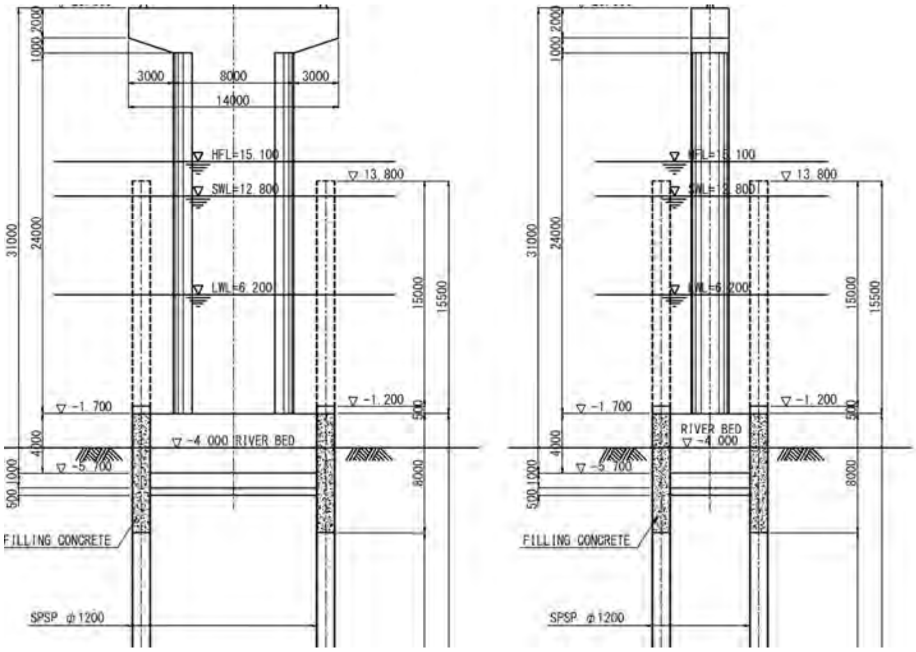
Based on the superstructure cost with bearing cost and the substructure cost, the best combination of superstructure and substructure can be selected and the optimum span of Steel Through Truss Bridge can be selected.

4.2. Selection of Substructure and Foundation Type

4.2.1. Selection of Substructure Type

According to the ADB-F/S report, in the bridge vicinity of the Jamuna River, scouring is expected to reach the elevation of PWD-30m due to the impact of the Bangabandhu Bridge and its guide bands which narrowed the river width to 4.8km. For this reason, an oval shape is chosen for the piers cross section with the main purpose to reduce the obstruction to the flow and thus, the scour depth. Detailed shape is shown in [Fig. 4.2.1].

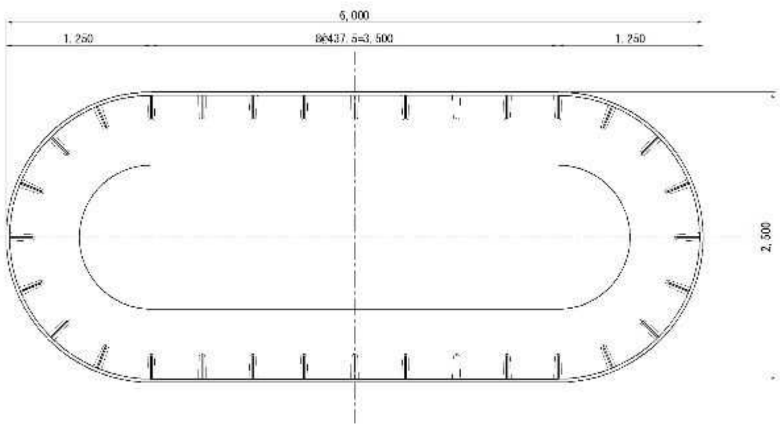
Although there are several alternatives for the material and shape of pier structure, RC overhanging pier structure is adopted according to the reasons below.



Source: Survey Team

[Fig. 4.2.1] Proposal of pier type

While the pier height changes according to the types and shapes of foundation, it is expected to be in the range of between 15m and 30m. As shown in [Fig. 4.2.2], if a steel pier is selected, the shape of the pier cross section should be an oval to reduce the disturbance to the flow. This shape of pier needs to be fabricated at the shop and steel weight becomes about 150t, which is not economical. Also this steel pier is located inside of the river and the corrosion protection becomes difficult so that it is better not to adopt this type of pier.



Source: Survey Team

[Fig. 4.2.2] Structure of Steel Pier

4.2.2. Selection of Foundation Type

Similar to the current the Bangabandhu Bridge, the new railway bridge of ADB-F/S proposed the multi-pile foundation (large-diameter battered steel pipe piles with filled concrete). One drawback of this type of foundation is that it might easily cause vortex around the pile cap (the structure binding piles at their top) and piles and exacerbate the scouring problem. In this survey, in consideration of constructability, reliability, and economic efficiency, alternatives are proposed and the comparison between different types of foundation is conducted.

(1) Candidate Foundation Types

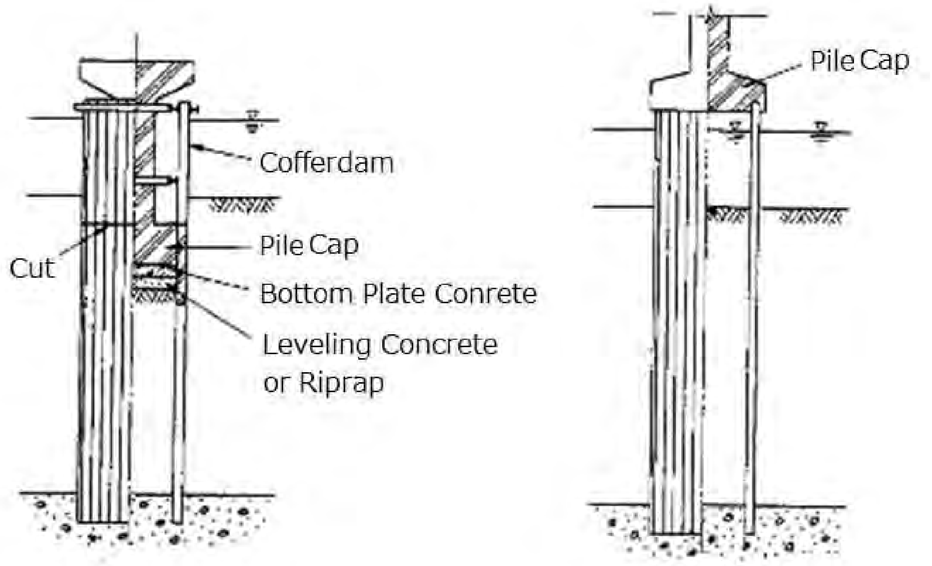
Candidate foundation types are selected based on the assumption that the new railway bridge's scale is similar to or larger than that of the Bangabandhu Bridge and natural conditions are the same.

Design conditions include the followings: span length is larger than 100m; foundation's embedment length is larger than 35m; deepest water depth during flood season exceeds 15m and in addition, scouring is expected to reach the depth of PWD-30m. In consideration of these conditions, construction safety, certainty, and stability after the bridge is in service, the following alternatives for foundation type are proposed based on past experiences.

- Alternative 1 : Multi-Piles Foundation (Large-Diameter Vertical Piles)
- Alternative 2 : Steel Pipe Sheet Pile Foundation (SPSP-F)
- Alternative 3 : Caisson Foundation

In Alternative 1, pile caps are basically constructed above the water level and thus, it is easy to deal with the large water depth or changes in the water level. Therefore, this type of foundation has widely been used for the large-scale bridges crossing over Mekong River in the countries such as Vietnam and Cambodia. Moreover, being different from the foundation suggested in ADB-F/S alternative, vertical piles have commonly been used in recent years due to the consideration of constructability and quality control. In terms of earthquake performance, multi-pile foundation has relatively low capacity and thus, is generally considered inferior to Alternative 2 and 3. However, it is not an major issue considering the modest scale of earthquake at the site.

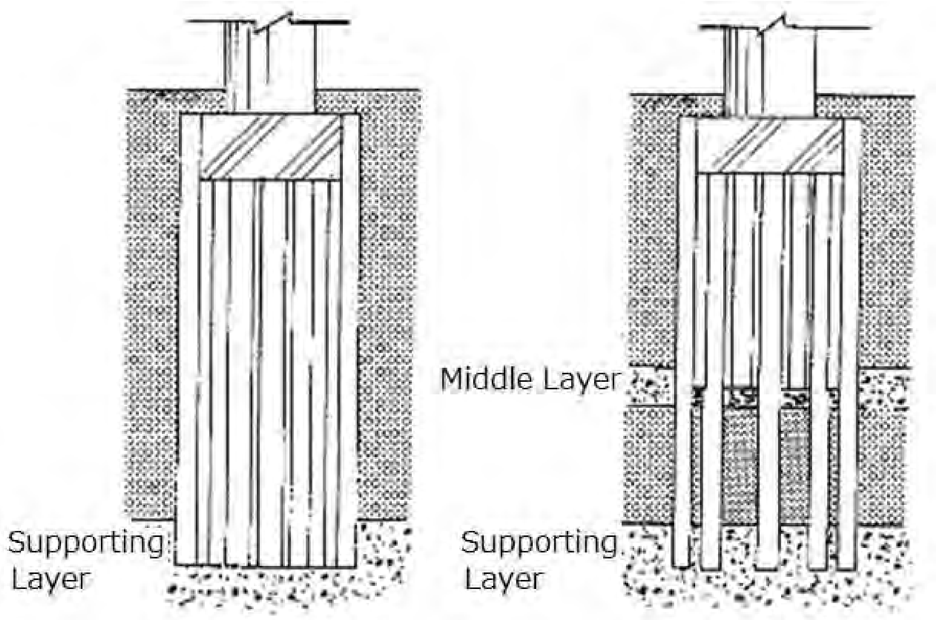
In regards to the Steel Pipe Sheet Pile Well Foundation (hereinafter SPSP-F) proposed as Alternative 2, according to the river and construction conditions, the methods such as a temporary cofferdam method or a rising method are applicable as shown in [Fig. 4.2.3]. Also, as shown in [Fig. 4.2.4], in addition to the normal well foundation type, for the cases in which an intermediate support layer exists and the bearing capacity is large, the foundation type with legs can also be applied in order to reduce the cost. The lateral load resistance does not depend only on the steel pipe sheet pile body's bending stiffness and the ground resistance but also on the interlocks' lateral resistance. For this reason, the high-stress-resistant interlocks can be utilized when the lateral load is large. In recent years, this type of foundation has increasingly been used in the areas such as Vietnam and Philippines.



(1) Temporary Cofferdam Method (2) Rising Method

Source: Survey Team

[Fig. 4.2.3] SPSP-F Structure



(1) Normal Well Foundation Type (2) Well Foundation with Legs

Source: Survey Team

[Fig. 4.2.4] Different Type of SPSP-F due to Different Bearing Layers

In regards to Alternative 3, there are two (2) main types of Caisson Foundation that are the Sinking Type and the Setting Type. In general, a Caisson Foundation provides larger bearing capacity and bending capacity and thus, is applicable to large-scale bridges. According to the sinking method, the Sinking Caisson Foundation can be divided into two (2) different types, they are an Open Caisson Foundation and a Pneumatic Caisson Foundation.

In the case of new railway bridge, a Pneumatic Caisson Foundation is more appropriate because it is easy for a Pneumatic Caisson to utilize the water load to sink the whole caisson by loading water into the hollow upper sections, it is easy to excavate precisely at the bottom cutting edge compared to the Setting Caisson, the sandy ground has a larger friction but the Pneumatic Caisson can be sunk to the specified depth reliably.

There is a high flexibility for the sectional shape of caisson foundation; also, Caisson Foundation shares the same advantage with SPSP-F regarding the consideration of scouring problem. However, based on the past experience, the Pneumatic Caisson can be applied up to 60m deep only. In recent years, a full automation has been developed in Japan but there has still been very little experiences in other countries.

(2) Selection of Foundation Type

The comparison between different foundation types including ADB-F/S Alternative is shown in [Tab. 4.2.1]. Herein, four (4) alternatives, including the multi-pile foundation (with large-diameter steel battered piles) chosen in ADB-F/S and other three (3) alternatives proposed in this survey are compared. The results are summarized in the categories below.

1) Construction Period

While there is no big difference in the construction period of one (1) foundation among four (4) alternatives, the order of construction period of four (4) alternatives is as follows; ADB-F/S Alternative and the proposed multi-pile foundation Alternative are the most advantageous, followed by SPSP-F and the Caisson Foundation. Although the construction period depends on the number of parties employed, only a small difference in construction period of one (1) pier foundation can have a large impact on the overall construction period of the whole project because there are 41 pier foundations. If this project is constructed as one (1) package and four (4) parties are employed, there will be about four (4) months difference between ADB-F/S Alternative and SPSP-F Alternative.

2) Ship Collision

The navigation width is relatively large and thus, there is no big difference among Alternatives in regards to ship collision. However, ADB-F/S Alternative and the proposed multi-pile foundation Alternative (Alternative 1) have larger pile caps, which form larger obstruction to the navigation width and thus, are considered slightly inferior to other alternatives in consideration of ship collision.

3) Scouring

At the Jamuna River near the planned railway bridge construction site, the river bed change, such that the sandbank’s location changes every year once the flood season ends, occurs. This leads to the change in water depth at the pier locations during the construction.

While all four (4) foundation types (ADB-F/S proposal, Alternative 1, 2, and 3) proposed are highly relevant to this condition, the following points can be pointed out in consideration of the scouring after the construction is completed. Namely, in ADB-F/S Alternative and the proposed Alternative 1 (Multi-pile Foundation Alternative), due to the impact of five (5) and six (6) circular pipe piles (with diameter not less thanφ3.0m) respectively arranged adjacent to each other, complex vortices may occur easily between the pile cap and the river bed. Therefore, in regards to the scouring problems, in a qualitative manner, these two (2) alternatives are considered to be most inferior. Especially, the ADB-F/S alternative uses the battered piles which have section location changes in vertical direction and thus, is the most inferior among all alternatives. On the other hand, Alternative 2 (SPSP-F Alternative) and 3 (Caisson Alternative) are more advantageous since the pier and the foundation form an oval section (the sectional shape that brings least resistance to the flow) and are parallel to the flow direction. Especially, in consideration of scouring problems, Alternative 3 is the best option since the caisson foundation’s wall surface is smooth.

4) Constructability

The qualitative comparison of constructability in terms of construction quality, degree of difficulty, and construction speed can be summarized as follows.

- ADB-F/S Alternative and the proposed Alternative 1:
  Steel pipes are made by bending thick steel sheets and thus, the shape uniformity and welded part’s quality can be an issue. In the case that joints are welded at the site, especially when the steel sheets are thick due to the pipe’s large diameter, there are big problems in regards to quality, strength and welding time. In consideration of construction quality control and degree of difficulty,

these alternatives are the most inferior.

- Proposed Alternative 2:
  Spiral steel pipes of market products are used and they have very few quality problems. Also, from the past experiences, there are less concerns regarding the joints welding at site compared to Alternative 1. Although the installation of the studs connecting steel pipe sheet piles to the top slab is the additional work only needed in Alternative 2, the mechanization has been advanced and thus, there will be no large time extension in construction period. The new railway bridge is a brand new built and thus, there will be no special construction conditions as in the reinforcement work of the Bangabandhu Bridge's foundation. Also, because the steel pipe diameter and construction depth studied all fall into the category with rich construction experiences in the past, no special machine supply is required and thus, does not impact the construction cost.

- Proposed Alternative 3:
  The caisson foundation has a large depth of 50m and thus, its construction period is longer than all the other alternatives even if construction is conducted continuously by rotating shift schedule using 2 to 3 teams. With regard to constructability, drawbacks are that it is necessary to blow Helium gas into the working chamber due to the large depth and that since the water depth is large a large scale steel cutting edge (small blocks are transported to the site and assembled therein above the water on the temporary stage) needs to be set on river bed before the start of sinking the caisson down which requires careful attention to the river flow velocity.

5) Economic Efficiency

There is no large difference between the proposed Alternative 1 and 2 for the economic efficiency. Compared to these two (2) foundation types, ADB-F/S Alternative is slightly less advantageous since large-diameter steel pipe piles need to be hammered down in the inclined direction. Especially in the case of long piles, it might be necessary to utilize the water jet method which involves a large amount of labor works, hence this alternative is slightly inferior. In regards to economic efficiency, the proposed Alternative 3 is the most inferior among all alternatives since Helium gas needs to be filled in the working chamber due to the large construction depth.

In Meghna Bridge, Gumti Bridge, and Kachpur Bridge, SPSP-F is adopted and the construction cost is reportedly high. However, the reason is that this involves the reinforcement of existing bridges with the special construction conditions which do not exist in the construction of a new bridge as in this project such as the use of special machines. Since the new railway bridge is a brand new one with no special construction condition such as the height limit and the close neighboring construction, from the perspective of economic efficiency, it is expected that there is no large difference between the proposed Alternative 1 and 2.

6) Technical Transfer Possibility

ADB-F/S Alternative shares the same foundation type with the Bangabandhu Bridge. The proposed Alternative 1 also uses the multi-pile foundation, which is structurally identical to that of ADB-F/S Alternative. Since there has already been a certain amount of experience in the construction of this type of foundation in Bangladesh, the use of this foundation type does not involve technology transfer component. On the other hand, the type of foundation used in the proposed Alternative number 2 and 3 are fairly new in Bangladesh and thus, the use of these two (2) alternatives are expected to involve technology transfer component. SPSP-F was used in Bangladesh but this includes the reinforcement of existing bridges. Since this project is a new bridge construction in which both the temporary cofferdam method and the rising method are planned to be used and thus, the SPSP-F foundation proposed in Alternative 2 is regarded as a new technology in Bangladesh. Two (2) types of SPSP-F of either Rising Method or the intermediate structure between the Rising Method and the Cofferdam Method may be employed due to the maximum height of the Cofferdam Method of about 20m in which Cofferdam Method will be employed when the water depth less than 20m.

7) Other Matters

In ADB-F/S Alternative and the proposed Alternative 1, large-diameter steel pipe piles (φ not less than 3.0m) are used. Because issues due to pile end closure effect are expected and the water jet method might have to be used in ADB-F/S Alternative, an intensive quality control measure is needed to counter the pile tip closure effect and assess the pile tip bearing resistance. Also, pile bodies protrude from the water and thus due attention to the corrosion control of the steel pipes near the water line must be paid which involves substantial cost increase.

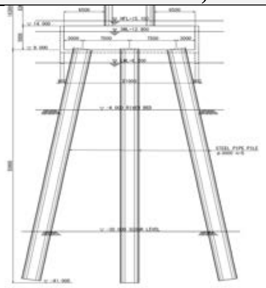
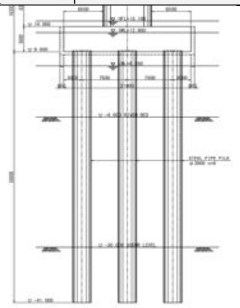
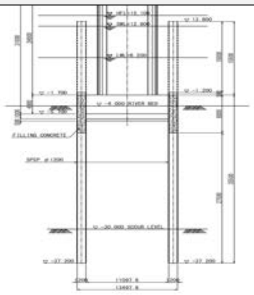
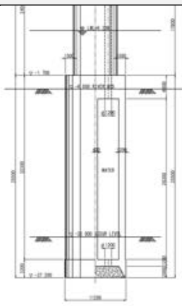
In the proposed Alternative 2, the foundation is built near the river bed and thus, a temporary cofferdam is required to provide a dry space for the construction works (different from Alternative 1 and 3). However, since a part of cofferdam can be used as the main body of the foundation, it is considered as a reasonable structure without wasting the temporary cofferdam.

The proposed Alternative 3 is the proposal with the most compact shape in which, all parts of the foundation including the top slab, the bottom, the side walls, and so on are fixed to each other to form a whole rigid body. There are almost no structural issues associated with this option.

Based on the comprehensive evaluation shown above, with a focus on the factors listed above from 1) to 7) such as the construction period, the economic efficiency, the constructability, and the structural characteristics, at present, the proposed Alternative 2 with SPSP-F foundation is recommended. The overall evaluation discussed is summarized in [Tab. 4.2.1]. Herein, Steel Truss Girders, which is lighter than PC Box Girders, are utilized for the superstructure.

However, in the present evaluation, since the water depth survey and the in-situ geotechnical investigation have not been conducted yet, it is also suggested to reconsider the proposed Alternative 1, with which the overall evaluation grade is close to that of the recommended alternative, at the F/S review stage.

[Tab. 4.2.1] Comparison Table of Pier Foundation for Steel Truss Bridge

Alternative	ADB-F/S Alternative	Alternatives		
	Multi Pile Foundation (Steel Pipe Piles φ3000: Battered Piles)	Alternative 1. Multi Pile Foundation (Steel Pipe Piles φ3000: Vertical Piles)	Alternative2. Steel Pipe Sheet Pile Foundation	Alternative 3. Pneumatic Caisson Foundation
Illustration	 As Superstructure is steel truss bridge which is lighter than PC Box Girder Bridge, number of piles is reduced. Number of Piles: 5nos	 Number of Piles: 6nos		
Period	5 months (10/10)	5 months (10/10)	6 months (8/10)	8 months (5/10)
Against Ship Collision	● Pile-Caps are large and probability of ship collision is a little higher. (4/5)	● Pile-Caps are large and probability of ship collision is a little higher. (4/5)	● Pier column sectional area is small and probability of ship collision is smaller. (5/5)	● Pier column sectional area is small and probability of ship collision is smaller. (5/5)
Scouring	● Vortices may occur due to inclined multi columns and scale of scour may be unpredictable. (2/5)	● As multi columns exist below water level, votices may occur easily and an unexpected scale of scour may occur. (3/5)	● Oval shaped pier from river bed upward has less influence on flow and less influence on scour. But local scour around pier occurs and steel pipe sheet piles protrude from river bed, then Alt3 Pneumatic Caisson Foundation has less influence on flow due to its smooth shape. (4/5)	● Oval shaped pier from river bed upward has less influence on flow and less influence on scour. (5/5)
Constructability	● Quality control of large diameter steel pipes, such as welding control, manufacturing error control, etc. is difficult. ● Confirmation of bearing capacity is important but difficult. Closure effect of pile end is difficult to confirm and reduction of bearing capacity of pile end may be needed. Additional works to ensure closure effect may be needed. ● Corrosion countermeasures of steel piles near water level are needed. ● Acquisition of large pile driving machine may be difficult. (6/10)	● Quality control of large diameter steel pipes, such as welding control, manufacturing error control, etc. is difficult. ● Confirmation of bearing capacity is important but difficult. Closure effect of pile end is difficult to confirm and reduction of bearing capacity of pile end may be needed. Additional works to ensure closure effect may be needed. ● Corrosion countermeasures of steel piles near water level are needed. ● Acquisition of large pile driving machine may be difficult. (8/10)	● There are many examples of this size of steel pipe diameter and the driving depth. As this is a new bridge construction, there are no special construction constraints and no special machines are needed. ● No special problems for acquisition of steel pipe sheet piles. (10/10)	● Air compressor equipment near construction site is needed. Unlike Alternative 1 or Alternative 2, a temporary staging around pier is needed. (8/10)
Cost Ratio	1.05 (11/15)	1.01 (14/15)	1.00 (15/15)	1.48 (8/15)
Technology Transfer	● There are precedent examples and no technical transfer is expected. (3/5)	● There are precedent examples and no technical transfer is expected. (3/5)	● As this is a new technology, a technical transfer can be achieved. (5/5)	● As this is a new technology, a technical transfer can be achieved. (5/5)
Evaluation	● Construction period may be shorter but there are issues to be solved for quality control and constructability. Hence the total evaluation is low. (36/50)	● Construction period may be shorter and Constructability is better than battered piles. But there are issues to be solved for quality control. Hence the total evaluation is low. (42/50)	● Construction Period is a little longer but as a result of total evaluation, this is the best alternative. Recommended (47/50)	● Construction period is long and construction cost is high. Hence total evaluation is also low. (36/50)

Source: Survey Team

Chapter 5 OPTIMUM STRUCTURE TYPE SELECTION (Step 2)

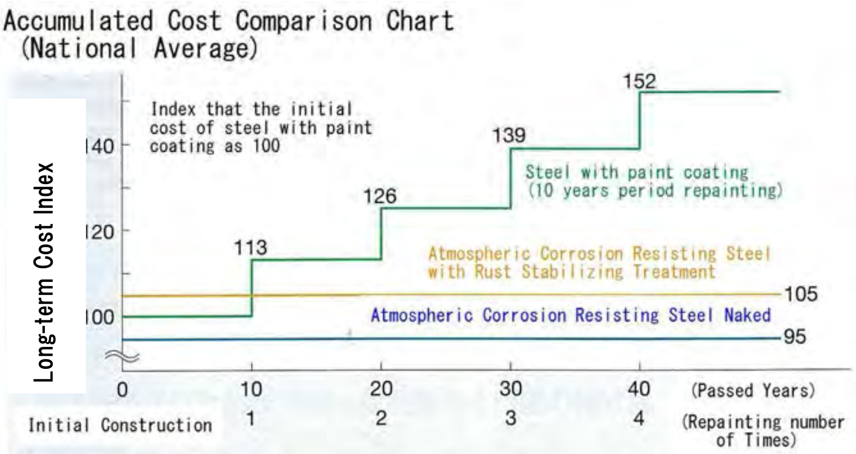
5.1. Innovative Technologies Application

The following Japanese technologies are the samples to be investigated in this study for application. They are, weathering steel, high tensile strength steel with low preheating temperature, curved Steel Truss Bridges, SPSP-F, head hardened rail, direct rail fastener on steel girder, derailment prevention guard, aluminum magnesium Alloy plasma spray coated bearings, high damping rubber bearings, etc. The derailment prevention guard has been utilized for a long time, even the Harding Bridge, which was constructed 100 years ago, adopted this system. But ADB-F/S did not adopt this guard so that the study team proposes the adoption of this guard. In ADB-F/S, the consultant suggested that the inside two (2) rails and outside two (2) rails work as derailment prevention guards for each other, but this is not true and there are no derailment prevention effects. SPSP-F is explained already in Chapter 4 and the explanation of this foundation is omitted here. Other technologies will be explained here.

5.1.1. Weathering steel sheet

In Chapter 4, a Steel Truss Bridge is proposed as a superstructure to compare with the result of ADB-F/S which selected a PC Box Girder Bridge. The innovative technologies of steel materials which can be applied to this type of Steel Bridge, are the weathering steel and the high tensile strength steel with low preheating temperature. But as studied in Section 5.2, the high tensile strength steel may not be needed for the 100m span Truss Bridges, as the higher stresses may not occur these bridges. If the span becomes longer than 200m, the stress becomes larger and the steel weight reduction by adopting high strength steel becomes beneficial. Therefore the high tensile steel will not be adopted for the new railway bridge. On the contrary, the adoption of weathering steel is beneficial because this steel alleviates the maintenance works and reduces the maintenance cost.

The weathering steel was originally invented in USA. Nippon Steel Company sold this weathering steel under the name of COR-TEN in post-war era. The weathering steel contains some chromium and copper, the contents of these metals are between the conventional steel and the stainless steel. Japanese companies excel in this technology of the weathering steel. Although the initial cost is slightly higher, the life cycle cost (LCC) is lower as shown in [Fig. 5.1.1].



Source: Brochure "High performance steel" by the Japan iron and steel federation

[Fig. 5.1.1] Cost comparison of weathering steel and conventional steel

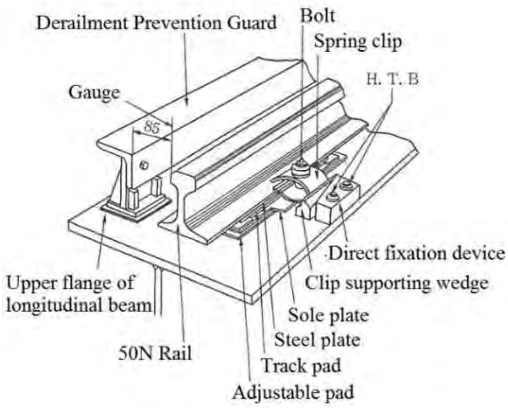
Recently, other countries also began to produce weathering steel plates but verification of long-term performance is considered to be insufficient since the history of application is short. In case that this technology is adopted to the new railway bridge, it is necessary to use the product which has passed the long-term performance verification test and accelerate test considering long-term usage

5.1.2. Innovative Technologies of Track Structure

(1) Direct Rail Fastener on Steel Girder

As the longitudinal gradient restriction of railway bridges is very strict compared to the road bridges, the lower rail level on bridges are more preferred. Because the approach bridge sections can be reduced and the total construction cost can be reduced. To reduce the rail level height, direct rail fasteners on steel girders are often adopted in Japan.

As shown in [Fig. 5.1.2], there are no concrete slab plates nor sleepers. Rails are directly fastened to the steel girders with the special fasteners and the special rail pads are utilized to adjust the longitudinal curvature. By this manner, the structural height, i.e. from the bottom of the bridge to the rail top level, can be minimized and the approach section length can be reduced. (According to the rough estimation in Section 3.4.2, roughly 2km of approach sections on both banks in total can be reduced.) Also there are no concrete slabs nor sleepers so that the dead load become smaller and the bridge structure can be economized more. The rail replacement work is easier and less maintenance works are needed. But this direct rail fastener causes larger noise and vibration and may not suitable for urban area. But this is not a case for the new railway bridge.



Source: Honshu-Shikoku Bridges, BOEA and Steel Bridge Design Documents (Fifth Edition)

[Fig. 5.1.2] Direct rail fastener on steel girder

The steel girders under the directly fastened rails need to be fabricated with high precision according to the rail longitudinal gradient, which needs high level of technology. Since the performance of track pad is very important for this technology, it is essential to pass the test specified by the Railway Technical Research Institute in Japan when it is applied in Japan.

In this survey, it is proposed that the center section of the new railway bridge is horizontal and the approach sections on both sides have a gradient of 5‰. Between the horizontal section and the 5‰ gradient section, more than R=2,000m vertical transition curve is needed.[1] This transition needs to be absorbed by the fabrication of the bottom chord of the Steel Truss Bridge.

[Fig. 5.1.3] shows an example of Dhaka Chittagong Railway Improvement Project. In this bridge, instead of fabricating the lower chord of the Steel Truss Bridge with high precision, railway sleepers of H Shaped Steel are used (Designed by Canarail). This structure looks like the “Direct Rail Fastener on Steel Girder”, but it neither lower the rail level nor reduce the dead weight.

From the same picture, derailment prevention rails are not installed inside of the rails. Instead broader gauge rails and narrower gauge rails are regarded as derailment prevention rails each other with more than 30cm gap. As they do not have the special direct rail fasteners, they substitute them by the conventional rail fasteners. But there are about 30cm gaps, these derailment prevention rails cannot work as a derailment prevention devices. The same design is adopted by Canarail in ADB-F/S, too.

[1] The vertical curve of conventional railway of Japan excluding Shinkansen Railway, should be more than R=2000m. At the section with the horizontal curve less than R=600m, R should be more than 3000m. When the difference between two gradients is less than 10/1000, the vertical curve can be omitted. For Shinkansen Railway, vertical curve of R=10,000m. At sections where train speed is less than 250km/h, R=5,000m. (Railway Technical Standard, Ministry of Land, Infrastructure, Transport and Tourism)

Note: Bridge No.207 (Span 120.5m)

Note: Bridge No.185 (Span 140.3m)

Source: Study Team

[Fig. 5.1.3] Example of Dhaka Chittagong Railway Improvement Project

(2) Derailment Prevention Guard

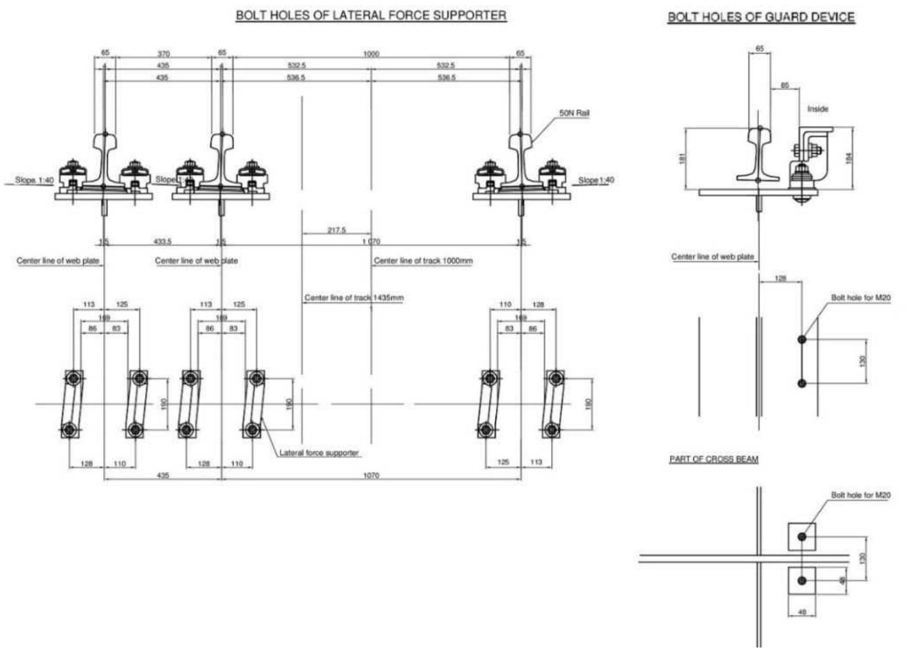
[Fig. 5.1.4] shows the derailment accident on the Bangabandhu Bridge. Luckily enough, the train turnover was prevented by the concrete barrier. As shown in this figure, the four (4) rail arrangement cannot prevent the derailment. In this accident, if the train leaned over on the other side, the worse accident might have happened.

Source: Google Jamuna Bridge photos Bangabandhu

[Fig. 5.1.4] Derailment accident on the Bangabandhu Bridge

In ADB-F/S, the four (4) rail configuration is proposed. In this survey, the survey team proposes the three (3) rail configuration with the addition of the dedicated derailment prevention guards inside (refer to [Fig. 5.1.2]). Four (4) rail configuration track requires four (4) sets of derailment prevention guard and furthermore it requires four (4) longitudinal girders if Direct Rail Fastener on Steel Girder is employed while three (3) rail configuration track requires only three (3) sets of them, which is economical and contributes to reduce structure weight.

The derailment guard is not a new technology, which was adopted even for the Harding Bridge, 100 years ago. But the directly fastened rails on the steel girders with the derailment guards require high precision as it was discussed above. [Fig. 5.1.5] shows three (3) rail configuration track structure.



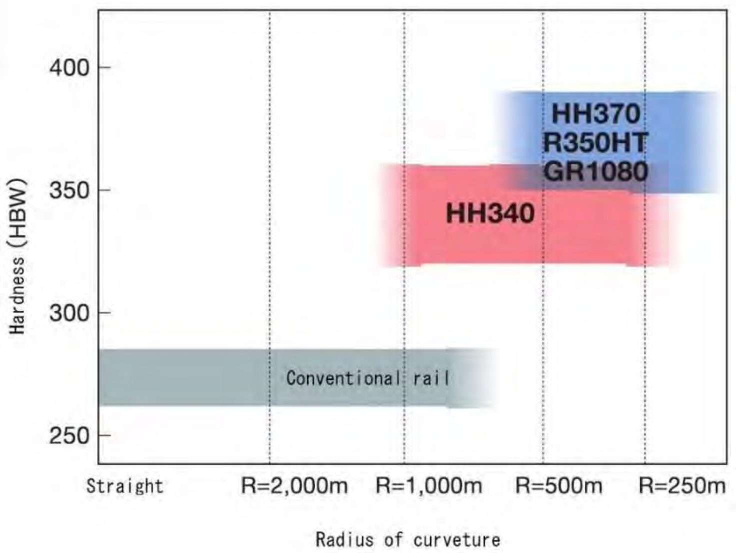
Source: Survey Team

[Fig. 5.1.5] Three (3) rail configuration track structure

(3) Head Hardened Rail

To increase the wear resistance and the toughness of rails, the head end of carbon steel rails is heat treated, i.e. quenched and tempered. It is sometimes called HH rail.[2] The method of heat treatment contains an innovative technology. The normal rails of Japan contains higher carbon content and they have a higher wear resistance even without the heat treatment. The head parts of these rails are heat treated to increase the even higher wear resistance.

When head hardened rail was first introduced, the primary purpose was to lessen rail replacement frequency due to rail head attrition attributable to increases of transportation volume, train weight, and speed, particularly in curved sections. However, lately it became popular to use the rail in conventional railway sections expecting reduction of maintenance burden and cost. [Fig. 5.1.6] shows comparison of hardness between head hardened rail and conventional rail.



Source: Nippon Steel & Sumitomo Metal

[Fig. 5.1.6] Hardness of head hardened rail

Meanwhile, Japan has a standard on head hardened rail use depending on track category as shown in [Tab. 5.1.1] in order to extend the rail wear life and to prevent damage on the rail head surface.

[Tab. 5.1.1] Head hardened rail use standard

Track Category \ Section		Straight Line	Curved Line: Inner Rail	Curved Line: Outer Rail
Class 1		End-head hardened rail	R>800 Standard length rail: End-head hardened rail Shorter rail: Normal rail R≤800 Standard length & shorter rail: Normal rail	R>800: End-head hardened rail R≤800: Head hardened rail
Class 2				
Class 3	Section for high speed operation: more than 100km/h			R>500: End-head hardened rail R≤500: Head hardened rail
	Other sections	Normal rail	Normal rail	R>500: Normal rail R≤500: Head hardened rail
Class 4	Section for more than 3 million passing tonnage			R>300: Normal rail R≤300: Head hardened rail
	Other sections			Normal rail

Note:
1) The classification mentioned above shall also be applied to the long rail section in principle. But normal rails shall be used for the long rail section without using end-head hardened rail
2) Normal rails shall be used for tunnel sections, in principle. The classification mentioned above shall be applied to the tunnel section where rail replacement is carried out due to rail wear and not caused by periodical replacement.
3) End-head hardened rail shall not be shorter rail by cutting.

Source: Structural Details of Track Facilities

[Tab. 5.1.2] shows the correspondence among track category, passing tonnage, operation speed and axle load in Japan.

[Table 5.1.2] Traffic volume by track category

Track Category	Standard Passing Tonnage	Maximum Speed				Max. Axle Load
		High Performance Train		Normal Train		
		Straight	Curve	Straight	Curve	
Class 1	More than 20 million ton/ year	120km/h	(*) +5km/h	110km/h	(*)	18ton
Class 2	10-20 million ton/ year	110~120km/h	ditto	100km/h	ditto	17ton
Class 3	5-10 million ton/ year	105km/h	ditto	95km/h	ditto	15ton
Class 4	2-5 million ton/ year	95km/h	(*)	85km/h	ditto	14ton

Note: (*) Allowable maximum speed passing through curve sections

Source: Track Management Regulation of Japan National Railways

Rail damage is often caused by an increase of longitudinal stress of rail and wheel load impact which is caused by narrowed or no joint gap between rails by rail move due to temperature fluctuation. [Fig. 5.1.7] shows an example of rail damage.

Source: Survey Team

[Fig. 5.1.7] Damaged rail example

Rail head wear and rail damage make periodical rail replacement/ repair cycle shorten, consequently, it causes maintenance cost increase. Measures to prevent rail damage include joint gap control, joint bolt tension control, adoption of sleeper for supported rail joint, ballast tamping under rail joint to avoid rail joint depression, periodical maintenance, and installation of head hardened rails. Especially in developing countries, sufficient maintenance costs will not be allocated due to the budget constrain therefore it is recommended to reduce the maintenance costs by applying head hardened rails.

According to the transport demand forecast in ADB-F/S, annual passing tonnage of freight transport is estimated at over 10 million ton/ year at the first year after completion of the project. Then, it is supposed to be 30 million ton/ year by increasing three (3) times 30 years after the project completion. [Tab. 5.1.3] shows the track feature at the first year after completion of the project.

[Table 5.1.3] Track feature of new railway bridge

Passing Tonnage (freight transport only)	Maximum Speed			Maximum Axle Load	
	Design Speed	Broad Gauge (1,676mm)	Meter Gauge 1,000mm	Broad Gauge (1,676mm)	Meter Gauge (1,000mm)
More than 10 million ton/ year (at the first year after completion of the project)	120km/h	100km/h	80km/h	25t	15t

Source: ADB-F/S

Referring the Japanese track category, annual passing tonnage on the new railway bridge is equivalent to Class 2 although it is only for freight transport. End Head Hardened Rail (EH Rail) shall be used for sections with large curve radius such as the new railway bridge section according to the Japanese regulation, but in reality Head Hardened Rail (HH Rail) is used in Japan for the entire section irrespective to [Tab. 5.1.1] instead of EH Rail in order to ease maintenance burden except for lower track category sections. Besides, considering the freight train operation with 25t axle load in the new railway bridge section which is larger than the standard axle load in Japanese, rail condition in the new railway bridge section is assumed to be much harder than the level expressed by the number of traffic tonnage. Therefore, it will better off to use HH Rail for the entire section of the new railway bridge. Furthermore, considering the actual heavy weight of axle load as mentioned above, it will be a better option to use Head Hardened Rail for heavy haul (HE Rail) which has much better durability than HH Rail.

The head hardened rail has been an exclusive technology of Japanese companies for a long time but recently, Chinese and Korean companies reportedly begins to produce these rails. But since the the application record is still short, the quality needs to be verified during the prequalification process of the new railway bridge construction project.

(4) Curved Steel Truss Bridge

The horizontal curvature of the Bangabandhu Bridge is R=12,000m. In this survey R=12,300m new railway bridge is proposed as shown in Section 3.4.1. A Steel Truss Bridge, as a superstructure, is proposed in this study so that the curved Steel Truss Bridge needs to be constructed as the new railway bridge. There are two (2) ways to construct a curved Steel Truss Bridge. One is to adopt curved upper and lower chords of a Steel Truss Bridge as shown in [Fig. 5.1.8]. The other is to bend the Truss Bridge only at above the piers as shown in [Fig. 5.1.9]. The upper and lower chords are straight between two (2) piers, but these chords are bent with some angle only above the piers. Inside of the Straight Truss Bridge, the train tracks are arranged with the horizontal curvature of R=12,300m.

Source: http://works-k.cocolog-nifty.com/.shared/image.html?/photos/uncategorized/2009/03/30/amagasaki6.jpg

[Fig. 5.1.8] Fukuchiyama Line branches out from Sanyo Line near Amagasaki

Source: Survey Team

[Fig. 5.1.9] Yoshima Bridge among Seto Ohashi Bridges

As bridges are constructed over two (2) points which form the shortest possible distance. As bridges connects two (2) shortest points, the bridges are generally speaking, straight. But when bridges are constructed over the urban areas or over the areas with other restrictions, curved bridges are sometimes adopted. The Steel Truss Bridge of Fukuchiyama Line adopted the curved alignment to pass over Sanyo Line (refer [Fig.5.1.8]). The Yoshima Bridge is planned over the curved section. The Yoshima Bridge is between the Kita-Bisan Seto Bridge (a Suspension Bridge) and the Iwagurojima Bridge (a Cable-stayed Bridge). Both the Suspension Bridge and the Cable-stayed Bridge cannot accept the curved alignment so that the Yoshima Bridge, a Steel Truss Bridge, needed to accept the curved alignment.

As stated above, steel Curved Truss Bridges are a special type of bridge .which commands a special know-how for the detailed design and fabrication of bending sections of chords based on long time experiences.

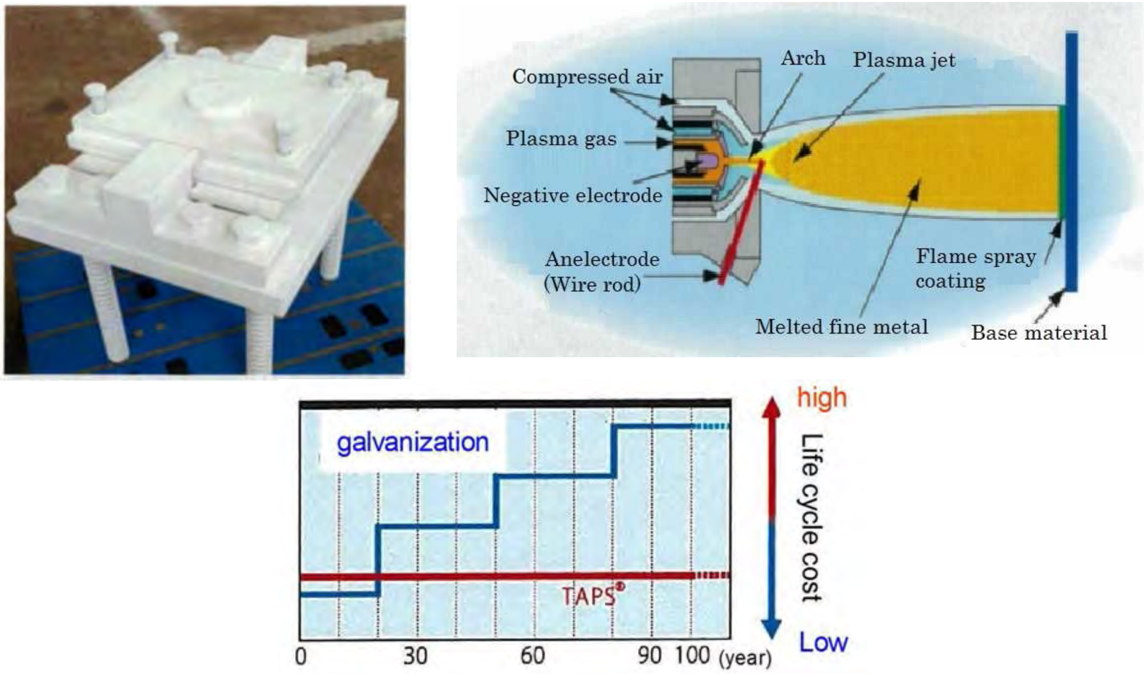
5.1.3 Other Innovative Technology

(1) Aluminum Magnesium Alloy Plasma Spray Coated Bearings

For the steel parts of steel bearings or rubber bearings, Flame spraying or Plasma spraying is sometimes adopted to have a higher corrosion resistance. Al-Mg plasma spray (Transfer Arc Plasma

Spray, TAPS) on the steel parts of bearings has a higher corrosion resistance than the conventional paint coating or the galvanization. Thus the repainting becomes unnecessary and the maintenance works can be reduced largely.

While the flame spraying is already popular at present, the plasma spraying, which can be done under the normal temperature, is more advanced and the adherence on the steel surface is stronger. In Japan, the effect of the corrosion resistance is being confirmed by the salty water spraying on the steel surface for more than 6,000 hours.



Note: under strict condition (coastal strip)

Source: Kawakin Core-Tech

[Fig. 5.1.10] Al-Mg Plasma Sprayed bearing

When this technology is applied in the new railway bridge construction project, the performance needs to be verified by the equivalent test as it is performed in Japan

(2) Super-High Damping Rubber Bearing (SHDR)

Bearings need to withstand the earthquake vibrations in the countries where earthquakes occur. The Bangabandhu Bridge adopted the pot bearings and longitudinal dampers together with the multiple steel bars embedded both on the piers and the girders. The earthquake motion is supposed to be absorbed by the dampers and the plastic deformations of the steel bars. Also the side stoppers are placed to prevent the girders from falling down sideways. But the functions of these devices are not clear.

In Japan, Super-High Damping Rubber Bearings (SHDR) are often adopted because the enhanced damping performance of the SHDR[2] enables to release earthquake vibration energy effectively and piers become more slender, thus the total construction cost becomes less expensive.

Key factor for the application of the SHDR for the new railway bridge construction project is to verify the performance of the SHDR to effectively release the earthquake energy. The following measures are proposed for the purpose.

- To require a test for all of the bearings instead of sample testing as it is the case in Japan.
- To require a 175% shear test for bearings made of high damping rubbers including SHDR in order to comply with earthquake vibration as it is the case in Japan.
- To require HDSR bearings to satisfy the certain performance specifications, the record of certain number of application, the performance test of elongation or the test of all number of bearings, etc.

- To require a special coating on the rubber surface of bearings to increase the ozone resistance of rubbers and to prevent rubber cracks.

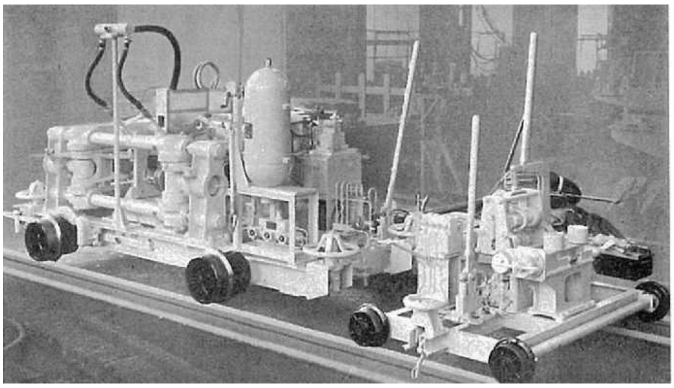
The Meghna Bridge adopts SHDR bearings, too.

(3) Gas pressure rail welding method

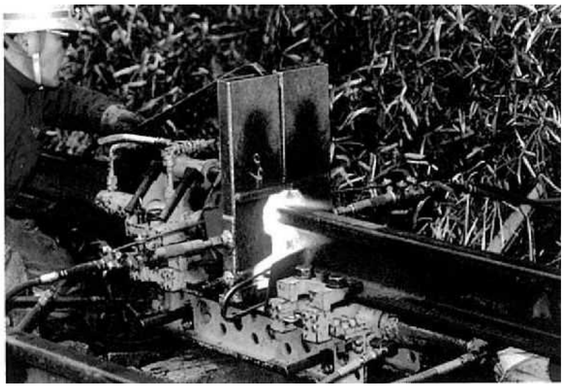
There are several methods to make a long rail by connecting standard length rails, such as the Alumino-thermic welding method, the Flash welding method, the Enclosed arch welding method, etc. But these methods apply heats more than 2,000 degree, change the characteristics of the base metal and weaken the fatigue strength. On the contrary to these conventional welding methods, the Gas pressure welding method apply about 1,200 degree heat to the base material and heighten the fluidity of the base material. In this condition, two (2) rails are pressured together to be connected each other in the solid phase condition of base materials. Therefore this method has a merit not to change the characteristics of the base material.

The Gas pressure welding method began to be developed in Japan and USA in around 1940. In Japan, the machine was realized and began to be used in 1955. The early type of this machine was fixed on the ground and weighed about 3 ton, which was not suitable for the site use and it was troublesome to remove the swelled portion of the connection. Afterwards the machine was improved more and in 1986, a small Gas pressure welding machine was developed which weighed only 95kg. In addition to this machine, another punching shearing device which weighed 65kg, was developed. With these machines, the site application became possible.

The Gas pressure welding machine began to be used worldwide. But some technical knowledge is required to use these machines and if these machines are utilized for the new railway bridge, a technical transfer can be achieved.



Fixed on ground Gas pressure welding machine



Rail connection beside track by small Gas pressure welding machine

Source: Railway Technical Research Institute Review (Sept. 2015)

[Fig. 5.1.11] Rail gas pressure welding machine

5.2. Optimum Span Length

5.2.1 Alternatives for comparison

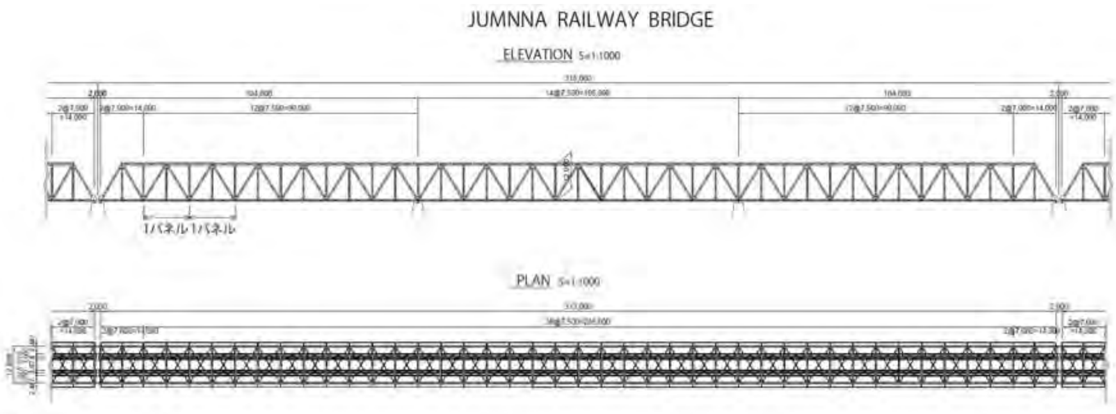
The best combination of superstructures and substructures is studied. If the span of superstructure becomes longer, the steel weight of superstructure per meter becomes heavier and more expensive. But the number of piers is reduced and the substructure cost becomes less. Therefore the best combination of superstructure and substructure needs to be studied.

The length of one panel of Steel Truss Bridge as defined in [Fig. 5.2.1] is selected as 15m long which is a standard size of Steel Truss Bridges. Based on this 15m long panel, three alternatives are proposed. They are,

① Alternative 1: 1 Span Length=15m×7 Panel=105m

② Alternative 2: 1 Span Length =15m×8 Panel =120m

③ Alternative 3: 1 Span Length =15m×9 Panel =135m



Source: Survey Team

[Fig. 5.2.1] One unit of Steel Truss Bridge (three span Continuous Truss Bridge)

The total bridge length is 4,810m as proposed in Section 3.4.1. Alternative 1 indicated as (1) in [Fig. 5.2.2] is adopted from three (3) alternative routes. Alternative 1 has a curvature of R=12,300m. The total length of 4,810m cannot be divided by 105m nor 120m nor 135m. The total bridge weight is calculated by multiplying the unit weight (t/m) of each span and 4,810m.

As one (1) bridge unit, a three (3) span Continuous Truss Bridge is assumed. In ADB-F/S, a six (6) span Continuous Truss Bridge is assumed. But this may be due to the fact that the consultant assumed a road bridge which needed to have a longer Continuous Bridge to have a more comfortable car riding. On the contrary, trains run over railways and the longer continuity is not needed. In this study, to avoid the concentration of the earthquake force on one fixed bearing and on one pier, a three (3) span Continuous Truss Bridge is assumed. But at the same time, even the continuous span becomes longer, the unit bridge weight may not vary largely.

Source: Google earth

[Fig. 5.2.2] Bangabandhu Bridge and new railway bridge

5.2.2 Optimization of Span Lengths of Steel Truss Bridge

Total construction cost ratio, i.e. the total of superstructure cost and the substructure cost, of three (3) alternatives are shown in [Tab. 5.2.1]. In this table, the total construction cost of 120m span alternative is defined as 1.0 and other construction costs are shown in relation to 120m span alternative.

The substructure is assumed to be SPSP-F foundation, as proposed in Section 4.2.2.

[Tab. 5.2.1] Cost ratio of Steel Truss Bridge + substructure

	Span length=Panel/2×number	7.5m×14=105m	7.5m×16=120m	7.5m×18=135m
1.	Number of piers	47	41	37
2.	Bridge Length (m)	4,810	4,810	4,810
3.	Total Steel Weight (t)	38,177	40,817	44,070
4.	Cost Ratio (Superstructure +Substructure)	1.016	1.000	1.011

Source: Survey Team

From the comparison above, it becomes clear that 120m span alternative is the best alternative. The Bangabandhu Bridge is 300m downstream of the new railway bridge and its spans are 100m long. According to the "Structure laws such as river management facilities" of Japan, the adjacent bridge special clauses will not be applied when the bridges are more than 200m apart or the river width apart. Therefore it can be assumed that piers of the new railway bridge will not influence on the piers of the Bangabandhu Bridge, as the new railway bridge has 120m spans and 300m apart, although at the detailed design stage, this must be examined further. Also both of the Bangabandhu Bridge and the new railway bridge belong to category II of navigational channel of BIWTA and secure the navigational clearance of 76m width and 12.2m height, so that there are no influences on the ship navigation.

Chapter 6 COMPARISON OF ADB-F/S RECOMMENDATION AND SURVEY PROPOSAL (Step 3)

6.1. Recalculation of Construction Cost of F/S

6.1.1. Unit Prices of Construction Cost for Comparison

In ADB-F/S, only the total construction cost of substructure and superstructure is listed and the breakdown of the cost is not shown. What kind of site situation or market situation is assumed, is not written. Therefore it is almost impossible to compare the cost of Steel Truss Bridge of this study and the cost of ADB-F/S. To achieve a fair comparison, the construction cost of the PC Box Girder Bridge of ADB-F/S needs to be recalculated. Afterwards the cost of F/S and the cost of Steel Truss Bridge of this study will be compared.

The quantity of the PC Box Girder Bridge will be calculated from the drawings and the cost will be calculated from the unit prices of this study. But in the drawings of ADB-F/S, only one standard 5-span Continuous Girder Bridge and one standard 4-span Continuous Girder Bridge at end section are shown. Only the typical sections of the bridge are shown. All of the bridge details are not shown.

Typical sections are shown for the substructures and the foundations, but the pile lengths and the height of piers are not shown in the drawings. Under these limited conditions, the superstructure cost will be calculated first from the quantities roughly estimated from the drawings, then the cost of substructure and foundations will be calculated by subtracting the superstructure cost from the total cost of ADB-F/S (Refer to Sec.6.1.2, for the reasons).

The unit prices for the calculation of the Superstructure cost is estimated from the previous records of similar projects in South East Asia area and adjusted for Bangladesh because in Bangladesh, concrete aggregates need to be imported from other countries. The estimated unit prices are shown in [Tab. 6.1.1].

[Tab. 6.1.1] Unit prices to estimate PC Box Girder Bridge cost

Items		Unit	1,000 yen	Spec.
Concrete	Bridge proper	m^3	100	40MPa
	Curbs, Inspection ways	m^3	200	30MPa
Reinforcement Bars		t	400	
PC Tendons	12S15.2	t	1,500	
	1S21.8	t	1,300	

Note: MPa is unit to express concrete strength MPa=Mega Pascal

Source : Survey Team

The unit prices to estimate the cost of Steel Truss Bridge and SPSP-F are decided based on the commodity prices in Bangladesh (refer to [Tab. 3.5.1]), the construction conditions including river conditions (Refer to Sec.3.5.1.), the cost estimate of the Japanese contractors, etc. They are shown in [Tab. 6.1.2]. Out of these unit prices, the steel unit price of the Steel Truss Bridge proper is a classified information at present (refer to Sec.6.2.1 for the conditions of the assumption).

[Tab. 6.1.2] Unit prices to estimate Steel Truss Bridge cost

(1) Steel Truss Bridge

Items	Unit	1,000 yen	Remarks
Steel Truss Bridge Proper	t	600	Refer to Sec.6.2.1.
Bearings	Lamp sum	1,174,560	For 4,810m（Span：120m）

(2) Piers and SPSP-F

Items		Unit	1,000 yen	Remarks
RC Pier		One	87,020	
SPSP-F	Material & Shipping	One	110,170	
	Pile Driving	One	500,390	

Source : Survey Team

6.1.2. Cost Estimate of ADB-F/S Recommendation

The quantities of substructures and foundations of PC Box Girder Bridge selected by ADB-F/S cannot be calculated from the drawings and the construction cost of substructures and foundations cannot be calculated directly. Thus the cost of the substructures and foundations needs to be estimated by subtracting the superstructure cost, which can be estimated from the drawings, from the total cost shown in ADB-F/S. Therefore the reliability of the cost of substructures and foundations becomes somewhat low. But the real construction cost of the foundations and the substructures may become larger because the piling of large diameter battered piles into the deep ground is very difficult and pushes up the cost. Therefore the cost estimate of substructures and foundations of this survey is rather small and modest for the comparison of two (2) alternatives.

(1) Total Construction Cost : 60,917million Yen

The total construction cost of the bridge is calculated from the total of the bridge related items of ADB-F/S report and converted to Yen. The total cost in [Tab. 6.1.3] comes from the report of ADB-F/S. This consists of Main Bridge, Box Culverts, Guide Bands Protection, others and 40% contingency. The price unit is Bangladesh Taka. In the column of “Bridge Portion”, only bridge related items are listed, they are Main Bridge, Misc. Works, and Contingency (40%). For other items, “0” is given. On the right column, Yen converted costs are listed. The exchange rate used for the conversion is 1.6 Yen/Taka in July, 2015.

[Tab. 6.1.3] Cost breakdown of PC box girder bridge of ADB-F/S recommendation

No.	Item of Works	Total Cost (BDT million)	Bridge Portion (BDT million)	Bridge Portion (Million Yen)
1	Main Bridge (Continuous PC Box Girder Bridge)	23,310	23,310	37,300
2	Box Culverts	39	0	0
3	Potential Repair to Existing Guide Bund	11,655	0	0
4	Misc. Works (Pile driving on Guide Band) a) Exposure of Existing Protection b) Large Dredging c) Risk of Damage d) Repair after Pile Driving e) Backfilling after Pile Driving f) Cofferdam	3,885	3,885	6,200
	Sub Total	38,889	27,195	43,500
5	Contingency (Sub total x 40%)	15,556	10,878	17,400
1-5	Grand Total	54,445	38,073	60,917

Note: 1Taka＝1.6Yen

Source : Recalculated from ADB-F/S report

(2) Superstructure Construction Cost : 18,730Million Yen

The superstructure quantity is calculated from the drawings of ADB-F/S. The construction cost is calculated from this quantity multiplying the unit prices shown in [Tab. 6.1.1]. The contents of the calculation are shown in [Tab. 6.1.4].

[Tab. 6.1.4] Calculation of superstructure cost of ADB-F/S recommendation

Items		Unit	Quantity per 100m	Unit Price (1,000 Yen)	Cost (1,000 Yen/100m)	Remarks
Concrete	Bridge Proper	m^3	1,202.900	100	120,290	40MPa
	Curbs, Inspection Ways	m^3	360.800	200	72,160	30MPa
Reinforcement Bar		t	344.009	400	137,600	
PC tendons	12S15.2	t	33.955	1,500	5,,930	
	1S21.8	t	6.473	1,300	8,410	
Construction Cost of PC Superstructure per100m					389,400	
Total Construction Cost of PC Superstructure					18,730,190	

Note: MPa is unit to express concrete strength MPa=Mega Pascal

Source: Survey Team

(3) Construction Cost of Substructure and Foundation：42,187Million Yen

From [Tab. 6.1.4], the cost of substructure and foundation can be calculated as follows.

[Cost of Substructure and Foundation] = [Total Cost] - [Cost of Superstructure]
= 60,917   18,730 Million Yen.

As already explained, the quantities of substructures and foundations of PC Box Girder Bridge selected by ADB-F/S cannot be calculated from the drawings and the construction cost of substructures and foundations cannot be calculated directly. So that the reliability of this estimate is low. But the real construction cost of the foundations and the substructures may become larger because the piling of large diameter battered piles into the deep ground is very difficult and pushes up the cost. Therefore the cost estimate of substructures and foundations of this study is rather small and modest for the comparison of two (2) alternatives.

6.2 Cost Estimate of This Survey Proposal

6.2.1. Cost Estimate of Superstructure

The construction cost per ton of Steel Truss Bridge is estimated as 600 thousand yen/t. This includes the cost of Steel Truss fabrication out of Bangladesh, transportation to the construction site and erection of the Truss Bridge. This cost is estimated from the various former records of Steel Bridge projects in South East Asia.

This unit price is different from unit price estimation supplied by some Japanese contractors, because the company estimation is a kind of strategic value considering market conditions while the unit price estimated in this survey is based on actual contracts after price competition.

Another reason why this survey preferred unit price assumed based on actual contracts is that the unit price for the PC Box Girder Bridge is based on actual contracts. It is necessary to make price comparison between the ADB-F/S proposal and this survey proposal on equal condition.

The total steel weight of 120m span Steel Truss Bridge over 4,810m section is 40,817t. To get the total construction cost, this weight is multiplied by 600,000 Yen/t and the cost of bearings is added. The total cost is 25,664,760 Thousand Yen as shown in [Tab. 6.2.1].

[Tab. 6.2.1] Cost calculation of Steel Truss superstructure

Items	Unit	Quantity	Unit Price (1,000 Yen)	Cost Price (1,000 Yen)	Remarks
Truss Bridge Proper	t	40,817	600	24,490,200	
Bearings	Lamp sum	1	1,174,560	1,174,560	
Superstructure Total				25,664,760	

Source: Survey Team

6.2.2. Cost Estimate of Substructure and Foundation

The construction cost of one pier and that of one SPSP-F are shown in [Tab. 6.2.2], they are calculated from the unit prices shown in [Tab. 6.1.2]. The total cost becomes 28,600,789 Thousand Yen.

[Tab. 6.2.2] Cost estimate of piers and foundations

Items		Unit	Quantity	Unit Price (1,000 Yen)	Cost (1,000 Yen)	Remarks
RC Pier		One	41	87,020	3,567,820	
SPSP-F	Material, transportation	One	41	110,170	4,516,970	
	Pile driving	One	41	500,390	20,515,990	
Substructure Total					28,600,780	

Source: Survey Team

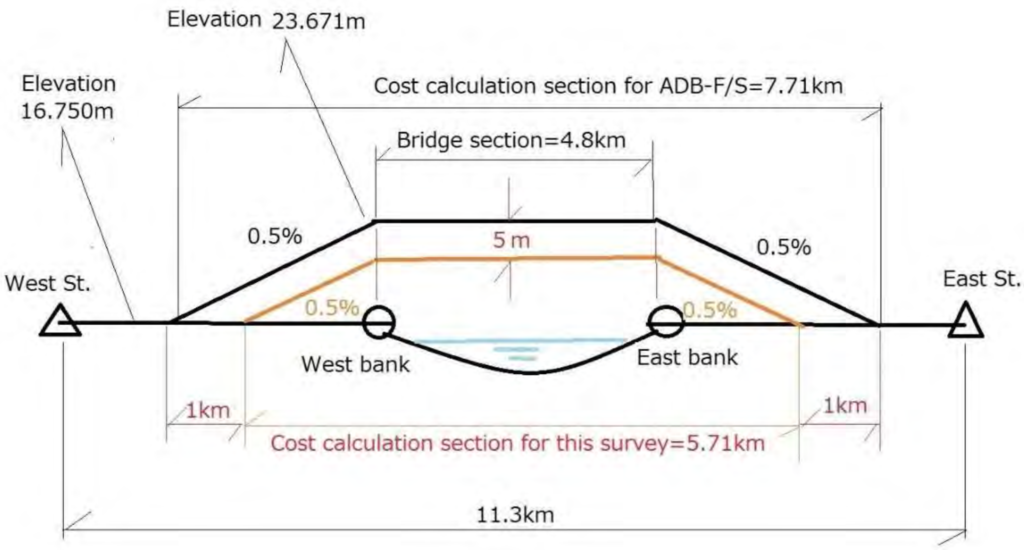
6.3 Comparison of LCC of Two Alternatives

6.3.1. Comparison of Initial Costs

The items of the initial cost comparison is as follows; Superstructure, Substructure, Tracks and Approach Viaduct. The difference of PC Box Girder and Steel Through Truss Bridge is examined for the superstructure. The difference of the Battered Large Diameter Steel Pipe Pile Foundation and SPSP-F is examined for the substructure. The difference of the four (4) rail configuration track and the three (3) rail configuration track including the direct rail fasteners, head hardened rails and derailment prevention guards, is examined for the track. The length difference of approach viaduct is examined because the Steel Through Truss Bridge has a lower rail level, which results in a shorter viaduct length.

The cost of tracks is estimated for the similar projects in the neighboring countries. The cost difference between the approach section e of west bank and east bank of PC Box Girder Bridge and that of Steel Through Bridge is estimated. The cost difference comes from the length difference of the approach sections. The difference of approach viaduct length is explained in [Fig. 6.3.1]. Here, in order for fair cost comparison between structures type, same unit prices are employed at each cost item. Therefore, ADB-F/S unit price is applied for one cost item and actual contract price taken from equivalent project in neighboring country is applied for another cost item. The [Tab. 6.3.2] explains the concept.

For other items such as the jetties which are needed for the construction, other approach bridges on both banks, signal systems and communication systems, which are not altered in this study, are not compared.



Source: Survey Team

[Fig. 6.3.1] Illustration of approach sections difference

The cost estimate of two alternatives is shown in [Tab. 6.3.1]. From the table, the Steel Truss Bridge alternative with SPSP-F is more cost competitive. It must be noted for the cost of the table that,

- The cost of dredging of sand bars is not included in the foundation construction for both alternatives of ADB-F/S and this survey, because the amount of dredging is unclear, the length of sand bars is unclear and the fact that the dredging is needed every year or not is unclear.
- The quantity of substructure and foundation of ADB-F/S alternative is unclear so that the construction cost of them are calculated by subtracting the superstructure cost from the total cost. Therefore the certainty of the cost of substructure and foundation is lower (But for the cost comparison of two (2) alternatives, a conservative cost estimate is used).
- The cost of fabrication and erection of Steel Truss Bridge per ton is estimated from the similar projects along with ADB-F/S cost estimation for PC Box Girder Bridge.

[Tab. 6.3.1] Initial cost comparison of two alternatives
(ADB-F/S recommendation and this survey proposal)

(Unit：Million Yen)

	ADB-F/S Recommendation		This survey proposal	
	Type	Cost	Type	Cost
Superstructure	PC Box	18,730	Steel Truss	25,665
Substructure + Foundation	Battered Pile Foundation	42,187	SPSP-F	28,601
Track -ADB-F/S=7.71km -Survey=5.71km	Bridge: 4 rails slab track Approach: 3 rails	5,560	Bridge: 3 rails direct track Approach: 3 rails	4,316
	Ordinary rail	0	Increase by HH	39
	Without derail prevention guard	0	With derail prevention guard	1,183
Approach (Embankment + Viaduct)	Length=2.61km (Total of both sides)	1,050	Length=0.61km (Total of both sides)	496
Total		67,527		60,300

Source：Survey Team

[Tab. 6.3.2] Unit cost base for cost comparison

	Cost Item	ADB-F/S		This Survey	
		Unit Price	Amount	Unit Price	Amount
Superstructure	PC Box	Market	4.8km	Not Applicable	0km
	Steel Truss	Not Applicable	0km	Market	4.8km
Foundation	Battered Pile	Market	49 unit	Not Applicable	0 unit
	SPSP-F	Not Applicable	0 unit	Market	41 unit
Pier	RC Pier	Market	49 unit	Market	41 unit
Track	Ordinary Rail	Market	(7.71-4.8)×6=17.46km 4.8km×8=38.4km	Market	(5.71-4.8)×6=5.46km
	HH Rail	Not Applicable	0m	Market	4.8km×6=28.8km
	Ordinary Fastener	ADB-F/S	7.71km	ADB-F/S	(5.71-4.8)×6=5.46km
	Direct Fastener	Not Applicable	0km	Market	4.8km×6=28.8km
	Sleeper	Market	4.8km×2=9.6km	Not Applicable	0km
	Derail Prevention	Not Applicable	0km	Market	4.8km×6=28.8km
	~~Base Concrete~~	~~Market~~	~~4.8km~~	~~Not Applicable~~	~~0km~~
Approach sections	Viaduct	ADB-F/S	ADB-F/S length	ADB-F/S	ADB-F/S length
	Embankment	ADB-F/S	ADB-F/S length	ADB-F/S	ADB-F/S length-2.0km

Note: Base concrete is already included in PC Box girder cost.

Source: Survey Team

Another alternative combination of super- and substructure is considered PC Box Girder with SPSP-F. However, the dead load of PC Box Girder is more than triple of that of Steel Truss Girder and the number of piles of SPSP-F increases and also the cost of SPSP-F increases more than 1.3 times of that of Steel Truss Girder. Therefore, the construction cost of PC Box Girder with SPSP-F exceeds that of Steel Truss Girder with SPSP-F.

6.3.2. Cost Comparison including LCC

(1) Maintenance Cost of PC Box Girder Bridge and Steel Truss Bridge

The balanced cantilever method is adopted for the PC Box Girder Bridge of ADB-F/S. According to 1989 F/S of the Bangabandhu Bridge, it is written that a special care is needed to quality-control fresh concrete in a hot and humid country, like Bangladesh so that the site casting concrete should be avoided and the precast concrete should be adopted as far as possible. It recommends to use site casting concrete only for the bridge deck connections.

If the balanced cantilever method is adopted, all of the concrete needs to be cast at site and the severe quality control of fresh concrete becomes necessary. If good quality fresh concrete is cast at the site and the quality of concrete is assured, the maintenance of PC Box Girder Bridges is not difficult. But if bad quality concrete is cast, the maintenance work will become troublesome.

On the contrary to the Concrete Bridges, Steel Truss Bridges are fabricated in the shops and the quality control is comparatively easier. The quality control of the site erection works is also easier and the quality of completed bridges is also reliable. In the case of conventional Steel Bridges, the periodical repainting cost is high and consequently the maintenance cost becomes high. But the weathering steel is planned to be adopted for this bridge and the repainting cost becomes unnecessary and the maintenance cost becomes smaller. If the maintenance cost is compared, the cost of PC Box Girder Bridge and the cost of Steel Truss Bridge are almost equal. The quality control during the construction is easier for the Steel Truss Bridge. For the PC Box Girder Bridge, if the quality control during the erection is not sufficient, the maintenance cost may increase.

(2) Cost Comparison including LCC

If a PC Box Girder Bridge is properly constructed, the maintenance cost may not different from that of a Steel Truss Bridge made of weathering steel. Therefore the maintenance costs are almost the same and the total cost may not be influenced by LCC. But when the economic benefits of projects are calculated, the renewal cost, the residual values, the maintenance costs, etc. are incorporated. From the point of view of this calculation, the demolish cost of Steel Bridges is cheaper and the steel members can be reused. Steel Bridges can be transported to other places for the reuse, too. In this survey, some innovative technologies are introduced. The direct rail fastened tracks and the head hardened rails will reduce the maintenance cost but the quantitative estimate of this reduction is too difficult. The bearing related technologies, such as the Aluminum-Magnesium Plasma Spray and the rubber coating, will reduce the maintenance cost, too.

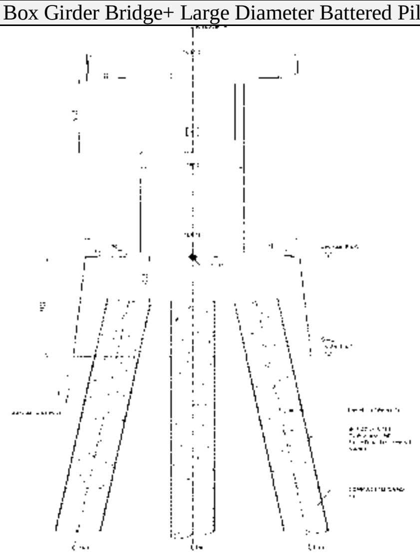
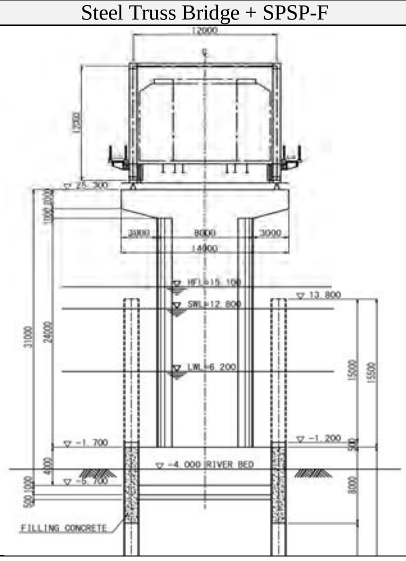
If the technology transfer of SPSP-F or gas pressure rail welding is achieved, local engineers can perform these works instead of foreign engineers, this can reduce LCC in the long run.

6.4 Conclusion

As stated above, the Steel Truss Bridge alternative proposed by this study has the cost competitiveness not only for the initial cost but also for LCC. The comparison of two (2) alternatives is shown in [Tab. 6.4.1].

As shown in the table, the combination of the Steel Truss Bridge and SPSP-F is better than the other alternative from the view point of not only the cost but also other various aspects. The numbers shown in the parentheses are the evaluations. Out of 70 points, ADB-F/S recommendation gets 48 points while this survey proposal gets 67 points.

[Tab. 6.4.1] Summary of comparison between two alternatives
(ADB-F/S recommendation and this study proposal)

Alternative	PC Box Girder Bridge+ Large Diameter Battered Piles	Steel Truss Bridge + SPSP-F
Illustration		
Construction Period	51 Months (8/10)	48 Months (10/10)
Against Ship Collision	● Cross sectional area above river bed is larger and probability of ship collision is higher than Alternative 2. (7/10)	● Cross sectional area above river bed is smaller and probability of ship collision is smaller. Also number of piers is less and ship collision probability becomes less. (9/10)
Scouring	● As cross sectional area is larger, scouring effect may be larger, too. But the multi pile effect and the single column effect may be different and it is difficult to estimate. (7/10)	● As cross sectional area is smaller, the scouring effect may be smaller. (8/10)
Substructure Constructability	● Pile-Caps can be constructed above the water level so that the temporary works are simple. ● Battered piles are difficult to position correctly. ● Large diameter piles need to be fabricated at site and largest machines are needed to handle piles. Quality control of large diameter steel pipes, such as welding control, manufacturing error control, etc. is difficult. ● Hammering down large diameter battered piles is very difficult. Confirmation of bearing capacity is important but difficult. Closure effect of pile end is difficult to confirm and reduction of bearing capacity of pile end may be needed. ● Large Diameter Steel Battered Piles are adopted against the larger superstructure weight. This adoption can reduce the number of piles. (6/10)	● Steel Pipe Sheet Piles form a temporary cofferdam. Lower part of these sheet piles is utilized as a permanent foundation, which is a rational structure. ● There are no problems for the substructure construction compared to large diameter battered piles. ● There are many examples of these diameter piles and depth of foundations. As this bridge is newly constructed, there are no special construction constraints. No special machines are needed. (10/10)
Superstructure Constructability	● Balanced Cantilever Method of Construction is stable and well-established. But careful quality control of concrete is needed. ● Superstructure is similar to the Banghabandu Bridge but rails are placed just above webs which is a better improvement from the Bangabandhu Bridge. ● Earthquake Resistance is improved because of adoption of rigid frame structure of piers and girders. (9/10)	● As the rail level is lower, the approach section becomes shorter. ● Piece by piece erection of steel truss bridge is stable and well-established. ● A Steel Truss Bridge with Direct Rail Fastening Devices, which is about 1/3 of weight of PC Box Girder Bridge. ● Shop fabricated steel members are assembled at the site and the construction period can be shortened more easily than Alternative 1. ● As members of bridge are prefabricated in shops, quality control of construction is comparatively easier. (10/10)
Cost Ratio	1.04 (9/10)	1.00 (10/10)
Technology Transferability	● As battered large diameter piles are difficult to fabricate and to construct. This may not be recommended for a technical transfer. (2/10)	● As this is a new technology, a technical transfer can be achieved. (10/10)
Evaluation	Better (48/70)	Best (67/70)

Note: The numbers shown in the parentheses are that the left is score and the right is full mark.

Source: Survey Team

Chapter 7 PROJECT IMPLEMENTATION PLAN

Based on the survey team's knowledge of railroad bridge construction projects in Japan, the proposals in the ADB-F/S, and information gathered from field surveys and discussions with the implementing organization, the survey team proposes the following construction method and project implementation schedule, procurement procedures, consultant organization for effective and fair implementation, and project costs including those for main bridge construction and related work as calculated in Chapter 6.

7.1. Construction Method

As discussed in Chapter 5 concerning bridge structural types and the ADB-F/S, a Steel Truss Through Bridge structure and SPSP-F are proposed as the optimum superstructure and substructure respectively for new railway bridge. There are several alternative construction methods for these structural types as shown in [Fig. 7.1.1], and the contractor(s) will finally choose construction methods considering cost performance, construction duration, maintenance, technology transfer, as well as site conditions.

The survey team proposes the following construction methods based on the investigations conducted as part of this supplemental survey.

7.1.1. Superstructure Construction Method

A Steel Truss Through Bridge is proposed for the superstructure and the following three (3) economical erection methods can be considered.

(1) Cantilever Single Piece Erection by Traveler Crane

A traveler crane on the steel truss is used to erect the truss members one by one and the erection work normally begins from both river banks and then proceeds toward the center of the river. All individual pieces for the steel truss members are carried over the already erected truss deck from the river banks. Since the steel truss members are assembled piece by piece, this method is not very fast. However, this is the most reliable erection method because river flow during the rainy season does not affect the work.

(2) Cantilever Panel Erection by Traveler Crane and Barge

Two-dimensional truss panels are assembled on the ground and transported by barges to the erection location. A traveler crane on the truss is then used to lift and erect the pre-assembled panels into the right position. Although the erection speed is faster than for alternative (1), river flow affects the erection work, making it difficult to erect the bridge during the rainy season.

(3) Cantilever Block Erection by Floating Crane and Barge

Three-dimensional truss bridge blocks are assembled on the ground and transported by barge to the erection location, and the pre-assembled blocks are then erected by a floating crane.

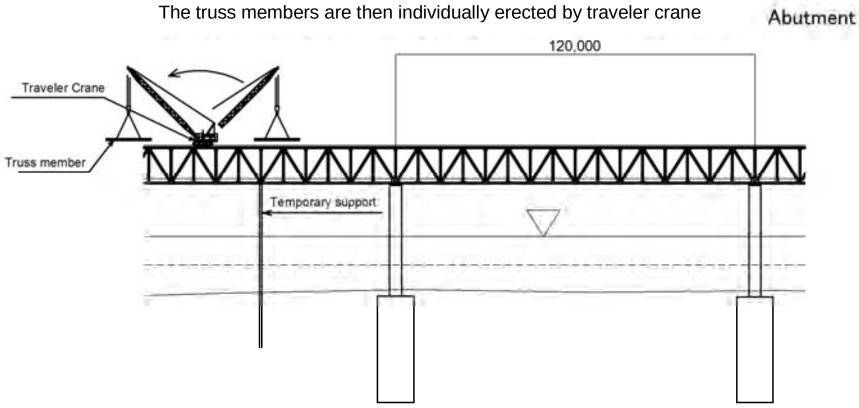
The capacity of the floating crane is between 100 and 150 tons and the erection speed is faster than for alternative (2) above. However river flow affects the erection work as with alternative (2), making it difficult to erect the bridge during the rainy season.

The various erection methods for the superstructure are shown in [Fig. 7.1.1].

(1) Cantilever Single Piece Erection by Traveler Crane

Truss members are carried from the abutment piece by piece

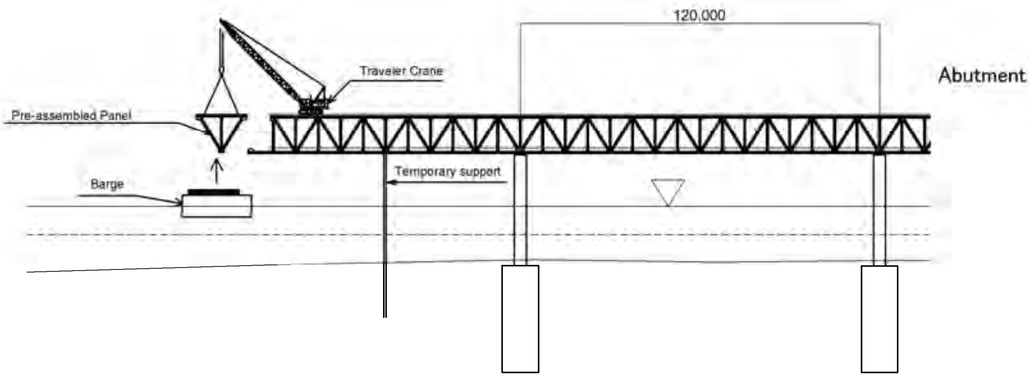
The truss members are then individually erected by traveler crane



(2)Cantilever Panel Erection by Traveler Crane and Barge

Two-dimensionally assembled truss members (panels) are transported by barges

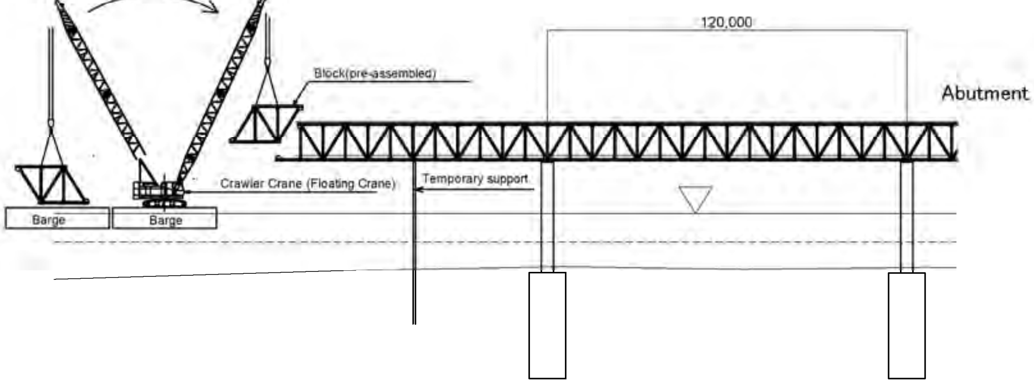
The pre-assembled panels are then erected by traveler crane



(3)Cantilever Block Erection by Floating Crane and Barge

Three-dimensionally assembled truss members (blocks) are transported by barges

The pre-assembled blocks are then erected by floating crane



Source: Survey Team

[Fig 7.1.1] Steel truss erection methods

From the methods shown above, the contractor(s) shall choose an erection method based on their examination of the site conditions and their available equipment. However, as the most reliable erection method, alternative (1) is selected for further discussion in this chapter. The following are the main uncertain factors which are difficult to determine at the present time.

1) Site conditions during the rainy season

2) Substructure construction speed (which largely affects the length of the entire construction period)

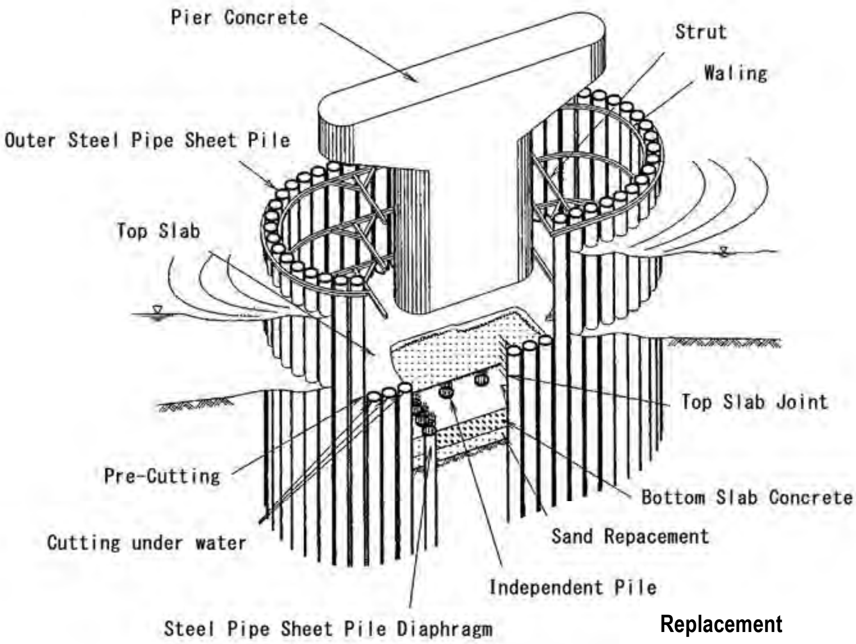
3) Manufacturing speed of steel truss members (mass production and transportation of steel truss members may be problematic)

4) Availability of barges and crawler cranes which have appropriate abilities for a adopted construction method and also of the number of those required

Although it seems rational to begin erecting the superstructure from both river banks, it may be necessary to start the erection work elsewhere such as in the middle of the river depending on the manufacturing speed of the steel trusses and sub-structure. However, this supplemental survey assumes that the erection work will begin from both river banks which is the most probable alternative.

7.1.2. Substructure Construction Method

A concrete pier with SPSP-F is recommended for the substructure which is shown in [Fig. 7.1.2].



Source: SPSP-F - Design & Construction (Steel Pipe Pile Association in Japan)
[Fig 7.1.2] Overview of SPSP-F substructure

A substructure construction includes the following building stages.

(1) Preparatory Work: Survey Platform Installation, Temporary Pile Driving, Light Buoy Installation

(2) Steel Pipe Sheet Pile (SPSP) Installation: Pile Guide Frame Installation,
1st Phase Piling (hydraulic vibration hammer), 2nd Phase Piling (hydraulic hammer)

(3) Excavation and Concreting inside Steel Pipes: Joint Grouting, Excavation and Concreting inside Steel Pipes

(4) Base Concrete: 1st Phase Scaffolding, Excavation inside SPSPs, Sand Replacement, Base Concreting

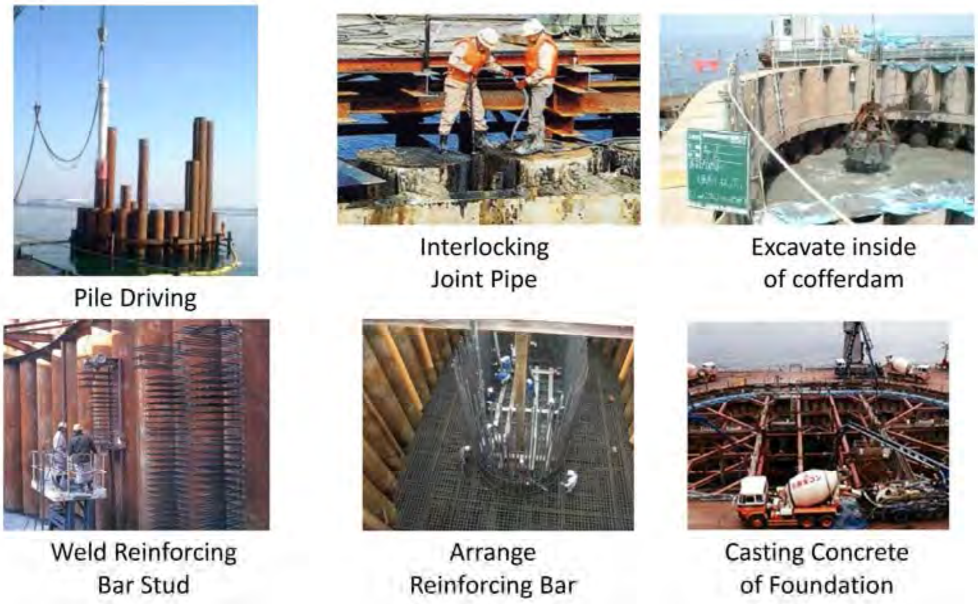
(5) Middle Portion Concrete: Drainage inside SPSPs, 2nd Phase Scaffolding, Middle Portion Concrete Work

(6) Top Slab Construction: Stud Reinforcement, Top Slab Construction

(7) Pier Construction: Rebar Assembly, Formwork, Concreting

(8) Substructure Finishing Works and Cleaning: Residual SPSP Cutting, Removal of Light Buoys and Survey Platforms

A construction process of SPSP-F is briefly shown in [Fig. 7.1.3].



Source: Nippon Steel & Sumitomo Metal Corporation

[Fig 7.1.3] Construction Process of SPSP-F

There are many uncertain factors when constructing substructures such as constructability during the rainy season, site conditions related to sandbank dredging, availability of barges, crawler cranes and other machines, as well as superstructure construction. Since these uncertain factors are difficult to identify at the present time, the most economical construction speed and availability of construction machines and workers are assumed. Sandbank dredging and other work which all substructure construction alternatives have in common are not considered in this chapter nor in Chapter 6 where the cost comparison is discussed.

7.1.3. Construction Schedule

The construction schedule is based on the assumptions made in section 7.1.1., 7.1.2., and the respective assumptions are listed again below.

(1) Superstructure

1) Steel Truss Girders are employed.

2) Cantilever Single Piece Erection by Traveler Crane is adopted.

3) The most realistic conditions are assumed for steel material procurement.

4) Two (2) sets of erection equipment including traveler cranes, truss member carriers and other machines, which are enable the most economical construction speed, are assumed to be prepared according to the construction schedule.

(2) Substructure

1) Steel Pipe Sheet Pile Well Foundations (SPSP-F) are adopted for the foundation.

2) A standard construction method is adopted, which uses permanent piles for also temporary cofferdam with underwater excavation.

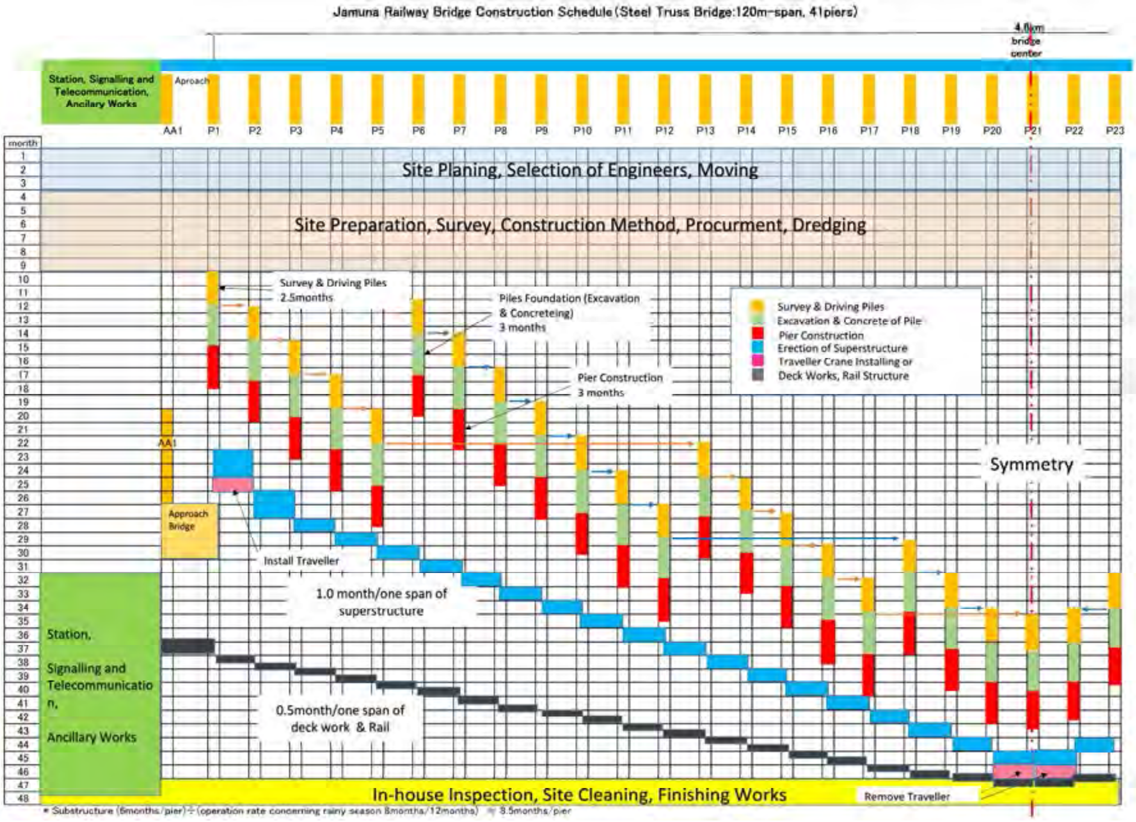
3) Sizes and quality of steel used for substructure are selected from its availability and constructability.

4) Crawler cranes, piling machines, earth augers, barges and other machines, which are appropriate

for the most economical construction speed, are assumed to be prepared according to the construction schedule. Up to four (4) sets of machines are assumed for this project.

5) River flow is assumed to have the same impact as in a typical year.

The following Construction Schedule [Fig. 7.1.4] is based on the above conditions.



Source: Survey Team

[Fig. 7.1.4] Construction Schedule

As shown in [Fig.7.1.4], the duration of substructure construction is assumed to be 8.5 months since piling works are limited during the rainy season. A total of four (4) piling machine sets are allocated and erection works are assumed to begin from both river banks for the 4.8km length of the bridge.

Three (3) work teams are considered for substructure construction although there are eight (8) construction phases.

① Piling Teams: Preparation and Piling

② Inside SPSP Working Teams: Excavation and Concrete Work inside SPSPs

③ Pier Construction Teams: Pier Construction and Substructure Finishing Work

The piling teams will use large piling machines, heavy crawler cranes and large barges to carry the machines and cranes. Availability of these machines and equipment is always crucial considering the construction schedule. The number of piling teams determines the speed of substructure construction and thus the entire construction duration. Since SPSP-Fs require temporary tight closure of the SPSP cofferdams against water, only a few piling companies worldwide can execute the precise piling required by this method. Up to four (4) sets of equipment and piling teams can be considered economical.

7.2. Procurement Procedure

There are two (2) kinds of procurement procedures involved in the Jamuna Railway Project, Consultant Selection and Contractor Procurement.

7.2.1. Consultant Selection

The design-build procurement method was adopted for consultant selection on the Bangabandhu Bridge project and the ADB-F/S also proposed the same method. However, based on site surveys and interviews with engineers and professors in Bangladesh, many problems caused by the insufficient design were discovered which have led to problems with quality and future maintenance. In order to attain a service life of more than 100 years and ensure proper maintenance of the structure, this survey proposes a detailed design prepared by a consultant with extensive knowledge and experience about bridges and railways.

- About consultant selection, Quality Based Selection (QBS) is recommended because the following aspects must be considered in addition to the large scale of the project. The consultant's scope is always changing because the site conditions including the river flow undergo constant change and significantly affect the construction work.
- The work is highly specialized and requires advanced technology.
- The work is very complicated and requires the coordination of multiple different works which all affect each other.

According to JICA's Procurement Guidelines, the following requirements of (a) through (d) are required for adoption of the Quality Based Selection (QBS) principle, and of these, (a), (b) and (c) are considered applicable to this project.

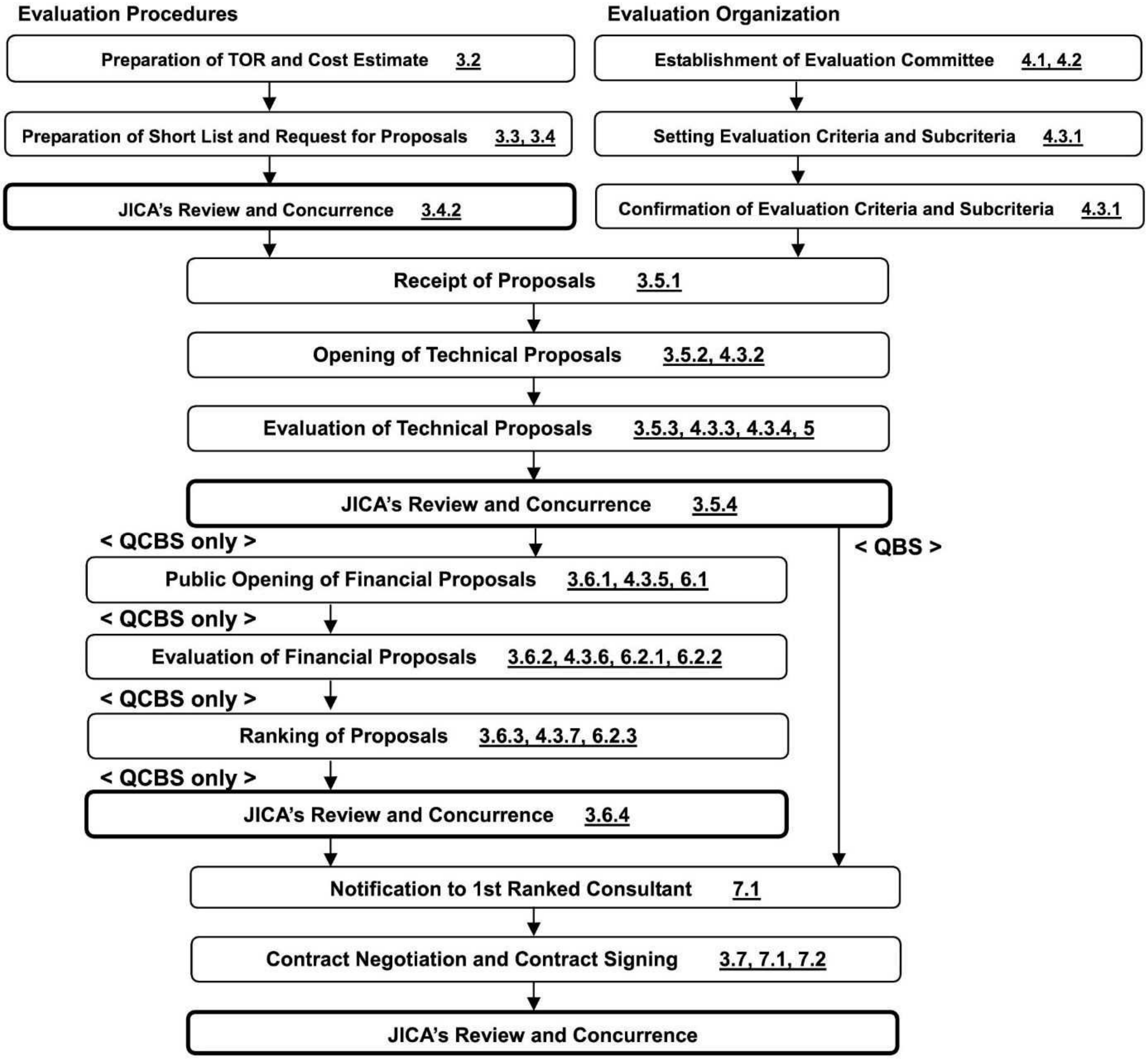
(a) Complex or highly specialized assignments for which it is difficult to define precise TOR and the required input from the consultants;

(b) Assignments where the downstream impact is so large that the quality of the service is of overriding importance for the outcome of the project (for example, engineering design of major infrastructure);

(c) Assignments that can be carried out in substantially different ways such that financial proposals maybe difficult to compare; or

(d) Assignments including supervision of large and complex construction works for which it is particularly important to take safety measures.

[Ref. 7.2.1] JICA Procurement guidelines for consultant selection



Note: QCBS=Quality and Cost Based Selection, QBS=Quality Based Selection

Source: JICA

7.2.2. Proposal for Procurement Process

(1) Consultant Selection

Professional consultants should be employed and selected based on technical proposals separating detailed design and construction supervision, since advanced technical expertise is required for the project.

(2) Contractor Procurement

The issue which caused the most arguments regarding contractor procurement was whether to determine the winner by examining the technical and financial proposals submitted by firms qualified at the P/Q stage (the most common procurement procedure), or by adopting the "Single-Stage Two-Envelope" Bidding where the technical qualification is confirmed in the technical proposals are evaluated at the same time. When it comes to large-scale projects like this, since the number of prospective bidders might be limited, the issue shall be reexamined during the detailed design stage.

7.3. Construction Cost and Implementation Schedule

7.3.1. Construction Cost

The main objective of the cost estimate in this supplemental survey is to establish a base for fair comparison of structural types, but not to verify the accuracy of the costs for determining the size of the yen-loan for the project. For example, cost estimates made in this survey for the purpose of comparing foundation structures do not include the cost of dredging because dredging work is required irrespective to any types of foundation structures and the cost is common to all types of foundation structure and is difficult to forecast accurately as they mostly depend on site conditions.

Track structure is changed from ADB-F/S to the system including Direct Rail Fastener, Head Hardened Rail and Three (3) Line Rail with Derailment Prevention Guard. Therefore the cost of track structure is recalculated with using unit costs of a similar project in neighboring countries. Also, the length of embankment in approach section becomes shorter because of adoption of Steel Truss Through Bridge and cost of approach section is recalculated with using unit costs of ADB-F/S, which is shown in [Tab. 6.3.1] of Chapter 6.

The other costs such as temporary framework platforms and jetties, approach bridges at both river banks, signaling & telecommunication facilities and so on are not changed in this survey, therefore these structures and facilities don't affect construction cost and calculations in ADB-F/S are just used for those costs. In the future, an accurate construction cost estimate shall be prepared in detail design.

The survey team inserted the data from the cost estimates in both the ADB-F/S and this supplemental survey into JICA's cost estimation toolkit. A summary of the results is a classified information at present.

Out of the estimated total project cost, the consulting service fee constitutes approximately 6.15% of the total cost. As the consulting services are to cover the F/S review, D/D, T/A, and C/S, the fee can be considered somewhat low compared to other typical cases. However, the fee is still reasonable based on the fact that the cost estimate is fairly inaccurate and the percentage of the consulting service fee tends to be small in large-scale projects.

7.4.2. Implementation Schedule

The implementation schedule consists of the following four (4) steps: (1) project approval, (2) loan application, (3) procurement, and (4) construction.

(1) Project Approval

The assumption of this step is based on past yen-loan projects, as approval procedures and their respective time spans vary depending on the country. The procedures necessary for project approval in Bangladesh are shown below, and the whole process is estimated to take approximately six (6) months.

- Submission of DPP Development Project Proposal (DPP) based on JICA's Fact Finding (F/F) agreement, from BR to MOR
- Examination of DPP by MOR (approx. thirty (30) days)
- Examination of DPP by Planning Commission
- Decision by Project Evaluation Committee (PEC) (ten (10) days)
- Examination of DPP by JICA
- Final approval by Executive Committee of National Economic Council (ECNEC) of Ministry of Planning (MOP)

(2) Loan Application

Under this project, there will be two (2) loan applications: one for Engineering Services (E/S) and another for construction. The following procedure covers both cases.

- Loan application from the Ministry of Foreign Affairs of Bangladesh (MOFA) to the MOFA of

Japan

- Dispatchment of JICA F/F mission
- Dispatchment of Japanese government F/F mission
- Dispatchment of JICA appraisal mission
- Approval by Japanese government
- Loan pledge by Japanese government
- Signing of Exchange of Note (E/N) by both governments
- Signing of Loan Agreement (L/A)

The E/S loan covers reviews of the F/S and EIA, as well as D/D, T/A, C/S and other work items which are to be performed by the consultant. The EIA is to be reviewed as part of the consulting services, and the report shall be examined by an advisory committee and approved and published one hundred twenty (120) days prior to signing the L/A for the project loan.

(3) Procurement Schedule

The procurement schedule consists of two (2) periods: one for consultant selection and another for contractor procurement, with the former covered by the E/S loan and the latter by the construction loan. The procurement schedule is made with assumption of one (1) consultant contract.

While the principle that contractor procurement shall be in compliance with JICA's procurement guidelines, the procurement schedule has been made based on the following assumptions.

1) Bidding is to be preceded by a P/Q stage (the "Single-Stage Two-Envelope" bidding system will not be used).

2) The design-build delivery system will not be employed (detailed design and construction work will be separated).

3) The project will be divided into two (2) packages for the west and east sections.

4) The Electrical and Mechanical (E&M) component will be separated from the bridge work.

The procurement schedule has been formulated based on the assumptions above as well as with reference to the time required for each step in accordance with past experience from Bangladesh. The schedule therefore has to be modified if the "Single-Stage Two-Envelope" bidding system is adopted, the design-build delivery system is employed, the whole section is incorporated into one (1) package, the E&M component is included in the bridge work.

(4) Construction Schedule

The construction schedule consists of a detailed design period and a construction period. The construction schedule is based on the construction plan detailed in Chapter 7.1, and the respective assumptions are listed again below.

1) Superstructure

- Steel Truss Girders are employed.
- Cantilever Single Piece Erection by Traveler Crane is adopted.
- The most realistic conditions are assumed for steel material procurement.
- Two (2) sets of erection equipment including traveler cranes, truss member carriers and other machines, which are enable the most economical construction speed, are assumed to be prepared according to the construction schedule.

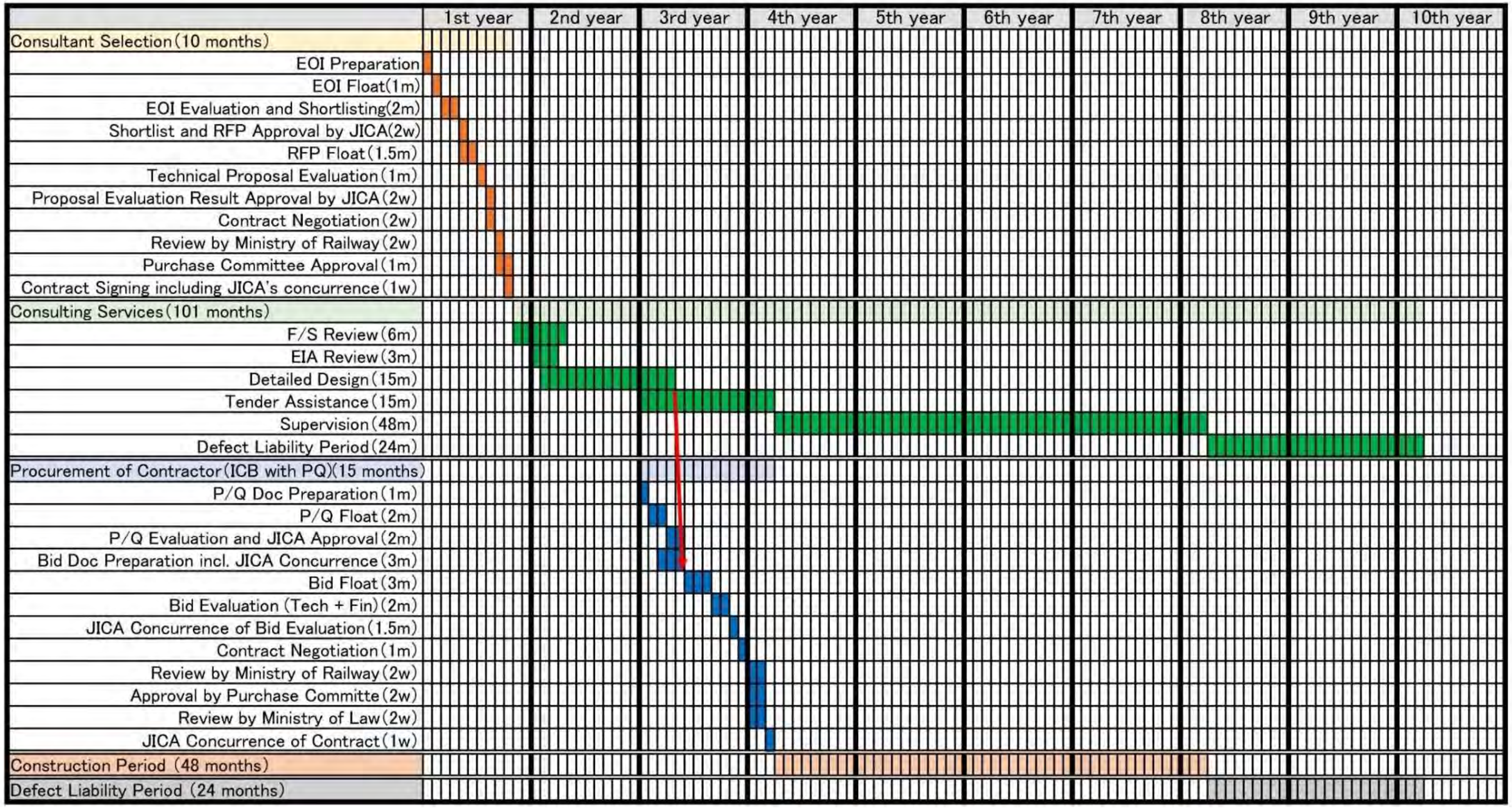
2) Substructure

- Steel Pipe Sheet Pile Well Foundations (SPSP-F) are adopted for the foundation.

- A standard construction method is adopted, which uses permanent piles for also temporary cofferdam with underwater excavation.
- Sizes and quality of steel used for substructure are selected from its availability and constructability.
- Crawler cranes, piling machines, earth augers, barges and other machines, which are appropriate for the most economical construction speed, are assumed to be prepared according to the construction schedule. Up to four (4) sets of machines are assumed for this project..
- River flow is assumed to have the same impact as in a typical year.

(5) Overall Schedule

[Fig. 7.3.1] shows the overall schedule including time periods for project approval, consultant selection, contractor procurement and construction work.



Source: Survey Team

[Fig. 7.3.1] Overall schedule

As shown in the figure, the time periods are as follows and the total schedule spans 111 months from the start of consultant selection.

1) Consultant Selection: 10 months

2) F/S Review and D/D: 18 months

3) Contractor Procurement: 15 months (4-month overlap with D/D)

4) Construction Work: 48 months

5) Defects Liability Period: 24 months

As for the past experience from construction of Bangabandhu Bridge, the completion report states that the contract period was 43 months while the actual work took 44 months. Although the contractor can thus be considered to be capable, the workmanship is most likely insufficient considering the fact that for example the water-jet method was reportedly used to drive steel-pipe piles as long as 80 meters in an oblique direction but pile bearing capacity management record does not exist. This is necessary to secure the bearing resistance of the piles but requires extra labor and costs more. In fact, the cracking can be observed almost everywhere on the girders allegedly as a result of the insufficient detailed design prepared by the contractor under the design-build contract.

The contractor, Hyundai Engineering and Construction, ran into financial difficulties partly due to the loss it suffered from the construction work soon after the bridge was completed, and it thus had to be merged with Hyundai Motor Company in the Hyundai group in order to stay in business. Hyundai was also banned from taking part in any projects in Bangladesh for some time since it did not properly deal with the cracking issue.

In order to prevent similar problems in the future and ensure high quality construction, it is necessary to prepare a construction schedule with enough leeway and proceed with the works at a steady pace. The proposal in this survey can be considered valid since it recommends selecting a structure type which enables rapid construction while ensuring a high level of quality.

7.4. Other Considerations

Although this survey uses the same live load and construction gauge as the ADB-F/S to allow for comparison, additional studies are necessary at the detailed design stage following discussions with BR in order to examine the possibility of electrifying the railway and enabling through-service by Indian Dedicated Freight Corridor (DFC) trains. In the long term, it is also necessary to examine increasing the design speed from 120km/h as proposed in the ADB-F/S to 350km/h to enable the passage of high-speed trains.

Attachment

RATES OF MAN, MATERIAL AND MARK-UPS

SL	Items	Rate	Unit
1	[illegible]		
1	Contractor's Profit	10.00%	
2	Contractor's Overhead Expenses	3.50%	
3	VAT	5.50%	
4	Additional Incidental Expenses for Gas Line Installation Works	10.00%	

SL	Items	Rate	Unit
C1	[illegible]		
1	Head mason / Head mosaic mistry	Tk. 493.00	Per day
2	Mason	Tk. 389.00	Per day
3	Skilled labour	Tk. 303.00	Per day
4	Ordinary labour	Tk. 245.00	Per day
5	Field Engineer (min BSc in Engg exp 3yrs OR Diploma in eng exp 8yrs)	Tk. 1,500.00	Per day
6	Skilled technician	Tk. 700.00	Per day
7	Semi skilled technician	Tk. 450.00	Per day
8	Foreman/Supervisor	Tk. 567.00	Per day
9	Electrician	Tk. 493.00	Per day
10	Asstt. Electrician	Tk. 356.00	Per day
11	Rod binder	Tk. 421.00	Per day
12	Mosaic mistry	Tk. 415.00	Per day
13	Plumber	Tk. 440.00	Per day
14	Painter	Tk. 423.00	Per day
15	Carpenter	Tk. 423.00	Per day
16	Welder	Tk. 423.00	Per day
17	Polish mistry	Tk. 544.00	Per day
18	Helper to carpenter/painter/plumber/rod binder/electrician/polish mistry/rig Operators	Tk. 304.00	Per day
19	Machine operator	Tk. 423.00	Per day
20	Pile rig operator	Tk. 499.00	Per day
21	Diesel hammer mounted rig operator	Tk. 732.00	Per day
22	Helper to diesel hammer mounted rig operator	Tk. 388.00	Per day
23	Rig operator in/c site allowances for soil exploration	Tk. 489.00	Per day
24	Asstt. laboratory technician	Tk. 450.00	Per day
25	Laboratory technician / diploma engg in relevant field, min 3yrs exp	Tk. 1,200.00	Per day
26	Laboratory engineer,min BSc in relevant field, min 3yrs exp.	Tk. 1,500.00	Per day
27	Ghorami	Tk. 397.00	Per day
28	Sweeper for Odd Job	Tk. 808.00	Per use

SL	Items	Rate	U
29	Tube-well mistry	Tk. 389.00	Per day
30	Tube-well head mistry	Tk. 499.00	Per day
31	Surveyor 10yrs Exp / diploma Engineer trained in survey	Tk. 1,200.00	Per day
32	Helper to surveyor	Tk. 750.00	Per day
2	EQUIPMENT, TOOLS & PLANT, VEHICLE, SCAFFOLDING ETC.		
33	Scaffolding	Tk. 7.20	Per sft.
34	Carrying charge of earth by 5-ton capacity truck in Dhaka city	Tk. 1,300.00	Per trip
35	do in Narayanganj / Chittagong / Sylhet	Tk. 1,000.00	Per trip
36	do in Rajshahi / Barishal / Khulna metropolitan area	Tk. 850.00	Per trip
37	do in all districts except Dhaka/ Ctg./ Rajshahi / Barishal / Khulna and N'ganj.	Tk. 700.00	Per trip
38	Carriage of earth by any means for site development in Dhaka city	Tk. 6.78	cft
39	Carriage of earth by any means for site development in Narayanganj / Chittagong / Sylhet city	Tk. 5.22	cft
40	Carriage of earth by any means for site development in Rajshahi / Barishal / Khulna city	Tk. 4.43	
41	Carriage of earth by any means for site development in all districts except Dhaka, Ctg, and N'ganj.	Tk. 3.65	cft
42	5-ton capacity truck-fare in Dhaka city in/c loading, unloading	Tk. 1,300.00	Per trip
43	Concrete mixer machine	Tk. 1,000.00	Per day
44	Concrete vibrator	Tk. 500.00	Per day
45	Hire charge of water pump for concreting or similar purposes	Tk. 432.00	Per day
46	Hire charge of diesel operated 1/4 cusec water pump	Tk. 588.00	Per day
47	Hire charge of electricity operated 1 cusec water pump	Tk. 760.00	Per day
48	Hire charge of 1 cusec diesel operated water pump	Tk. 1,030.95	Per day
49	Fuel, lubricant for mixer machine, vibrator and pump etc.	Tk. 1,051.00	Per day
50	Mosaic cutting machine	Tk. 300.00	Per day
51	Marble cutting and shaping in/c cutting disc.	Tk. 300.00	Per day
52	Marble polishing machine in/c polishing stone	Tk. 400.00	Per day
53	Hire charge of marble cutting disk	Tk. 775.14	Per day
54	Hire charge of electric grinding machine	Tk. 206.00	Per day
55	Hire charge of cast in situ pile boring complete rig set in/c operational expenses	Tk. 8,820.00	Per day
56	Hire charge of pre-cast pile driving complete rig set in/c -do-do- etc.	Tk. 10,550.00	Per day
57	Hire charge of pre-cast micro pile driving complete rig set in/c -do-do- etc.	Tk. 5,500.00	Per day
58	Hire charge of load testing devices in/c hydraulic fluid: up to 125 ton capacity	Tk. 10,642.00	Per test
59	-do -do-: up to 275 ton capacity	Tk. 12,519.00	Per test
60	Hire charge of diesel hammer mounted completed rig set.	Tk. 23,707.00	Per day
61	Lifting and movement of crane for diesel mounted hammer up to site	Tk. 50,000.00	Per set
62	Truck fare for carrying diesel hammer mounted rig	Tk. 12,000.00	Per trip

SL	Items	Rate	Unit
63	Hire charge for 8 - 12 ton road roller	Tk. 5,063.00	Per day
64	Hire-charge of chain dozer	Tk. 12,774.45	Per day
65	Fuel & lubricants, spares, maintenance, driver etc. for 8-12 ton road roller.	Tk. 1,268.00	Per day
66	Hire charge of paint spray machine	Tk. 4.00	Per sft.
67	Small boat	Tk. 688.00	Per day
68	Drum (defects free)	Tk. 1,605.20	each
69	Hire charge of boring rig for soil exploration	Tk. 5,313.00	Per day
70	Machine charge for cutting terrazzo tiles	Tk. 406.00	Per % sft.
71	Chisel for heavy duty power hammer (100 sft. capacity)	Tk. 1,594.00	each
72	Hire charge of heavy duty chisel machine	Tk. 634.00	Per day
73	Shuttering in/c prop for partial dismantling of R.C.C.	Tk. 20.00	Per sft.
74	Hire charge of welding machine	Tk. 695.38	Per day
75	Hire charge of survey instrument (Level / Theodolite etc.)	Tk. 884.00	Per day
C3	WORK RATE EXCLUDING COST OF MATERIALS		
76	Breaking 50 mm downgraded brick chips	Tk. 719.00	Per % cft.
77	Breaking 20 mm downgraded brick chips	Tk. 894.00	Per % cft.
78	Breaking 12 mm (1/2") downgraded brick chips	Tk. 1,091.88	Per % cft.
79	Breaking 20 mm downgraded stone chips	Tk. 1,531.07	Per % cft.
80	Breaking 12 mm downgraded stone chips	Tk. 2,025.14	Per % cft.
81	Placing and removing shutter for form-work	Tk. 12.00	Per sft.
82	Making steel shutter for form-work	Tk. 69.17	Per sft.
83	Making steel door-window frame and shutter	Tk. 58.00	Per sft.
84	Making fixed steel glazed frame	Tk. 46.91	Per sft.
85	Making steel grill	Tk. 45.71	Per sft.
86	Filling and stitching gunny bags	Tk. 8.64	Per bag
87	Load testing result sheet preparation	Tk. 6,250.00	Per test
88	Carrying cost of timber	Tk. 37.53	Per cft.
89	Seasoning timber in plant	Tk. 333.00	Per cft.
90	Carrying cost of steel door and window	Tk. 53.30	each
91	Fabrication and erection of mild steel truss	Tk. 1,891.23	Per cwt.
92	Fabrication of light section steel	Tk. 275.85	Per cwt.
	[illegible]		
93	Point welding	Tk. 3.25	Per point
94	Line welding at field	Tk. 5.00	Per inch
95	Bitumenous coating for damp proof course (D.P.C)	Tk. 822.00	Per % sft.
96	Coal-tar over timber surface	Tk. 6.00	Per sft.

SL	Items	Rate	Unit
97	Glass pan fitting in/c putty	Tk. 15.46	Per sft.
98	Making form work water-tight	Tk. 2.25	Per sft.
C5	BRICKS AND SCREEN BLOCKS		
99	1st class/Picked jhama standard bricks: BDS	Tk. 7,500.00	Per % 0 Nos.
100	Automatic Machine Made 1st class standard Bricks : BDS	Tk. 9,000.00	Per % 0 Nos.
101	1st class 10 holes machine made 9.5"x4.5"x2.75" ceramic bricks	Tk. 17,500.00	Per % 0 Nos.
102	9.5" x 4.5" x 2.75" size machine made solid klinker facing bricks	Tk. 13,125.00	Per % 0 Nos.
103	9.5" x 4.5" x 2.75" size 10 hole machine made Rock-face/textured klinker facing bricks	Tk. 13,067.83	Per % 0 Nos.
104	9.5" x 4.5" x 2.75" size 3 hole machine made reinforcing facing bricks	Tk. 20,000.00	Per % 0 Nos.
105	200 x 100 x 50 mm/8" x 4" x 2" machine made hard pressed klinker facing bricks	Tk. 18,500.00	Per % 0 Nos.
106	200 x 50 x 50 mm/8" x 2" x 2" machine made klinker facing RED or Maroon strips	Tk. 14,000.00	Per % 0 Nos.
107	200 x 62 x16.51mm/8" x 2.5" x 0.65" machine made klinker red strips	Tk. 16,750.00	Per % 0 Nos.
108	4" x 4" x 4" fancy screen block	Tk. 28,000.00	Per % 0 Nos.
109	5.5" x 5.5" x 4" fancy screen block	Tk. 28,000.00	Per % 0 Nos.
110	6" x 6" x 4" fancy screen block	Tk. 32,000.00	Per % 0 Nos.
111	190 mm x 190 mm size glass bricks	Tk. 328.33	each
C6	CEMENT		
112	Ordinary Portland Cement, BDS-EN - 197-1- CEM1, 52.5N (52.5MPa)/ ASTM C-150 Type-I, 50 kg bag	Tk. 470.00	Per bag
113	Portland Composite Cement / CEM-II/A – M, 42.5N (42.5MPa) (6-20% constituents other than clinker): 50 kg bag	Tk. 440.00	Per bag
114	White Cement	Tk. 25.00	Per kg
C7	STONE/BOULDER/MOSAIC CHIPS/PIGMENT/ADMIXTURE/MEMBRANE [illegible]		
115	Uncrushed boulder	Tk. 12,500.00	Per % cft.
116	19 mm (3/4") downgraded crushed stone chips	Tk. 14,500.00	Per % cft.
117	12 mm (1/2") downgraded stone chips	Tk. 13,500.00	Per % cft.
118	Stone shingles	Tk. 8,100.00	Per % cft.
119	Pea-gravel	Tk. 5,500.00	Per % cft.
120	Slaked lime	Tk. 19.00	Per kg
121	Surki from 1st class brick	Tk. 58.00	Per cft.
122	Pakistan origin (onix) mosaic chips	Tk. 19.00	Per kg
123	Indian origin (deradun) mosaic chips	Tk. 17.00	Per kg
124	Pumice stone for finishing mosaic work	Tk. 60.00	each
125	Minar stone for finishing mosaic work	Tk. 400.00	each
126	Color pigment	Tk. 55.00	Per lbs
127	20 mm x 50 mm glass strip	Tk. 8.00	Per rft.
128	80/20 Bitumen for road work	Tk. 65,333.33	Per M. ton

	Items	Rate	Unit
129	Water-proofing PVC membrane	Tk. 605.00	Per sqm.
130	Primer for laying PVC membrane on wall	Tk. 500.00	Per litre
131	Water reducing admixture in concrete: Type - A	Tk. 150.00	Per litre
132	Retarding admixture in concrete: Type - B	Tk. 155.00	Per litre
133	Accelerating admixture in concrete: Type - C	Tk. 160.00	Per litre
134	Water-reducing and retarding admixture in concrete: Type - D	Tk. 145.00	Per litre
135	Water-reducing and accelerating admixture in concrete: Type - E	Tk. 165.00	Per litre
136	Water-reducing high range admixture in concrete: Type - F	Tk. 180.00	Per litre
137	Water-reducing high range retarding admixture in concrete: Type - G	Tk. 147.00	Per litre
138	Micro Fibre for concrete	Tk. 725.00	Per kg
	EARTH / SAND [illegible]		
139	Royalty of earth	Tk. 700.00	Per % 0 cft.
140	Royalty of sand	Tk. 6,875.00	Per % 0 cft.
141	Royalty of turf	Tk. 9.00	Per % sft.
142	Sand (F.M. 0.8)	Tk. 900.00	Per % cft.
143	Sand (F.M. 1.2)	Tk. 1,700.00	Per % cft.
144	Sand (F.M. 2.2)	Tk. 3,000.00	Per % cft.
	TIMBER/B[illegible]BER PRODUC[illegible]		
145	Garjan/Jam/local Sal	Tk. 2,000.00	Per cft.
146	Mohgani	Tk. 1,900.00	Per cft.
147	Silkarai/Chikrashi	Tk. 2,800.00	Per cft.
148	Teak-Chambal	Tk. 3,100.00	Per cft.
149	Chittagong teak	Tk. 4,500.00	Per cft.
150	Kathal	Tk. 2,250.00	Per cft.
151	Gamari	Tk. 1,950.00	Per cft.
152	Chapalish	Tk. 2,100.00	Per cft.
153	Timber for form-work	Tk. 470.00	Per cft.
154	Bamboo	Tk. 12.00	Per rft.
155	Shal ballah (avg. dia 6") for driving	Tk. 120.00	Per rft.
156	Burma teak veneered flush door shutter	Tk. 335.69	Per sft.
157	Champ veneered flush door shutter	Tk. 240.61	Per sft.
158	Chapalish veneered flush door shutter	Tk. 239.59	Per sft.
159	Garjan veneered flush door shutter	Tk. 216.42	Per sft.
160	12 mm thick Plain Particle board : 550kg/m3	Tk. 35.34	Per sft.
161	Melamine board (12 mm thick): 8' -0" x 4'-0" size: 700kg/m3	Tk. 1,946.50	Per pc.
162	9 mm thick gypsum board	Tk. 25.98	Per sft.

SL	Items	Rate	Unit
163	9 mm thick perforated gypsum board	Tk. 30.57	Per sft.
164	12 mm thick laminated vinyl board : 550kg/m3	Tk. 46.88	Per sft.
165	12 mm thick Burma Teak veneered board : 550kg/m3	Tk. 110.42	Per sft.
166	Burma teak	Tk. 5,571.38	Per cft.
167	50 mm thick glass wool	Tk. 197.48	Per sft.
168	Rubber gum	Tk. 602.71	Per kg.
169	PVC water stopper	Tk. 206.12	Per rft.
C10	STEEL: Ductility Class B, ratio of fu to fy = or ≥ 1.25		
170	Grade 300(300Mpa / 300N/mm2 ≈ 43500psi/40 Grade): BDS- 6935-2006 - B300 and Ratio fy to fu =>1.25, fy not exceeding 314 MPa	Tk. 59,000.00	Per M. to
171	Grade 400(400Mpa / 400N/mm2 ≈ 60900psi/ 60 Grade), BDS-6935-2006, B400: and ratio fy to fu => 1.25, fy not exceeding 418 MPa	Tk. 61,500.00	Per M. to
172	M.S sheet/plate	Tk. 85,000.00	Per M. to
173	M.S. angle, T and Z-section, Channel etc.	Tk. 62,500.00	Per M. to
174	M.S. plain bar and F.I. bar (non-structural use)	Tk. 56,000.00	Per M. to
175	Solid square bar	Tk. 63,000.00	Per M. to
176	0.45 mm thick C.I. sheet:	Tk. 90,500.00	Per M. to
177	0.45 mm thick colored C.I. sheet:	Tk. 91,000.00	Per M. to
178	0.27 mm thick 6'-0" x 18" ridging:	Tk. 315.00	Per pc.
179	0.27 mm thick 6'-0" x 18" colored ridging:	Tk. 364.96	Per pc.
C11	GLAZED/ MARBLE/ TERAZZO TILES: [illegible]		
180	18 mm thick marble stone, Black/white (Indian)	Tk. 395.00	Per sft.
181	16 mm thick marble stone, Black/white (Indian)	Tk. 350.00	Per sft.
182	12 mm thick marble stone, Black/white (Indian)	Tk. 315.00	Per sft.
183	18 mm thick colored/ grey marble stone (Indian)	Tk. 410.00	Per sft.
184	16 mm thick colored/ grey marble stone (Indian)	Tk. 360.00	Per sft.
185	12 mm thick colored/ grey marble stone (Indian)	Tk. 345.00	Per sft.
186	18 mm thick colored/ grey marble stone (Italian)	Tk. 550.00	Per sft.
187	wall tiles less than , equal or equivalent to 250mmx330mm in sizes	Tk. 46.00	Per sft.
188	wall tiles more than 250 x 330 mm & less than 310 x510 mm in sizes or equivalent	Tk. 54.00	Per sft.
189	wall tiles more than 310 X 510 mm in sizes or equivalent	Tk. 75.00	Per sft.
190	GP (Gress Porcellanato) - Glazed Homogeneous 300 x 300 mm floor tiles	Tk. 64.00	Per sft
191	GP (Glazed Homogeneous) 400 x 400 mm floor tiles	Tk. 74.00	Per sft
192	GP (Mirror polished) 300 x 300 mm floor tiles	Tk. 78.00	Per sft
193	GP (Mirror polished) 400 x 400 mm floor tiles	Tk. 88.00	Per sft

Sl	Items	Rate	Unit
194	GP (Mirror polished) 600 x 600 mm floor tiles	Tk. 107.00	Per sft.
195	GP 300 x 300 mm stair tiles	Tk. 70.00	Per sft.
196	Unglazed Homogeneous Floor Tiles 300 x 300 mm	Tk. 68.00	Per sft.
197	Unglazed Homogeneous Floor Tiles 400 x 400 mm	Tk. 75.00	Per sft.
198	Pasting Tiles Adhesive	Tk. 16.00	Per kg.
199	Tiles grout / Joint filler	Tk. 75.00	Per kg.
200	Acid stone	Tk. 384.00	each
201	Water Proofing Paper (12 Size)	Tk. 17.00	each
202	Water Proofing Paper (320 Size)	Tk. 20.00	each
[illegible]	PROPS, PIPES, I-SECTION, BOX CHANNEL FOR CONCRETING WORK [illegible]		
203	Bamboo prop in/c top supports	Tk. 110.00	each
204	Salballah prop in/c top supports	Tk. 933.00	each
205	50 mm/2" dia M.S. pipe	Tk. 135.00	Per rft.
206	38 mm/1.5" dia M.S. pipe	Tk. 110.00	Per rft.
207	50 mm/2" dia G.I. pipe	Tk. 175.00	Per rft.
208	38 mm/1.5" dia G.I. pipe	Tk. 140.00	Per rft.
209	19 mm/3/4" dia G.I. pipe	Tk. 70.00	Per rft.
210	13 mm/1/2" dia G.I. pipe	Tk. 50.00	Per rft.
211	Adjustable mechanism in/c top and bottom plate	Tk. 550.00	Per set
212	I-section joist to support inclined prop	Tk. 482.00	Per rft.
213	4" x 2" M.S. box channel with 1/8" thick M.S. sheet	Tk. 450.00	Per rft.
214	Steel prop with adjustable mechanism in/c top and bottom plate	Tk. 1,680.00	Per set
215	Turn-buckle in/c tie rod	Tk. 487.30	Per set
[illegible]	PAINT [illegible]		
216	Cement paint/Cement Coating	Tk. 90.00	Per kg.
217	Weather coat / Acrylic based exterior emulsion	Tk. 318.40	Per liter
218	Weather coat sealer (Exterior)	Tk. 209.60	Per liter
219	Silicon based paint/coating	Tk. 322.22	Per liter
220	Ready-mix putty (Exterior-interior) water based	Tk. 76.00	Per liter
221	Sealer for ready-mix putty (Exterior-interior)	Tk. 228.00	Per liter
222	Synthetic Enamel paint (alkyd based)	Tk. 310.00	Per liter
223	Synthetic Enamel Under-coat	Tk. 149.00	Per liter

SL	Items	Rate	Unit
224	Thinner for oil-based paint (Turpentine) for general purpose	Tk. 140.00	Per liter
225	Synthetic Polyvinyl (S.P.) Distemper	Tk. 116.66	Per liter
226	Synthetic Polyvinyl (S.P.) Distemper Primer /sealer	Tk. 209.60	Per liter
227	Acrylic Plastic Emulsion Paint	Tk. 247.25	Per liter
228	Acrylic Plastic Emulsion Paint sealer	Tk. 205.00	Per liter
229	Acrylic Emulsion Paint	Tk. 228.70	Per liter
230	Acrylic Emulsion Paint Primer/under-coat	Tk. 226.60	Per liter
231	Chlorinated Rubber Paint	Tk. 700.00	Per liter
232	Chlorinated Rubber sealer	Tk. 545.00	Per liter
233	Chlorinated Rubber Paint Thinner	Tk. 212.00	Per liter
234	Textured Coating in/c sealer, top coat, gloss finish	Tk. 288.93	Per liter
235	Wood varnishing: Yacht (alkyd based)	Tk. 250.00	P[illegible]lter
236	Wood varnishing: Egg-shell (alkyd based)	Tk. 250.00	Per liter
237	Wood varnishing: Matt (alkyd based)	Tk. 250.00	Per liter
238	Thinner for alkyd based wood varnishing	Tk. 104.00	Per liter
239	Oxalic acid	Tk. 95.00	Per lite
240	Wax for polishing	Tk. 299.00	Per kg
241	Red/black oxide	Tk. 197.25	Per lite
242	~~De salt s 01~~	~~Tk.~~	~~Per lite~~
243	~~Foam lub~~	~~Tk.~~	~~Per lit~~
C-14 French Polishing			
244	French powder	Tk. 40.00	Per k
245	Spirit	Tk. 92.00	[illegible] li
246	Gala	Tk. 1,600.00	Per k
247	Karpa	Tk. 500.00	Per
248	Sand paper	Tk. 11.33	eac
249	Putty	Tk. 78.00	Per
250	Markin cloth	Tk. 15.00	Per y
251	Cotton	Tk. 75.00	Per

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