6. PRELIMINARY DESIGN

6.1 Introduction

The preliminary design of MTHL dealt with in this chapter comprises various engineering aspects.

The purpose of this preliminary design are 1) to calculate appropriate project quantities and project costs in order to formulate a Japanese Yen loan scheme and 2) to carry out a basic study in order to prepare the bid documents in the Design Build scheme.

This project comes after various studies spanning around 40 years, and as such, the previous study results are reflected. However, improvements have been proposed where appropriate.

A notable proposed improvement point is the bridge form in the sections where long spans are required, such as creeks, jetties and pipelines. In these sections, steel box girders with steel slabs have been proposed in order to shorten the construction period, improve the quality and increase the site safety during construction and technology transfer although the PC box girder was applied in a previous study. Countermeasures for salt damage to steel bridges are described in chapter 6.5.4.

Design standards for road and bridge design (given in chapter 6.2 and 6.3) are mainly based on IRC latest codes and previous study results.

6.2 Design Standard for Road Design

6.2.1 Design Standard

(1) Design Standard for Road Design

Road design standards to be applied in this study are given in the following table. Of these, IRC SP 87-2013 and IRC 73-1980 are given precedence

Although IRC SP 87-2013 is mainly applied to widening of highways to 4-6 lanes through Public Private Partnerships (PPP), it can be applied to non-PPP projects as well. Some values specified in the geometric design standards in IRC SP87-2013 are based on IRC 73-1980.

Table 6.2.1 Geometric Design Standards in India

Title of Publication	Code No.
Manual of Specifications & Standards for Six Lane Highways through Public Private Partnership	IRC SP 87-2013
Manual of Specifications & Standards for Four Lane Highways through Public Private Partnership	IRC SP 87-2013
Two-lane Highways through Public Private Partnership Manual of Specifications & Standards	IRC SP 73-2007
Geometric Design Standards for RURAL (NON-URBAN) HIGHWAYS	IRC 73-1980
Geometric Design Standards for URBAN ROADS IN PLAINS	IRC 86-1983
Recommendations About the Alignment Survey and Geometric Design of Hill Roads	IRC 52-1981

Source: JICA Study Team

[About SP: 99-2013]

Applicable geometric design standards are SP: 87-2013 and SP: 99-2013. For the road design, SP: 87-2013 was adopted in consideration of the following:

- Legally, the Project Highway is not classified as an Expressway, National Highway or State Highway.
- In the Final FS 2012, the design complied with SP: 87-2010, or the one before the revision to SP: 87-2013.
- Because the construction is managed by the Mumbai Metropolitan Region Development Authority (MMRDA), SP: 99-2013, which is inappropriate for urban areas, is not appropriate.
- The SP-99-2013 is mainly for earth work (Green Field).
- The intention of MMRDA: Highway standard has been used as the road design standard, so SP: 87-2013, which is a highway standard, shall be the one to follow for the design.

(2) Design Standard for Environmental Clearance

The roads should be designed using the standard for roads, EIA notification and CRZ notification. The EIA notification and CRZ notification are shown in 12.3.

6.2.2 Composition of Cross Section

The following policies are applied for the width of the road, road shoulder, and emergency platform.

(1) Width of Carriageway

Under IRC: SP-87-2013, the width of a carriageway is 3.5 meters when the design speed is 100km/h. For reference, if the large vehicle ratio is low, the width of a lane is 3.5 meters under the proposed standards on the geometry design of Japan standard. The same width applies to Asian highways as well. According to the traffic demand forecast, the large vehicle ratio will be as low as 9.4% (2022), allowing judgment that the lane width at 3.5 meters will ensure sufficient safety and road functions.

Table 6.2.2 Forecast of Large Vehicle Ratio at MTHL

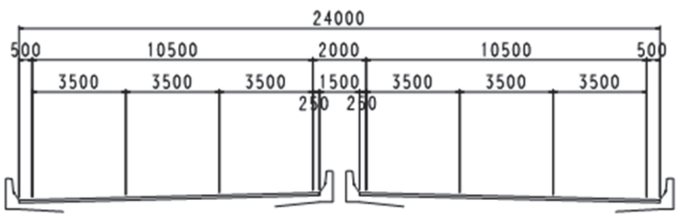
2022	9.4%
2032	6.1%
2042	5.6%

Source: JICA Study Team

(2) Width of Shoulder

1) Result of Previous Studies

Under the Final FS 2012 Report, left side shoulder width is 0.5m and right side shoulder is 0.25m. However, when compared with the international standard, design speed shall be restricted to less than 80kph in consideration of safety.



Source: JICA Study Team

Figure 6.2.1 Typical Cross Section (Final FS 2012)

2) Function of Shoulder

Shown below is the main function of the shoulder.

Passage for vehicles:

Keep some lateral clearance is needed to secure safety and comfortability for the vehicles.

Stopping of the vehicles:

Prevent the confusion of drivers due to traffic accidents since the damaged vehicles can be removed from the carriageway.

Table 6.2.3 Function of Shoulder

Shoulder Width	Function
2.4m － 3.6m	All vehicles can park temporarily
1.25m － 1.8m	Some lateral clearance can be secured for passing vehicles. Sedan can park temporarily.
0.5m －0.75m	Minimum lateral clearance can be secured for passing vehicles. No temporary parking space.

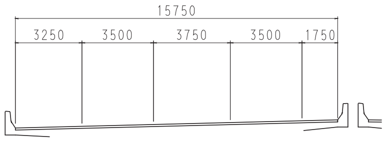
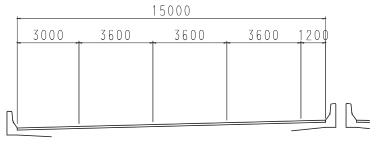
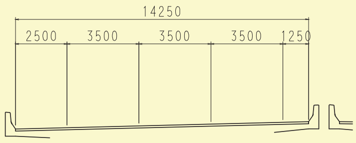
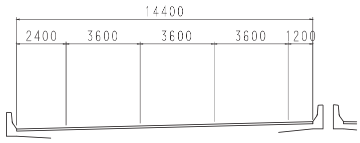
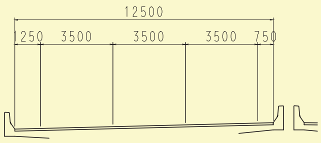
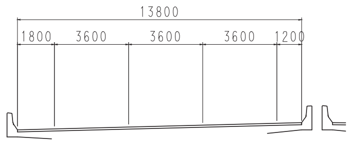
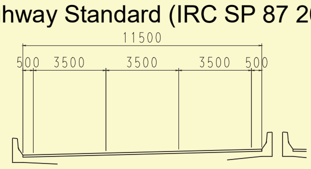
Source: Japan Standard

The shoulder width shall be decided to comply with the international shoulder standards.

(3) Typical Cross Section

Table 6.2.4 shows the ideal typical cross section depending on the design speed considinering the traffic safety aspect according to Indian Standard and Japanese Standard

Table 6.2.4 Ideal Cross Section by Design Speed

Design Speed	Indian Standard	Japanese Standard	Reference (AASHTO)
120		 Construction Cost Ratio:1.30	 Construction Cost Ratio:1.23
100	Highway Standard (IRC SP 87 2013) is specified with design speed 100kph. However, when it compares with the international standard, operation speed shall be restricted to less than 80kph (60kph) in consideration of safety.	 Construction Cost Ratio:1.18	 Construction Cost Ratio:1.19
80		 Construction Cost Ratio:1.07	 Construction Cost Ratio:1.15
60	Highway Standard (IRC SP 87 2013  Construction Cost Ratio:1.00		

Source: Japan Study Team

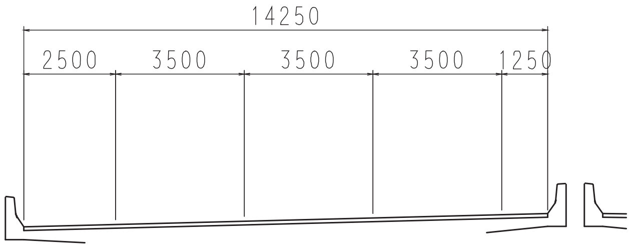
The following points are considered to set the alternatives for the typical cross section by each design speed;

1. Typical cross section of 120kph: This design speed was not studied in the Final FS 2012, therefore we do not examine the case of 120kph in this study.
2. Typical cross section for 100kph and 80kph: Highway Standard (IRC SP 87 2013) has the typical cross sections at 100kpn. However, it has narrow shouldes compared with the international standard and operation speed should be restricted to less than 80kph (60kph) in consideration of safety from the viewpoint of international standards. Therefore, the typical cross-section should be selected based on the Japan standard
3. Typical cross section for 60kph: Select from the Indian standard

Alternative-1

Design Speed is 100kph

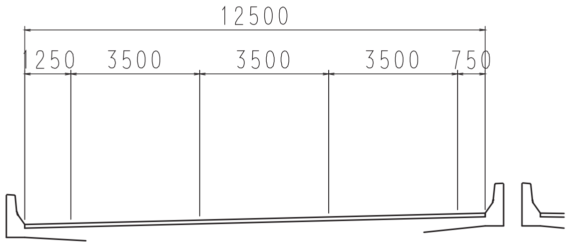
Operation speed (speed limit): 100kph



Alternative-2

Design Speed is 100kph

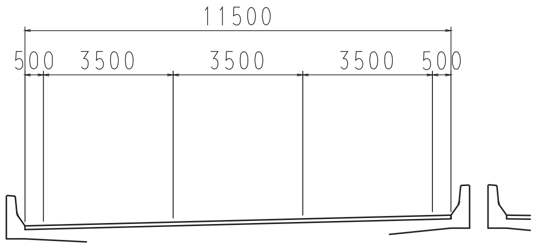
Operation speed (speed limit): 80kph



Alterntive-3

Design Speed is 100kph

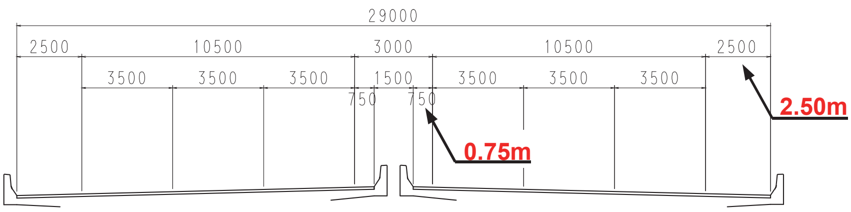
Operation speed (speed limit): 80kph



Source: Japan Study Team

Figure 6.2.2 Comparison of Typical Cross Sections

Figure 6.2.53 showes the selected typical cross section from three alternatives mentioned above and it was accepted at the meeting with MMRDA.



Source: Japan Study Team

Figure 6.2.3 Typical Cross Section

6.2.3 Road Classification and Design Speed

The secion where MTHL runs through plain and rolling terrain, the design speed of the main alignment is 100kph. However, on the east side, the section over Shivaji Nagar IC where the MTHL runs through mountainous and steep terrain, 60kph of the design speed is applied.

Table 6.2.5 Design Speed

Unit: Kph

Nature of the Terrain	Design Speed	
	Recommended	Allowable
Plain and Rolling	100	80
Mountainous and Steep	60	40

Source: IRP SP 87-2013

6.2.4 Geometric Design Standard

Geometric design standards applied to the preliminary design of MTHL are as follows. These values mainly follow IRC code. However, some values are based on previous designs from 2012 which were approved by the MMRDA in the meeting on 20 April 2015.

(1) Main Alignment

Geometric design standards for the main alignment are given below. As reference, the values of Japanese standard and AASHTO are also described in the table below.

Table 6.2.6 Geometric Design Standard of Main Alignment

Items		Unit	Values to be applied	IRC		Japan Standard	AASHTO
				73-1980	SP-87-2013		
Main Road Alignment (Ch 0+495 – 21+723)							
Width of each carriageway		m	3.50	3.50	3.50	3.50	3.6
Shoulder Width	Left Side	m	2.50	-	0.50	2.50	3.0
	Right Side	m	0.75	-	0.50	0.75	1.2
Central median width	Earth work section	m	3.0-5.0	3.0-5.0	3.0-5.0	3.0	
	Bridge/Viaduct	m	1.50	1.50 (1.20)	-	3.0	
Taper transition from single lane to multi-lane		rate	1:15-1:20	1:15-1:20	-	1/15	
Cross fall		%	2.5	2.0 – 2.5	2.5	2.0	1.5-2.0
Design speed for main line		km/h	100				
Minimum Horizontal Curve Radius (Recommended)		m	400	360	400	460	328
Minimum Horizontal Curve Length		m	170	-	-	170	
Minimum Horizontal Radius (Recommeded)Without Super elevation		m	2,600	2,600	2,600	5,000	3,720
Maximum Super-elevation (rotation about median edge)		%	5%	7%	5%	10%	12%
Minimum Transition Length	R = 400m R = 600m R = 1,000m R = 1,800m R = 2,500m R = 4,200m	m m m m m m	115 80 50 30 not required not required	115 80 50 30 not required not required	115 80 50 30 not required not required	85	56
Minimum Radius (No transaction Curve)		m	2,000	2,000	2,000	3,000	2,770
Super elevation Rubbed Rate			1/150	-	-	1/150	1/227
Sight Distance	Safe Stopping	m	180	180	180	160	185
	Overtaking	m	640	640	640	500	320
Minimum vertical gradient		%	0.5	0.5	0.5	-	
Maximum vertical gradient		%	2.5	3.3	2.5 (Recommended) 3.3 (Allowabel)	3.0	3.0
Minimum length of vertical curve		m	60m	60m	60m	85m	
Minimum Radius of vertical curve, Top		m	6,500	-	-	6,500	
, Bottom		m	3,000	-	-	3,000	
			10.0	-	-	10.0	

Source: JICA Study Team

(2) Interchange Alignment

Geometric design standards for Interchanges are given below.

IRC 73-1980 is applied to interchange ramps since IRC SP 87-2013 does not contain applicable provisions. For items not covered therein, design guidelines and Japanese Highway Standards shall be used.

The vicinity of interchange is the section where the running speed changes. There is no Indian standard for this section. Below tables show the geometric design of interchange ramps and main alignment near the interchanges respectively.

Table 6.2.7 Geometric Design Standard of Interchange Ramps

Items		Unit	Values to be applied	IRC 73-1980	Japan Standard	AASHTO
Width of each carriageway		m	3.50	3.50	3.50	3.6
Shoulder Width	Sewri	m	0.25*	0.5*	0.75	3.0
	Shivaji/Nagar,SH54, Chilre	m	0.50	0.5*	0.75	1.2
Design Speed		kph	40			
Minimum Horizontal Radius		m	60	60	50	36
Minimum Horizontal Curve Length			-	-	70	45
Minimum Horizontal Radius(Ruling)Without Super elevation		m	420	420	600	804
Cross fall		%	2.5	2.0 – 2.5	2.0	1.5-2.0
Maximum super elevation		%	7.0	7.0	10.0	10
Minimum Transition Length	R = 45m	m	45	45		
	R = 60m		60	60		
	R = 90m		90	90		
	R = 100m		100	100		
	R = 150m		150	150	35	22
	R = 170m		170	170		
	R = 200m		200	200		
	R = 240m		240	240		
	R = 300m		300	300		
Minimum Radius (with no transaction Curve)		m	500	500	500	594
Super Elevation Rubbed Rate			1/100	-	1/100	1/143
Sight Distance	Safe Stopping	m	45	45	40	
	Overtaking	m	90	90	150	65
Minimum vertical gradient		%	0.5	0.5	-	160
Maximum vertical gradient		%	3.3	3.3	6.0	5.0
Minimum length of vertical curve		m	30	30	35	
Minimum Radius of vertical curve, Top		m	450	-	450	
, Bottom		m	450	-	450	

* Confirmed with MMRDA in the meeting on 20th May 2015. The shoulder width was classified as follows.

- 0.25m width: Sewri is a bridge section or restricted land area.
- 0.50m width: Shivaji Nagar, SH54 and Chirle are earth work sections and not restricted land area.

Source: JICA Study Team

Table 6.2.8 Geometric Design Standard in the Vicinity of an Interchange (Main Alignment)

Item		Unit	Japanese Standard		
Design Speed		kph	100	80	60
Minimum Horizontal Radius		m	1,500	1,100	500
Maximum Vertical Grade		%	2.0	3.0	4.5
Minimum Radius Vertical Curve	Top	m	25,000	12,000	6,000
	Bottom	m	12,000	8,000	4,000
Weaving Length		m	275	215	215

Source: JICA Study Team

Table 6.2.9 Geometric Design Standard in the Vicinity of an Interchange (Ramp)

Item		Unit	Japanese Standard		
Design Speed		km/h	100	80	60
Minimum Horizontal Radius		m	200	170	100
Minimum Transaction		m	70	60	50
Minimum Radius Vertical Curve	Top	m	1,000	800	450
	bottom	m	850	700	450

Source: JICA Study Team

(3) Transition Curves and Extra Width of Interchange

The transition curves and extra width were not considered for interchange design in the Final FS 2012. They are necessary for vehicles to have smooth entry from a straight section into a circular curve. Therefore, the standard of transition Curves and Extra Width are considered for interchanges in this study as follows.

As for the main alignment, it was considered in a previous design, and the widening is not required because the curve radiuses are large.

Table 6.2.10 Minimum Transition Lengths (Design Speed 40km/h)

Curve Radius (m)	Minimum Transition Length (m)
R= 45	Not Applicable
R= 60	75
R= 90	50
R=100	45
R=150	30
R=170	25
R=200	25
R=240	20
R=300	None Required

Source: IRC-73-1980

In the Indian standard, the lane widening width is different for a one-lane road and a 2-lane road. On the other hand, in the Japanese standard, it is given per lane. Table 6.2.7 shows the respective values.

The adopted radius of all ramps in MTHL is about 100m. The required extra width of the Indian standard for 100m radius is wider than the Japanese one. Therefore, the India standard is applied for the extra width at horizontal curves.

Table 6.2.11 Extra Width at Horizontal Curves

India standard			Japan Standard	
Radius curve (m)	Two-lane road	One-lane road	Radius Curve (m)	Each one lane
More than 300m	-	-	More than 160m	-
101 to 300	0.6	-	160 to 90	0.25
61 to 100	0.9	-	90 to 60	0.50
41 to 60	1.2	0.6	60 to 45	0.75
21 to 40	1.5	0.6	45 to 32	1.00
Less than 20m	1.5	0.9	32 to 26	1.25
			26 to 21	1.50
			21 to 19	1.75
			19 to 16	2.00
			16 to 15	2.25

Source: IRC-73-1980 and Japanese standard

(4) Acceleration and Deceleration Lanes

Two types of acceleration and deceleration lanes are adopted for the merging/diverging sections. The one is the “taper transition type”, other one is the “deceleration and acceleration type”. The applications are classified as follows.

- If the design speeds of the lanes are equal; the taper transition type is adopted.
- If the design speeds of the lanes are different, the deceleration and acceleration type is adopted.

This classification is the same as the previous study in 2012.

Table 6.2.12 Types of Acceleration and Deceleration Lane

Type	Interchange
Taper Form	Sewri IC
Acceleration and Deceleration	SH54IC,Shivaji Nagar IC, Chirle IC

Source: JICA Study Team

Table 6.2.13 Taper Transition Length and Acceleration Deceleration

Taper form

Items	Unit	Value	IRC SP-87-2013
Taper transition From single lane to multi-lane	rate	1:15-1:20	1:15-1:20

Acceleration and Deceleration Form

Items	Unit	Value	IRC SP-87-2013
Deceleration Length	m	145	145
Acceleration Length	m	150	150

Source: JICA Study Team

(5) Suggestion of Deceleration and Acceleration Lane

The acceleration and deceleration type is applied as the form of merging/ diverging between the acceleration and deceleration lane and the ramp for the following reasons:

- Acceleration and deceleration type is applied for diverging and merging sections of interchanges under both the Indian standard and Japanese standard.
- The form of merging/diverging needs to be unified for the entire road, and application of the acceleration and deceleration type is preferable because it is more common.
- The acceleration and deceleration type clarifies the acceleration and deceleration section between the ramp and main road, which differ from each other in terms of the speed of vehicles, and therefore reflects safety considerations.
- The taper form type should be applied where the number of lanes with the same speed limit increases or decreases. The acceleration and deceleration type should be applied for sections where the speed of vehicles changes.

At the Sewri IC, four lanes merge and diverge at the same time. Accordingly, with the method applied for this interchange, two adjacent ramps are merged with each other, and where the merger is completed, still another ramp is merged with it.

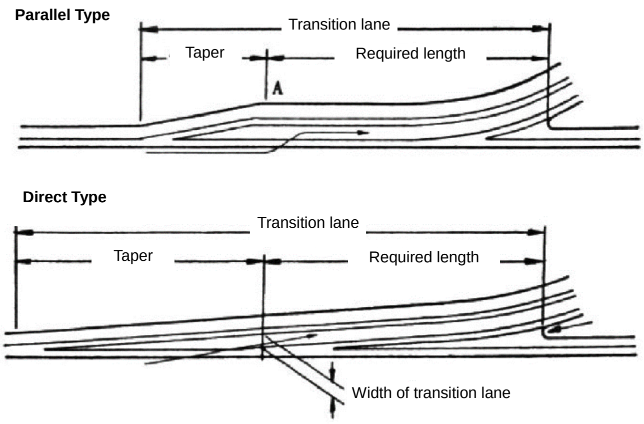
The acceleration and deceleration type is divided into the parallel type and direct type. This time, the direct type is applied for both acceleration and deceleration because most interchanges are circular curves. The parallel type is applied only for the acceleration section on the SH54IC side of Shivaji Nagar IC and weaving section of Chirle IC. Features of the parallel type and direct type are as described below.

1) Parallel Type

The transition lane is shifted after a parallel section. The drivers can confirm the status of the main alignment before shifting.

2) Direct Type

Directly come together or separate from the main alignment. It is not affected by the status of the main alignment.



Source: Japanese standard

Figure 6.2.4 Parallel Type and Direct Type

3) Planning Method for the Confluence and Separation of 2-Lane Ramps

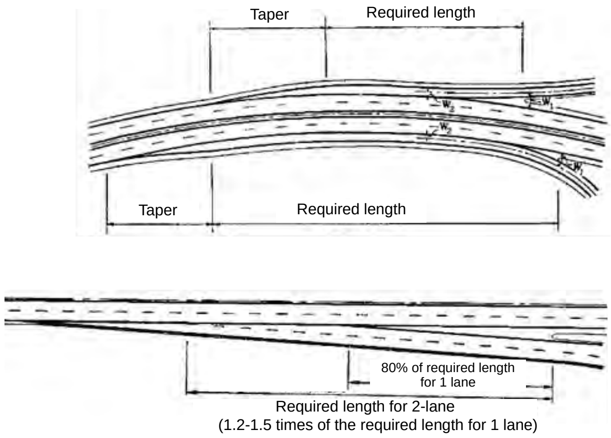
As for the confluence and separation of 2-lane ramps, it is desirable not only to connect the end of transition length from the ramp nose with main carriagway, but also to provide the section securing of 2 traffic lanes in the middle. In this study, we properly apply parallel type and direct type.

<u>Parallel Type: Straight Section</u>

SH54 side acceleration of Shivaji Nagar IC /Weaving section of Chirle IC

<u>Direct Type: Curve Section</u>

Other than those above IC



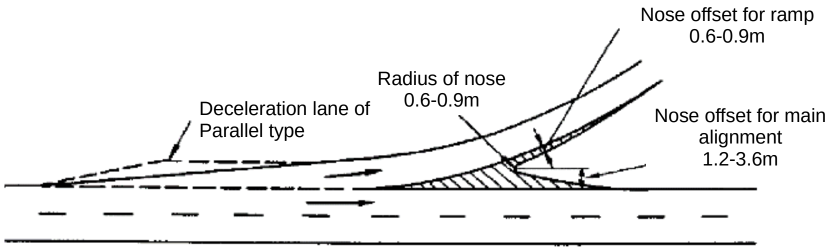
Source: Japanese standard

Figure 6.2.5 Confluence and Separation of 2-Lane Ramps

4) Other Details

Nose offset

If the driver makes a wrong direction, some space shall be provided in front of the nose in order for him to come back to the main alignment smoothly. However, it is impossible to provide this in Sewri IC because of the site restriction.



Source: Japanese standard

Figure 6.2.6 Nose Offset

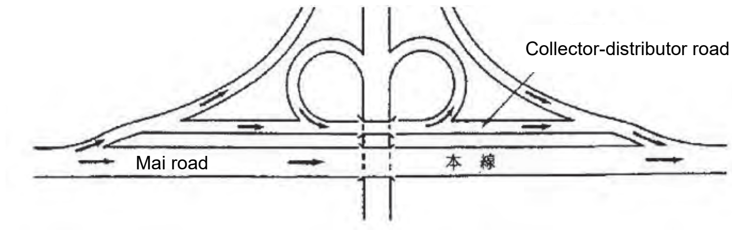
Correction of speed change section

If the vertical gradient of the main road exceeds 2%, the length of the speed change section needs to be corrected (Japanese standard). However, in this instance the correction is not necessary because the vertical gradient of the interchange section is 2% or below.

Collector-distributor road

At an interchange with successive separation and confluence of on-ramp and off-ramp like Chirle IC, a collector-distributor road for dispersing the traffic on the main road and the ramp is often provided.

However, in this instance a collector-distributor road will not be provided because the site conditions have been finalized and space for the collector-distributor road cannot be secured.

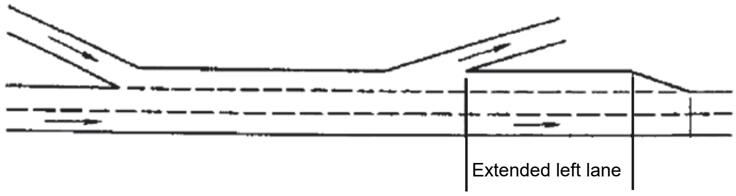


Source: Japanese standard

Figure 6.2.7 Collector-Distributor Road

Extended left lane for changing to the main road

Where an on-ramp is followed immediately by an off-ramp, the left lane is extended to give enough space to vehicles changing to the main road. An extended left lane is provided at Chirle IC. Shivaji Nagar IC also has such a section. However, the section has a setback for securing sight distance, and it was deemed possible to use this extra space as a lane for changing to the main road.



Source: Japanese standard

Figure 6.2.8 Extended Left Lane for Changing to the Main Road

Figure 6.2.5 shows the applied deceleration and acceleration length in MTHL.

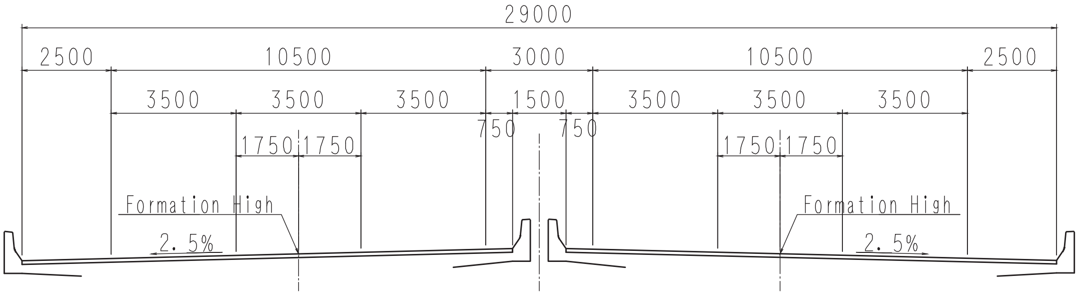
Table 6.2.14 Deceleration and Acceleration Length

		Japan Standard			India Standard
Design speed(km/h)		100	80	60	100
Base deceleration length excluding taper length	1-lane 2-lane	90 130	80 110	70 90	80m (1Lane)
Base Acceleration lane length excluding taper length	1-lane 2-lane	180 260	160 220	120 160	95m (1Lane)
Taper Length	1-lane	60	50	45	55
Outflow angle	1-lane 2-lane	1/25	1/20	1/15	-
In flow angle	1-lane 2-lane	1/40	1/30	1/20	-
Nose Distance	-	275	215	215	-

Source: JICA Study Team

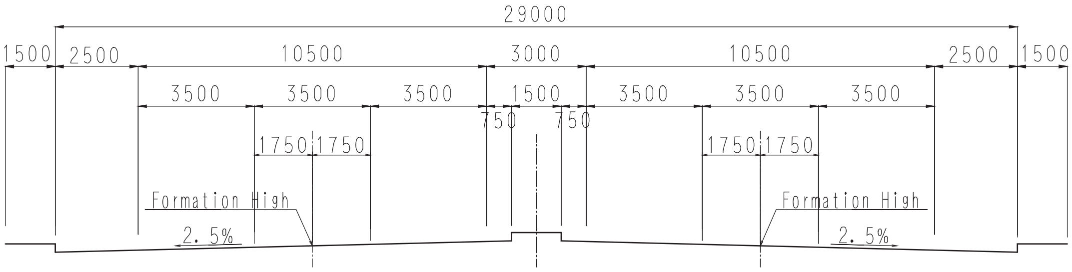
6.2.5 Typical Cross Section

Shown below are each of the typical cross sections.



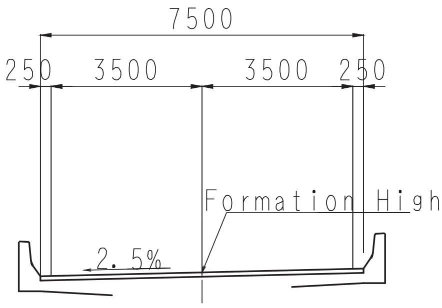
Source: JICA Study Team

Figure 6.2.9 Main Alignment (Viaduct) Section



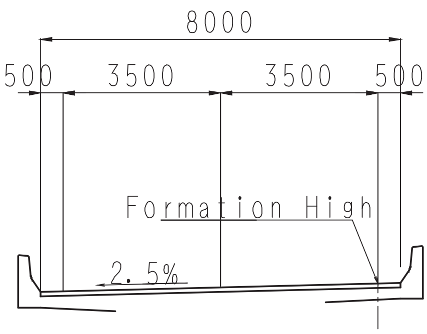
Source: JICA Study Team

Figure 6.2.10 Main Alignment Earth Works Section (18+950 – 19+950)



Source: JICA Study Team

Figure 6.2.11 Sewri IC



Source: JICA Study Team

Figure 6.2.12 Shivaji Nagar, SH54 and Chirle IC

6.3 Design Criteria for Structural Design

6.3.1 Design Codes

Main code list for bridge structure design is shown in Table 6.3.1.

Table 6.3.1 Main Code List for Bridge Structure Design

Code No.	Title
IRC: 5-1998	Standard Specifications & Code of Practice for Road Bridges. Section I - General Features of Design
IRC: 6-2014	Standard Specifications & Code of Practice for Road Bridges. Section II - Loads and Stresses
IRC: 7-1971	Recommended Practice for Numbering Bridges and Culverts
IRC: 18-2000	Design Criteria for Pre-stressed Concrete Road Bridges (Post-Tensioned Concrete)
IRC: 21-2000	Standard Specifications and Code of Practice for Road Bridges. Section III - Cement Concrete (Plain and Reinforced)
IRC: 22-2008	Standard Specifications and Code of Practice for Road Bridges. Section VI - Composite Construction
IRC: 24-2010	Standard Specifications and Code of Practice for Road Bridges. Section V - Steel Road Bridges (Limit State Method)
IRC: 45-1972	Recommendations for Estimating the Resistance of Soil Below the Maximum Scour Level in the Design of Well Foundations of Bridges.
IRC:46-1972	A Policy on Roadside Advertisements
IRC: 54-1974	Lateral and Vertical Clearances at Underpasses for Vehicular Traffic.
IRC: 78-2000	Standard Specifications and Code of Practice for Road Bridges. Section VII - Foundations & Substructure
IRC: 83-1999 Part I	Standard Specifications and Code of Practice for Road Bridges. Section IX - Bearings, Part 1 : Metallic Bearings
IRC: 83-1987 Part II	Standard Specifications and Code of Practice for Road Bridges, (Part-II) Section IX - Bearings, Part II: Elastomeric Bearings
IRC:83-2002 Part III	Standard Specifications and Code of Practice for Road Bridges, (Part-II) Section IX - Bearings, Part III: Pot, Pot-cum-PTFE Pin and Metallic Bearings
IRC: 89-1997	Guidelines for Design & Construction of River Training & Control Works for Road Bridges.
IRC: 112-2011	Code of Practice for Concrete Road Bridges
IRC:SP-13-2004	Guidelines for the Design of Small Bridges and Culverts
IRC:SP-18-1996	Manual for Highway Bridge Maintenance Inspection
IRC:SP-33-1989	Guidelines on Supplemental Measures for Design, Detailing & Durability of Important Bridge Structures.
IRC:SP-35-1990	Guideline for Inspection and Maintenance of Bridges
IRC:SP-37-2010	Guidelines for Load Carrying Capacity of Bridges
IRC:SP-40-1993	Guidelines on Techniques for Strengthening and Rehabilitation of Bridges
IRC:SP-47-1998	Guidelines on Quality Systems for Road Bridges (Plain, Reinforced, Prestressed and Composite Concrete)
IRC:SP-54-2000	Project Preparation Manual for Bridges
IRC:SP-56-2011	Guidelines for Steel Pedestrian Bridges
IRC:SP-65-2005	Guidelines for Design and Construction of Segmental Bridges
IRC:SP-66-2005	Guidelines for Design of Continuous Bridges

Code No.	Title
IRC:SP-67-2005	Guidelines for use of External and Unbonded Prestressing Tendons in Bridge Structures
IRC:SP-69-2005	Guidelines and Specifications for Expansion Joints
IRC:SP-70-2005	Guidelines for the Use of High Performance Concrete in Bridges
IRC:SP-71-2006	Guidelines for the Design and Construction of Pre-tensioned Girders of Bridges
IRC:SP-74-2007	Guidelines for Repair and Rehabilitation of Steel Bridges
IRC:SP-80-2008	Guidelines for Corrosion Prevention, Monitoring and Remedial Measures for Concrete Bridge Structures
Japanese Standard	Handbook for protection of bridge painting and corrosion protection (December, 2005)

Source: JICA Study Team

6.3.2 Design Concept

(1) Design Life

The target design life for main structures shall be 100 years according to IRC: 112-2011.

(2) Environmental Equipment for Bridge Design

The following environmental requirements shall be incorporated into the bridge plans and designs.

- The bridge type shall be considered so as not to have significant impacts on the flying course of migratory birds in the mud flat area, e.g. the lesser flamingo.
- The span arrangement and substructure type shall be designed so as to minimize any adverse environmental impacts in tidal and mangrove areas.

6.3.3 Design Loads

There are several loads to be considered for the bridge design.

(1) Dead Loads

The dead load shall include the weight of all components of the structure, utilities attached, pavement wearing surface and future overlays. In absence of precise information, the unit weights prescribed by IRC: 6-2014 can be used to calculate the dead load of the structure.

Table 6.3.2 Unit Weight of Bridge Materials for Dead Load Calculation

Material		Weight (t/m^3)
Concrete	Asphalt	2.2
	Cement-Plain	2.5
	Cement-Reinforced	2.5
	Cement-Prestressed	2.5
Steel	(Rolled or Cast)	7.8

Source: IRC: 6-2014

The unit weight of High Performance Concrete (hereinafter called HPC) which was recommended by the Technical Committee for MTHL, shall be taken as 2.6 t/m^3. HPC shall be used for the marine bridges to prevent the salt damage

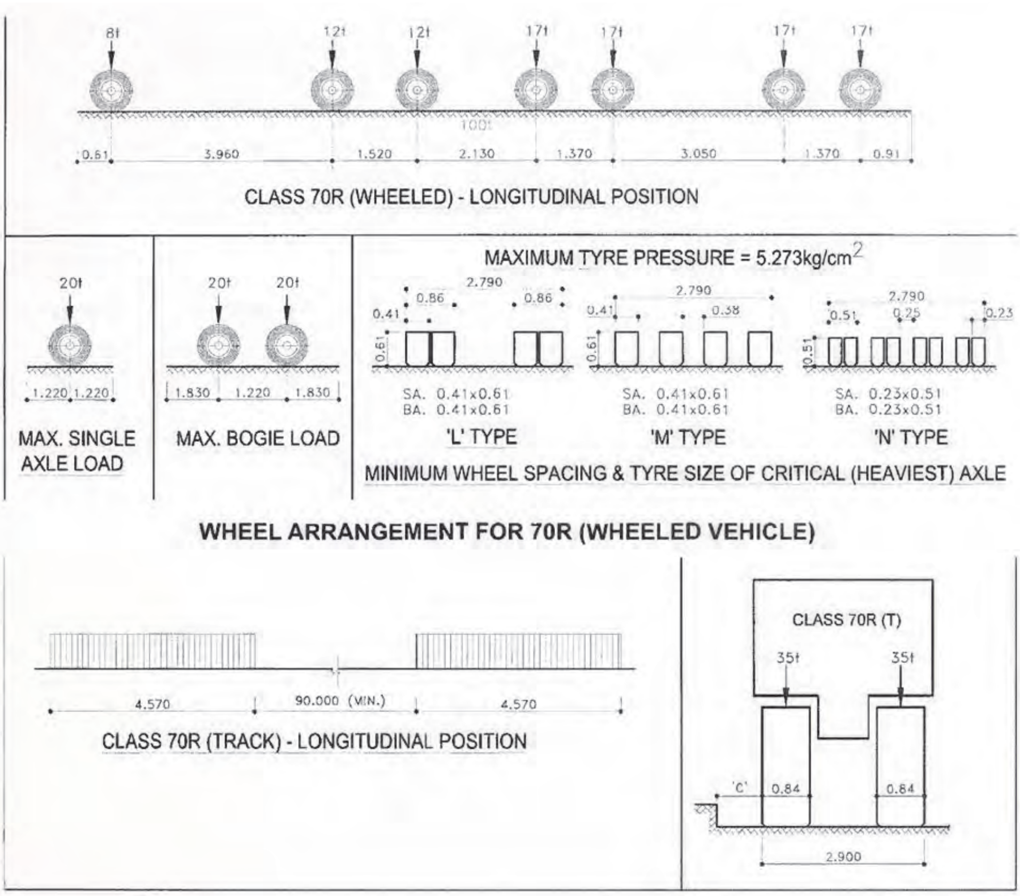
A load intensity of 5 kN/m along each outer parapet and the central median parapet shall be allowed for services such as lighting, emergency telephones, fire hydrants, etc.

(2) Live Loads

Traffic loading shall be as defined in IRC: 6-2014 with Class 70R design vehicle and Class A.

1) Class 70R Tracked and Wheeled Vehicles

The weights and spacing of axles and wheels for the design truck shall be as per the specification shown in Figure 6.3.1.

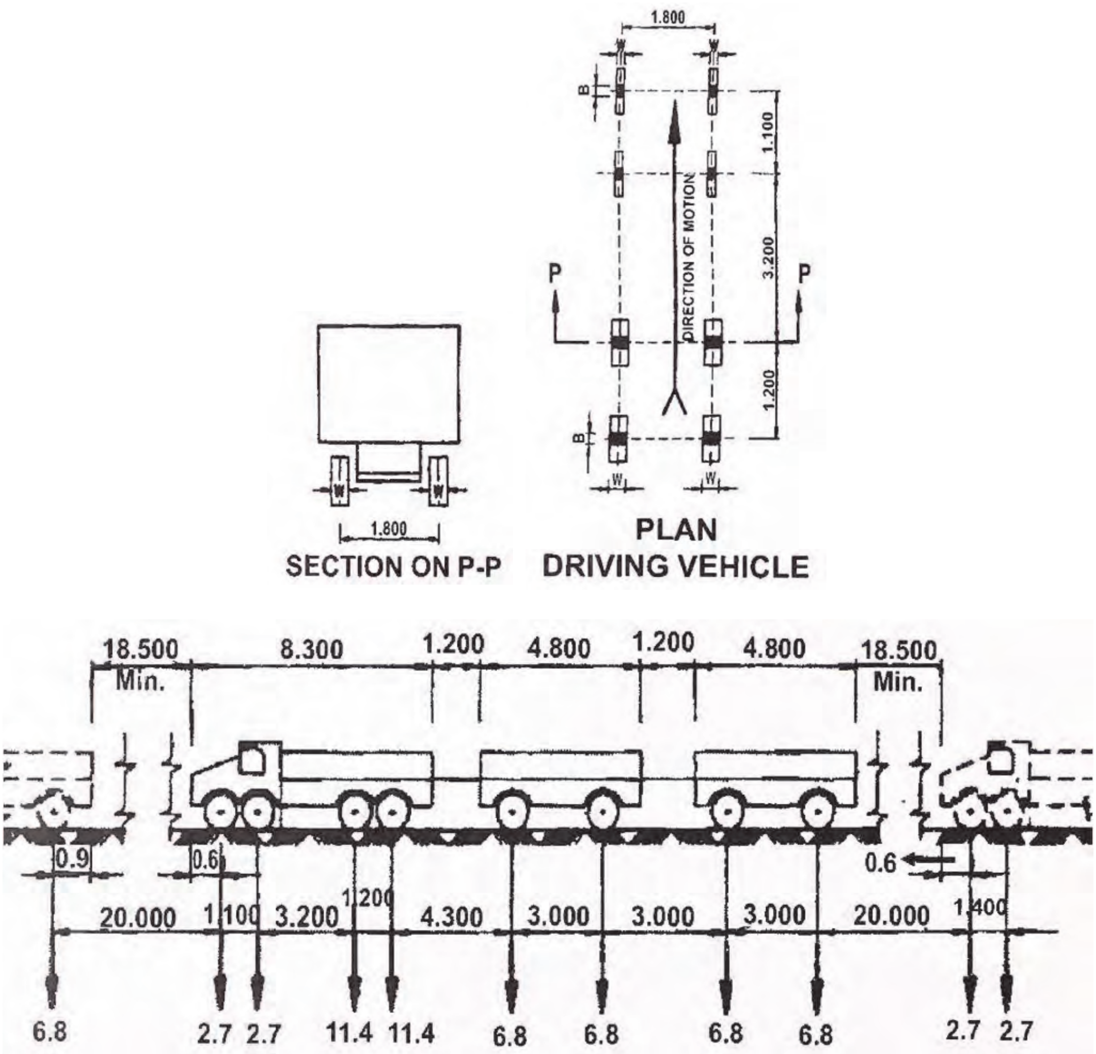


Source: IRC: 6-2014

Figure 6.3.1 Class 70R Tracked and Wheeled Vehicles

2) Class 'A' Train of Vehicles

The weights and spacing of axles and wheels for the design truck shall be as per the specifications for Class A shown in Figure 6.3.2.

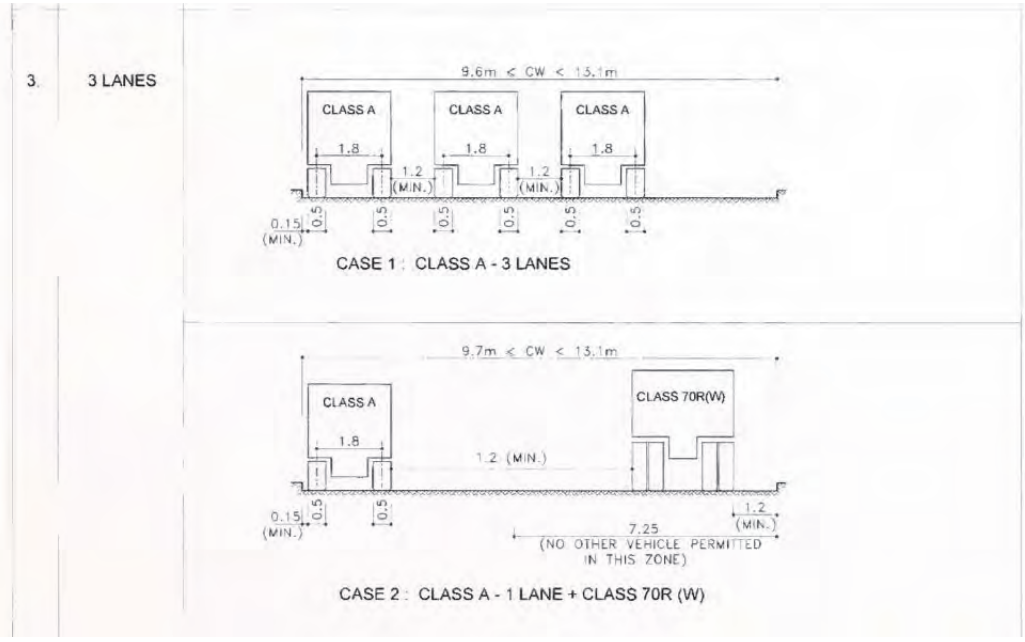


Source: IRC: 6-2014

Figure 6.3.2 Class 'A' Train of Vehicles

3) Combination of Live Loads

The live load combination on carriageways shall be considered for the design as shown in Figure 6.3.3.



Source: IRC: 6-2014

Figure 6.3.3 Live Load Combination

4) Reduction in the Longitudinal Actions on Bridges Accommodating more than Two Traffic Lanes

For bridges with more than two traffic lanes, the longitudinal actions (bending moment, shear force and torsion in the longitudinal direction) should be reduced to account for the degree of probability that all lanes will be subjected to the characteristic loads simultaneously. This reduction shall be in accordance with Table 6.3.3.

Table 6.3.3 Reduction in Longitudinal Effect

Number of lanes	Reduction in longitudinal effect
2	No reduction
3	10% reduction
4 or more	20% reduction

Source: IRC: 6-2014

5) Impact

(a) Class A Loading

For the members of any bridge designed for Class A loading, the impact fraction shall be determined from the following equations (applicable for spans between 3 m and 45 m).

- For RC/PC bridges =4.5/(6+L) (3m<L<45m)
- For steel bridges = 9/(13.5+L) (3m<L<45m)

(b) Class 70R Loading

a) Bridge for Spans of 9m or more

The value of the impact percentage shall be taken as follows (for spans of 9 m or more):

[RC/PC bridges]

- Tracked vehicles: 10 percent up to a span of 40 m and for spans in excess of 40 m: 4.5/(6+L)(40m<L<45m).
- Wheeled vehicles: 25 percent for spans up to 12 m and for spans in excess of 12 m: 4.5/(6+L)(12m<L<45m)

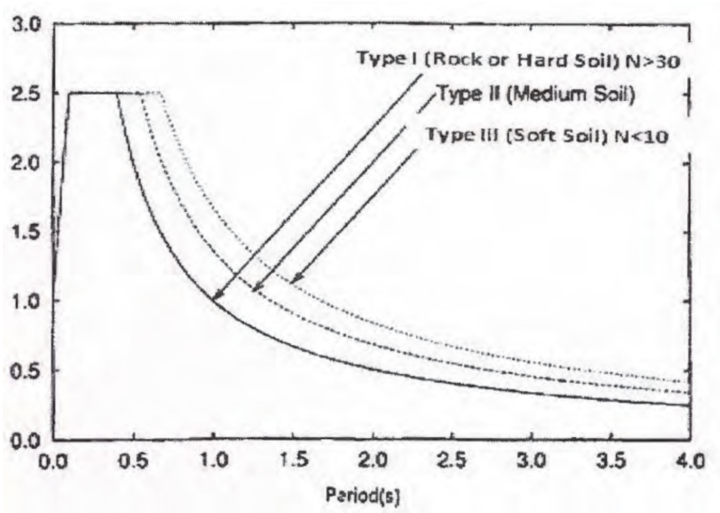
[Steel bridges]

- Tracked vehicles: 10 percent for all spans
- Wheeled vehicles: 25 percent for spans up to 23 m and for spans in excess of 23 m: 4.5/(6+L)(23m<L<45m)

For span lengths in excess of 45m, the impact percentage for 45m span length shall be utilized.

(3) Earthquake Load

The design shall be based on the IRC: 6-2014 and IS: 1893-1984. The elastic seismic acceleration method shall be adopted using spectra as defined in Figure 6.3.4.



Source: IRC: 6-2014

Figure 6.3.4 Response Spectra

The following equation shall be applied to calculate the seismic force for the bridge design.

Feq=Ah=(Z/2) x (I) x (Sa/g)

Where

Feq: Resistance force against Earthquake

Ah : Coefficient of Seismic Force

Z : Area Factor (Z=0.16)

I : Importance Factor of the Bridge (I=1.5)

Sa/g: Response Factor from Figure 6.3.4

(4) Wind Load

Winds loads shall be based on the basic wind speed for Mumbai, as defined in IRC: 6-2014.

1) Basic Wind Speed

The basic average wind speed for MTHL bridges shall be 44m/s, considering the historical date in the Mumbai area and the average wind load shall be 879N/m2 because the bridge elevation in MTHL is lower than 50m in elevation from the ground level.

2) Design Wind Force on Superstructure

(a) Transverse Wind Force

The transverse wind force F_T (in N) shall be taken as acting at the centroids of the appropriate areas and horizontally and shall be estimated from:

$$F_T = P_Z A_1 G C_D$$

Where,

P_Z : The hourly mean wind pressure in N/m^2
A_1 : The solid area in m^2
G : The gust factor

- For bridge decks supported by a single beam or box girder, C_D shall be taken as 1.5 for b/d ratio of 2 and as 1.3 if b/d > 6. For intermediate b/d ratios C_D shall be interpolated.
- For a deck supported by two or more beams or box girders, where the ratio of clear distance between the beams or boxes to the depth does not exceed 7, the C_D for the combined structure shall be taken as 1.5 times the C_D for the single beam or box.
- For a deck supported by a single plate girder, it shall be taken as 2.2. When the deck is supported by two or more plate girders, for the combined structure C_D shall be taken as 2 (1 + c/20d), but not more than 4, where c is the centre to centre distance of adjacent girders, and d is the depth of the windward girder.

(b) Longitudinal Force

The longitudinal force on a bridge superstructure F_L (in N) shall be taken as 25 percent and 50 percent of the transverse wind load as calculated as per ‘(a) Transverse wind force’ for beam/box/plate girder bridges and truss girder bridges respectively.

(c) Vertical Wind Load

An upward or downward vertical wind load F_V (in N) acting at the centroid of the appropriate areas, for all superstructures shall be derived from:

$F_v = P_Z A_3 G C_L$

Where,

- P_Z : The hourly mean wind pressure in N/m^2
- A_3 : The area in plan in m^2
- C_L : The lift coefficient which shall be taken as 0.75 for normal type of slab, box, I-girder and plate girder bridges.
- G : The gust factor as defined in '(a) Transverse wind force'.

3) Design Wind Force on Substructure

The substructure shall be designed for wind induced loads transmitted to it from the superstructure and wind loads acting directly on the substructure. Loads directly acting on the substructure shall be calculated as follows;.

$F_t = P_Z A_1 G C_D$

Where,

- P_Z : The hourly mean wind pressure in N/m^2
- A_1 : The area in plan in m^2
- C_d : The resistance coefficient depending on the shape of the substructure according to Table 6 of IRC 6-2014.
- G : The gust factor as defined in '(a) Transverse wind force'.

(5) Water Currents

The current speed in each direction acting on a substructure should be taken as not less than 3m/s.

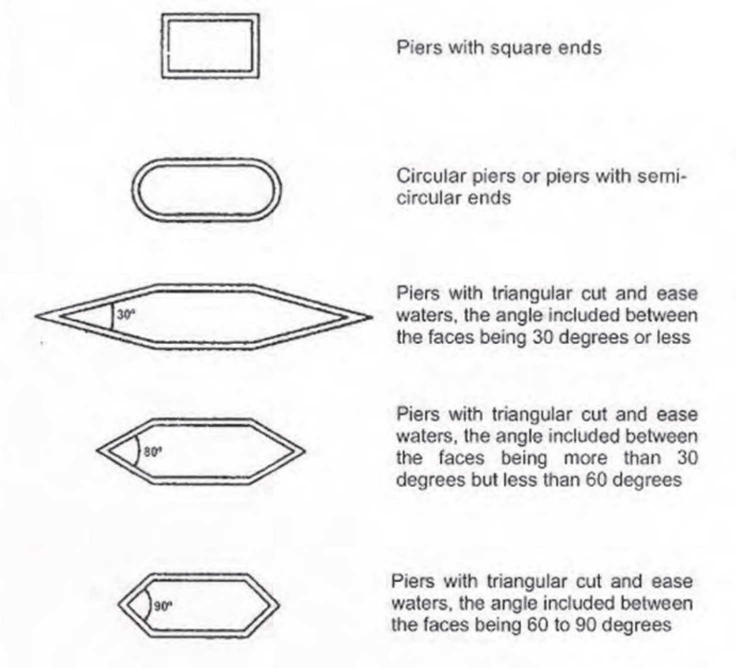
On piers parallel to the direction of the water current, the intensity of pressure shall be calculated from the following equation:

$P = 52KV^2$

Where,

- P: intensity of pressure due to water current, in kg/m^2
- V: the velocity of the current at the point where the pressure intensity is being calculated, in metres per second
- K: a constant having the following values for different shapes of piers illustrated in Figure 6.3.5.

- Square ended piers (and for the superstructure): 1.50
- Circular piers or piers with-circular ends: 0.66
- Piers with triangular cut and ease waters, the angle included between the faces being 30° or less: 0.50
- Piers with triangular cut and ease waters, the angle included between the faces being more than 30° but less than 60°: 0.50 to 0.70
- Piers with triangular cut and ease waters, the angle included between the faces being more than 60° but less than 90°: 0.70 to 0.90



Source: IRC: 6-2014

Figure 6.3.5 Shapes of Bridge Piers

(6) Temperature Load

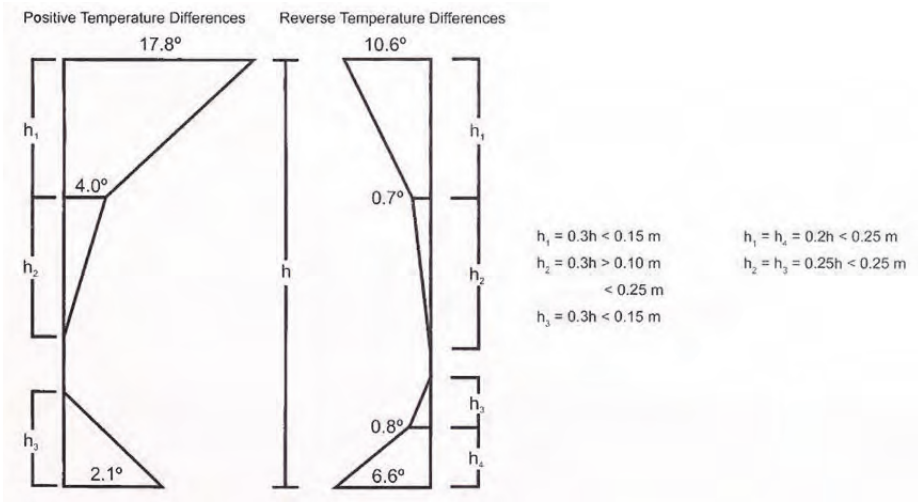
1) Design Temperature Range

Loads incurred by change in temperature shall be based on a difference between the basic maximum and minimum temperature in Mumbai. According to historical data the maximum temperature is approximately 40°C, the minimum temperature is approximately 10°C. The subject bridge location has a difference between maximum and minimum air shade temperatures of >20°C.

The temperature range considering the bridge design shall be ±10°C according to IRC:6-2014.

2) Thermal Gradient

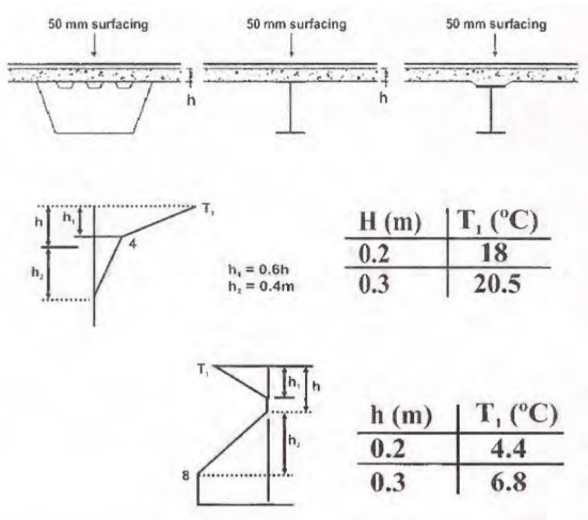
Positive and reverse temperature differences for the purpose of design of concrete bridge decks shall be assumed as shown in Figure 6.3.6 according to IRC:6-2014. These design provisions are applicable to concrete bridge decks with 50 mm of wearing surface.



Source: IRC: 6-2014

Figure 6.3.6 Design Temperature Differences for Concrete Bridge Decks

So far as steel and composite decks are concerned, Figure 6.3.7 may be referred to for assessing the effect of temperature gradient. These design provisions are applicable to the bridge decks with 50 mm of wearing surface.



H (m)	T_1 (°C)
0.2	18
0.3	20.5

h (m)	T_1 (°C)
0.2	4.4
0.3	6.8

Source: IRC: 6-2014

Figure 6.3.7 Temperature Differences across Steel and Composite Section

(7) Special Loads

1) Vehicle collision Impact with Substructure and Guard wall

Design impact loads from vehicles colliding with the substructure shall be as defined in IRC: 6-2014.

The nominal loads given in Table 6.3.4 shall be considered to act not only horizontally but also parallel to the carriageway as Vehicle Collision Loads. Loads normal to the carriageway below and loads parallel to the carriageway below shall be considered to act separately and shall not be combined.

Table 6.3.4 Nominal Vehicle Collision Loads on Guard wall of Bridge

	Load Normal to the Carriageway Below (Ton)	Load Parallel to the Carriageway Below (Ton)	Point of Application on Bridge Support
Main load component	50	100	At the most severe point between 0.75 and 1.5 m above carriageway level
Residual load component	25(10)	50(10)	At the most severe point between 1 m and 3 m above carriageway level

Source: IRC: 6-2014

The loads indicated are assumed for vehicles travelling at speeds of 60 km/hour. In the case of vehicles travelling at lower speed, the loads may be reduced in proportion to the square of the speed, but cannot be reduced to less than 50 percent.

The guard wall on the bridge shall be designed for the residual load component only.

2) Ship Collision Impact on Piers

Piers shall be designed for ship collision impact as per IRC: 6-2014.

(a) Design Vessel

The design vessel for the bridges across Thane and Panvel Creek navigation channels is given in Table 6.3.5.

Table 6.3.5 Type and Specification of Ship

Type	Ship
DWT	4,000 tonnes
Length	LOA = 96.0m
Beam	BM = 13.8m
Vessel Transit Speed	VT = 10 knots
Minimum Impact Velocity	VMIN = 2 knots

Source: IRC: 6-2014

(b) Barge Collision Energy: KE

$KE = 500 \times C_H \times W \times V^2$

Where,

KE = Barge Collision Energy (N-m)

W = Barge Displacement Tonnage (T) : 4,000 tonnes

V = Barge impact speed (m/sec) : 10knots=10/1.9438=5.145m/sec

C_H = Hydrodynamic coefficient= 1.05 to 1.25 for Barges depending upon the clearance under keel available.

- If clearance under keel is more than 0.5 x Draft, CH=1.05;
- If clearance under keel is less than 0.1 x Draft, CH= 1.25.
- For any intermediate values of under keel clearance, linear interpolation shall be done.

(c) Barge Damage Depth: a_B

$a_B = 3{,}100 \times \{[1+1.3\times10^{(-7)} \times KE]^{0.5}-1\}$

Where,

a_B: Barge bow damage depth (mm)

(d) Barge Collision Impact Force: PB

The barge collision impact force shall be determined based on the following equations;

For a_B <100mm, $P_B=6.0 \times 10^4 \times (a_B)$, in N

For a_B ≥100mm, $P_B=6.0 \times 10^6 +1{,}600 \times (a_B)$, in N

6.3.4 Materials

(1) Concrete

The concrete performances were determined by the Technical Advisory Committee for MTHL which were held from 2012 to 2013. As a result, the high performance concrete is used in the structures. The cube strength in each part is shown in Table 6.3.6.

Table 6.3.6 Concrete Strength

Parts	Strength (MPa)
Concrete for bored piles and caissons	45
Pile caps	45
Pile cap skirts	55
Abutments, Walls	45
Piers	55
Deck	55
Parapets and median	45

Source: Technical Advisory Committee, 2012-2013
Feasibility Final Report of Detailed Feasibility Study and Bid Process Management for Selection of Developer for MTHL, 14th, December, 2012

(2) Reinforcement Steel

The specifications for reinforcement steel are based on IRC: 21-2000 and its strengths depending on the steel type are shown in Table 6.3.7.

Table 6.3.7 Reinforcement Steel Strength

Types	Strength (MPa)	Elastic Modulus (GPa)
Fe 240	240	200
Fe 415	415	200
Fe 500	500	200

Source: IRC: 21-2000

(3) Pre-Stressing Steel

The specifications for pre-stressing steel are based on IRC: 112-2011 and its strength by the steel type are shown in Table 6.3.8.

Table 6.3.8 Pre-Stressing Steel Strength

Class	Type of Pre-stressing Steel	Area (mm^2)	Yield Strength (kN)	Yield Strength (kN)
I	11.1mm, 7 ply	70.0	105.86	108.00
	12.7mm 7 ply	92.9	139.90	144.10
	15.2mm 7 ply	139.0	192.83	216.20
II	11.1mm 7 ply	74.2	117.21	124.10
	12.7mm 7 ply	98.8	156.11	165.30
	15.2mm 7 ply	140.0	222.23	234.60

Source: IRC: 112-2011

(4) Steel

The specifications of steel are based on IRC: 24-2010.

6.3.5 Design Standard for Environmental Clearance

The bridges should be designed using the standard for bridges, EIA notification and CRZ notification. The EIA notification and CRZ notification are shown in 12.3.

6.4 Preliminary Design for Road

6.4.1 General

As described in chapter 3, the road horizontal alignment of the main carriageway complies with Indian standards and has been designed with extreme care in previous studies. Additionally, it is in accordance with the result of the topographic survey.

On the other hand, while the clearance needed by the crossing object is secured in the vertical alignment, the position and limits of the ship route have been reviewed. Accordingly, the vertical alignment has also been reviewed in consideration of economic efficiency. Points that were examined in this study, including the vertical alignment, are as listed below.

1) Improvement of the vertical alignment: Vertical alignment plan that matches the ship-route position and ship-route limits in the sea section
2) Number of lanes on the main road and number of toll booths: Changed based on the result of the traffic demand analysis
3) Interchange alignment: The alignment was corrected in consideration of the transition curve and nose interval, and diversion and confluence plans are implemented for 2-lane ramps.
4) Number of ramp lanes and toll booths: The number of lanes was decided in consideration of vehicle traffic and the number of toll booths based on the result of the traffic demand analysis
5) Emergency platforms: Interval between emergency platforms is based on Japanese standard
6) Cut section plan: Vertical alignment and standard cross-section
7) Pavement structure: Suggestion of the optimal pavement structure with a special focus on the pavement on the box girder with steel deck slabs
8) Drainage plan: Surface drainage plan in the marine section

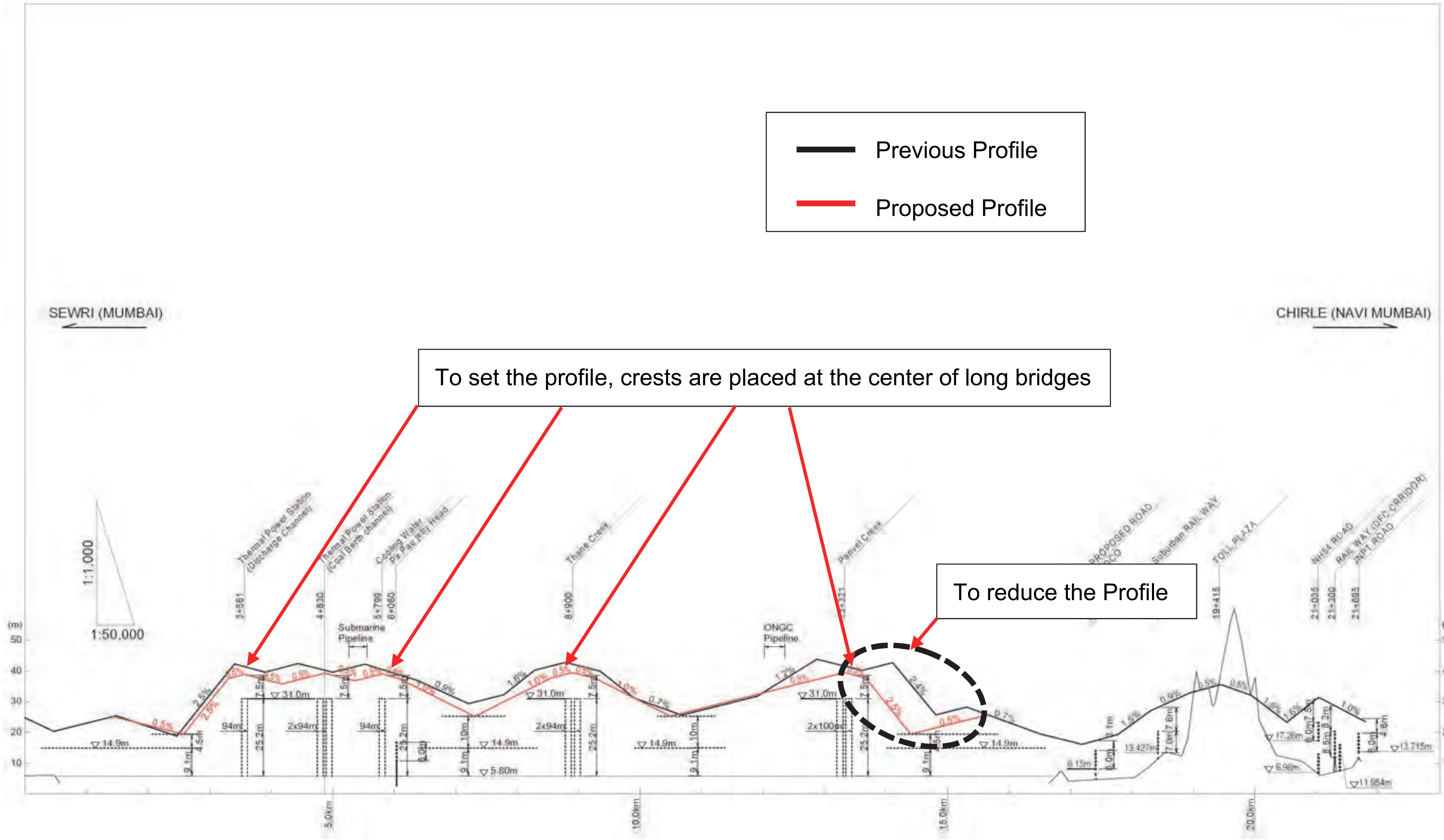
6.4.2 Preliminary Design for Road

There is some margin between the vertical alignment and the navigation clearance in the sea section in the Final FS 2012. Therefore, improvement of the vertical alignment was studied.

The conditions of the vertical study are:

- According the design standard, maximum vertical gradient is 2.5%.
- The top of the vertical curves shall be placed on the centre of the bridge span.
- Sharp angles shall be avoided.

Figure 6.4.1 shows the proposed vertical alignment.



Source: JICA Study Team

Figure 6.4.1 Proposed Vertical Alignment

6.4.3 Review of Traffic Lanes on Main Alignment

Six lanes for the main alignment were chosen based on the upper plan of Maharashtra government. In this study it was reviewed based on the forecast result of future traffic volume by using the Manual of Specifications and Standards for Expressways (IRC:SP:99-2013).

The review indicated that 6-lanes will be required in 2032 (10 years after traffic opening). Although 8-lanes will be required in 2042, it is assumed that the function of MTHL will be kept as metro and the additional lanes will be constructed in parallel with MTHL.

Table 6.4.1 Required Traffic Lanes

Year	Traffic Volume (vehicle/day)	Traffic Volume (PCU/day)	Design Service Volume for Expressways (PCU/day) Based on SP:99-2013	Required Traffic lanes
2022	31,155	39,300	< 86,000 4-lane	4-lane
2032	88,613	103,886	< 130,000 6-lane	6-lane
2042	125,000	145,510	< 173,000 8-lane	8-lane

Source: JICA Study Team

6.4.4 Study on the Number of Toll Booths on the Main Alignment

The toll booths of the main alignment are located between Shivaji Nagar IN and SH54IC. As mentioned in chapter 3, although 14 toll booths were considered in the previous study, the reason is not clear. Therefore, it is studied in consideration of the result of traffic demand forecast in 2042. As a result, 8 toll booths shall be provided.

Table 6.4.2 Number of Toll Booths on Main Alignment

Direction	Traffic Volume in 2042 (Vehicle/day)	Traffic Volume of Peak Hour in 2042 (Vehicle/ hour)	Traffic Volume for ETC lane (vehicle/hour)	Traffic volume for manual lane (vehicle/hour)	Number of required ETC lane	Number of required manual lanes	Total number of toll booths
Chirle	25,000	1,800	630	1,170	1	3	4
Sewri	23,000	1,550	540	1,010	1	3	4

Note: The capacity of manual lanes is 780 vehicles/hour for 2 booths, 1230 vehicles/hour for 3 booths and 1670 vehicles/hour for 4 booths

Source: JICA Study Team based on Japanese Standard

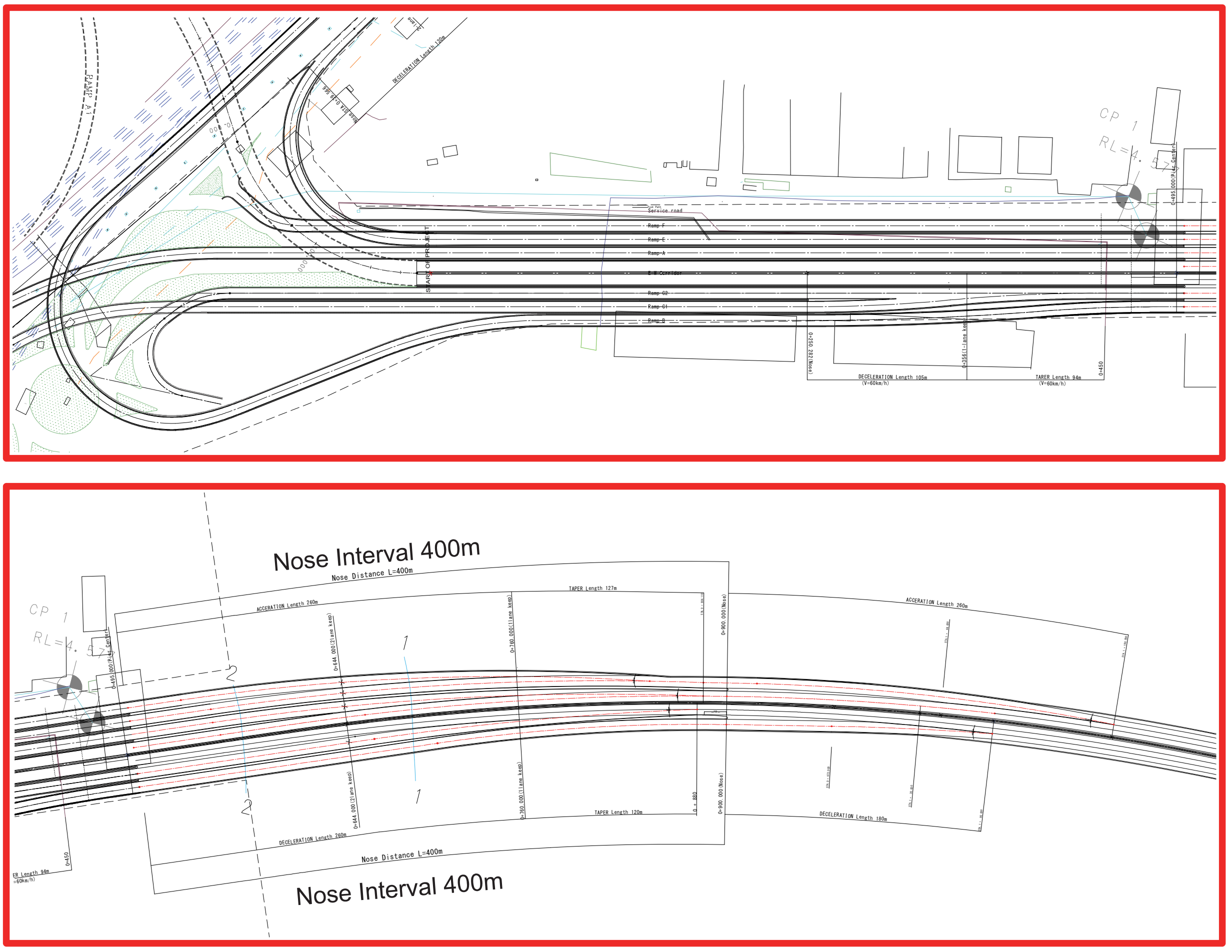
6.4.5 Improvement of Interchange Alignment

In the Final FS 2012, transition curves were not considered in all ramps. On the other hand, it was considered in the main alignment.

The following figures show the difference of with/without the transition curves for each interchange. Although there is little difference in the drawings, the traveling performance and safety will be improved by providing the transition curves.

(1) Ramp Alignment

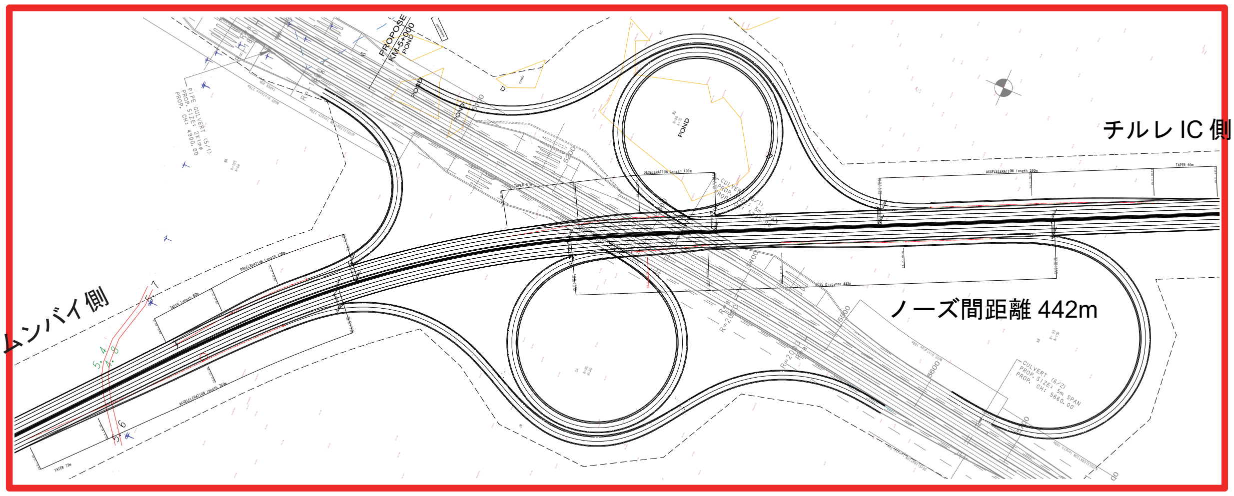
The adjacent ramps are joined, then, the ramps are joined again. Nose distance is 400m rather than the standard distance of 275m.



Source: JICA Study Team

Figure 6.4.2 Sewri IC

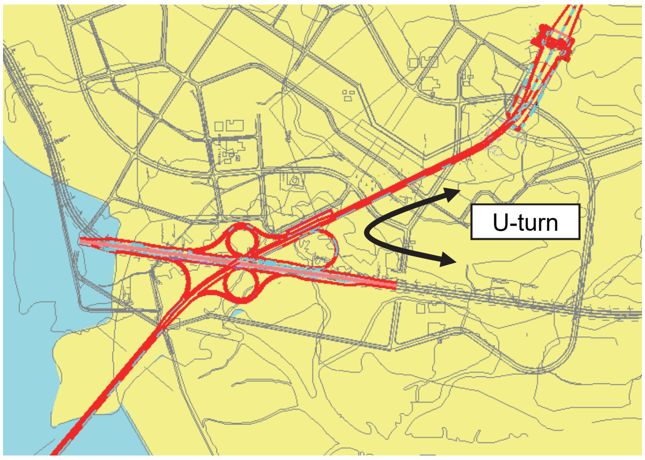
There is only one place where appropriate nose distance should be secured. Nose distance of 442m is rather than the standard nose distance of 275m.



Source: JICA Study Team

Figure 6.4.3 Shivaji Nagar IC

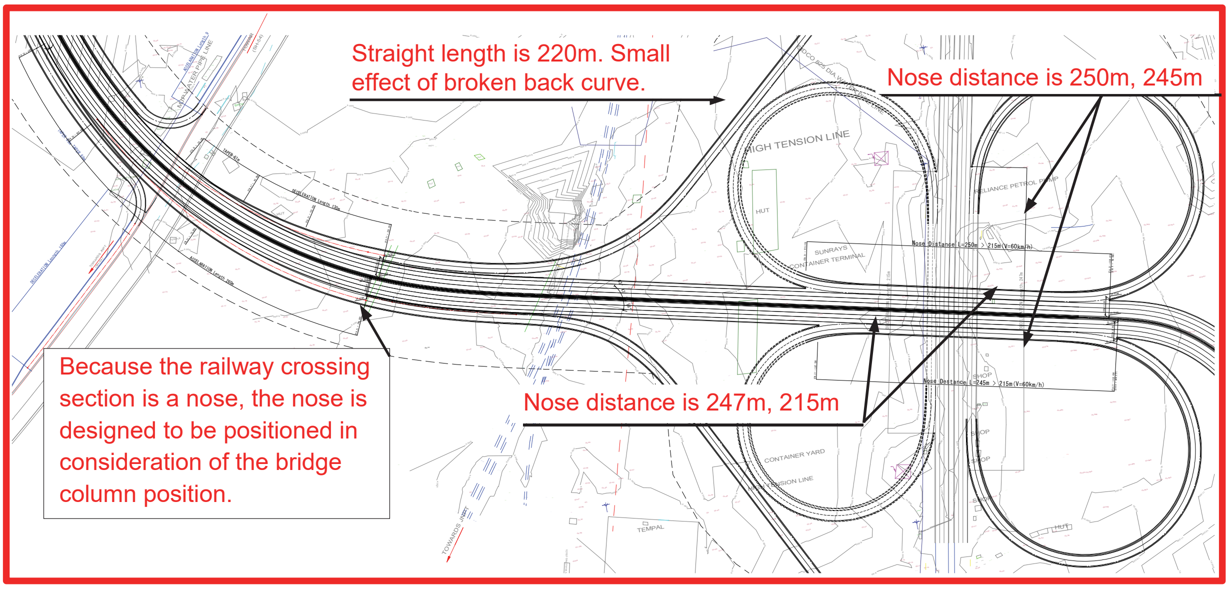
Shivaji Nagar is not a full access interchange. There is no ramp corresponding to a U-turn route.



Source: JICA Study Team

Figure 6.4.4 Planned Shivaji Nagar IC

Shivaji Nagar is a provisional interchange with an extension plan. It is designed for 60km/h including the near main road.



Source: JICA Study Team

Figure 6.4.5 Chirie IC

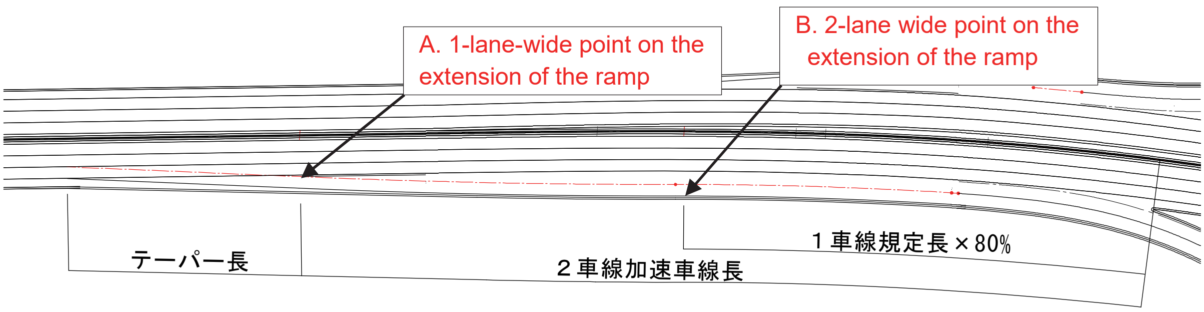
(2) Approach to Acceleration and Deceleration Sections

The plan of a 2-lane ramp is based on 2 control points, as shown in the following sections, A and B.

A. Specified length of 2-lane section is secured as an acceleration and deceleration section. Width equivalent to one lane is secured at the end of the tapered section.

B. Width equivalent to two lanes is secured in the middle of the acceleration and deceleration sections (at a point that is away from the nose by a distance which is 80% of the specified length of one lane).

The 2-lane-wide point in the middle of the acceleration and deceleration sections will ensure smooth alignment and smooth transition to and from the main road. All the planned ramps are based on A and B, because of all ramps have 2-lanes.



Source: JICA Study Team

Figure 6.4.6 Diversion and Merger Form of a 2-Lane Ramp

6.4.6 Study of the Number of Lanes on Interchange Ramps

More than 2-lanes are proposed on interchange ramps in the Final FS 2012. However, it is not clear why. Therefore, it is studied based on the Japanese standard in consideration of the result of the traffic demand forecast in 2042.

Required number of traffic lanes from the traffic demand forecast is shown in below.

Sewri IC

2-lanes are required on C2 ramp connecting the main alignment and Mumbai port. Other ramps require 1-lane.

Shivaji Nagar IC

2-lanes are required on the on and off ramps connecting the main alignment and Navi-Mumbai Airport. Other ramps require 1-lane.

SH54IC

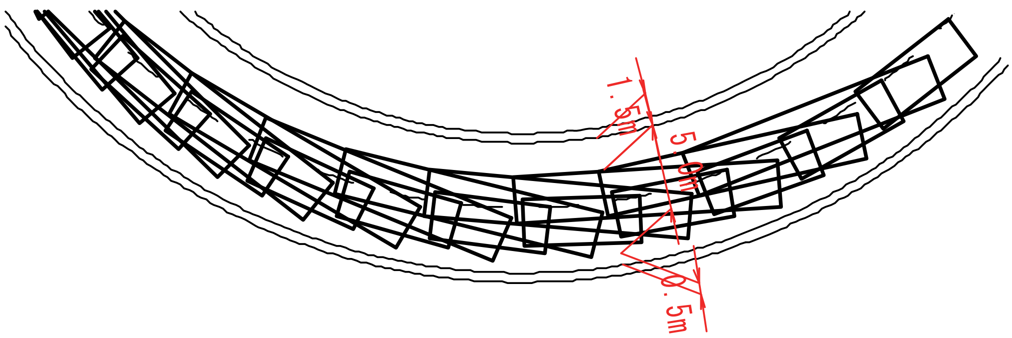
1-lane is required on both ramps.

Chirle IC

1-lane is required on all ramps.

From the above, the required number of ramps are 1-lane or 2-lane. However, one lane ramps shall be wide enough for a vehicle to get by a disabled vehicle parked on the side of the road.

In the case of a small curve radius, the required width for a semi-trailer will be approximately 6.0m (=5m +0.5m on both sides to give some room). This width is not so different from the 2-lane width of 7.0m.



Source: JICA Study Team

Figure 6.4.7 Traveling Locus of Semitrailer (SH54IC)

In addition, the ROW has been secured in consideration of 2-lane ramps in the previous study. Therefore, the numbers of traffic lanes on ramps are decided as follows.

Table 6.4.3 Number of Traffic Lanes on Ramps

Ramp	Lane Number in 2012	Required Lane Number in 2042	Applied Lane Number	Remarks
Sewri IC, all ramps	2	1 2 for C2	2	Except for connection ramp to western freeway
Shivaji Nagar IC	2	1	2	
On-and-off ramps connecting to the main alignment and Navi-Mumbai airport	2	2	2	
Other ramps		1		
SH54IC, all ramps	2	2	2	
Chirle IC, all ramps	3	1	2	

Source: JICA Study Team

6.4.7 Study on the Number of Toll Booths on Interchange Ramps

Toll booths are provided on Shivaji Nagr IC. The traffic volume passing Shivaji Nagar IC turned out to be more than in the previous study. The reason is mentioned in section 4.3.

In this section, the number of toll booths at Shivaji Nagar IC was examined based on the forecast traffic volume in 2042.

As a result, 6 toll booths will be required for the ramps connecting the main alignment and Navi-Munbai airport in 2042. Other ramps require 3 toll booths.

Table 6.4.4 Required Number of Toll Booths at Shivaji Nagar IC (2042)

Ramp (direction)	Required Toll Booths
Navi-Mumbai Airport ⇒ Swri	6
JNPT Port ⇒ Sewri	3
Sewri ⇒ Navi-Mumbai Airport	6
Sewri ⇒ JNPT Port	3
Navi-Mumbai Airport ⇒ Chirle	3
Chirle ⇒ Navi-Mumbai Airport	3

Source: JICA Study Team

On the other hand, the ROW of Shivaji Nagar IC has already been secured and a maximum of 4 toll booths can be provided on the ramps connecting the main alignment and Navi-Mumbai airport within the current ROW. In the case of 4 toll booths, they will be utilized without any congestion until 2032. However, after 2032, it is proposed to do away with the toll booths on ramps and establish new large toll booths on the main alignment (around

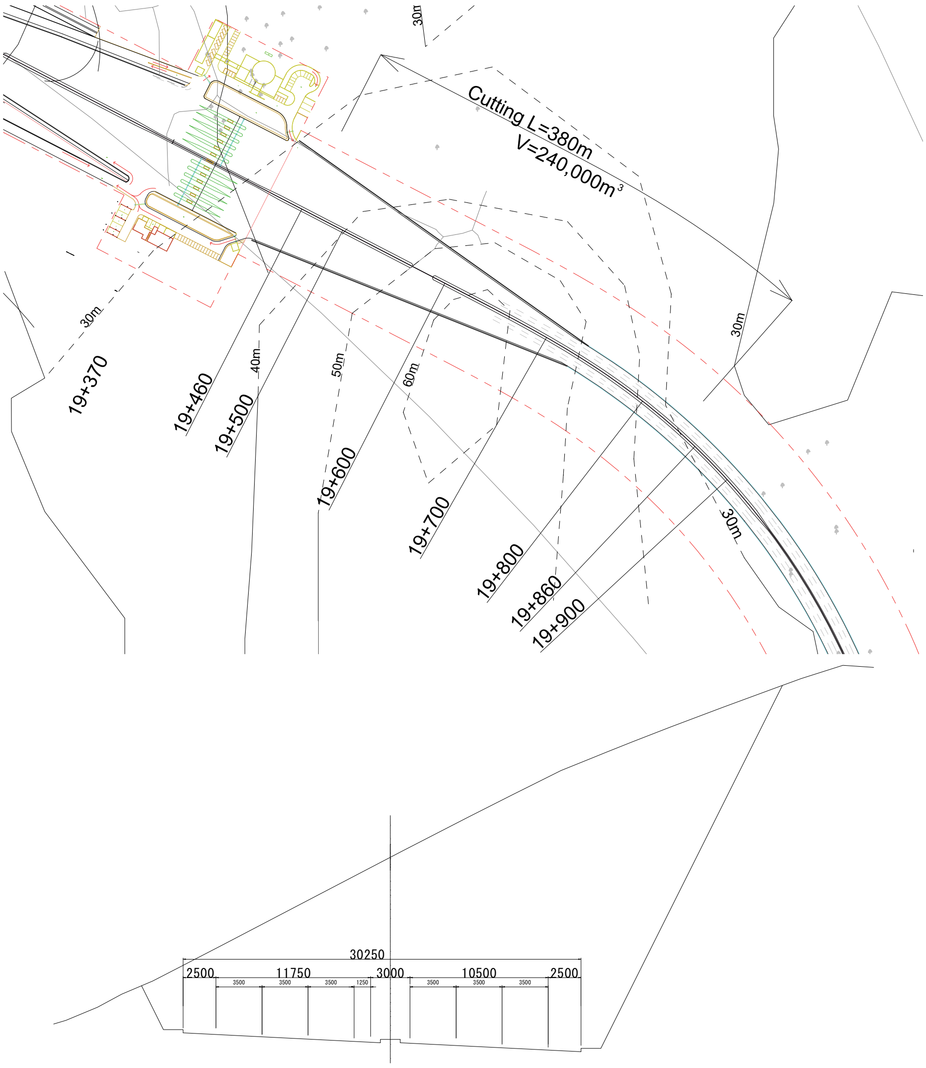
Ch.17+000). Besides, it is recommended that necessary environmental clearances shall be obtained before establishment of the new toll booths.

For sections where the lanes are broadened, such as an acceleration or deceleration section of an interchange and a toll gate, the extra space is designed to be the alternative to an emergency platform for effective utilization of the space.

6.4.8 Design of Cut Section

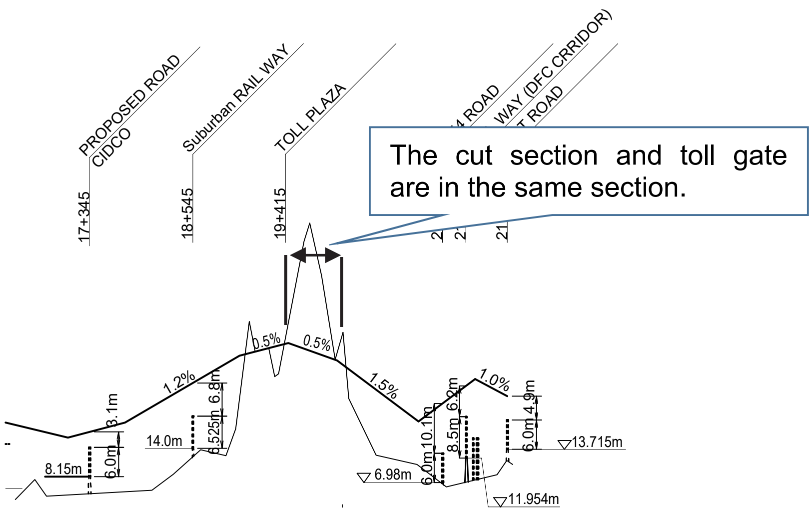
There is a large cut section 25m in height in the Navi-Numbai side. The cut section was studied in the previous study. Blasting shall be needed for the excavation since there is basalt rock on the Navi-Munbai side according to the geological report. Accordingly, the cut slope can be 1:0.5. Before beginning the excavation, it is necessary to reconsider the cut slope and width of the berm based on a geometric survey in the mountainous section.

In the cut section, it is a method to change vertical alignment for reducing the volume of the earth moving. However, since a Toll Gate is planed in this area, it is not an option to change the vertical alignment here.



Source: JICA Study Team

Figure 6.4.8 Typical Cross Section of Cut



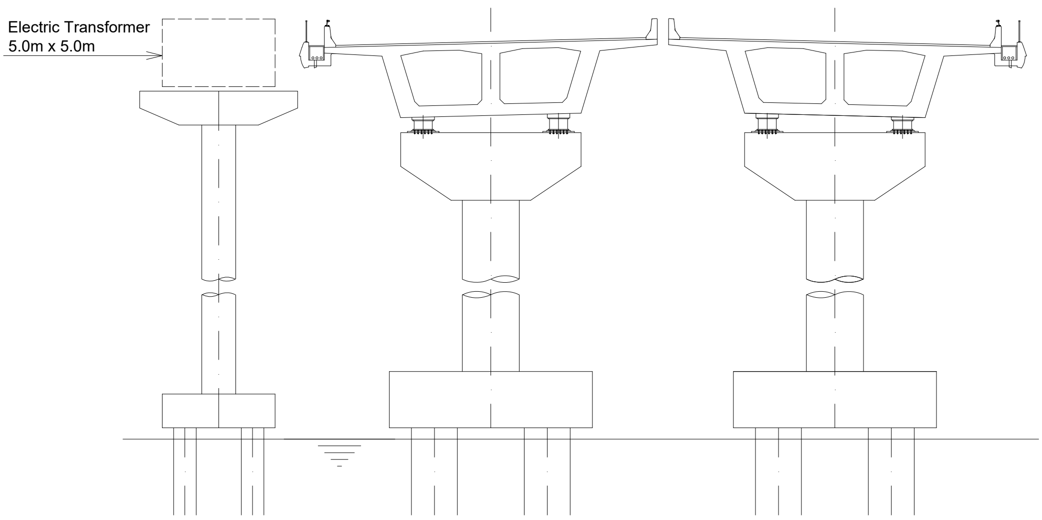
Source: JICA Study Team

Figure 6.4.9 Toll Gate and Cut Section

6.4.9 Platform for Electric Transformer and Emergency Rescue Station

The support structure for the platform for the electric transformers and substations shall be provided separately apart from the bridge piers. From discussions with Bombay Electric Supply & Transport (BEST) authorities, the electric transformers and substations are needed to supply the electricity along MTHL. BEST requested construction of platforms of 5.0m x 5.0m size at every 3km intervals along the bridge on both sides for placing electric transformers and substations of adequate capacity. Image of the platform is shown in Figure 6.4.10.

Emergency rescue stations are installed along MTHL alignment on both sides of the inbound and outbound lanes. The emergency rescue station structure is a single span with dimensions of 50m length and 7m width and will be installed within the median open area of the general section of the MTHL, i.e. PC Box Girder Bridge section.



Source: JICA Study Team

Figure 6.4.10 Platform for Electric Transformer on Pier

6.4.10 Pavement Design

(1) General Requirements

The pavement must be designed to accept the required traffic demand without major structural distress. The required performance of the pavement is as follows:

- Make driving comfortable
- Improve the comfortable and safe feeling for the road user by keeping the road surface flat and having moderate sliding resistance
- Create a beautiful road landscape by using the pavement material suitable for the neighbouring environment.

In addition, the main role for using asphalt materials and asphalt layers on the bridges is to protect the bridge system from some possible defects and to increase their durability.

(2) Layers on the Bridge Deck

Pavement on the bridge shall meet many requirements as described below:

- Resistance to permanent deformation
- Skid resistance
- Rigidity
- Evenness
- Aging resistance, etc.

It also must protect the bridge structure under the heavy load of traffic and weather conditions and is also required to absorb traffic load and transfer them to the supporting bridge structures.

As mentioned above, there are different requirements for the pavement structure on a bridge. Those functions cannot be fulfilled by one pavement material. Several layers are required for the pavement in order to satisfy the different requirements.

In general, the asphalt pavement on the bridge can be divided into four different layers: sealing/bonding layer (primer), waterproofing layer, protecting layer and surface layer. The waterproofing layer and the protecting layer are often called waterproofing systems.

The sealing layer can be made from various materials, including bituminous materials.

1) Sealing/Bonding Layer (Primer)

Asphalt layers cannot be bonded directly on a concrete or steel slab. Therefore, an intermediate sealing layer is necessary to establish a good bond to the waterproof layer.

Functions of the bonding layer on a steel bridge are:

- Assuring strong adhesion to the steel deck and the waterproofing layer
- Giving reliable protection against corrosion
- Being resistant to fatigue
- Being resistant to shear forces

The bridge deck surface has to be prepared properly to be clean, dry, sound, and free of all bond-inhibiting substances.

2) Waterproofing System

A waterproofing system consists of a waterproofing layer and protective layer.

(a) Waterproofing layer

The durability of bridges greatly depends on the effectiveness of the bridge deck waterproofing system and expansion joints.

The main function requirements for the waterproofing are:

- Tightness under all conditions
- Adhesion between the bridge deck and the bituminous layer
- Mechanical resistance (loads from traffic and thermal action)
- Compatibility with the bituminous mixture
- Resistance to high temperatures during the application of the hot asphalt mixture

The waterproofing products can be divided two main categories:

Sheet Type

This consists of preformed sheets mainly based on bituminous polymeric and elastomeric materials. They are bonded to the bridge deck using bitumen adhesive.

Liquid (Spray) Type

This type is divided into the following categories viz. acrylics, Methyl methacrylate polymer, polyurethanes and bituminous base materials.

In this project it is recommended to apply a liquid type in consideration of workability and experience in India. The liquid type spray to be recommended /specified shall be IRC/ISO/BBA or equivalent accredited. The bridge deck water proofing system manufacturer shall have a minimum 20 years international track record.

(b) Protective layer

This layer serves as a second waterproofing layer and has to protect against corrosion and to make a flexible transfer of load from the surface layer to the deck.

Recently, other than mastic asphalt, the Stone Mastic Asphalt (SMA) which added some fibre reinforcement material is applied.

The functions, such as flow property resistance, abrasion resistance, sliding resistance, and the reflection crack suppressant effect are improved by applying this SMA, and the quality and the durability are also improved.

(c) Surface / Asphalt Layer

High skid resistance, flat surface and low noise are required from a surface layer for a safe and comfortable drive. To ensure the durability of the required characteristics of the surface layer, the surface layer needs to have the following:

- sufficient resistance against deterioration
- resistance against oil, water and minerals
- less susceptibility to weather conditions
- protection of the bridge deck and the waterproofing layer
- high stability
- resistance to fatigue
- resistant to permanent deformation
- Possession of the function of load dispersion

The surface layer is made of asphalt. Generally asphalt mixture types used on the bridge are Normal Dense Grade Asphalt (NDGA), Mastic Asphalt (MA) and Stone mastic Asphalt (SMA).

(3) Asphalt Layers

1) Asphalt Layers on Concrete Bridge Deck

Concrete bridge decks are the most common and they are also susceptible to cracking under live loading and shrinkage. The estimated life of a concrete bridge is 100 years. One condition to ensure this long lifetime is waterproofing of the deck together with a high quality asphalt pavement.

The main function of asphalt pavement is waterproofing under all conditions, and it has to maintain mechanical stability/strength for traffic loads.

The asphalt layers normally consist of a protective layer and a surface layer. As mentioned above, MA and SMA are normally applied as the protective layer in consideration of the quality and high durability.

The surface layer should be a hard grade or polymer-modified bitumen.

Table 6.4.5 shows the comparison of the asphalt layers on a concrete bridge deck.

MTHL is the prime route. Temperature becomes very high in summer and traffic volume will be increased in the future.

Therefore, SMA with polymer-modified bitumen, which is superior in flow property resistance, waterproof resistance and durability, is applied to the protecting layer.

For the surface layer, NDGA is recommended in consideration of workability, maintenance and cost.

The pavement thickness on the bridge deck is 80mm based on the past experience of international projects.

Table 6.4.5 Asphalt Layers on Concrete Bridge Deck

Asphalt Layer	Case -1	Case-2	Case-3
Protective layer	MA (40mm)	SMA(40mm)	SMA(40mm)
Surface layer	SMA (40mm)	SMA (40mm)	NDGA (40mm)
Total Thickness	80mm	80mm	80mm
Features	- MA has high durability and flexibility. But it requires special asphalt, plant and machine.	- SMA is the improved asphalt with natural fibre mixed in and it is reinforced. - It has high flow resistance and high waterproofing properties. - Conventional plant and method can be used.	- Applying SMA to the protecting layer preserves functionality. - Conventional plant and method can be used.
Flow property resistance	A	A	B Protective layer (SMA) has high resistance
Against deflection	A+	A	B Not required on the concrete bridge deck
Adhesive property	A+	A	B
Waterproof property	A+	A+	B Protective layer (SMA) has high resistance
Workability	B (Needs special plant and machinery)	A	A
Construction period	B	A	A
Durability	A	A	A+ High durability on the concrete bridge deck
Initial Cost	C	A	A
LCC	A	A	A+ High durability on the concrete bridge deck
Maintenance	C	A	A
Evaluation	-	-	**Recommended**

Legend: A+: Superior/Very good, A: Good, B: Moderate, C: Inferior/Poor
Source: JICA Study Team

2) Asphalt Layers on Steel Bridge Deck

There are large deformations in the steel deck so that fatigue of the asphalt layer is more important for steel bridges than for concrete bridges. According to the table below, the pavement that is superior in deformation resistance (against deflection) is Case-1 and 3.

However, Case-2 is recommended for a steel bridge deck in MTHL in consideration of workability, maintenance, initial cost, and so on.

Table 6.4.6 Asphalt Layers on Steel Bridge Deck

Asphalt Layer	Case -1	Case-2	Case-3
Protective layer	MA (40mm) (Guss Asphalt)	SMA with Type II (40mm)	SMA with Type III (40mm)
Surface layer	MA (40mm) (Guss Asphalt)	SMA with Type II (40mm)	SMA with Type II (40mm)
Total Thickness	80mm	80mm	80mm
Features	- MA has high durability and flexibility. But requires special asphalt, plant and machinery. - It has high deformability.	- SMA is improved asphalt with natural fibre material mixed in for reinforcement. - It has high flow resistance and waterproofing properties. - Conventional plant and method can be used.	- SMA with Type III applied to the protective layer has high performance against deflection. - Conventional plant and method can be used. However, the Type III material has to be imported.
Flow property resistance	A	A	A
Against deflection	A+	A	A+
Adhesive property	A+	A	B
Waterproof property	A+	A	A+
Workability	C (Needs special plant and machinery)	A	A
Construction period	B	A	A
Durability	A+	A	A
Initial Cost	C	A	B
LCC	A	A	A
Maintenance	C	A	B
Evaluation	-	**Recommended**	-

Legend: A+: Superior/Very good, A: Good, B: Moderate, C: Inferior/Poor

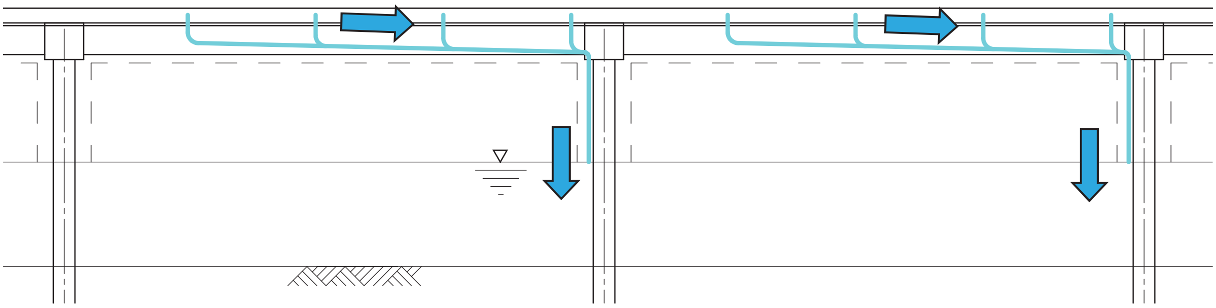
Note: Type II: polymer-modified bitumen type II, Type III: polymer-modified bitumen type II

Source: JICA Study Team

6.4.11 Drainage Design

The surface drainage on the marine section can be directly discharged into the bay. However, in the mud flat section, the surface run-off shall be collected and discharged in a manner that prevents erosion of the mud flat.

An image of the drainage flow is shown in the figure below.

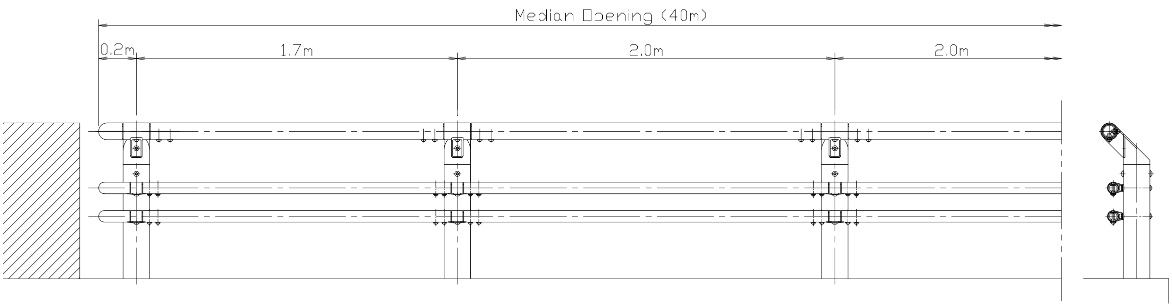


Source: JICA Study Team

Figure 6.4.11 Drainage Flow in Mud Flat Area

6.4.12 Median Opening for Emergency Exit

Median openings shall be provided for traffic operation during maintenance and repair works as well as for emergency vehicles attending serious accidents on the carriageway. The median openings shall be installed at 2km intervals according to the Japanese expressway design standards.



Source: JICA Study Team

Figure 6.4.12 Median Opening for Emergency Exit

6.4.13 Noise Barrier

The noise barriers shall be installed in the tidal area on the Mumbai side and Navi Mumbai side to protect the lesser flamingo from the noise of the traffic.

Table 6.4.7 Noise Barrier

Chainage	Length	Height
CH. 0+500 to 4+000 (North side)	3,500m	3m
CH. 0+500 to 5+500 (South side)	5,000m	3m
CH. 16+980 to 17+580 (Both side)	600m	3m

Source: JICA Study Team

6.4.14 View Barrier

The view barrier shall be installed to hide the Bhabha Atomic Research Centre. It is to be installed along the northern side only of the main carriageway.

Table 6.4.8 View Barrier

Chainage	Length	Height
CH. 4+000 to 10+000 (North side)	6,000m	3m

Source: JICA Study Team

6.4.15 Safety Fence

Safety fences shall be installed across the roads, railways and shipping channels to protect the road users, railways and ships from falling objects.

Table 6.4.9 Safety Fence

Chainage	Length	Height	Facilities to be Protected
CH. 5+500 to 6+078 (South Side)	578 m	3m	Pipeline, conveyer, etc.
CH. 8+720 to 9+080 (South Side)	360m	3m	Thane Coal Berth
CH. 13+138 to 13+510 (Both Side)	372m	3m	Panvel Navigation Channel
CH. 16+840 to 16+880 (Both Side)	484 m	3m	Road
CH. 18+087 to 18+127 (Both Side)	40 m	3m	Road (Planned)
CH. 18+187 to 18+217 (Both Side)	30 m	3m	Road
CH. 18+317 to 18+357 (Both Side)	40 m	3m	Road (Planned)
CH. 18+424 to 18+492 (Both Side)	68 m	3m	Suburban Railway/Road
CH. 18+574 to 18+644 (Both Side)	70 m	3m	Road (Planned)
CH. 18+884 to 18+929 (Both Side)	45 m	3m	Road (Planned)
CH. 20+225 to 20+260 (Both Side)	35 m	3m	Road
CH. 21+009 to 21+079 (Both Side)	70 m	3m	SH54
CH. 21+228 to 21+423 (Both Side)	195 m	3m	Railway
CH. 21+659 to 21+729 (Both Side)	70 m	3m	NH4B

Source: JICA Study Team

6.5 Preliminary Design for Bridge

6.5.1 Introduction

The MTHL structure comprises an elevated sea portion and mostly elevated land portion with various bridge types and spans.

Whereas the Sewri IC consists of a grade-separated interchange, three ICs at the Navi Mumbai side consist of grade separators and approach sections at grade.

In the marine section of MTHL, a PC box girder with a basic span length of 50m, which is typically applied in India since it is easy to construct, offers easier maintenance and is more economical, is therefore recommended in the Final FS 2012. It can be judged that the selection of this type is appropriate from the viewpoint of structural attributes. The standard continuous span is six continuous spans of 50m in order to reduce the bending moment of the structure and eliminate the need for bearings and expansion joints.

In the land portion, a PC box girder type with basic span length of 30m is recommended in the study in consideration of constructability, cost and construction period. This type is also commonly applied in India and hence is easy to construct. Moreover, the number of expansion joints is reduced by connecting deck ends, hence maintenance requirements are reduced and driving is smoother.

As for the locations in which a long span bridge (150-180m) is required to cross significant obstacles such as channels, pipelines and creeks, the comparison of the optimum bridge type is carried out in this chapter. The steel box girder bridge with steel deck is selected because the construction period can be greatly shortened by using the large block erection method.

6.5.2 Improvement of Main Bridge Plan

(1) Span Arrangement

1) General Section (Free of Obstacles)

The basic span length of 50m in the marine area is determined considering fishing boats and vessels for seabed dredging. There is a fishing port nearby the MTHL and the fishing boats which go in and out of the port for fishing activities shall cross under the MTHL. Furthermore, sand from rivers easily accumulates in the Mumbai bay necessitating periodic dredging of the Mumbai bay sea bed.

In the mudflat area, span of more than 50 m should be applied from envriomental requirements . The above was indicated in both the Final Feasibility Report, 2012 and the Advisory Technical Committee.

The span length over the land areas is planned as 30m basically. The bridge with a span length of 30m gives satisfactory results in India, and is an economical type.

2) Special Section over Marine Areas

The span arrangement was determined based on the utility survey in section 5.4 and the determined span length is shown in Table 6.5.1.

Table 6.5.1 Crossing Utilities and Span Arrangement

Obstacles	Horizontal clearance	Chainage	Span arrangement (m)
Tata Intake and Discharge Channels	94m	No. 3+395～No. 3+715	85+150+85=320m
Tata Coal Berth Channel	2x94m	No. 4+625～No. 6+078	90+2@150+2@100+93=683m 120+180+120+140+120+90=770m
Pipelines	-		
Coal Conveyor	5m		
Cooling Water	94m		
Pir Pau Jetty	-		
Thane Creek	2x94m	No. 8+620～No. 9+180	100+2@180+100=560m
ONGC pipelines BPCL pipelines	-	No. 11+880～No. 13+610	(Mumbai to Navi Mumbai) 84+2@130+180+115=639m 74+4@95+65=519m 112+2@180+100=572m (Navi Mumbai to Mumbai) 98+140+150+180+90=658m 55+4@95+65=500m 100+2@180+112=572m
Panvel Creek	2x100m		

Source: JICA Study Team

3) Mangrove Section (Navi Mumbai side)

There is a mangrove area that begins near the sea shore and extends about 2km along the MTHL on the Navi Mumbai side . The mangrove section is divided between the shore area and land area at the Shivaji Nagar IC. The span lengths are 50m in the mangrove section as was recommended in the Feasibility Study Report, 2012. Since the flow of sea water will be blocked at the Shavaji Nagar IC after completion of the planned coastal road by CIDCO near the IC, the 30m span can be generally applied from Shivaji Nagar IC to Chirle IC in consideration of construction cost and construction period.

Source: JICA Study Team

Figure 6.5.1 Mangrove Section (Navi Mumbai Side)

Reduction of the adverse impacts on the mangrove in the shore section has also been studied in this study and a span length of 80m is proposed. However, this proposal was not adopted due to the high construction cost.

4) Railway Crossing Section

Regarding the railway crossing, consultations were held between MMRDA and Indian Railway. Through the consultations, a bridge type, pier location and shape were concluded. Determined span length at each railway crossing is shown in Table 6.5.2.

Table 6.5.2 Crossing Railways and Span Length

Crossing railways	Horizontal clearance	Chainage	Span length (m)
Suburban railway	70m	No. 18+421.5～No. 18+491.5	70m
Railways (DFCC corridor, Panvel-Uran, JNPT railway)	195m	No. 21+232～No. 21+427	3@65=195m

Source: JICA Study Team

Source: JICA Study Team

Figure 6.5.2 Crossing Railway Section

5) Crossing Road Section

The span length was studied with reference to the Utility, Facility and Navigation Survey (shown in section 5.4) and was decided considering the horizontal clearance for the crossing roads. The existing and planned crossing roads were identified in consultation with CIDCO. Determined span lengths are shown in Table 6.5.3.

Table 6.5.3 Crossing Road and Span Length

Crossing roads	Horizontal clearance	Chainage	Span length (m)
Existing Road	About 6m	No. 16+840～No. 16+880	40m
CIDCO Coastal Road (Planned)	About 27m	(Mumbai to Navi Mumbai) No. 17+320～No. 17+471 (Navi Mumbai to Mumbai) No. 17+341～No. 17+482	(Mumbai to Navi Mumbai) 45+49+57=151m (Navi Mumbai to Mumbai) 57+34+50=141m
Planned Road	About 33m	No. 18+087～No. 18+127	40m
Existing Road	About 7m	No. 18+187～No. 18+217	30m
Planned Road	About 24m	No. 18+317～No. 18+357	40m
Existing Road	About 6m	No. 18+421.5～No. 18+491.5	70m
Existing Road	About 4m	No. 18+421.5～No. 18+491.5	70m
Planned Road	About 30m	(Mumbai to Navi Mumbai) No. 18+574～No. 18+644 (Navi Mumbai to Mumbai) No. 18+554～No. 18+644	(Mumbai to Navi Mumbai) 35+35=70m (Navi Mumbai to Mumbai) 40+50=90m
Planned Road	About 30m	No. 18+884～No. 18+929	45m
Existing Road	About 15m	No. 20+225～No. 20+260	35m
SH54	About 26m	No. 21+012～No. 21+079	67m
Planned Road	About 12m	No. 21+427～No. 21+467	40m
NH4B	About 25m	No. 21+660～No. 21+730	2@35=70m

Source: JICA Study Team

(a) SH54

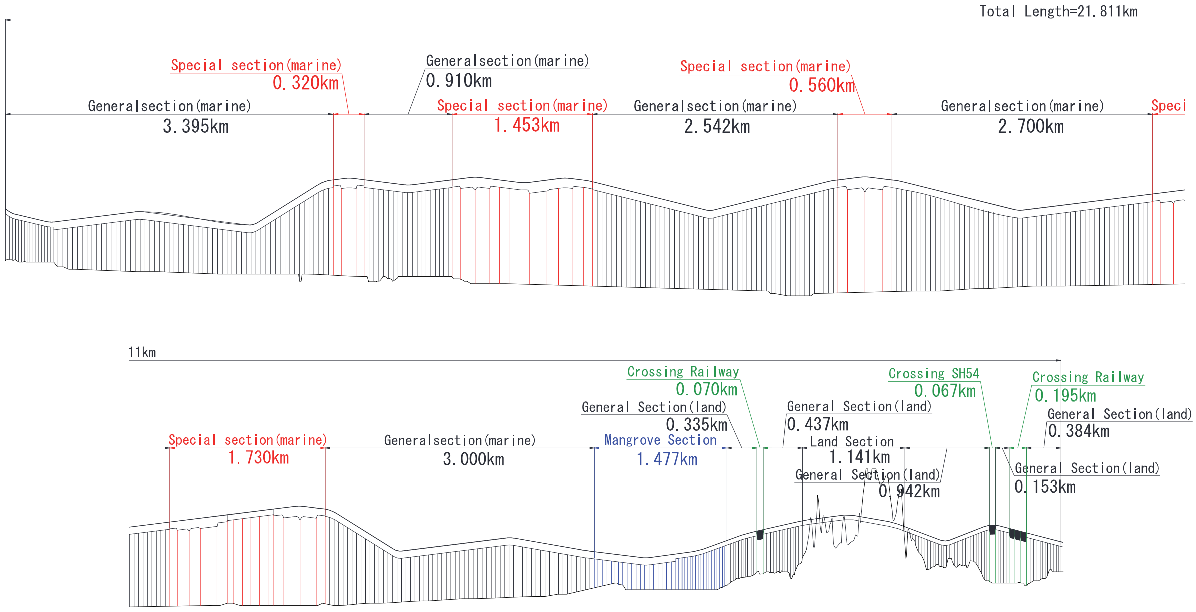
(b) NH4B

Source: JICA Study Team

Figure 6.5.3 Crossing Road Section

6) Conclusion

The span arrangement for the whole of MTHL is shown in Figure 6.5.4 and Table 6.5.4 to Table 6.5.5.



Note: General section (marine section), span arrangement 50m
General section (land section), span arrangement 30m
Special section, span arrangement is shown in Table 6.5.4 and Table 6.5.5
Source: JICA Study Team

Figure 6.5.4 Span Arrangement on Main Bridge

Table 6.5.4 Span Arrangement on Main Bridge-1

Chainage	Category	Span Arrangement
No. 0+495～No. 3+395	General Section (marine area)	2,900m (2@50m, 3@50m, 3x2@50m, 5@50m, 7x6@50m)
No. 3+395～No. 3+715	Special Section (marine area)	320m (85m+150m+85m)
No. 3+715～No. 4+625	General Section (marine area)	910m (2x6@50m, 40m+2@50m+40m, 40m+50m+40m)
No. 4+625～No. 6+078	Special Section (marine area)	1,453m (90m+2@150m+2@100m+93m, 120m+180m+120m+140m+120m+90m)
No. 6+078～No. 8+620	General Section (marine area)	2,542m (6x6@50m, 2x5@50m, 46m+3@50m+46m)
No. 8+620～No. 9+180	Special Section (marine area)	560m (100m+2@180m+100m)
No. 9+180～No. 11+880	General Section (marine area)	2,700m (9x6@50m)
No. 11+880～No. 13+610	Special Section (marine area)	1,730m (Mumbai→Navi Mumbai) (84m+2@130m+180m+115m, 74m+4@95m+65m, 112m+2@180m+100m) (Navi Mumbai→Mumbai) (98m+140m+150m+180m+90m, 55m+4@95m+65m, 100m+2@180m+112m)
No. 13+610～No. 16+610	General Section (marine area)	3,000m (10x6@50m)
No. 16+610～No. 16+840	Mangrove Section	230m (40m+3@50m+40m)
No. 16+840～No. 16+880	Crossing Road Section	40m
(Mumbai→Navi Mumbai) No. 16+880～No. 17+320 (Navi Mumbai→Mumbai) No. 16+880～No. 17+341	Mangrove Section	(Mumbai→Navi Mumbai) 440m (45m+4@50m, 45m+3@50m) (Navi Mumbai→Mumbai) 461m (45m+3@50m+30m+20m, 45m+3@50m, 21m)
(Mumbai→Navi Mumbai) No. 17+320～No. 17+471 (Navi Mumbai→Mumbai) No. 17+341～No. 17+482	Crossing Road Section	(Mumbai→Navi Mumbai) 151m (45m+49m+57m) (Navi Mumbai→Mumbai) 141m (57m+34m+50m)
(Mumbai→Navi Mumbai) No. 17+471～No. 18+087 (Navi Mumbai→Mumbai) No. 17+482～No. 18+087	Mangrove Section	(Mumbai→Navi Mumbai) 616m (46m, 2x30m, 2x20m, 14x30m, 2x25m) (Navi Mumbai→Mumbai) 605m (35m, 2x30m, 2x20m, 14x30m, 2x25m)
No. 18+087～No. 18+127	Crossing Road Section	40m
No. 18+127～No. 18+187	General Section (land area)	60m (2@30m)
No. 18+187～No. 18+217	Crossing Road Section	30m
No. 18+217～No. 18+317	General Section (land area)	100m (2x30m+2x20m)
No. 18+317～No. 18+357	Crossing Road Section	40m
No. 18+357～No. 18+421.5	General Section (land area)	64.5m (30m+34.5m)
No. 18+421.5～No. 18+491.5	Crossing Railway Section	70m

Source: JICA Study Team

Table 6.5.5 Span Arrangement on Main Bridge-2

Chainage	Category	Span Arrangement
(Mumbai→Navi Mumbai) No. 18+491.5～No. 18+574 (Navi Mumbai→Mumbai) No. 18+491.5～No. 18+554	General Section (land area)	(Mumbai→Navi Mumbai) 82.5m (37.5m+45m) (Navi Mumbai→Mumbai) 62.5m (37.5m+25m)
(Mumbai→Navi Mumbai) No. 18+574～No. 18+644 (Navi Mumbai→Mumbai) No. 18+554～No. 18+644	Crossing Road Section	(Mumbai→Navi Mumbai) 70m (2@35m) (Navi Mumbai→Mumbai) 90m (40m+50m)
No. 18+644～No. 18+884	General Section (land area)	240m (8@30m)
No. 18+884～No. 18+929	Crossing Road Section	45m
No. 18+929～No. 20+070	Land Area	
No. 20+070～No. 20+225	General Section (land area)	155m (4x30m+35m)
No. 20+225～No. 20+260	Crossing Road Section	35m
No. 20+260～No. 21+012	General Section (land area)	752m (35m+23x30m+27m)
No. 21+012～No. 21+079	Crossing Road Section	67m
No. 21+079～No. 21+232	General Section (land area)	153m (4x30m+33m)
No. 21+232～No. 21+427	Crossing Railway Section	3@65=195m
No. 21+427～No. 21+467	Crossing Road Section	40m
No. 21+467～No. 21+660	General Section (land area)	193m (38m+2x37m+3x27m)
No. 21+660～No. 21+730	Crossing Road Section	70m (2x35m)
No. 21+730～No. 21+811	General Section (land area)	81m (3x27m)

Source: JICA Study Team

(2) Bridge Type

1) General Sections on Marine and Land

(a) Superstructures

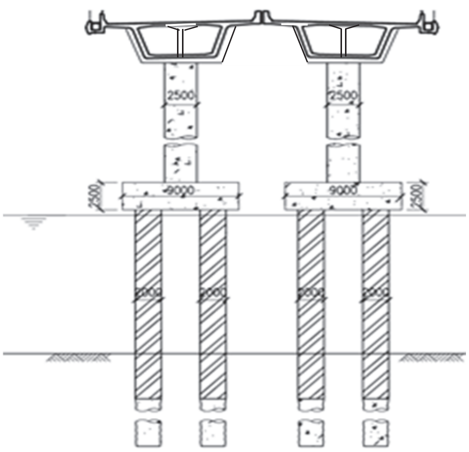
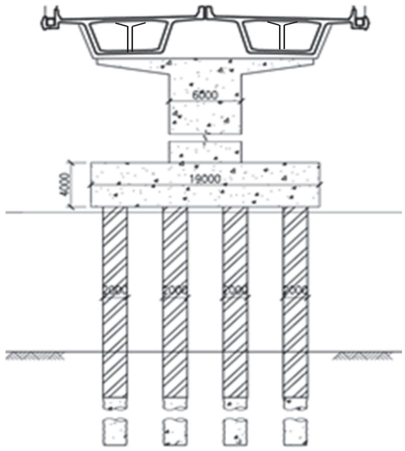
Essentially, the span length is planned as 50m in marine areas and 30m in land areas. Generally, in India a PC box girder type uses spans ranging from 30m to 50m long. PC box girder bridges are generally accepted as more economical than other bridge types in this range in India. In Japan, there exist many PC box girder bridges with span lengths from 30m to 60m for the same reason as in India. Therefore, it is said that PC box girder bridges are optimal. On the other hand, as the maintenance costs are high, more so on the sea, the number of both expansion joints and bearings that require periodic maintenance should be reduced as much as possible. As a result, continuous bridges and rigid frame structures structurally connecting the superstructure with the substructure are selected. In land areas, simple beam bridges are accepted due to their lower cost and shorter construction periods. However, the bridge deck shall be structurally connected after the erection of the girders in order to reduce the number of expansion joints.

(b) Substructures and Foundations

a) Pier Type

A comparison of substructure forms was undertaken between separate single-column piers and integrated hammerhead piers for both directions.

Table 6.5.6 Comparison of Pier Form (Pier)

	Single-column piers	Hammerhead piers
Diagram		
Structural performance	This form has good stability against asymmetric erection forces of the superstructure's main girders during construction, because its columns are immediately below where the girders will load.	Superstructure erection loads and the main girder loads may act asymmetrically on the pier during construction, so there is a risk of generating large rotational moments in the pier heads. Therefore, it is necessary to design girders to ensure their rigidity.
Constructability	This form is good for ease of construction, because precast pier caps could be adopted.	It is easy to construct columns and pier caps compared to other options but requires careful construction of pier beams
Security	One pier can be used if another pier was collapsed	If the pier was collapsed, whole MTHI become closed
Economic efficiency	OK	OK
Conclusion	This form was adopted for its good stability and ease of construction during superstructure erection, and good aesthetics. [Adopted]	This form was rejected for its potential to detrimentally affect main girders during construction. [Rejected]

Source: JICA Study Team

Considering hammerhead piers, there is a possibility that torsional moments will be generated in the main girder during erection, because of one-sided (eccentric) loading of the main girder and launching gantry. Therefore, the overhang of the pier head (crossbeam) has been designed with a haunch to ensure rigidity.

The comparison assessed overall design considering structural integrity, constructability and economy, and determined that single-column piers should be adopted.

In addition, single-column piers were also chosen because of the need to adopt similar substructure forms for viaduct sections both over water and on land.

A number of options were considered for the foundation form, including pile bents, cast-in-situ concrete piles, steel pipe sheet pile foundations and caisson foundations. The span lengths for the viaduct sections over water are 50m and the span lengths for those over land are 30 m, so the span lengths are relatively short and the loads to be supported by piers and foundations are considered small.

Steel pipe sheet pile foundations and caisson foundations are normally applied to medium to large bridge spans, so it would be economically disadvantageous to apply them to this viaduct. In addition, cast-in-situ concrete piles are often employed for small to medium bridge spans, so it is considered reasonable to apply them to this viaduct.

In the analysis, a pile bent type for both pier and foundation was considered. However, application of 2,400mm diameter for pier and foundation, which is the maximum size of pile in Indian practice, cannot satisfy the structural requirements as shown in the structural analysis due to lower bearing capacity.

The pile diameter for cast-in-situ concrete piles was decided by comparing several pile diameters.

2) Obligatory Marine Section

(a) Superstructures

The main span length for bridges in the obligatory marine section becomes 150m and 180m. Bridge types that fit the span range should be selected. The results of this primary selection are shown in Table 6.5.7.

Table 6.5.7 First Selection for Bridge Types

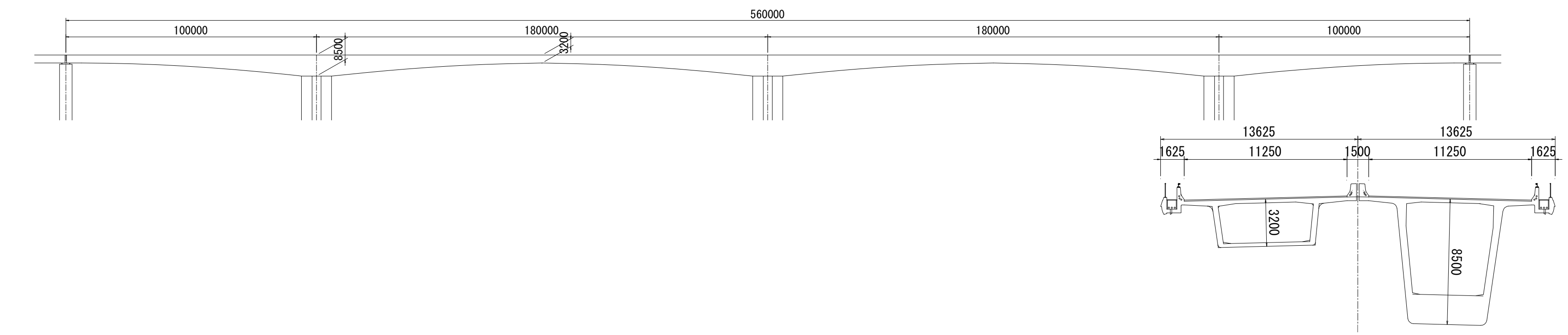
Bridge types	Normal span	Selection reason	Yes or No
PC rigid frame box girder bridges	50m to 140m	Though the span length exceeds the normal span length, this can be selected.	Yes
Steel deck slab box girder bridges	30m to 200m	There are many satisfactory construction results. This can be selected.	Yes
Steel truss bridges	40m to 120m	This can be used but the span length is rather larger than the normal span length and the economical aspect is bad. The aesthetic is not good due to discontinuous parts at the beginning point and ending point of the bridges.	No
Steel arch bridges	50m to 200m	This can be used but there is almost no case of 4-span or 5-span continuous bridges, this should not be adopted. The aesthetic is not good due to discontinuous parts at the ends of the bridges.	No
PC extradosed bridges	100m to 200m	There are many satisfactory construction results. This can be selected.	Yes
PC stay cable bridge	110m to 400m	This can be used but the economical aspect is bad comparing to PC extradosed bridges.	No

Source: JICA Study Team

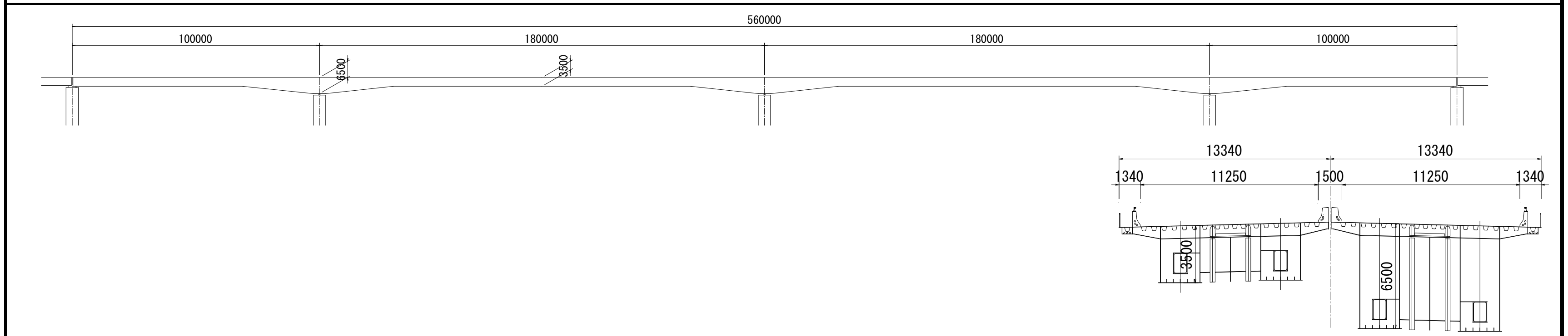
The second comparative review shall be carried out for the three alternatives in the above table. The comparison table is shown in Table 6.5.8 and Table 6.5.9. Here the target bridge is for Thane Creek with a span of 180m.

Table 6.5.8 Second Selection for Bridge Types (1/2)

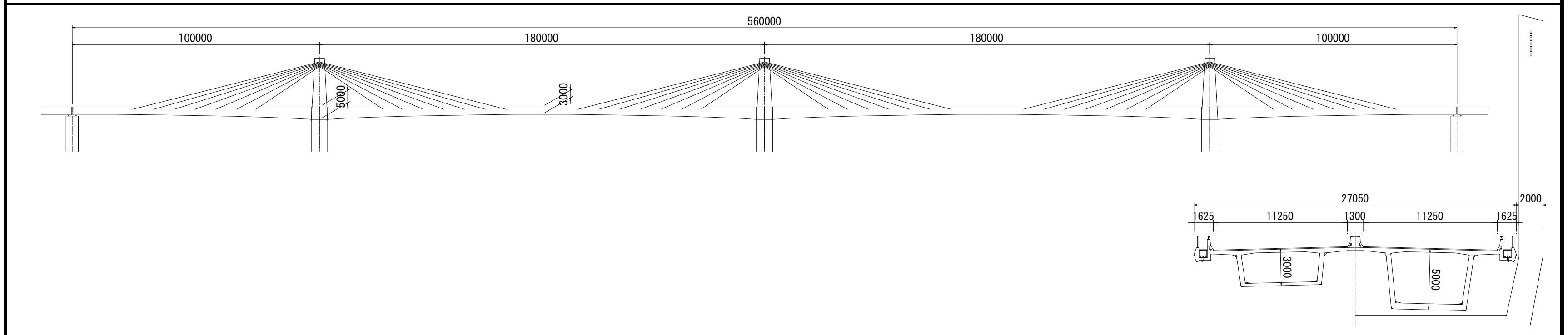
Option-1 Continuous 4 spans PC box girder bridge



Option-2 Continuous 4 spans steel box girder bridge



Option-3 Continuous 4 spans extra-dosed bridge



Source: JICA Study Team

Table 6.5.9 Second Selection for Bridge Types (2/2)

Bridge type **Thane Creek (100+180+180+100)**			Option-1			Option-2			Option-3		
			Continuous 4 spans PC box girder bridge (Original Bridge Type)			Continuous 4 spans steel box girder bridge with steel slab			Continuous 4 spans extra-dosed bridge		
Bridge Image											
Structural performance	Applicability	Record of usage	Many	◎	△	Many	◎	◎	Some	○	○
		Standard span length	Economical span length is 50m to 140m	△		Standard span length is 60m to 200m	◎		Standard span length is 100m to 200m	◎	
	Durability		High	◎		High	◎		High	◎	
	Seismic resistance	Weight of superstructure	Moderate (because of heavy weight)	○		Advantageous (because of light weight)	◎		Moderate (because of heavy weight)	○	
Constructability	Construction method	Difficulty level of construction	Normal (Cantilever method)	○	○	Normal (Large block erection)	○	◎	Difficult (Cantilever after completion of pylon)	△	△
	Quality control	Construction at bridge site or construction at factory	At bridge site	△		At factory	◎		At bridge site	△	
Construction period (for whole MTHL when this bridge type is applied)			**6 years (from previous study)**		△	**Approximately 4.5 years***		◎	**Approximately 6 years**		△
Ease of maintenance	Periodic maintenance	Repainting	Not necessary	◎	◎	Repainting once in 35 years	△	○	Not necessary	◎	○
		Expansion joint	Replacement once in 20 years	○		Replacement once in 20 years	○		Replacement once in 20 years	○	
		Bearing	Replacement once in 40 years	○		Replacement once in 40 years	○		Replacement once in 40 years	○	
	Others								Necessary of high maintenance technology	△	
Aesthetics	Aesthetic view		Matching with the bridge type of general section		○	Matching with the bridge type of general section		○	Monumental appearance		◎
Environmental impact	Marine environmental conservation	Size of foundation	Normal	○	○	Small	◎	◎	Large	△	△
		Size of pier	Normal	○		Thin	◎		Thick	△	
	Environmental impact during construction		Moderate	○		Small (because of short construction period)	◎		Large (because of long construction period)	△	
New Technology (Technical Transfer)			None		△	New type of steel girder Large block erection Thick anti-corrosion coating		◎	None		△
Evaluation			**2**			**1**			**3**		
Construction cost (Ratio)		for Thane Creek Portion	1.00		◎	1.29		○	1.37		△
		for entire section	1.00			1.07			1.13		
Economic Benefit (Economical Internal Return Ratio)			Approx. 14%		◎	Approx. 14%		◎	Approx. 13%		○

Legend: ◎ Good/ Superior, ○ Moderate, △ Poor/Inferior

Source: JICA Study Team

The evaluation method for each factor is indicated as follows.

Structural Performance

There are three aspects of structural performance: Applicability, Durability, and Seismic Resistance.

The applicability of structures is evaluated based on construction records. It is assumed that the higher the frequency of construction of a particular structure, the higher its applicability is. However, even in the case of frequent construction records, if the span length is larger than the normal span length for the structure type, the applicability is not high. Therefore, the applicability shall be evaluated considering construction frequency records based on span lengths.

The durability of structures refers to the life of the structures. The higher the durability is, the longer the structure can be used. The bridge is composed of deck slab, main girders, piers, and piles. As the deck slab receives the direct live load, its durability is different from the main girders, piers and piles. An RC deck slab has a short life comparing to PC deck slab and steel deck slab. It is said generally that the life is about 50 years for RC deck slab and 100 years for PC deck slab and steel deck slab. Therefore, the evaluation shall be concentrated on the deck slab's durability.

The seismic resistance is evaluated based on the weight of structures. The seismic forces and the weight of structures are closely related. The heavier the structure is, the larger the acting seismic force is. Conversely, the lighter the structure is, the smaller the acting seismic force is. In order to reduce the acting seismic forces, the weight of structures should be decreased. Therefore, this item shall be evaluated based on the weight of the structures.

Constructability

There are two aspects of Constructability: Difficulty of Construction and Quality Control.

The difficulty of construction is an important aspect to construct a bridge safely. The higher the difficulty level is, the higher the construction accuracy is required. The difficulty level of construction depends on construction methods. The simple construction method is precast segment and span by span erection method. The high difficulty level of construction method is pointed out such as the cantilever method. Furthermore, the extradosed bridge and the cable stay bridge have higher difficulty level of construction due to the construction of cables in addition to cantilever construction. Therefore, the evaluation point shall consider the construction method.

Quality control of construction is an important aspect in constructing a bridge of high quality. It is easy to control the quality of a structure which is made in a factory. As a result, the structure shall have high quality and be supplied stably to the site. On the other hand, it is difficult to control the quality of a structure which is made in-situ, and in order to stably get a high quality, extremely high quality control is required. Therefore where a structure is made is a key point for evaluation.

Construction Period

Navi Mumbai Airport is currently under construction and is planned to be opened in 2019. The Special Economic Zone is also being constructed simultaneously. After finishing these constructions, traffic between Mumbai and Navi Mumbai is expected to increase drastically. Thus, it is desirable that the Mumbai Trans Harbour Link shall be opened for traffic as soon as possible. Reducing the construction period is important in consideration of economic activities of Mumbai and Navi Mumbai.

Ease of Maintenance

There are two aspects of ease of maintenance: Repainting and Member Replacement.

The repainting is necessary to lengthen the life of bridges. Otherwise, a steel member would be corroded in places where the paint is deteriorated and this demands a huge scale of remedy for the bridges. A thick anticorrosion coat has a life of about 35 years and then it is necessary to repaint. As repainting is costly, a structure which does not require repainting is preferred. Therefore, the evaluation point shall be put on whether repainting is required or not.

Replacement of both members and accessories is necessary to keep bridges safe for users. The members which need to be replaced are expansion joints and bearing supports. The replacement interval is about 20 years for the expansion joints and about 40 years for the bearing supports. As replacing the expansion joints and bearing supports is costly, a structure which does not require expansion joints or bearing supports is preferred. Furthermore, it is necessary to close the existing road when replacing the expansion joints or bearing supports. Therefore, the evaluation point shall be put on whether expansion joints or bearing supports are required or not.

Aesthetics

The MTHL is an important line which connects Navi Mumbai to the centre part of Mumbai. And as it is also a gate to enter Mumbai from the Navi Mumbai Airport, the Project Road will become a new land mark. When a tourist gets off at the Navi Mumbai Airport, one of structures which the tourist will see in his first view is the Project Road and it represents Mumbai growth. Therefore, an evaluation point is allotted for aesthetics.

Environmental impact

The Project Road is planned to cross the Mumbai bay. As the Mumbai bay is the home for various kinds of fishes, flamingos, mangrove etc…, it is important to protect the natural environment. The shorter construction period of structures, the smaller scale of piers and foundations and the less water pollution during construction are expected to mitigate adverse effects to the natural environment. Therefore, the evaluation point shall be put on the construction period and the size of piers or foundations.

New technology application (Technical transfer)

The new technology which is more meaningful than the existing technology should be adopted in the MTHL construction project. As the adopted new technology shall be transferred to Indian counterparts and this contributes to the technical growth of India, the evaluation point shall be put on whether a new technology is adopted or not.

Construction cost

The construction cost including foundations, abutments, piers, and superstructures is shown in Table 6.5.9.

Economic benefit (Economic Internal Return Ratio)

The economic benefit is calculated at the target date when the MTHL is operational for 40 years.

Conclusion

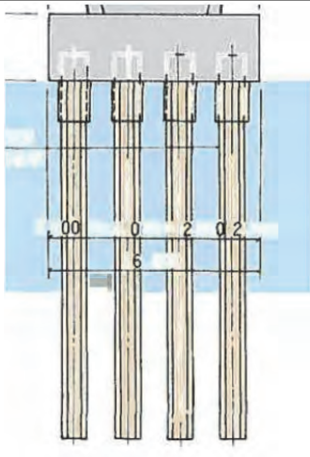
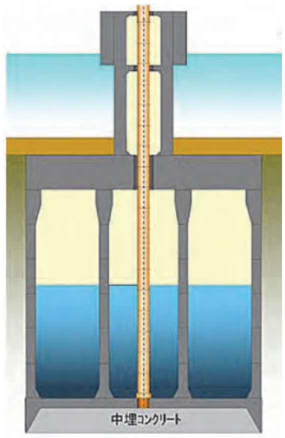
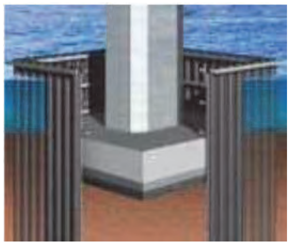
According to results in Table 6.5.8 and Table 6.5.9, the Option-2: steel box girder with steel slab shall be adopted for the superstructure.

(b) Substructures

A number of options were considered for the foundation form, including cast-in-situ concrete piles, steel pipe sheet pile foundations and caisson foundations. Since a steel box girder with steel deck type was selected for the span lengths ranging between 150 m to 180 m in the comparison mentioned above, the superstructure weight can be regarded medium-sized but not large sized.

From the above, a comparison of multiple-pile foundations (cast-in-situ concrete piles), caisson foundations and steel pipe sheet pile foundations was undertaken to determine the form of foundations.

Table 6.5.10 Comparison of Foundation Form for Marine Bridge Sections

	Group pile foundations	Caison foundations	Steel pipe sheet pile foundations
Diagram			
Properties	・ Pile foundations are common practice in India. There are many cases of their application.	・ Caison foundations are fairly common practice in India.	・ There are no cases of this type of foundation being constructed.
	・ Pile foundations have an advantage considering the scale of bridge loads.	・ The bridge loads are not large enough to make caisson foundations a valid choice.	・ The bridge loads are not large enough to make caisson foundations a valid choice.
	・ There are no construction issues.	・ Large-scale equipment is required for construction below depth of 0 m underwater, which is a disadvantage compared to group pile foundations.	・ This method has some issues because this one has no experience in India.
Conclusion	Suitable	Feasible	Not feasible

Source: JICA Study Team

In India, multiple-pile and caisson foundations are common foundation types. The superstructure for bridge sections of the viaduct over water is a steel box girder form (with a maximum span length of 180m), so the loads are not large and there is an advantage to adopting multiple-pile foundations.

A caisson foundation is a suitable foundation type for relatively large loads. However, large construction facilities would be necessary to construct foundations of 10 m or more in depth for the sections that are over water.

The degree of difficulty for constructing this bridge is high because it crosses the sea, so it is believed that adopting Steel pipe sheet pile foundations, which are an uncommon form of construction in India, should be avoided.

For the reasons described above, multiple-pile foundations (cast-in-situ concrete piles) have been adopted for the foundations of the bridges of the viaduct.

In addition, the diameter of cast-in-situ piles will be determined based on the results of performance comparisons.

3) Mangrove Section in Navi Mumbai Side

(a) Superstructures

The environmental factor is an important point to determine the structural type. The PC box girder type with 50m span length, which is the same as for the general marine section, was finally selected in consideration of minimizing the adverse impact on the mangrove forest and constructability in the area.

Although the option spanning 80m with steel box girder was studied as an alternative option to further minimize the adverse impact on the mangrove forest, it was abandoned due to significantly higher cost compared to the selected option.

(b) Substructures

Single-column piers have been adopted for the substructure, similar to the general sections over water. Cast-in-situ concrete piles have been adopted for the foundations, again similar to the general sections over water.

Similar to the sections over water, cast-in-place pile foundations with undersides at +6.00 m above elevation 0.00 C.D. were adopted for the mangrove forest area, because they would have less effect on the forests compared to the excavations needed to have pile caps below ground level.

4) Railway Crossing Section

(a) Superstructures

MMRDA had consulted with the related railway administrators about the railway crossing section before this study and it has already been agreed that steel truss bridges shall be adopted.

(b) Substructures

As mentioned above, foundation type has also been decided in consultation between MMRDA and the related railway administrators. Based on the agreement, bored piles are adopted for the foundation.

5) Road Crossing Section

(a) Superstructures

The span length is 50m which is adopted in this area generally. Therefore, PC box girder with rigid frame type is applied.

(b) Substructures

The substructure of the overpass section consists of single-column piers, based on it needing to be the same structure type as the general land-based sections.

The foundations will be cast-in-situ concrete piles, which are also the same as the general land-based sections.

6.5.3 Improvement of Bridge Plan for Interchange Ramps

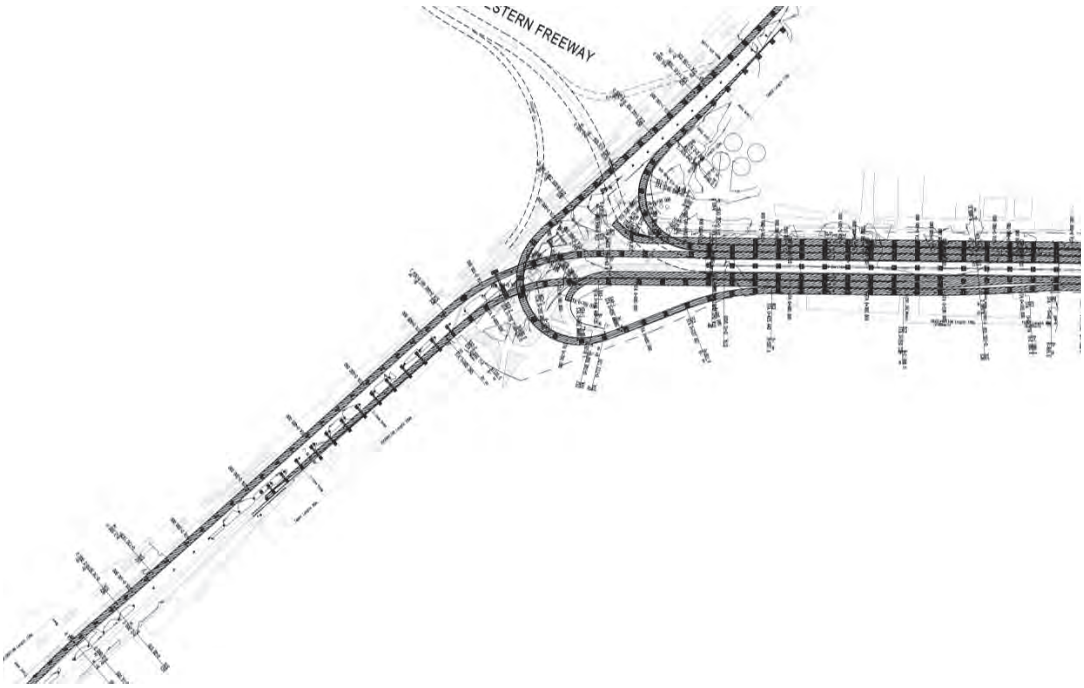
The MTHL includes four interchanges.

- Sewri IC (Mumbai side)
- Shivaji Nagar IC (Navi Mumbai side)
- SH54 IC (Navi Mumbai side)
- Chirle IC (Navi Mumbai side)

(1) Sewri IC

1) Span Arrangement and Superstructure

The Sewri IC is planned with PC box girder having basic span length of 30 m considering economy and construction period. The span length at cross ramps and connecting existing roads is determined considering the clearance of the crossing objects, which ranges from 30 m to 50m. The span arrangement is shown in Figure 6.5.5 and Table 6.5.11.



Source: JICA Study Team

Figure 6.5.5 Span Arrangement at Sewri IC

Table 6.5.11 Span Arrangement of Each Ramp at Sewri IC

Ramp	Pier Number	Chainage	Bridge Type	Span Arrangement
Ramp A	AP1 - MP1	-0+495	PC box	1,698m (26m, 23m, 30m, 7x26m, 25m, 3x35m, 17x26m, 35m, 2x51m, 35m, 2x25m, 2x30m, 60m, 23m, 15x30m, 50m)
Ramp B	BP1 - MP1	-0+495	PC box	1,530m (2x33m, 4x26m, 21m, 2x30m, 3x26m, 31m, 11x26m, 32m, 49m, 23m, 3x35m, 2x30m, 25m, 18x30m, 50m)
Ramp C1	C1P1 - C2P9		PC box	910m (12m, 22m, 11x26m, 30m, 25m, 30m, 23m, 30m, 32m, 50m, 40m, 11x30m)
Ramp C2	C2A1 - MP1	-0+495	PC box	500m (15x30m, 50m)
Ramp E	EP1 - MP1	-0+495	PC box	908m (20m, 2x26m, 32m, 4x26m, 31m, 15m, 25m, 2x30m, 44m, 25m, 15x30m, 50m)
Ramp F	FA1 - MP1	-0+495	PC box	440m (13x30m, 50m)

Source: JICA Study Team

2) Substructures and Foundation

A pile bent type cannot be applied for the ramp because the superstructure of the ramp has a curved alignment with widened sections. The ramp structure will be a basic single-column hammerhead pier. However, ramp A straddle pier is partially applied where it crosses the East Freeway and cast-in-situ pile foundations shall be adopted.

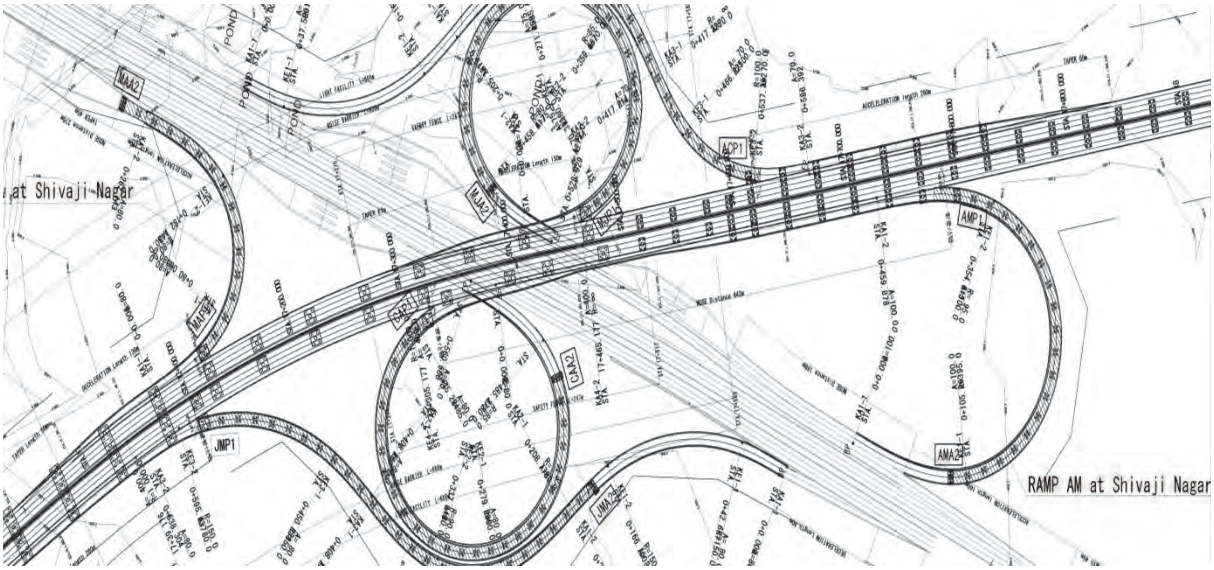
(2) Shivaji Nagar IC

1) Span Arrangement and Superstructure

There are no restrictions for construction of Shivaji Nagar IC. Therefore, the RC hollow slab type, which has many track records of construction in India due to its low cost, is selected. The superstructure can be constructed at the staging with a support beam

2) Substructure and Foundation

The substructure shall consist of single-column hammerhead pier and cast-in-situ pile foundations shall be adopted.



Source: JICA Study Team

Figure 6.5.6 Span Arrangement at Shivaji Nagar IC

Table 6.5.12 Span Arrangement at Shivaji Nagar IC

Ramp	Pier No.	Chainage	Type	Span Arrangement
MA Ramp	MP289 - MAA2	No. 17+125 -	RC hollow slab	225m (15x15m)
AC Ramp	MP302 -ACA2	No. 17+617 -	RC hollow slab	285m (19x15m)
JM Ramp	MP288 - JMA2	No. 17+105 -	RC hollow slab	390m (26x15m)
MJ Ramp	MP296 - MJA2	No. 17+471 -	RC hollow slab	388m (11m, 2x10m, 7x15m, 14m, 5x13m, 12m, 2x13m, 9x15m)
CA Ramp	MP293 - CAA2	No. 17+320 -	RC hollow slab	373m (10m, 12x15m, 6x13m, 7x15m)
AM Ramp	MP308 - AMA2	No. 17+797 -	RC hollow slab	285m (19x15m)

Source: JICA Study Team

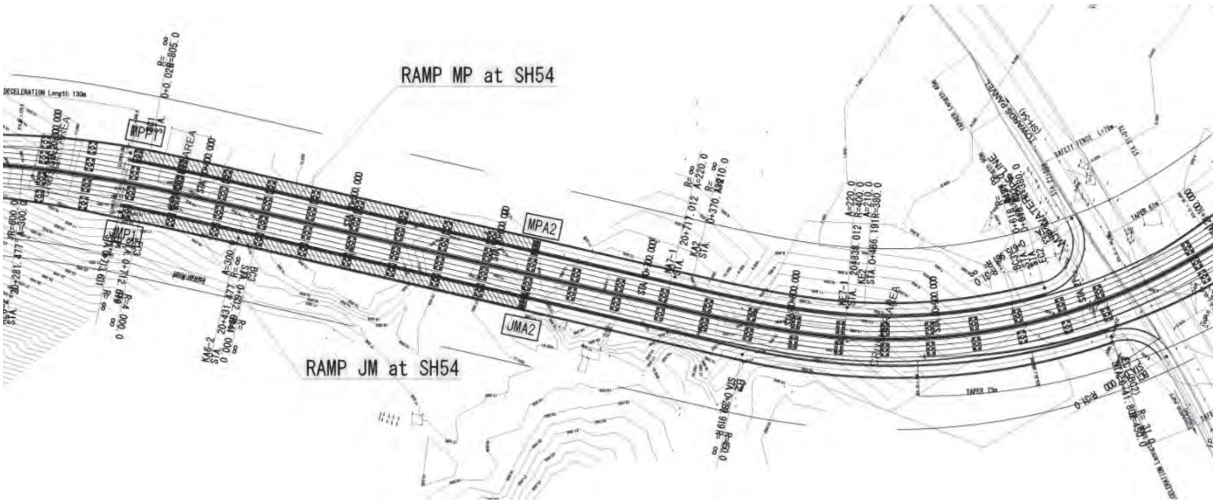
(3) SH54 IC

1) Span Arrangement and Superstructure

A PC box girder type, which is the same as for the main road, shall be adopted because SH54IC runs parallel to the main road.

2) Substructure and Foundation

The substructure shall consist of single-column hammerhead pier and cast-in-situ pile foundations shall be adopted.



Source: JICA Study Team

Figure 6.5.7 Span Arrangement at SH54 IC

Table 6.5.13 Span Arrangement at SH54 IC

Ramp	Pier No.	Chainage	Type	Span Arrangement
MP Ramp	LP9 - MPA2	No. 20+355 -	PC box	270m (9x30m)
JM Ramp	LP9 - JMA2	No. 20+355 -	PC box	270m (9x30m)

Source: JICA Study Team

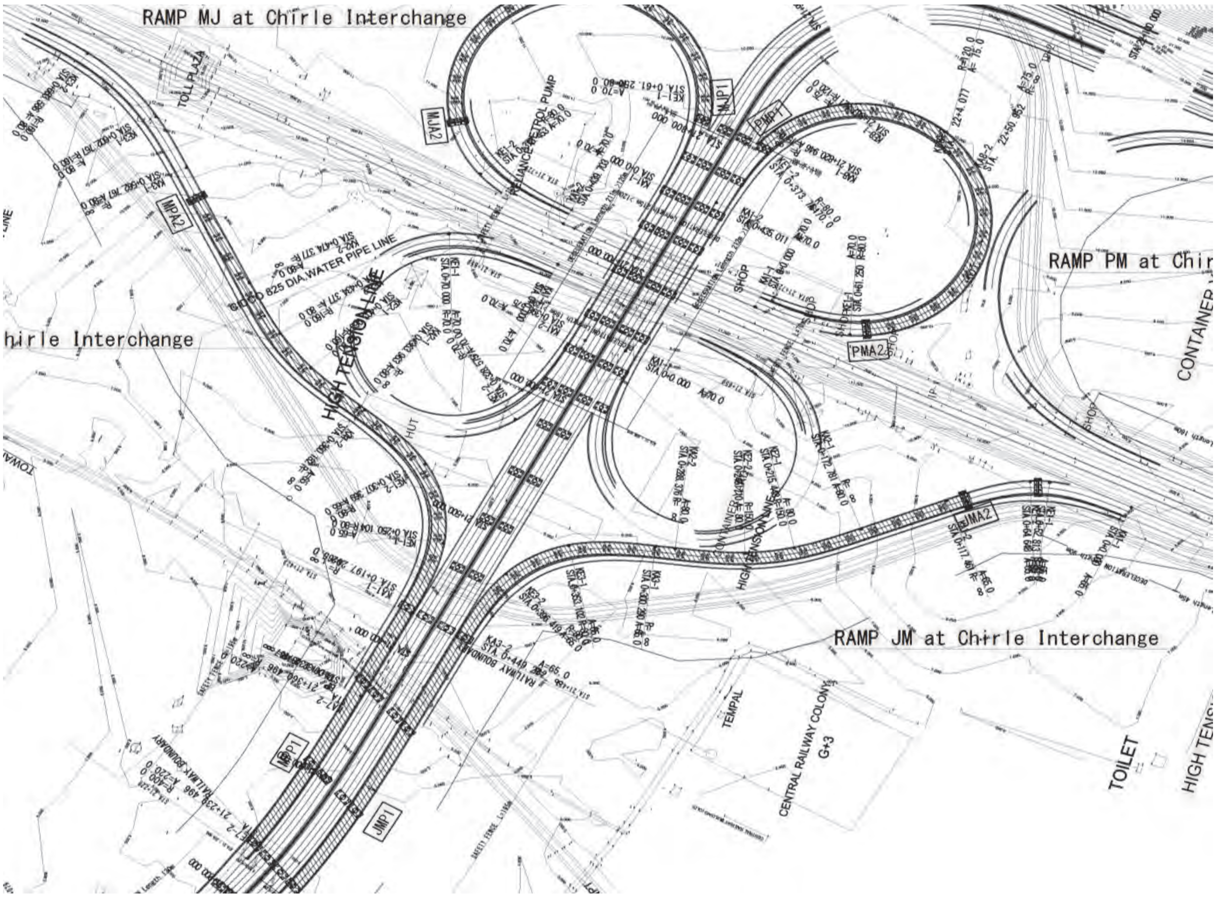
(4) Chirle IC

1) Span Arrangement and Superstructure

There are no restrictions for construction of Chirle IC. Therefore, a RC hollow slab type, which has many track records of construction in India due to its low cost, is selected. This type can be constructed at staging with a support beam. The steel box girder type is adopted for the part across the railway.

2) Substructure and Foundation

The substructure shall consist of single-column hammerhead pier and cast-in-situ pile foundations shall be adopted.



Source: JICA Study Team

Figure 6.5.8 Span Arrangement at Chirle IC

Table 6.5.14 Span Arrangement at Chirle IC

Ramp	Pier No.	Chainage	Type	Extension Ramp (Only Bridge)
MP Ramp	LP37 - MPA2	No. 21+232 -	Steel truss bridge PC box girder bridge RC hollow slab bridge	535m (3x65m, 40m, 20x15m)
JM Ramp	LP37 - JMA2	No. 21+232 -	Steel truss bridge PC box girder bridge RC hollow slab bridge	535m (3x65m, 40m, 20x15m)
MJ Ramp	LP52 - MJA2	No. 21+811 -	RC hollow slab bridge	270m (18x15m)
PM Ramp	LP52 - PMA2	No. 21+811 -	RC hollow slab bridge	300m (20x15m)

Source: JICA Study Team

6.5.4 Consideration to Salt Damage

It is necessary to pay attention to a corrosion issue since a steel box girder was applied to the marine section. This sub-chapter describes (i) examples of the steel bridges over water, (ii) anticorrosion method for steel bridges, (iii) recommended specifications for anticorrosion method for MTHL bridge, and (iv) maintenance method for the steel bridge.

(1) Examples of Steel Bridges over water

1) Long-Life Steel Bridges over water

Generally, it is thought that a steel bridge is much more problematic with corrosion than a concrete bridge over water. However, there are some examples which remained in a sound condition for more than 100 years by carrying out appropriate anti-rust treatment and maintenance. The typical examples of such steel marine bridges are the Force Bridge which was completed in 1890 in Edinburgh, Scotland and the Brooklyn Bridge which was constructed in 1883 in New York City, USA.

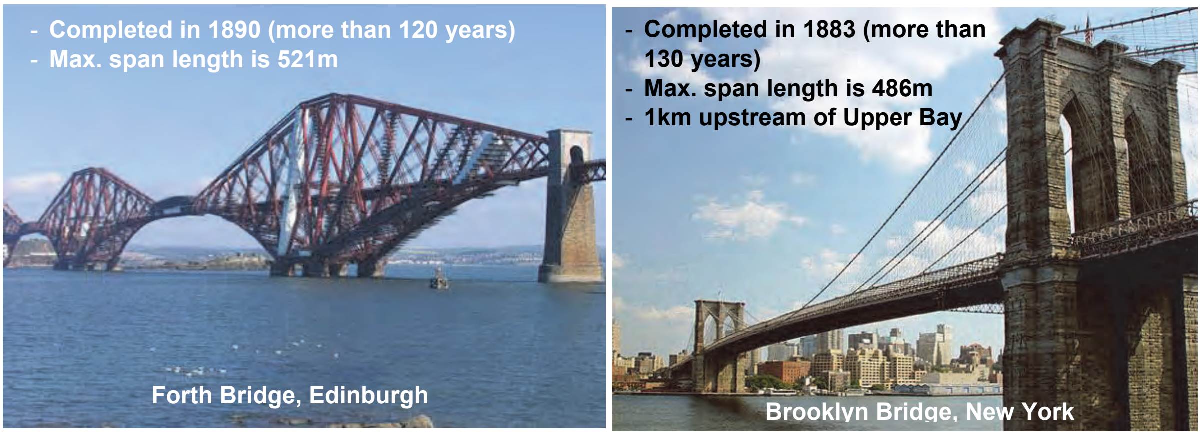


Figure 6.5.9 Examples of the Steel Bridges over the Sea

2) Examples of Marine Steel Bridges in Japan

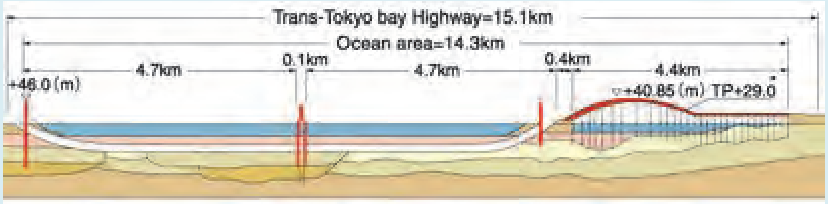
In Japan, there have been a lot of marine steel bridges because of its topographical feature as an island country and the issue of corrosion on the steel bridges has already been overcome with in depth research on this topic. The main reasons that a steel bridge is applied to the marine bridge are as follows.

- Long span length is required for navigation channels and etc.
- Quality control is easy and the quality is stable because of production in a factory.
- Site work (on the sea) can be shortened and is superior in safety.
- Maintenance is easy since corrosion and damage can be observed from outside.
- Partial repair can be done easily.
- Extension of its life is possible by conducing appropriate maintenance

The following are major steel marine bridges in Japan.

Tokyo Bay Aqua-Line

- Shield Tunnel (9.5km) + Steel Box Girder 4.4km
- Completed in 1997
- Large Block Erection by Floating Crane



Steel box girder with steel deck. Maximum span length is 240m. Thick anti-corrosion coating was applied. Steel column at tidal portion was covered by titanium plate and one at underwater portion by electric anticorrosion method.

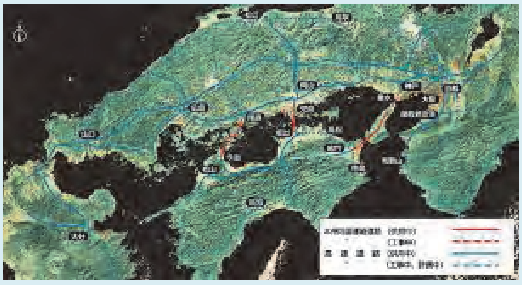


Source: JICA Study Team

Figure 6.5.10 Steel Marine Bridge in Japan (Tokyo Bay Aqua-Line)

Honshu - Shikoku Connecting Bridge

- Completed in 1999 (3 routes)
- 3 route total length: 89+37.3+59.4 = 185.7km
- 3 route total bridge length: 6.5+9.4+9.5 = 25.4km



Akashi Bridge (longest suspension bridge) and Tatara Bridge (2nd longest cable-stayed bridge) are included in Honshu – Shikoku Bridge.

Most bridges are steel with thick anti-corrosion coating. In addition, Cable-coating was also applied to the cable-stayed bridge and suspension bridge. Those bridges are a compilation of Japanese advanced technology and have been kept in a sound condition more than 20 years after completion by conducting appropriate maintenance.



Source: JICA Study Team

Figure 6.5.11 Steel Marine Bridges in Japan (Honshu – Shikoku Bridge)

Iou Island Bridge
- Steel Box Girder (max. span 240m) with thick anti-corrosion coating
- Completed in 2011
- Large Block Erection by Floating Crane




Source: JICA Study Team

Figure 6.5.12 Steel Marine Bridge in Japan (Iou Island Bridge)

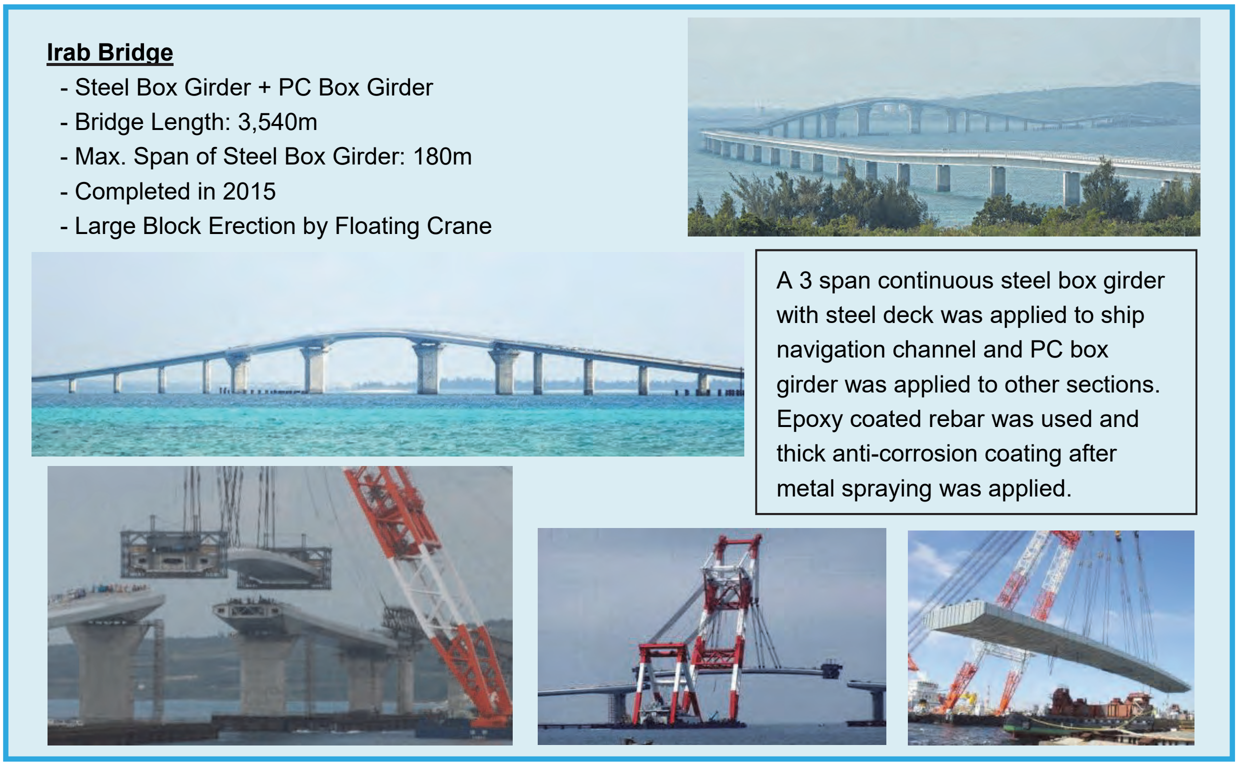
Tokyo Gate Bridge
- Steel Truss + Steel Box Girder
- Completed in 2012
- Large Block Erection by Floating Crane


Main bridge is a 3 span continuous steel truss-box bridge and Approach Bridges are steel box girder with steel deck. Maximum span length is 440m. Truss structure of main bridge was applied in consideration of ship navigation channel with 54m height and aviation limit of Tokyo airport. Steels for Bridge High Performance Structure (SBHS) and thick anti-corrosion coating were applied.



Source: JICA Study Team

Figure 6.5.13 Steel Marine Bridge in Japan (Tokyo Gate Bridge)



Source: JICA Study Team

Figure 6.5.14 Steel Marine Bridge in Japan (Irab Bridge)

(2) Anticorrosion Method for Steel Marine Bridges

A road bridge has to serve its function continuously as a part of the road network for a long term after traffic opening. Hence, it should be avoided to spoil the function or to have an adverse impact on the surroundings even temporarily.

Steel is easily corroded on the sea because salt particles splash in the air and adhere on the surface of the steel which promotes corrosion of the steel. The corrosive environment is undoubtedly severe on the sea.

Therefore, there are some minimum conditions which the anticorrosion method for a steel marine bridge must meet in order to provide the required function of anticorrosion.

- Possessing high reliability as demonstrated by many practical applications
- Maintenance (partial repair and full-scale repair) is possible

The anticorrosion methods for a steel bridge can be classified into four methods namely, coating, application of weathering steel, improvement of the corrosion environment, and electric protection (see Table 6.5.15). Among those, methods that have been applied a lot are coating and application of weathering steel. Improvement of the environment is impossible on the sea and electric protection is usually applied to steel in the water, but is seldom applied on the sea.

Although application of weathering steel can be applicable on land away from the sea, it is difficult to apply it in an environment where stable rust cannot be developed.

A thick anticorrosion coating has seen many applications on marine bridges and has high reliability. In addition, maintenance is relatively easy. Hence, a thick anticorrosion coating is recommended for the steel bridges in MTHL.

Table 6.5.15 Comparison of Anticorrosion Method for Steel Bridges

Method	Coating		Weathering Steel	Hot Dip Galvanizing	Metal Spraying
	Ordinary Coating	Thick Anticorrosion Coating			
Principle of Anti-corrosion	Isolation from external environment by coating	Isolation from external environment by coating and anti-corrosion by zinc rich paint	Development of stable rust	Isolation from external environment by zinc thermal oating	Isolation from external environment by metal sprayed coating
Painting Method	Coating by spray, brush, or roller		Add some alloy elements during fabrication	Soak in zinc tank in factory	Spray with a thermal spray gun
Applicable Place	Land (**not applicable in high salinity area**)	**Marine and Coastal Area**	Low salinity area	Anywhere	
Appearance	Any colour can be painted on the surface		Dark brown	Silver white	Silver white
Cost	Moderate	Slightly High	Slightly High	Very High	Very High
Maintenance	Repainting every 30 years on land	(every 35 years)	No need for repainting	Painting after 25 years (no experience)	Metal spray or painting after 60 years (no experience)
Evaluation	Not applicable	**Applicable and Recommended**	Not applicable	Not recommended	

Source: JICA Study Team based on handbook of Coating and Anticorrosion Handbook, Japan

However, if the bidders propose the metal spraying method which has higher durability than the thick anticorrosion coating, applicability of the metal spraying methods are to be judged using the table below.

Table 6.5.16 Comparison of Metal Spraying Method and Painting Method

	Metal Spraying Method				Painting Method
	1) Al-Mg	2) Aluminium	3) Zinc	4) Zn-Al	5) Thick Anticorrosion Coating (MTHL)
Blasting	ISO Sa3	ISO Sa3	ISO Sa2 1/2	ISO Sa2 1/2	Refer to above table
Material	Alloy of Al-Mg	Aluminium	Zinc	Alloy of Zn-Al	
Spraying	Plasma Spraying	Flame Spraying or Arc Spraying	Flame Spraying or Arc Spraying	Flame Spraying or Arc Spraying	
Thickness	More than 150μm	More than 150μm	More than 100μm	More than 100μm	
Remarks	· The durability is high however the cost is very high. · It is difficult to carry out the metal spraying on large areas at one time because this method needs to spray the metal materials within 4 hours after the blasting. Therefore this method needs time to apply. · The past record is really sparse near marine and coastal areas. · The uneven area cannot be applied. · Depending the surrounding environmental conditions, the sealing treatment, undercoating, intermediate coating and top coating are required on this coating.				The cost is low. It has many past records. It can be applied to uneven areas.

Source: JICA Study Team based on Structure Painting Vol.41 Metal Spraying on Steel Bridges, Japan

(3) Recommended Specifications for Anticorrosion Method for MTHL Bridges

A thick anticorrosion coating is recommended for the steel box girders in MTHL in accordance with the above comparison result.

Steel marine bridges with an anticorrosion coating can be maintained in a sound condition for more than 100 years by conducting the appropriate maintenance. As mentioned previously, the thick anticorrosion coating is applied to most steel marine bridges these days since there is little difference in detail.

This anticorrosion coating satisfies the standards listed below;

- ISO 2810-2004: Paints and varnishes - Natural weathering of coatings - Exposure and assessment
- ISO 9223-1992: Corrosion of metals and alloys - Corrosivity of atmospheres - Classification
- ASTM D1014-02: Standard Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates

The coating includes Primer, Under coating 1, Under coating 2, Intermediate coat, and Top coat and prevention of corrosion is achieved in combination of those. Each role is as follows:

1) Primer

Steel materials on which blast processing was carried out easily generate corrosion. In order to prevent this, the prompt coating after blasting is called a primary primer.

2) Under Coating 1

It has a role to prevent corrosion of steel materials. Inorganic zinc paint is used.

3) Under Coating 2

It has a role to prevent the penetration of corrosive materials such as water or salt. Under coat epoxy resin paint is used.

4) Intermediate Coat

It has a role to bond the under coating with the top coat. Fluororesin paint is applied.

5) Top Coat

There is a function to maintain the lustre and hue for a long time by choosing good weatherproofing resin and pigment.

Table 6.5.17 shows the specifications of the recommended thick anticorrosion coating for steel bridges in MTFL. The equivalent specification that secures long durability the same as the said specification may be applicable if any.

Table 6.5.17 Specification of Recommended Thick Anticorrosion Coating

Outer Surface painting System		Paint Name	Standard Thickness (μm)
Pre-treatment	First base plate conditioning	Preliminary plate blasting	-
	Primer	Inorganic zinc primer	(15)
Factory paint	Secondary base plate conditioning	Assembled member blasting	-
	Under coating 1	Inorganic zinc paint	75
	Mist coating	Under coat epoxy resin paint	-
	Under coating 2	Under coat epoxy resin paint	120
	Intermediate coat	Intermediate fluororesin paint	30
	Top coat	Top coat fluororesin paint	25

Source: JICA Study Team based on handbook of Coating and Anticorrosion Handbook, Japan

(4) Maintenance Method for Steel Bridges

1) Periodic Inspection

Visual inspection shall be carried out twice a year. Especially coating appearance should be checked for things such as rusting, spalling, swelling, discoloration, etc. The observation results shall be recorded including any leaking or stagnant water.

2) Detailed Inspection

Detailed inspection shall be carried out once in five years and as needed by visual inspection, using mobile units and equipment. In addition, it needs to grasp the severity of coating deterioration by viewing all parts as much as possible.

3) Re-Painting

It is predicted that a repainting of girder is required once in 35-40 years based on the deterioration speed mentioned below

- Top coat: 25μm / (2/3 μm / year) = 37.5 year

6.5.5 Preliminary Design of Substructures and Foundations

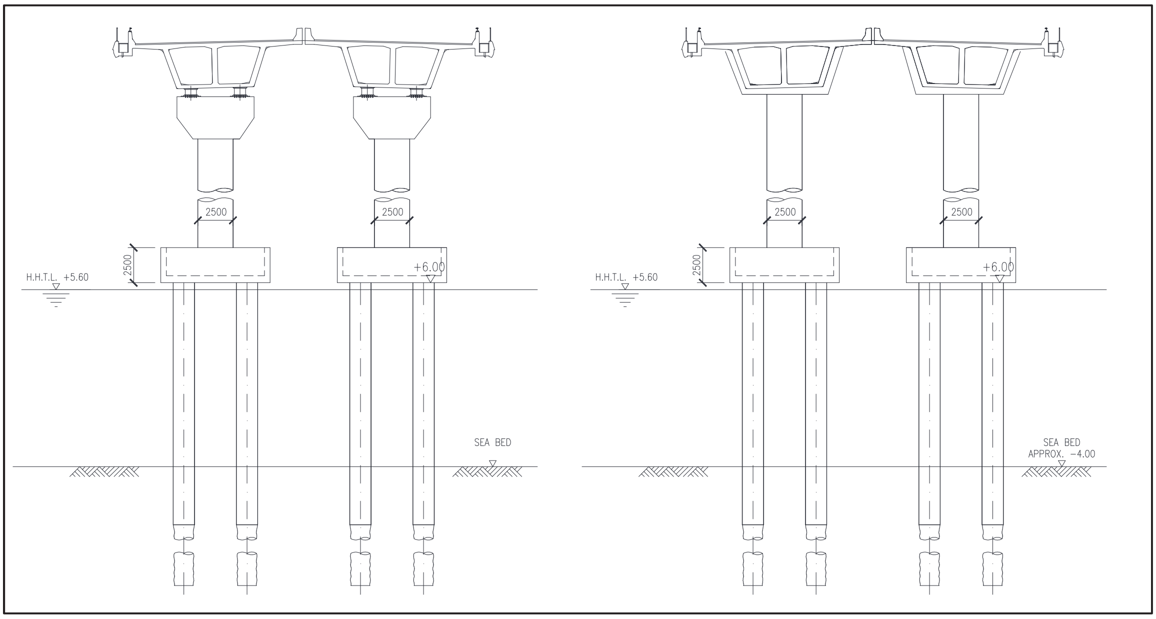
(1) General Viaduct Sections over Water, General Land sections and those over Mangroves

Single-column piers with pile caps supported by cast-in-situ concrete piles are applied for substructures of PC box-girder bridge sections in general sections on both water and land as well as in the mangroves.

The sections where a cast-in-situ concrete pile is adopted are: between CH 0+495 and 3+395 for a length of 2,900 m, 3+715 and 4+465 for a length of 910 m, 6+078 and 8+620 for a length of 2542 m, 9+180 and 11+880 for a length of 2,700 m, and 13+610 and 16+840 for a length of 3,230 m.

Single-column piers with cast-in-situ group pile foundations have 2,500-mm diameter columns in the form of single-column bents. The beam ends shall bear onto the pier caps, and intermediary piers have a rigid structure by integrating the two prestressed concrete box girders with a solid crossbeam and they do not have bearings. The advantage of this arrangement is its ease of maintenance.

The elevation of the underside of the pile caps is set at +6.00 m C.D., so it is above the high water level. The reason for this arrangement is to minimize the piers' effect on the tidal currents and to reduce the adverse impact on the environment by not excavating during pile cap construction. In addition, it is possible to construct the pile caps without considering the influence of sea level, thereby improving the substructure's ease of construction. Furthermore, it is possible to improve the efficiency of the pile cap construction, such as by using left-in-place pre-cast moulding.



Source: JICA Study Team

Figure 6.5.15 Single-Column Piers with Pier Cap

Cast-in-situ pile diameters of 1,500 mm and 2,000 mm were selected for comparison after considering current practice of 50-m-span structures in India and the loading of the PC box girder. The results of the comparison are shown in Figure 6.5.15.

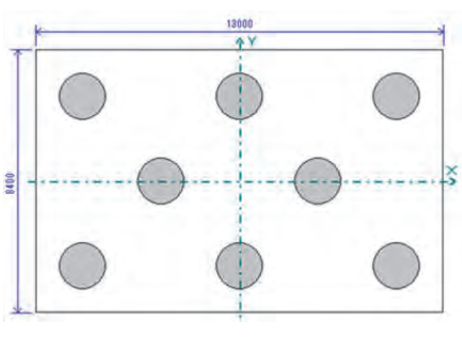
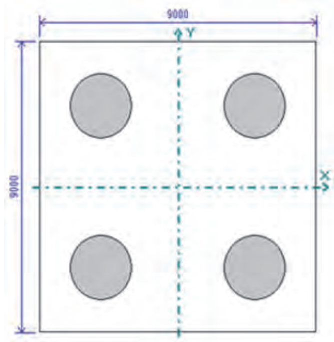
Averaged pier heights were used for the comparison. The number of piles required with 2,000-mm-diameter piles was found to be half the number required with 1,500-mm-diameter piles. Finally the 2,000-mm-diameter piles were adopted because they were found to have lower construction costs and also because they contributed to reducing construction times.

Piles supported by 2,000 mm diameter piles shall have steel pipe casing during their construction. The steel piping is considered as a means to reduce the detrimental effect on the marine environment.

The relationship between the diameter of the pile and the thickness of the steel pipe is shown below:

- If more than 2.0m diameter pile is used, 16mm thick steel pipe is adopted.
- If 1.5m to 2.0m diameter pile is used, 12mm thick steel pipe is adopted.
- If less than 1.5m diameter pile is used, 8mm thick steel pipe is adopted.

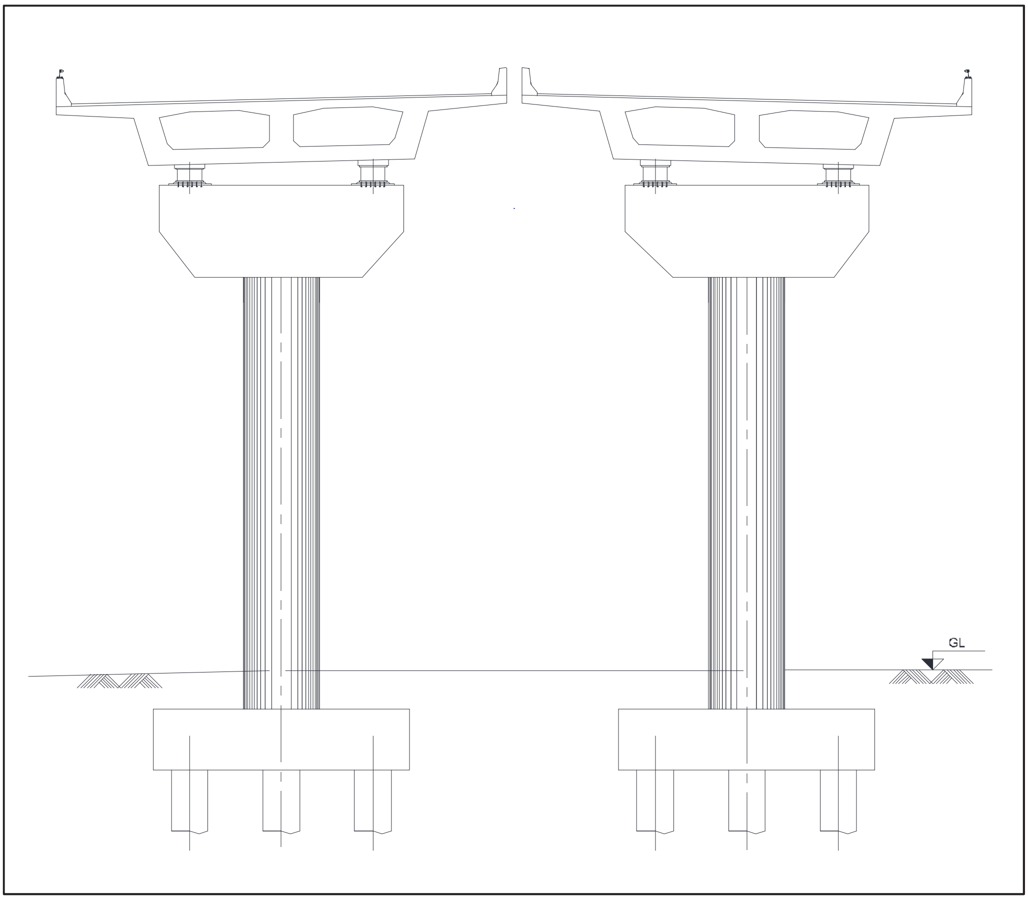
Table 6.5.18 Pile Diameter Comparison Table for General Marine Viaduct Sections

	1,500-mm-diameter piles	2,000-mm-diameter piles
Pile arrangement diagram		
Cost estimation	8 piles of dia. 1,500 mm Length = 29 m 1,700 USD/m × 29 m × 8 =394 400 USD	4 piles of dia. 2,000 mm Length = 29 m 2,900 USD/m × 29 m × 4 =336 400 USD
Appraisal	Conclusion: 1,500-mm-diameter piles were rejected.	Conclusion: 2,000-mm-diameter piles were adopted for their lower construction costs and shorter construction period compared to 1,500-mm- diameter piles.

Source: JICA Study Team

CH 16+840-17+517 (total length of 677m) section on land applies a cast-in-situ concrete pile the same as the general marine section because the scale of the superstructure is 50m in span length. In this section, since the existing ground level is relatively high, the soil cover on the pile cap was kept at 1.2m. The diameter of the pile needs to be 2,000 mm the same as the marine section.

Whereas 50m of span arrangement with PC box girder is applied to the section from the end of the marine portion to Shivaji Nagar IC, 30 m span arrangement with the same bridge type is adopted for the Shivaji Nagar IC to the end of MTHL considering construction cost, constructability and construction period. In the 30m span arrangement section with PC box girder, 2,500 mm diameter single column pier with hammer beam was applied in order to set the bearings for the superstructure. The soil cover of the minimum 1.2m shall be kept the same as the other land section.



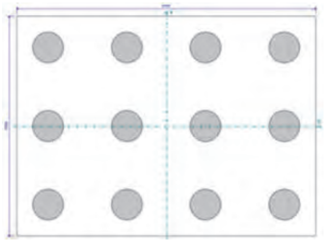
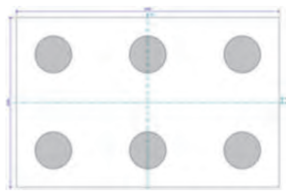
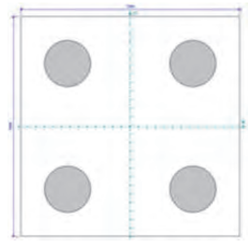
Source: JICA Study Team

Figure 6.5.16 Pier Form of General Land Sections

Cast-in-situ pile diameters of 1,000 mm, 1,200 mm and 1,500 mm were selected for comparison after considering the current 30-m-span structures in India and the loading of the PC box girder. The results of the comparison are shown in Table 6.5.19.

Average pier heights were used for the comparison. Piles with a diameter of 1,000 mm were found to be far less economical than those with diameters of 1,200 mm or 1,500 mm. Furthermore, piles with a diameter of 1,200 mm were found to be five percent more economical than those with a diameter of 1,500mm. The general land section on the Navi Mumbai side in the vicinity of the toll plaza has shallow support layers. Construction of larger-diameter piles may encounter issues in this portion due to the shallow support layers and the construction costs of the foundation may increase. Therefore, this portion should be adjusted and smaller-diameter piles of diameter 1,200 mm shall be adopted.

Table 6.5.19 Pile Diameter Comparison Table for General Land-Based Sections

	1,000-mm-diameter piles	1,200-mm-diameter piles	1,500-mm-diameter piles
Pile arrangement diagram			
Cost estimation	12 piles of dia. 1,000 mm Length = 7 m 750 USD/m × 7 m × 12 ＝63 000 USD	6 piles of dia. 1,200 mm Length = 7 m 960 USD/m × 7 m × 6 ＝40 320 USD	4 piles of dia. 1,500 mm Length = 7 m 1,500 USD/m × 7 m × 4 ＝42 000 USD
Appraisal	Conclusion: 1,000-mm-diameter piles were rejected because they have higher construction costs than 1,200-mm-diameter and 1,500-mm-diameter piles.	Conclusion: 1,200-mm-diameter piles were adopted for their significantly lower construction costs than 1,000-mm-diameter piles and their 5% lower construction costs than 1,500-mm-diameter piles.	Conclusion: 1,500-mm-diameter piles were rejected because larger-diameter piles may encounter issues due to shallow support layers and the construction costs of the foundation may increase.

Source: JICA Study Team

Table 6.5.20 Result of Substructure at General Section and Mangrove Section

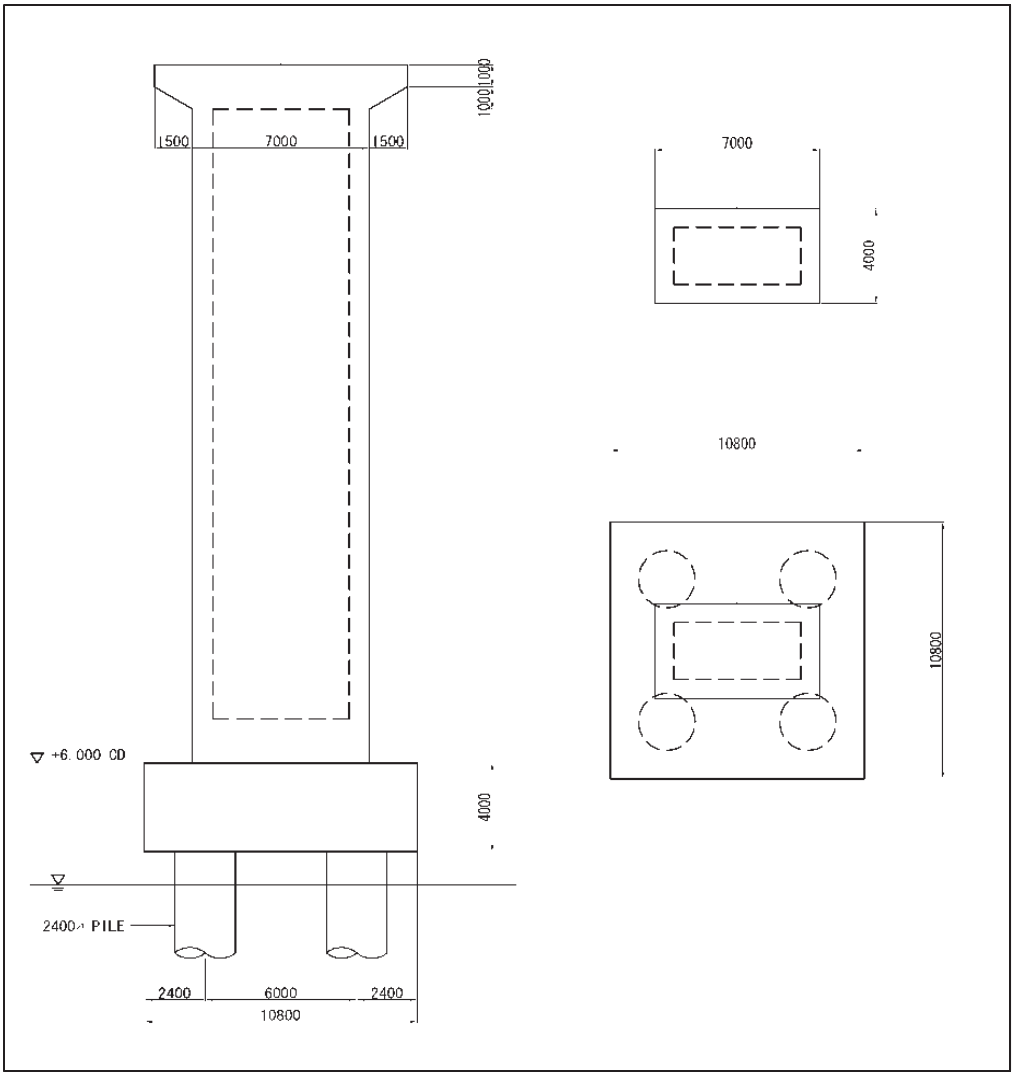
<table>
<tr><th>Category</th><th>Chainage</th><th>Substructure</th><th>Foundation</th></tr>
<tr><td>General Section
(marine area)</td><td>No. 0+495～No. 3+395
No. 3+715～No. 4+625
No. 6+078～No. 8+620
No. 9+180～No. 11+880
No. 13+610～No. 16+610</td><td rowspan="2">Pile cap bottom is set at +6.00m C.D.</td><td rowspan="3">ϕ2.0m - 4piles</td></tr>
<tr><td rowspan="3">Mangrove Section</td><td>No. 16+610～No. 16+840</td></tr>
<tr><td>No. 16+840～No. 17+517</td><td rowspan="3">Pile cap top is set 1.2m below ground surface</td></tr>
<tr><td>No. 17+517～No. 18+087</td><td rowspan="2">ϕ1.2m - 6piles</td></tr>
<tr><td>General Section
(land area)</td><td>No. 18+127～No. 18+187
No. 18+217～No. 18+317
No. 18+357～No. 18+424
No. 18+492～No. 18+574
No. 18+644～No. 18+884
No. 20+070～No. 20+225
No. 20+260～No. 21+009
No. 21+079～No. 21+228
No. 21+423～No. 21+659
No. 21+729～No. 21+834</td></tr>
</table>

Source: JICA Study Team

(2) Bridges in Obligatory Marine Sections

Bridges in obligatory marine sections have longer spans than general viaduct marine sections due to the existence of waterways. A steel box girder with steel deck was applied to this section. In the sections between CH 3+395 and 3+715 for a length of 320 m, between 4+625 and 6+078 for a length of 1453 m, between 8+620 and 9+180 for a length of 560 m, and between 11+880 and 13+610 for a length of 1730 m, a rectangular hollow column with hammerhead is selected in order to reduce weight.

If the pile cap undersides were positioned at +6.00 m C.D. in the same way as the general marine sections are positioned above sea level and are visible, then there would be an excessive length of pile protruding beneath the pile cap and the size of foundations would be excessively large. To avoid excessively large foundations, the pile cap topsides shall be positioned at +6.00 m C.D.



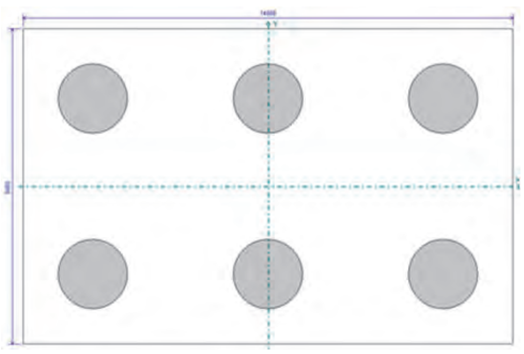
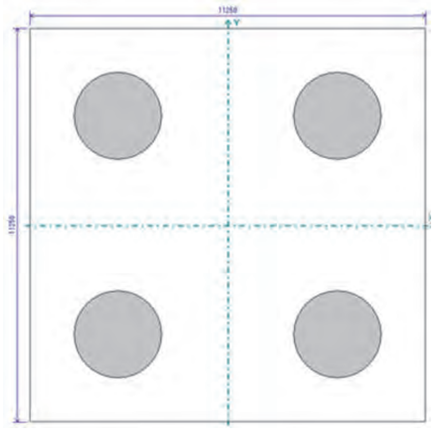
Source: JICA Study Team

Figure 6.5.17 Substructure Form of Marine Bridge Sections

The cast-in-situ pile diameters of 2,000 mm and 2,400 mm were selected for comparison after considering the loads being applied. The spans of the obligatory marine sections vary between 100 m and 180 m. Considering that span length, and thus loads, vary greatly over these sections, it was decided that a single representative pier was not sufficient for comparison, so the number of piles for all piers were calculated for the comparison.

The comparison considers 60 pier-base pile groups and calculates the number of piles required for piles with a diameter of 2,000 mm and 2,400 mm, and compares the total number of piles for all pile groups. Although the construction costs are almost the same, 2,400-mm-diameter piles were adopted because their construction time would be approximately 30% shorter than 2,000-mm-diameter piles.

Table 6.5.21 Pile Diameter Comparison Table for Obligatory Marine Bridge Sections

	2,000-mm-diameter piles	2,400-mm-diameter piles
Pile arrangement diagram		
Cost estimation	60 pile groups of 4 to 8 piles ∴ 348 piles of dia. 2,000 mm Average length = 31 m 2,900 USD/m × 31 m × 348 ＝31 285 200 USD	60 pile groups of 4 piles ∴ 240 piles of dia. 2,400 mm Average length = 31 m 4,100 USD/m × 31 m × 240 ＝30 504 000 USD
Appraisal	Conclusion: 2,000-mm-diameter piles were rejected.	Conclusion: 2,400-mm-diameter piles were adopted for their approximately 30% shorter construction period compared to 2,000-mm-diameter piles. The overall construction costs are similar for both pile types.

Source: JICA Study Team

(3) Railway Overpass

Piers of the steel truss bridge for the railway overpass shall be two-single-column piers, which are similar to the general land sections. Pile foundations with diameters of 1,200 mm were selected after considering the load sizes.

(4) Highway Overpass

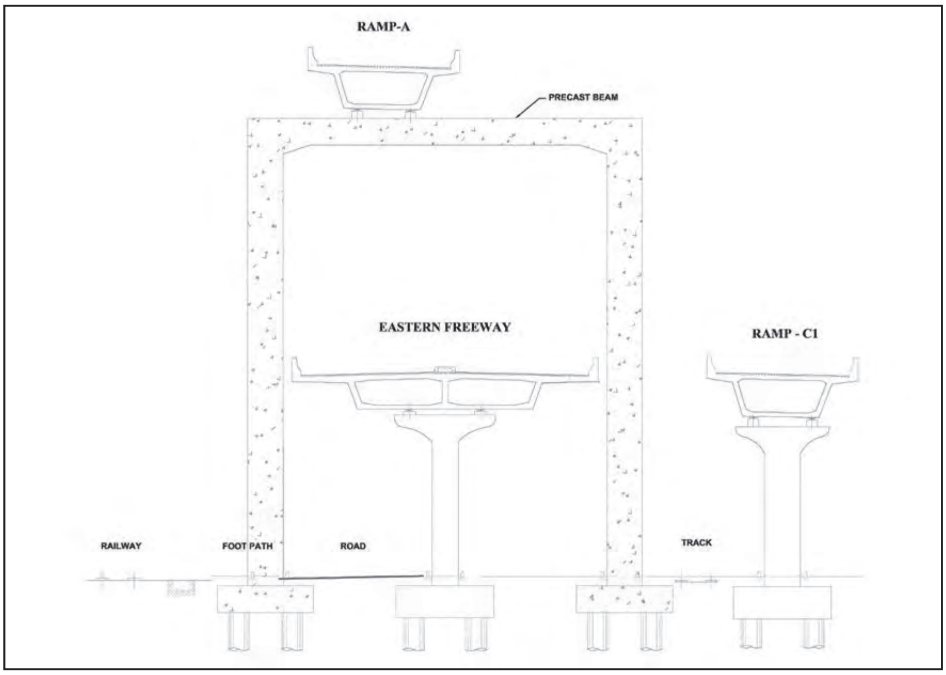
Piers of PC box girder for the highway overpass shall be two-single-column piers, which are similar to the general land sections. Pile foundations shall be cast-in-situ with diameters of 1,200 mm.

(5) Interchange Sections

1) Sewri IC

The piers of Sewri IC, which support PC box girders, shall be hammerhead piers. Cast-in-situ pile foundations with diameters of 1,200 mm were selected after considering the loads of the PC box girders with spans of 30 m to 50 m.

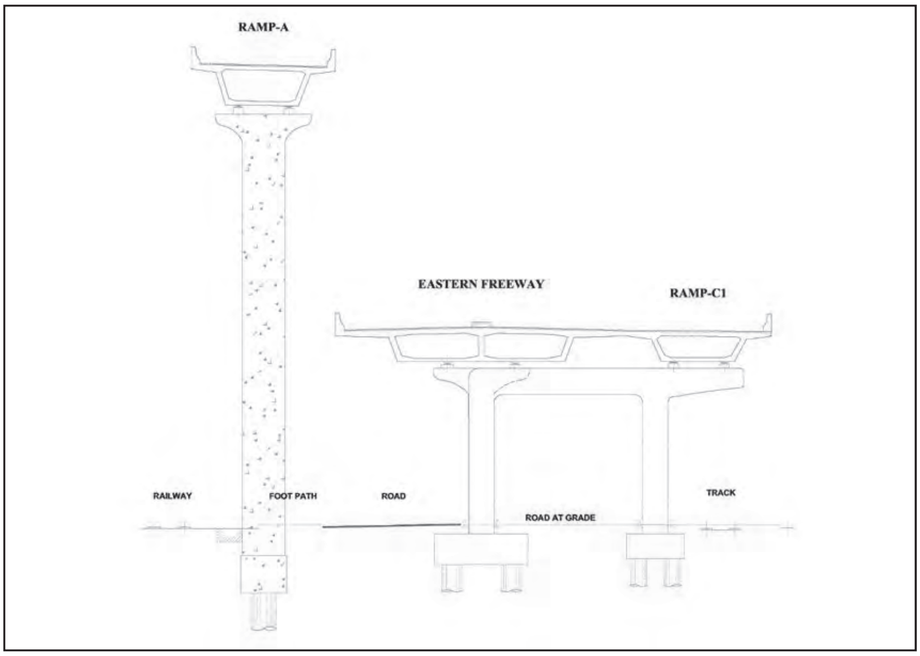
Ramp A mainly has hammerhead piers; however, one rigid-frame straddle bent type shall be adopted for the flyover section where ramp A crosses over the East Freeway. The crossbeam of the straddle bent shall be constructed at a high elevation above the freeway, so cast-in-situ concrete construction is expected to be difficult. In this case, a prestressed concrete crossbeam or similar method shall be used.



Source: JICA Study Team

Figure 6.5.18 Ramp A Cross Section Showing the Rigid-Frame Straddle Bent

After Ramp A crosses over the East Freeway and runs parallel to it, the pile foundations shall have piles placed in tandem (in line) because of the narrow space between the piers and the boundary of the railway track. Where Ramp A runs parallel to the railway track, it shall have piles with a diameter of 1,500 mm and each pier shall have two piles placed in parallel to the ramp. Furthermore, at the point where Ramp A crosses over the East Freeway, there are span lengths of about 50m and piles in tandem with a diameter of 2,000 mm are necessary, because the loads are larger than other piers.

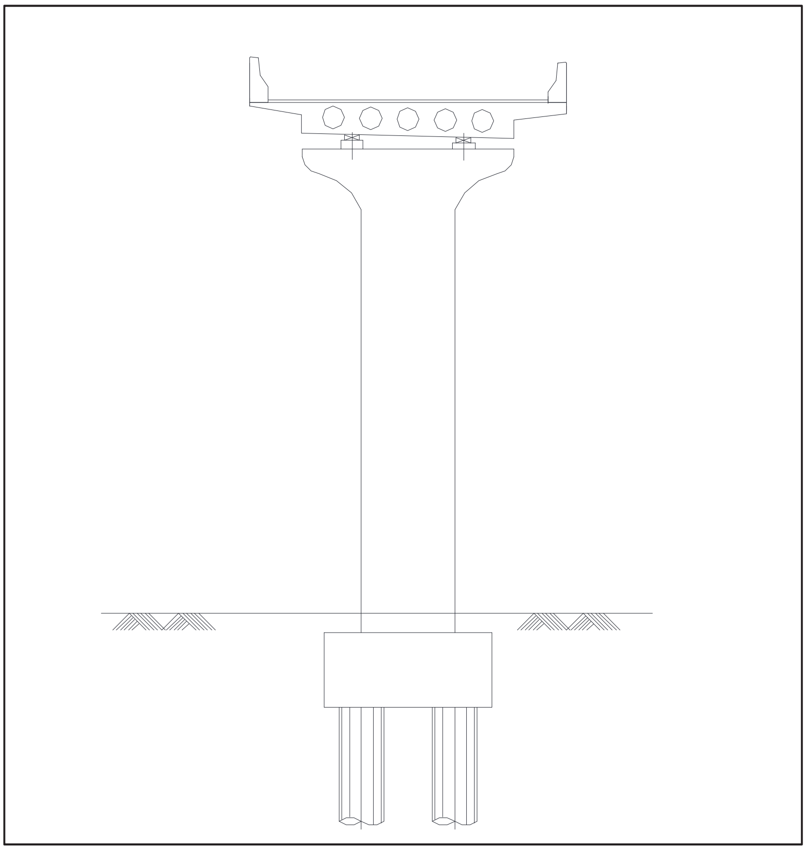


Source: JICA Study Team

Figure 6.5.19 Ramp A Cross Section Showing a Hammerhead Pier

2) Shivaji Nagar IC

The interchange shall have RC hollow slab type with 15-m spans and the piers shall be single-column hammerhead piers. Considering the loads, the foundations shall be cast-in-situ concrete piles with a diameter of 1,000 mm.

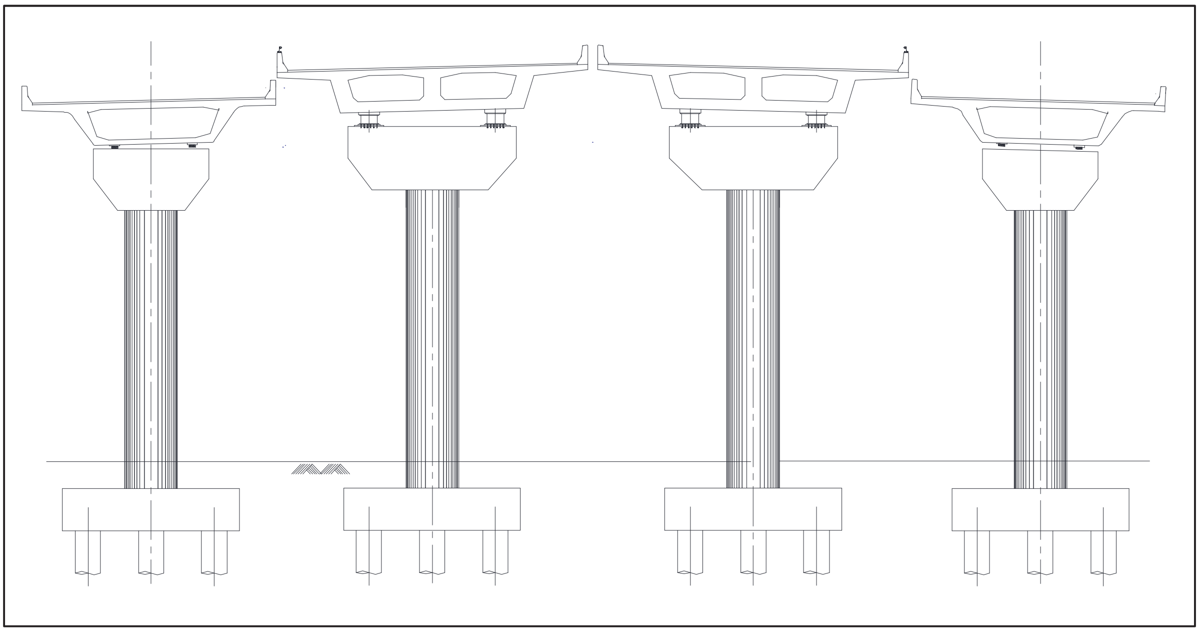


Source: JICA Study Team

Figure 6.5.20 Shivaji Nagar IC Cross Section

3) SH 54 IC

The interchanges shall have RC hollow slab type with 15-m spans and the pier columns shall be single-column hammerhead piers. Considering the loads, the foundations shall be cast-in-situ concrete piles with a diameter of 1,000 mm.



Source: JICA Study Team

Figure 6.5.21 SH 54 IC

4) Chirle IC

Same as the Shivaji Nagar IC, the piers shall be single-column hammerhead piers and the foundation shall be cast-in-situ concrete piles with a diameter of 1,000 mm.

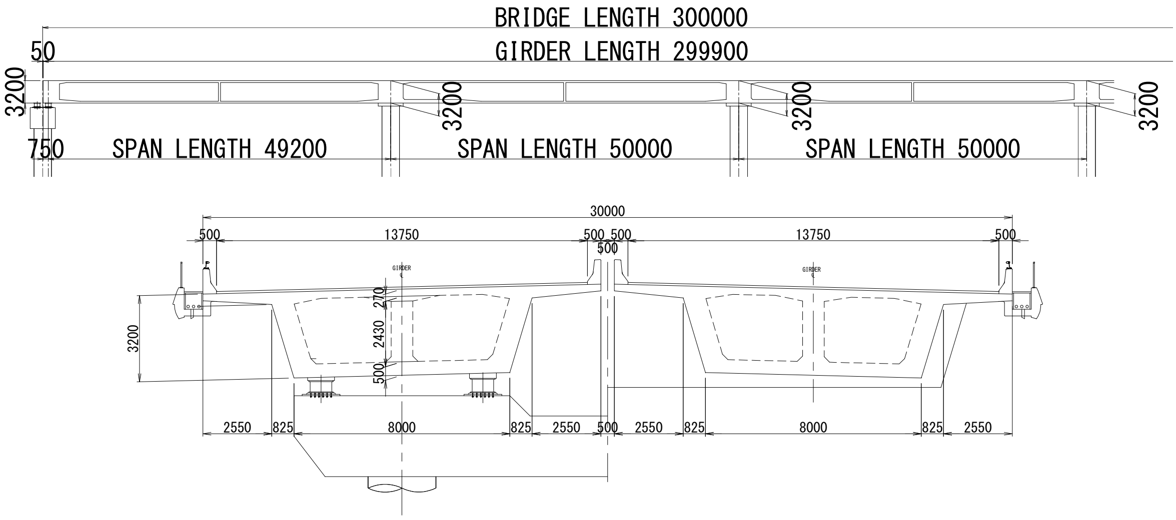
6.5.6 Preliminary Design of Superstructures and Foundations

(1) General Section (Marine and Land)

Whereas the span length on the general marine section is 50m generally and the PC box girder type is applied, the span length on land is 30m generally and the PC box girder bridge is also applied considering the current Indian practice. In this sub-chapter, the results of the preliminary design of the PC box girder type are summarized below.

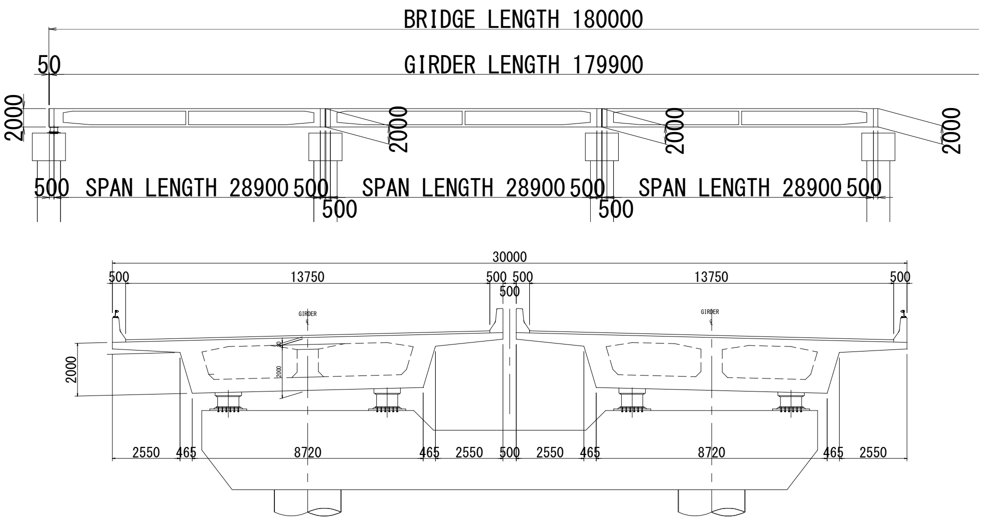
On the general marine section, the bridge width is 14.75m generally therefore the two cell box girder type is applied. The superstructure height is 3.2m according to the continuously optimal girder the height/span ratio is 1/15 to 1/20 for this superstructure type. On the general land section, the bridge width is 14.75m generally, therefore, the single box type with 2.0m of girder depth is applied according to the optimal girder height for PC simple box girder.

The profile and cross section of the superstructure is shown in Figure 6.5.22 and Figure 6.5.23.



Source: JICA Study Team

Figure 6.5.22 Profile and Cross Section of Superstructure on Marine Section for General Section (PC box Girder)



Source: JICA Study Team

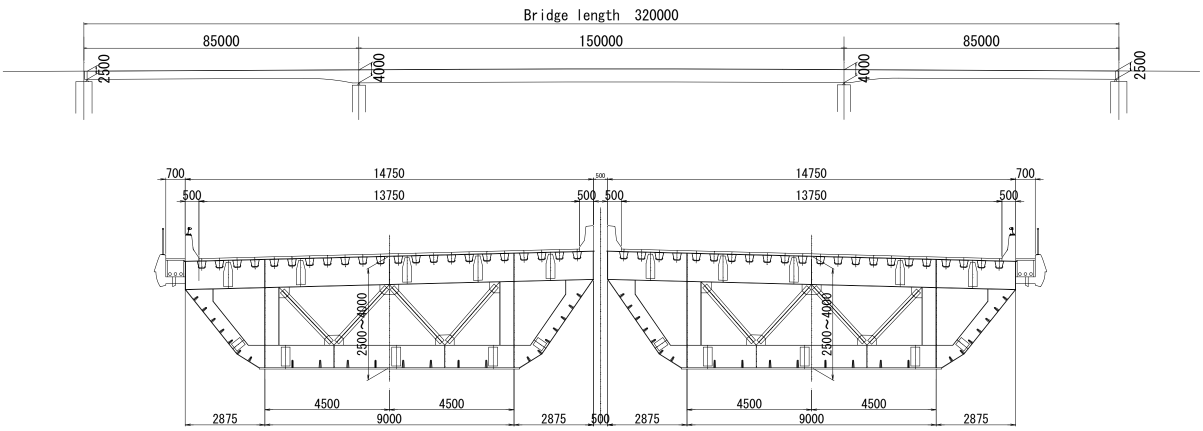
Figure 6.5.23 Profile and Cross Section of Superstructure on Land Section for General Section (PC box Girder)

(2) Obligatory Marine Sections

The span length ranges from 150m and 180m on the section and the steel box girder with steel deck type is applied. The result of preliminary design for a steel box girder with steel deck shall be described in the following

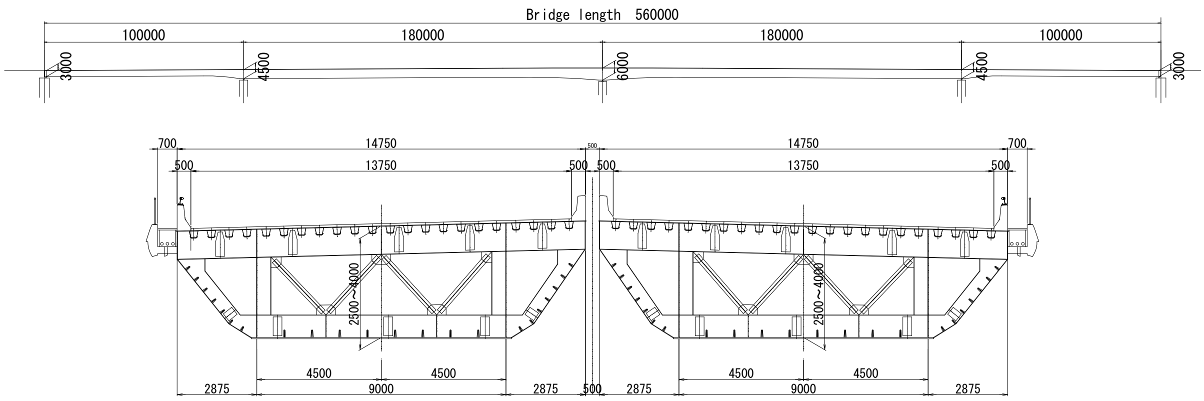
For the obligatory marine section, the bridge width is 14.75m generally therefore the single cell box girder type is applied. The superstructure height is variable depending on stress distriburion against the loads in order to reduce the weight of the superstructure.

The profile and cross section of the superstructure is shown in Figure 6.5.24 and Figure 6.5.25.



Source: JICA Study Team

Figure 6.5.24 Profile and Cross Section of Superstructure for Special Section (Span Length 150m) (Steel Box Girder with Steel Deck)



Source: JICA Study Team

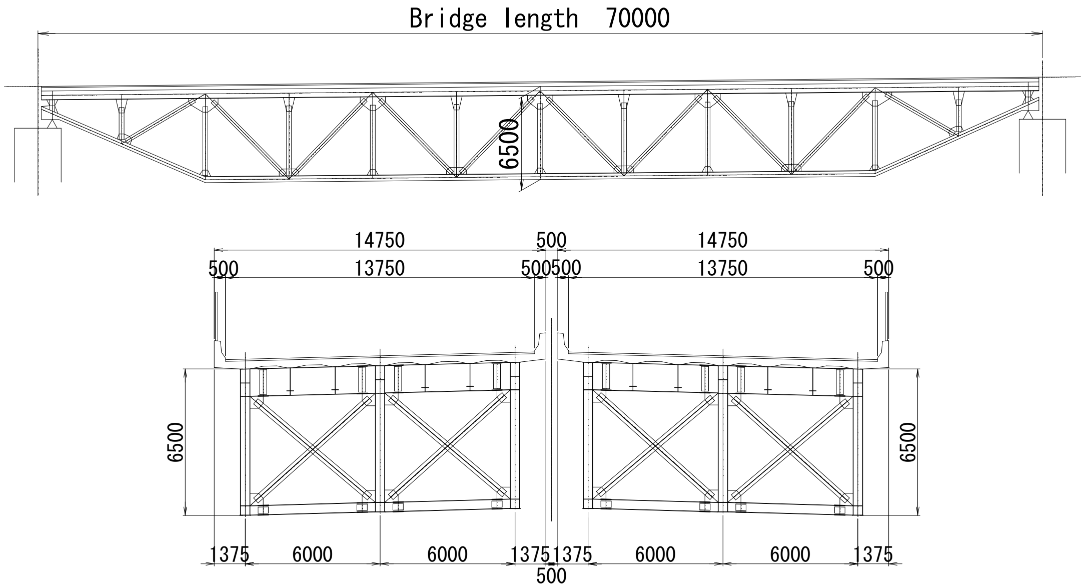
Figure 6.5.25 Profile and Cross Section of Superstructure for Special Section (Span Length 180m) (Steel Box Girder with Steel Deck)

(3) Mangrove Section (Navi Mumbai Side)

The PC box girder bridge is applied because the span lengths are 50m and 30m. The profile and cross section of the superstructure is the same as the ones for the general sections for both marine and land.

(4) Railway Crossing Section

The steel truss bridge is applied because the span lengths are 65m and 68m. The profile and cross section of the superstructure are shown in Figure 6.5.26.



Source: JICA Study Team

Figure 6.5.26 Profile and Cross Section of Superstructure for Railway Crossing Section (Steel Truss Bridge)

(5) Road Crossing Section

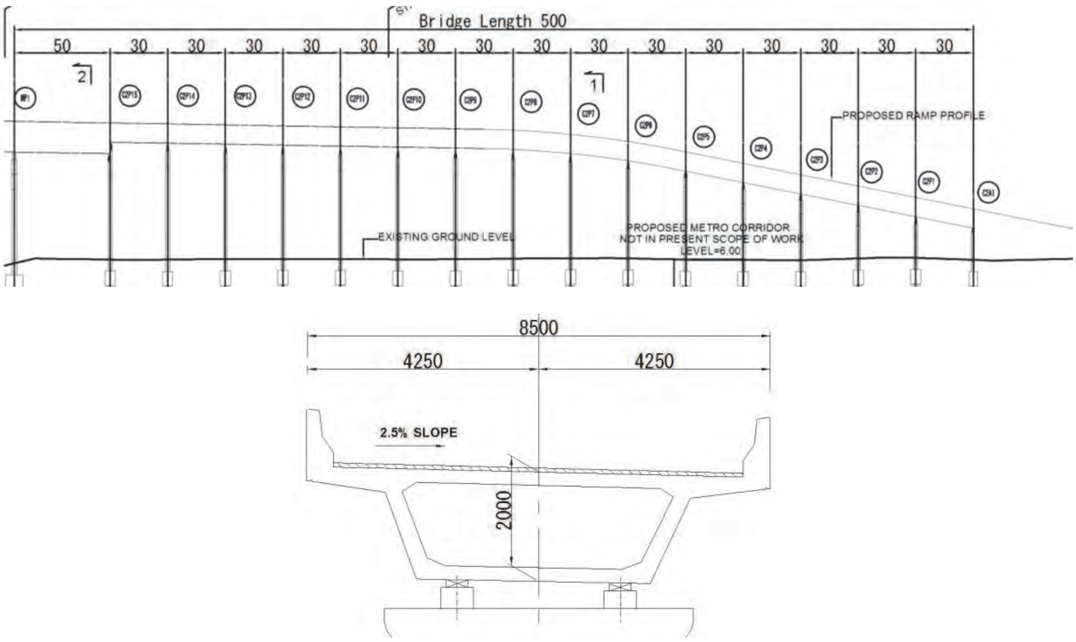
The PC box girder bridge is applied because the span length is 50m generally. The profile and cross section of the superstructure are the same as for the general sections both marine and land.

(6) Interchanges

A PC box girder for the superstructure is selected the same as for the general sections for both marine and land because the span length is 50m generally

1) Sewri IC

A PC box girder for superstructure is selected because the span length is 30m generally. The profile and cross section of the superstructure are shown in Figure 6.5.27 which is the result of the preliminary design.

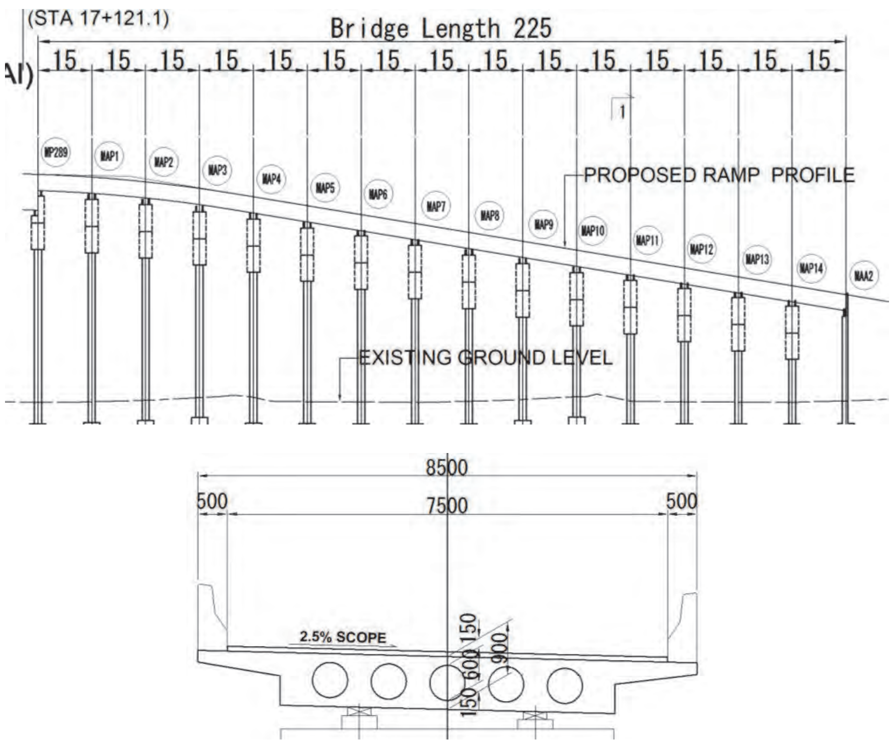


Source: JICA Study Team

Figure 6.5.27 Profile and Cross Section of Superstructure for Sewri IC (PC Box Girder)

2) Shivaji Nagar IC

A PC hollow slab for the superstructure is selected because the span length is 15m generally. The profile and cross section of the superstructure are shown in Figure 6.5.28 which is a result of the preliminary design.

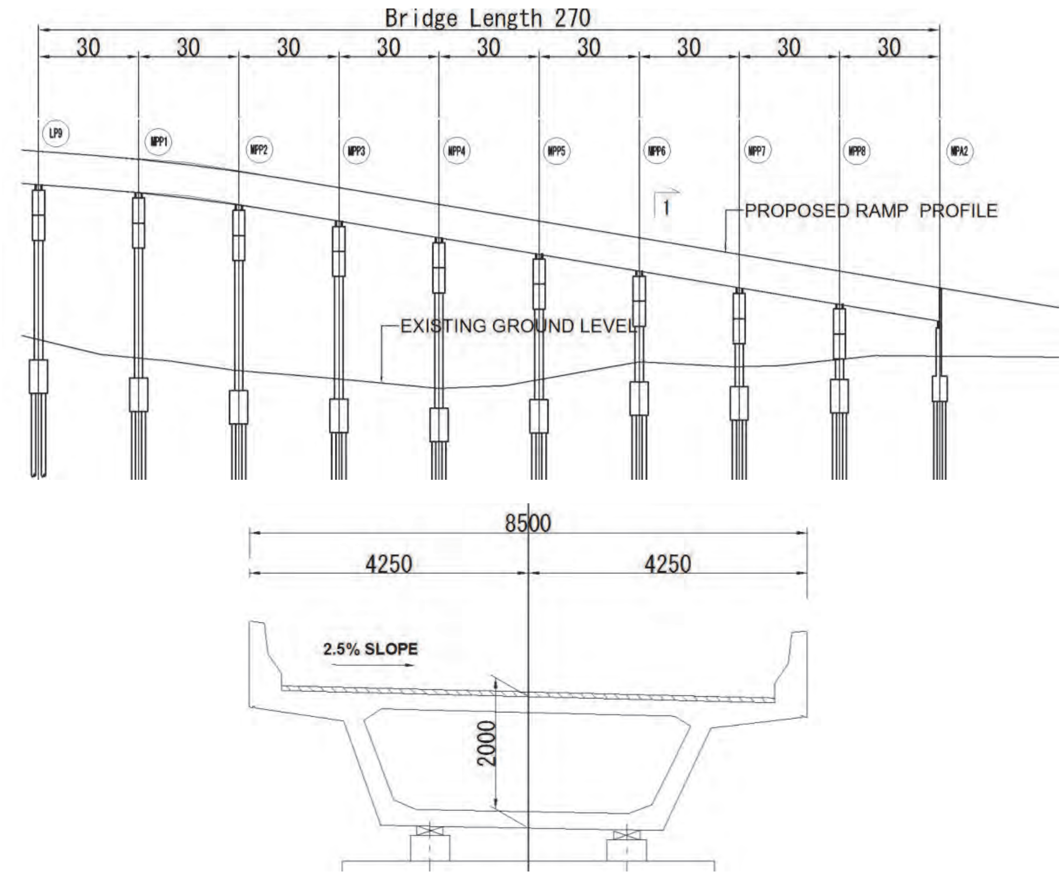


Source: JICA Study Team

Figure 6.5.28 Profile and Cross Section of Superstructure for Shivaji Nagar IC (PC hollow slab)

3) SH54 IC

A PC box girder for the superstructure is selected because the span length is 30m generally. The profile and cross section of the superstructure are shown in Figure 6.5.29 which is the result of the preliminary design.

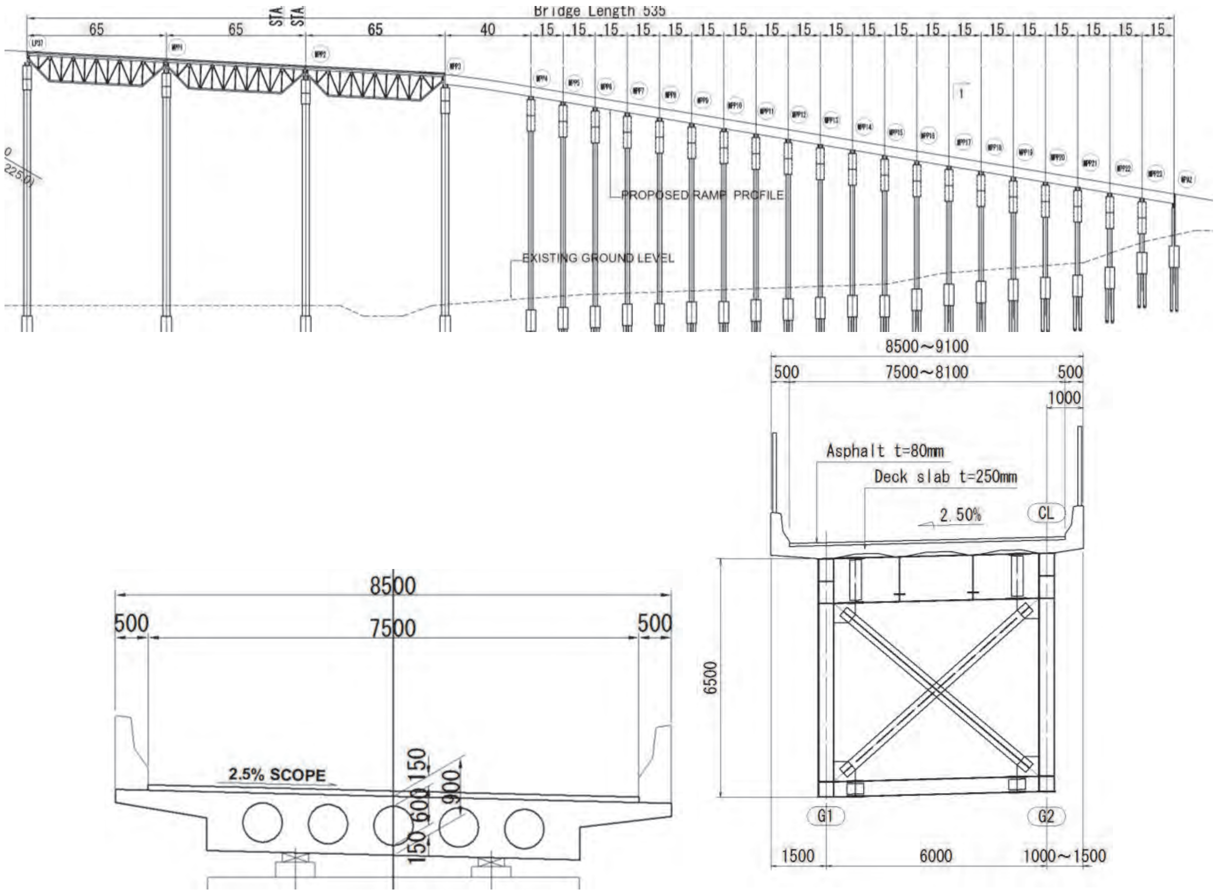


Source: JICA Study Team

Figure 6.5.29 Profile and Cross Section of Superstructure for SH54 IC (PC Box Girder)

4) ChirleIC

A steel box girder is applied for the superstructure where it crosses over the railway because the span length is 65 m in general. For the remaining section, a RC hollow slab is applied for the superstructure because the span length is 15 m generally. The profile and cross section of the superstructure are shown in Figure 6.5.30 which is the result of the preliminary design.



Source: JICA Study Team

Figure 6.5.30 Profile and Cross Section of Superstructure for Chirle IC (PC Hollow Slab and Steel Box Girder)

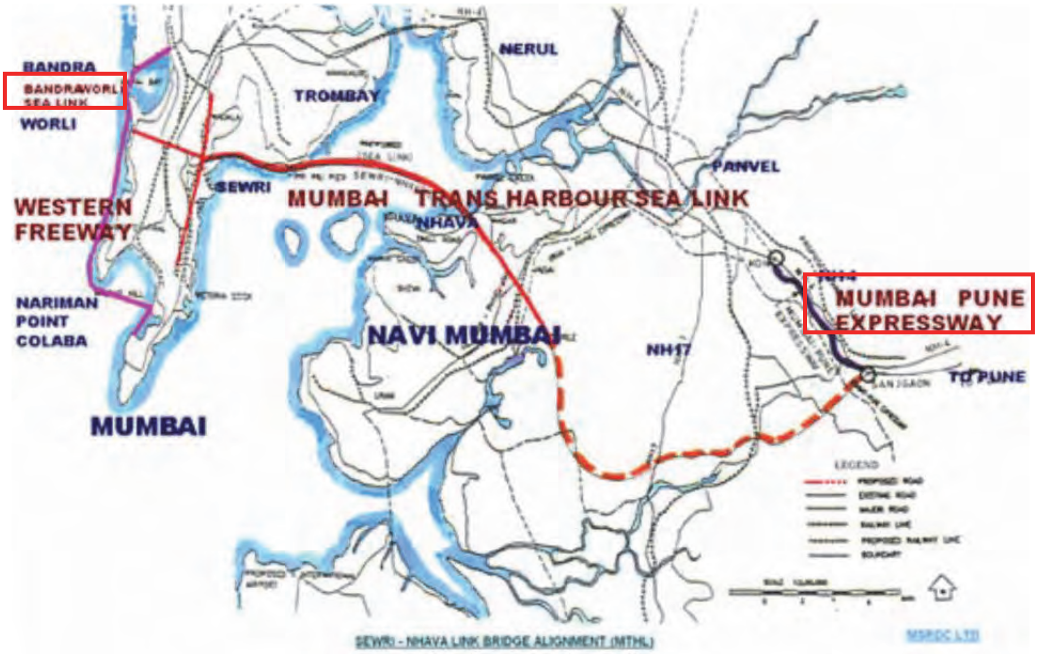
6.6 ITS

6.6.1 Introduction

In this section, the introduction of ITS (Intelligent Transportation System) in MTHL is considered. MTHL will be an access controlled toll road, so MTHL should be considered based on the situation of introduction of ITS in similar roads of MMR. Accordingly, the appropriate Toll Management System and Traffic Management System of MTHL shall be planned in consideration of the special features of the road and the organizational structure of MTHL.

6.6.2 Situation of ITS Introduction in Peripheral Toll Roads

The situation of ITS introduction in “Bandra Worli Sea Link” and “Mumbai Pune Expressway” are mentioned as examples of toll roads around MTHL. In addition, the situation of ITS introduction on roads in Mumbai city is mentioned as well.



Source: MSRDC

Figure 6.6.1 Location of the Toll Roads

(1) Bandra Worli Sea Link (BWSL)

1) Outline of BWSL

This project aimed to reduce the traffic congestion of the North - South traffic corridor from the island city to western suburbs. This project is to construct toll road bridges in the marine area between Bandra and Worle, and BWSL also forms a part of the proposed western freeway. BWSL of 5.6 km in length was opened in March, 2010. BWSL, exclusive motor-vehicle way was designed to support eight traffic lanes.

The implementing agency of this project is “Maharashtra State Road Development Corporation Ltd.” (MSRDC), and the Operation and Maintenance Company is “MEP Infrastructure Developers Ltd.”. The contract for the Operation and Maintenance is in phase 2 and has been for three years.

BWSL has similar conditions to MTHL, which are marine, long span and access controlled toll road.

Source: JICA Study Team

Figure 6.6.2 Bandra Worli Sea Link

2) Toll Management System

There is only a single toll plaza for BWSL which is on the Bandra side. The toll plaza which is equipped with an electronic toll collection system (ETC) has 16 approach lanes including two lanes of exclusive ETC. The ETC system uses (Radio Frequency Identification) RFID TAG.

The EFKON Toll Management System (ETMS) was installed as the toll management system of BWSL. The system is divided into two parts, namely Lane side and Control room side. The systems or equipment in the lane side are connected with the lane controller, who with help of lane engine software application executes all toll collection transactions and other lane monitoring tasks. The control room consists of workstations which execute point of sale operation, cash up operations, lane equipment monitoring and toll collector monitoring etc.

The payment options for the toll are manually by cash in the manual lane and purchasing of RFID TAG by ETC in ETC lane. The tolls Tariff for every classification are shown in Table 6.6.1.

Table 6.6.1 Toll Rates (BWSL)

Vehicle Type	Single Journey	Return Journey	Daily Pass	Monthly Pass	Discount Card (50 trip) 10%	Discount Card (100 trip) 20%
Car / LMV	60	90	150	3,000 / -	2,700 / -	4,800 / -
Tempo / LCV	95	140	235	4,750 / -	4,275 / -	7,600 / -
Truck / Bus	125	185	310	6,250 / -	5,625 / -	10,000 / -

Source: Study Team

Figure 6.6.3 Toll Plaza (BWSL)

3) Traffic Management System

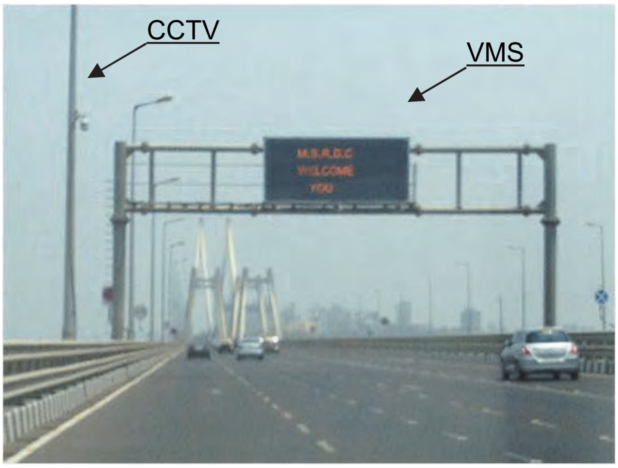
Road side facilities on BWSL are shown in Table 6.6.1.

CCTV cameras were installed around every 250m on the both sides of the main route, and around every 400 m under the girders for security. Operators always monitor in a traffic control room.

EFKON's Highway Traffic Management System was installed as the road traffic management system of BWSL. Field side systems and control room side systems are connected with each other through a Fibre optic network.

Table 6.6.2 Road Side Facilities (BWSL)

Item	Quantity	Interval	Location
CCTV (road side)	57	Approx. 250m	Road side
CCTV (under girders)	15	Approx. 400m	Under slab of median
Emergency Call Box (ECB)	11	Approx. 1km	Road side
Variable Message Signs (VMS)	3	―	Entrance of toll plaza After getting on toll road /each direction
Automatic Traffic Counter -cum – Classifier (ATCC)	2	―	Toll Plaza /each direction



Source: JICA Study Team

Figure 6.6.4 Road Side Facilities (BWSL)

Source: Study Team

Figure 6.6.5 Traffic Control Room (BWSL)

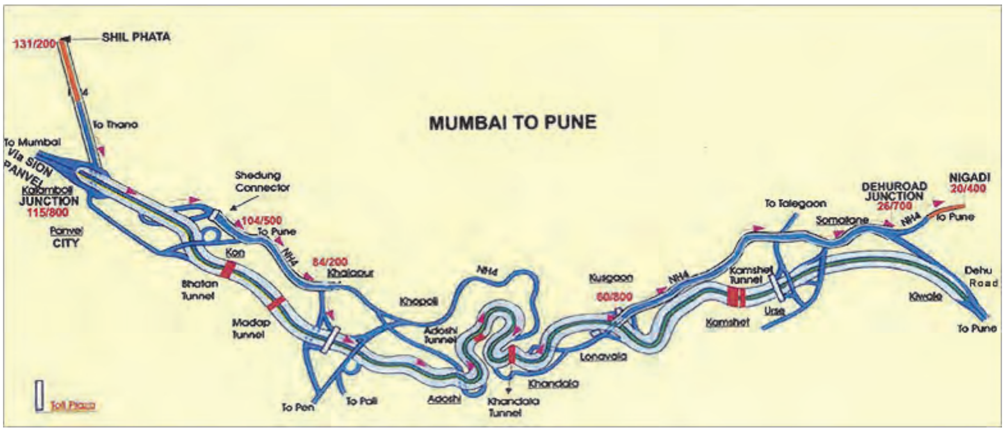
(2) Mumbai Pune Expressway (Yashwantrao Chavan Expressway)

1) Outline of Mumbai Pune Expressway

The Mumbai Pune Expressway, officially the “Yashwantrao Chavan Expressway”, is India's first access controlled tolled expressway. The expressway is a stretch of 94.5 km, six-lane concrete, connecting Mumbai, the administrative capital of Maharashtra, with Pune, an industrial hub and cultural capital of the state. The expressway starts at Kalamboli (near Panvel), and ends at Dehu Rd. (near Pune).

The expressway is the project of a BOT scheme, including improvement (expansion to 4 lanes) on NH4, and it was opened in 2002.

The implementing agency of this project is MSRDC, and the concessionaire is IRB Infrastructure Developers Ltd. The period of concession is for 15 years (2004 through 2019).



Source: MSRDC

Figure 6.6.6 Route Map of Mumbai Pune Expressway

Source: JICA Study Team

Figure 6.6.7 Mumbai Pune Expressway

2) Toll Management System

The Mumbai Pune Expressway has four toll plazas, which consist of two toll plazas on the main carriageway (Khalapur and Telagaon) and two at interchanges (Kusgaon and Lonavala).

The Khlapur toll plaza on the Mumbai side has 17 approach lanes including two lanes of exclusive ETC and the Telegaon toll plaza on the Pune side also has 16 approach lanes including two lanes of exclusive ETC. The ETC system uses RFID TAG.

The payment options for the toll are the touch & go pre-paid IC card, cash by manual transaction and the purchasing of RFID TAG.

The payment options for the toll are cash manually in the manual lane and purchasing of RFID TAG by ETC in the ETC lane. But there is no compatibility with RFID TAG of BWSL.

The tolls Tariff for the journey from Mumbai towards Pune paid at Khalapur Interchange are shown in Table 6.6.3.

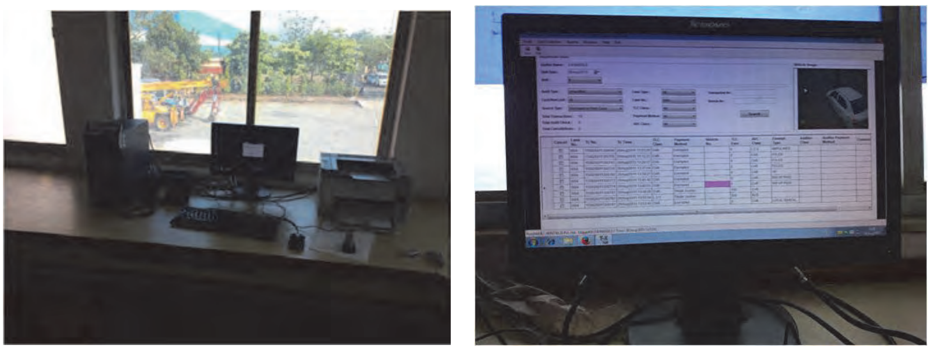
Table 6.6.3 Toll Rates (Mumbai Pune Expressway at Khalapur)

Vehicle Type	Dehu Road / Pune	Kusgaon / Lonavala
Car	195	117
Tempo	300	180
Truck / Bus	418	251
Bus	572	343
3 Axle	990	594
M Axle	1,317	790

All toll collection transactions in the toll booth are monitored by the systems in the control room. The operators in the control room check the vehicle types identified by toll collectors and vehicle type identifiers installed at the tollgates, and the processing data such as vehicle types and toll rates is accumulated.

Source: JICA Study

Figure 6.6.8 Toll Plaza (Mumbai Pune Expressway)



Source: Study Team

Figure 6.6.9 Control Room (Mumbai Pune Expressway)

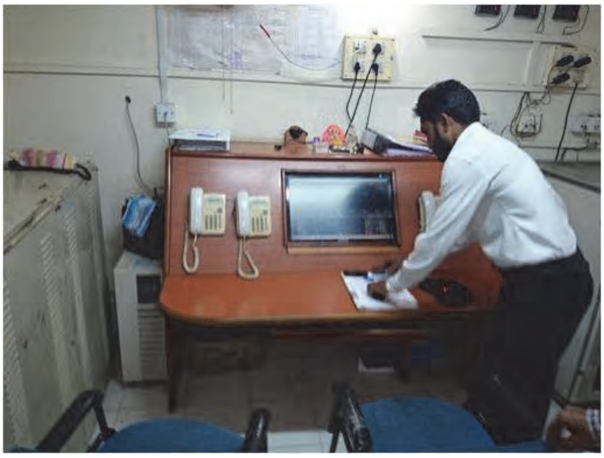
3) Traffic Management System

The road side facilities installed on Mumbai Pune Expressway are shown in Table 6.6.3.

No Traffic Management System for monitoring of traffic condition is installed, and the operators in the call centre receive the emergency calls and make required initial responses such as a notification to relevant organizations including the police.

Table 6.6.4 Road Side Facilities (Mumbai Pune Expressway)

Item	Quantity	Interval	Location
ECB	Approx. 100	Approx. 2km	Road side
ATCC	4		Toll Plaza /each direction



Source: Study Team

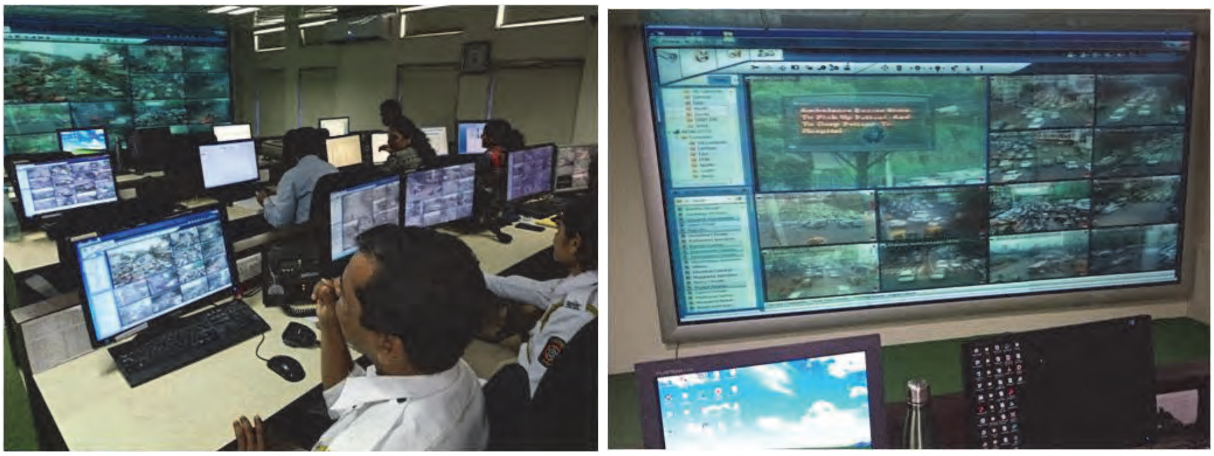
Figure 6.6.10 Call Centre (Mumbai Pune Expressway)

(3) Roads in Mumbai District

1) Traffic Management System

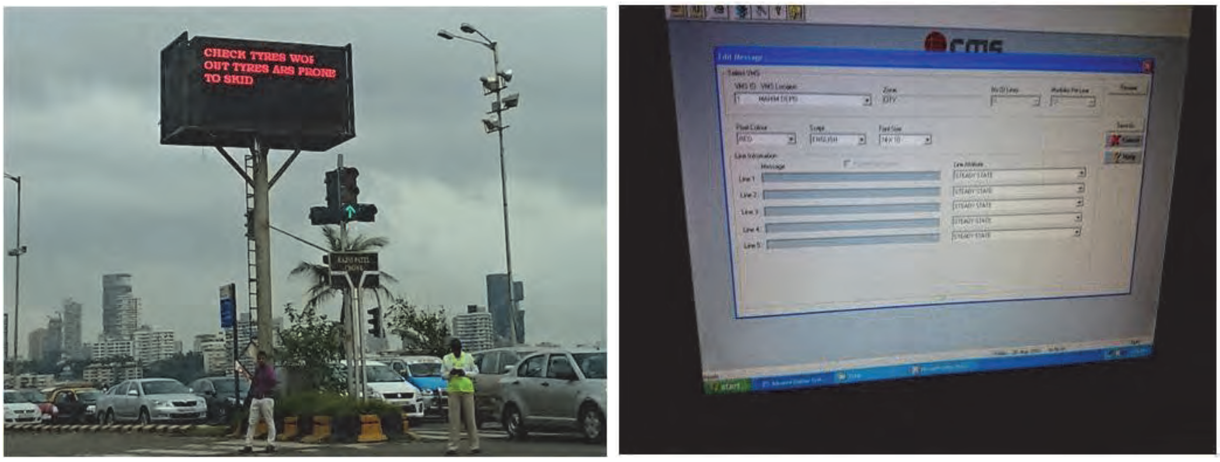
In Mumbai city, a traffic control centre is installed in the Mumbai Traffic Police facilities. A total of 229 CCTV cameras, ATC (Area Traffic Control) signals and 250 non-ATC signals are installed in Mumbai city and monitored in the traffic control centre. The signal indications are adjusted based on the confirmation of the congestion situation with images and the communication from traffic police that are placed at main intersections. The officers of the Traffic Police and the staff of Technical Consultants, which the Municipal Corporation of Greater Mumbai (MCGM) contracted, are operating in the traffic control center. The staff of the consultant conducts various operations following the instructions of the Traffic Police. The traffic management system made by the Spanish Televent company was installed in the Mumbai Urban Transport Project (MUTP) with the support of World Bank.

A total of 48 VMSs are installed in Mumbai urban area, and the messages to display in the VMS are set individually using the VMS system in the traffic control centre. However, the provided information is limited to static and enlightening messages such as warnings on speed limit and wearing of helmets. The dynamic road and traffic information such as expected travel time, congestion level and route guidance is not available. In addition, the enlightening messages are decided twice a month by the Joint Commissioners of the Traffic Police.



Source: JICA Study Team

Figure 6.6.11 Traffic Control Centre (Mumbai Traffic Police)



Source: JICA Study Team

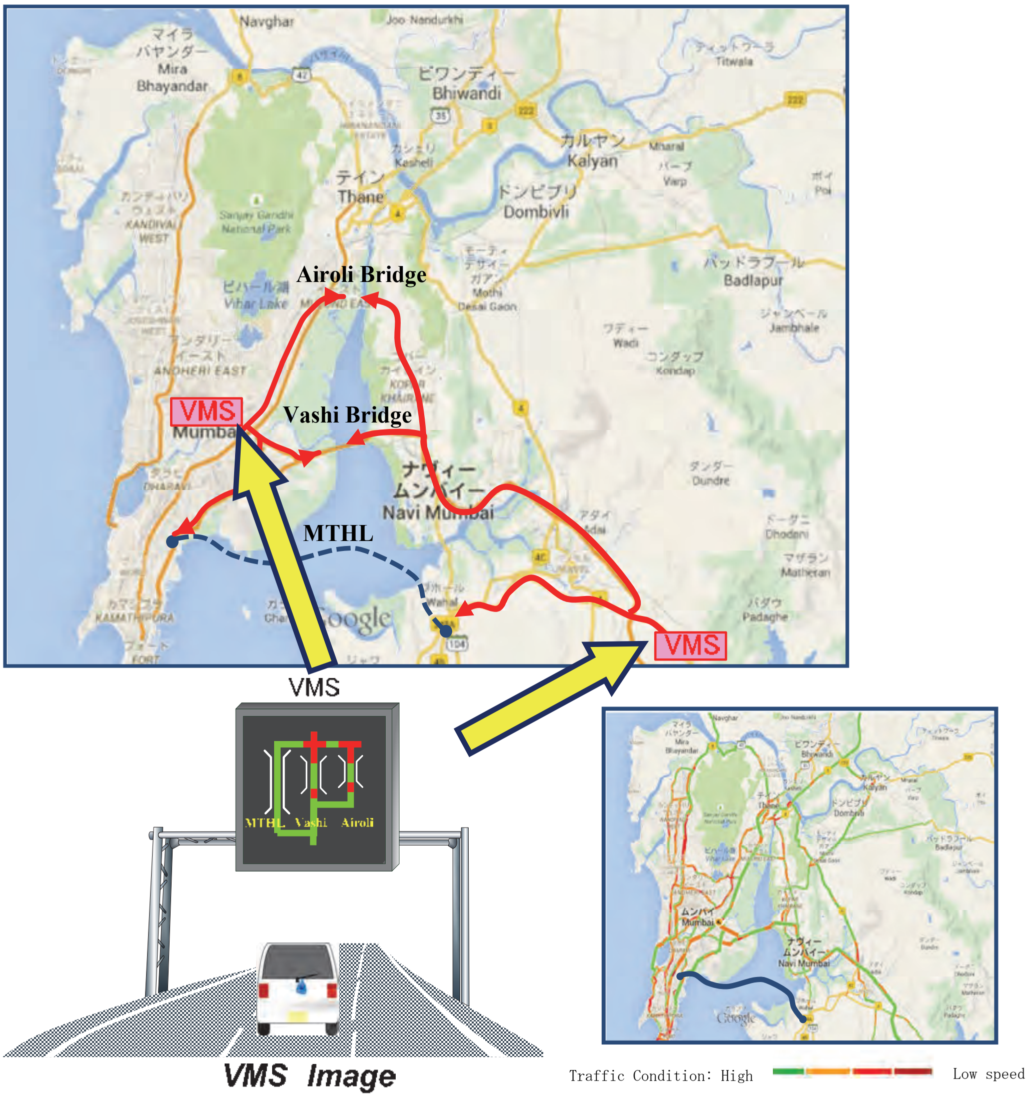
Figure 6.6.12 VMS System (Mumbai)

2) Conception of ITS in Mumbai Metropolitan Region (Recommended)

Access routes between Mumbai and Navi Mumbai will be strengthened by the development of MTHL. Providing traffic information to enable the selection of the most suitable route by road users shall be indispensable to enhance the effect of development. To achieve this, VMSs should be installed in both the Mumbai and Navi Mumbai sides, and it is desirable to promote the road users' selections of routes corresponding to their destinations by providing traffic information of congestion level and expected travel time.

The conception of ITS is summarized as follows;

- To Provide road traffic information in Mumbai to road users
- To plan the dispersion of inflow traffic to Mumbai district by installation of VMS at main intersections
- To Display the traffic condition to VMS (Traffic information such as proven data of commercial vehicles can be purchased from suppliers)



Source: JICA Study Team

Figure 6.6.13 Image of the Conception of ITS in MMR

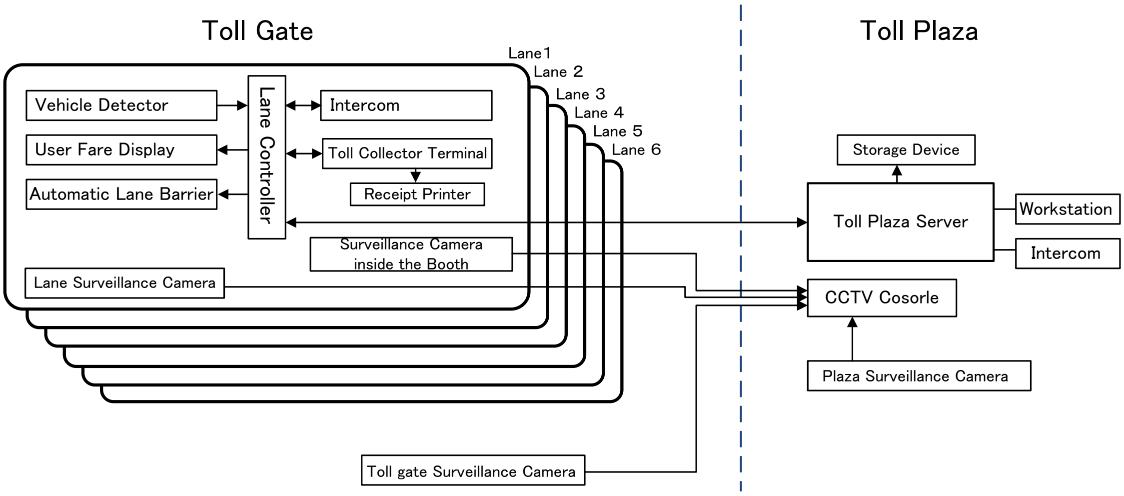
6.6.3 Toll Management System

(1) System Configuration of Toll Management System

The toll management system introduced into MTHL, which is a toll road, shall collect tolls from all road users of MTHL basically. Two types of toll collection methods will be adopted; Electronic Toll Collection (ETC) and Manual (paying by cash).

The lanes corresponding to these toll collection methods are dedicated ETC lanes and Manual lanes, and the Manual lane equipment (cash collection) shall be installed in ETC lanes for backup to be able to cope at the time of the trouble or of ETC equipment failure.

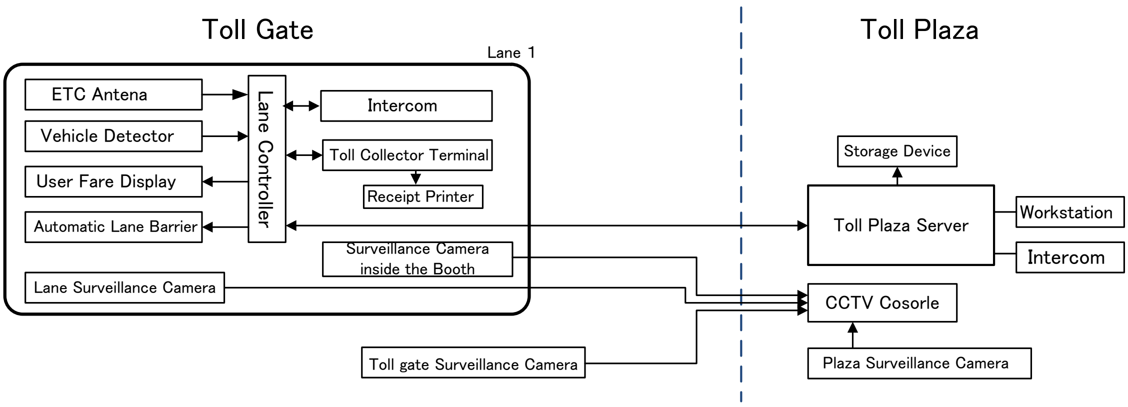
1) Manual Lane System Configuration



Source: JICA Study Team

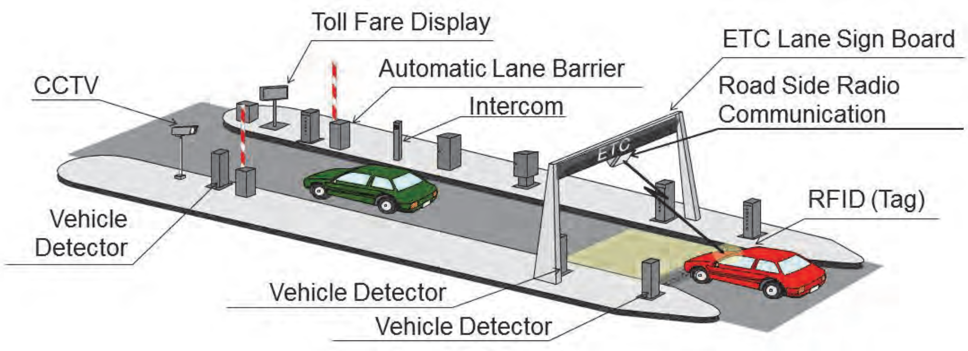
Figure 6.6.14 Manual Lane System Configuration

2) ETC Lane System Configuration



Source: JICA Study Team

Figure 6.6.15 ETC Lane System Configuration



Source: JICA Study Team

Figure 6.6.16 ETC Lane

(2) Lane Equipment

1) Manual Lane Equipment

Table 6.6.5 Manual Lane Equipment

Equipment	Function / Objective
Lane controller	Toll processing in the lane
Toll collector terminal	POS to be controlled by a toll collector
Receipt printer	Issuance of receipt of toll
Intercom	Communication with Toll office
Vehicle detector	Vehicle detection and vehicle classification
User fare display	Display of granting or not granting the permission to pass and the amount of toll
Automatic lane barrier	Controlling of the departure of a vehicle with movable gate bar
Lane surveillance camera	Monitoring of a lane
Booth surveillance camera	Monitoring of a toll collector

2) ETC Lane Equipment

Table 6.6.6 ETC Lane Equipment

Equipment	Function / Objective
Lane controller	Toll processing in the lane
ETC antenna	An Antenna to communicate with on-vehicle equipment for ETC
Toll collector terminal	POS to be controlled by a toll collector
Receipt printer	Issuance of receipt of toll
Intercom	Communication with Toll office
Vehicle detector	Vehicle detection and vehicle classification
User fare display	Display of granting or not granting the permission to pass and the amount of toll
Automatic lane barrier	Controlling of the departure of a vehicle with movable gate bar
Lane surveillance camera	Monitoring of a lane
Booth surveillance camera	Monitoring of a toll collector

3) Toll Plaza Computer System

Table 6.6.7 Toll Plaza Computer System

Equipment	Function / Objective
Toll plaza server	Calculation of the data of each lane
Workstation	A console to operate the above-mentioned server
Intercom	Communication with each lane
Storage device	Storage of data, status and operation logs
CCTV console	Controlling cameras, storage of images
Tollgate surveillance camera	Monitoring of Toll plaza

(3) Number of Required Lanes

The required number of lanes is calculated by considering the traffic volume (the average distance between in-coming vehicles), average service time and the level of the service (expressed as the average number of vehicles in a queue) at the recommended location of the tollgate.

1) Numbers of Vehicles to be processed

Table 6.6.8 shows the maximum number of vehicles to be processed Manually (cash collection) in an hour with given number of lanes based on Service Time and Service Level.

- Service Time is eight seconds as the standard service time for the manual toll collection adopting the flat rate system.
- Service Level is defined as the average number of vehicles waiting in a queue at a tollgate. While the service level of one vehicle per queue is generally used as the standard in Japan, the average number of vehicles waiting in a queue of three shall be adopted for MTHL in consideration of a margin for the processing time and the numbers of vehicles waiting in queues of tollgates in the peripheral toll roads.

Table 6.6.8 Maximum Number of Vehicles to be Processed in an Hour with Given Number of Lanes

(Unit: Vehicles/hour)

	1 lane	2 lanes	3 lanes	4 lanes	5 lanes
Flat-rate toll/ toll collection in cash	340	780	1,230	1,670	2,120

(Service Time: 8 seconds, Average Number of Waiting Vehicles: 3)
Source: Design Standard of East Nippon Expressway Co, Ltd.

Number of vehicles to be processed by ETC shall be 1,200 vehicles/hour based on the IRC Standard (SP99-2013).

2) Utilization Rate of ETC

According to the interviews of the Concessionaires of peripheral toll roads, the utilization rate of ETC was less than 10 % in 2015, and has a tendency to increase. In consideration of this situation, a 1% increase is anticipated every year. The utilization rate of ETC shall be set at 10% in 2022, 20% in 2032 and 30% in 2042.

3) Number of Required Lanes

The required number of lanes is usually calculated from the hourly traffic volume in the peak hours.

(Design hourly traffic volume) = (Annual average daily traffic volume (AADT)) x (Peak Ratio)

The number of the required lanes of each tollgate calculated using traffic at a peak hour in the pricing Case 2 of 2042 is shown in Table 6.6.9.

Table 6.6.9 Number of Required Lanes by Type at Interchange

IC	Toward	Entry /Exit	Required No. of ETC Lanes	Required No. of Manual Lanes	Total No. of required lanes	Remarks
Toll Plaza	Sewri	Entry	1	3	4	Ch19+370
	Chirle	Exit	1	3	4	
Shivaji Nagar	Airport→Sewri	Entry1	1	5	6	Ch17+400
	JNPT→Sewri	Entry2	1	2	3	
	Airport→Chirle	Entry3	1	2	3	
	Sewri→Airport	Exit1	1	5	6	
	Sewri→JNPT	Exit2	1	2	3	
	Chirle→Airport	Exit3	1	2	3	

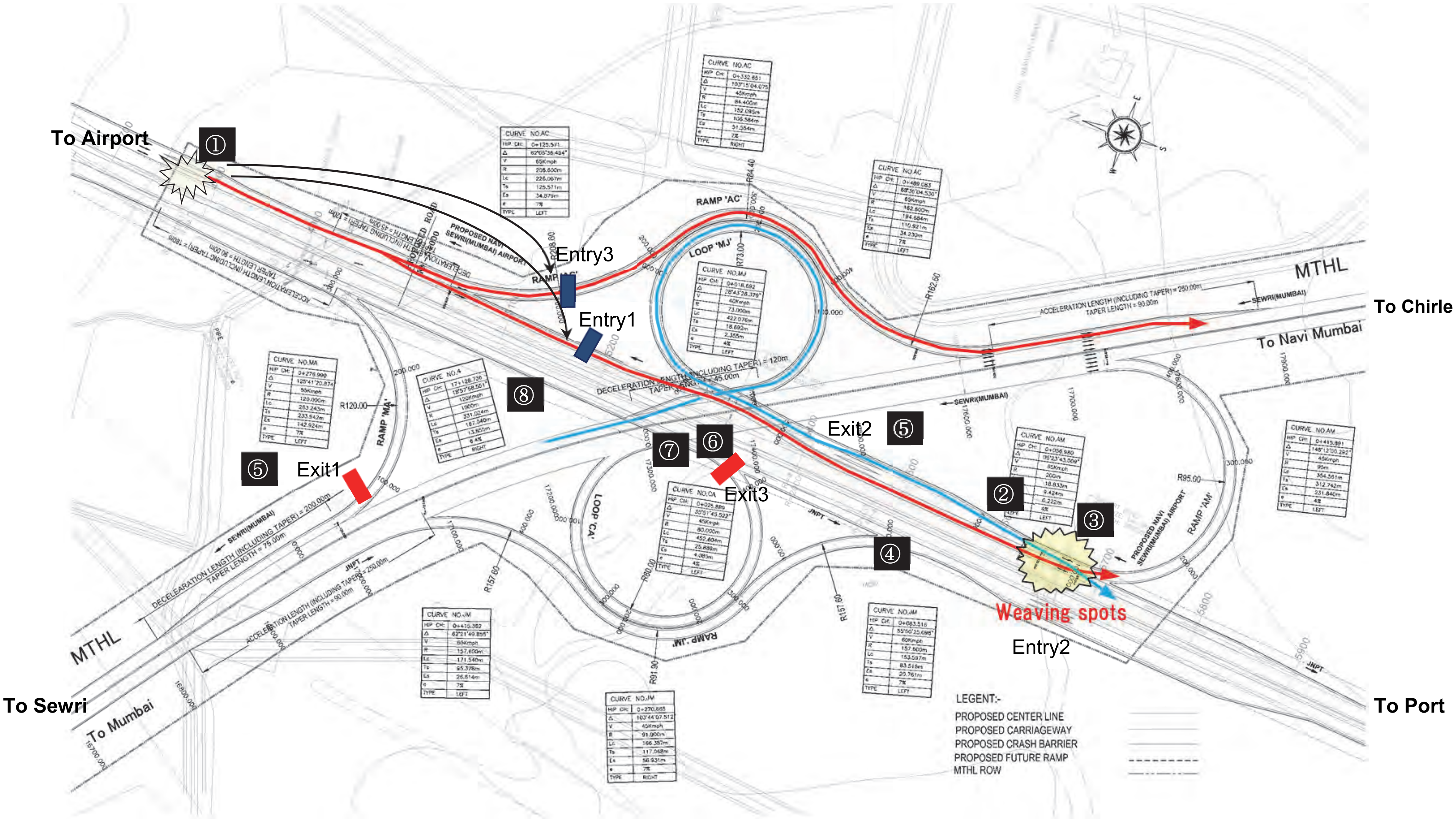
4) Concern of the Black Spot in the Interchange

The Shivajinagar IC (CH:17+400) is the modified clover leaf type. There is a weaving spot (crossing at short distance) at the confluence of the ramp traffic, and there is a concern about it becoming the black spot. There is a point where the traffic flow from the planned road (from the new airport) to MTHL (toward Mumbai) overlaps with the traffic flow from MTHL (from Mumbai) to the planned road (toward JNPT). The arrangement Plan of Shivejinagar IC with the weaving spot is shown in Figure 6.6.17.

Other diverging/merging sections have enough distance to diverge/merge.

And in “a” section (between Sewri and Shivajinagar) and “b” section (between Shivajinagar and Main Toll Plaza), it is thought that the accounting process has some problems.

- Problem ①: It is impossible to determine the driver's destination when he is traveling toward Chirle or Sewri at the Toll Plaza of the existing design.
    - Measure: Toll plaza (Entry) of existing design should be moved to the section of diversion, and the Entry 1 (toward Chirle) and the Entry 3 (toward Sewri) should be established.
- Problem ②③: Weaving Spot occurs.
- Problem ④: After the Entry 2 passage, drivers can go straight on without flowing into the ramp.
    - Measure: The route going straight after the Entry 2 passage should be closed.
- Problem ⑤: It is impossible to collect tolls for the section (from Sewri to Airport) at the Toll Plaza (Exit 2) of the existing design.
    - The Exit 1 (from Sewri to the Airport) should be established.
- Problem ⑥: It is impossible to determine the driver's destination which could be either Shivajinagar or Sewri coming from Chirle at the Main Toll Plaza.
    - Measure: The Exit 3 (from Chirle to the Airport) should be established. The toll for all sections (from Chirle to Sewri) shall be collected at the Main Toll Plaza, and the balance should be refunded in Exit 3.
- Problem ⑦: It is necessary to prepare for cash to refund in Exit 3 and would be difficult in operation.
- Problem ⑧: The location of the Toll Office and the passages for Toll collectors at Shivajinagar IC need to be considered.
- Supplementary: Manual lane of the Entry 3 issues entry tickets, and the toll shall be collected at the Main Toll Plaza.



Source: Study Team

Figure 6.6.17 Arrangement Plan at Shivajinagar IC (Reference)

(4) Toll Management System Cost Estimation

Table 6.6.10 shows the rough estimated cost of the Toll Management System.

Table 6.6.10 Rough Estimated Cost of Toll Management System

	Item	Estimated amount (in million INR)	Year of expenditure
1	Toll Management System	204	The completion year of the construction and every 10 years thereafter for renewal

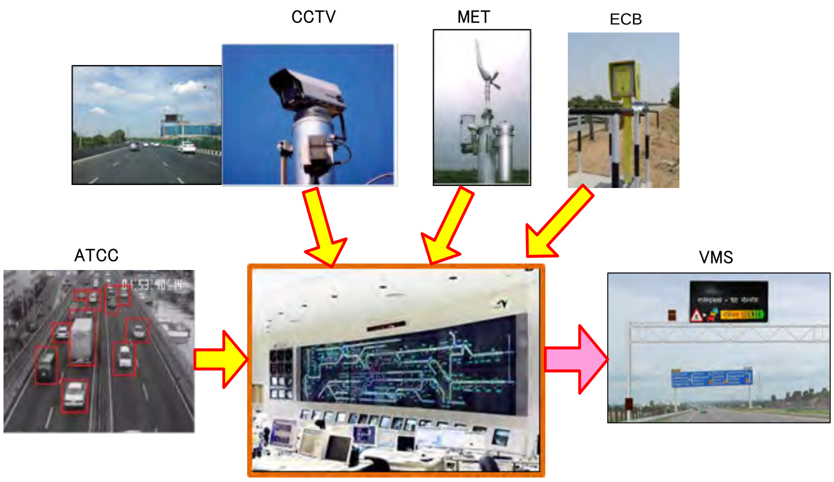
Source: JICA Study Team

6.6.4 Traffic Management System

(1) Outline of Traffic Management System

The Traffic Management System is a support system to manage the traffic on MTHL safely and efficiently. The conceptual system configuration is shown in Figure 6.6.18. The system consists of the Information collection system including CCTV, Emergency Call Box (ECB), Automatic Traffic Counter-cum-Classifier (ATCC) and Meteorological Observation System (MET), and the Information Dissemination System including Variable Message Signs (WMS).

CCTV cameras shall be installed at about three places per kilometre, on both sides of the main route, and the monitoring of the traffic condition of almost all of MTHL will be done in the Traffic Control Centre. In addition, the information of ECB, MET and ATCC is also collected in the Traffic Control Centre and VMS displays the appropriate information for road users based on the collected information. The information collected by these devices is transmitted to the Traffic Control Centre through the medium of an optical fibre cable laid in MTHL.



Source: JICA Study Team

Figure 6.6.18 Conceptual System Configuration

(2) Facility for Traffic Control

1) Information Collection System and Information Dissemination System

Table 6.6.11 Information Collection System and Information Dissemination System

Facility	Objective / Function
CCTV : on-road (Closed Circuit Television)	- Monitoring of traffic condition, traffic congestion and accidents, etc. - Operation such as zoom and turning by the remote control function from the traffic control center
CCTV : under-girder (Closed Circuit Television)	- Monitoring of security under the bridge
MET (Meteorological Observation System)	- Monitoring of weather condition of Mumbai bay - Precipitation, fog, wind direction, wind velocity
ECB (Emergency Call Box)	- Report support system to the traffic control center at the time of the first aid in a disaster, trouble and accidents, etc.
ATCC (Automatic Traffic Counter-cum-Classifier)	- Measurement of traffic volume - Classification of vehicle type
VMS (Variable Message Sign)	- Dissemination of information such as road condition and weather condition

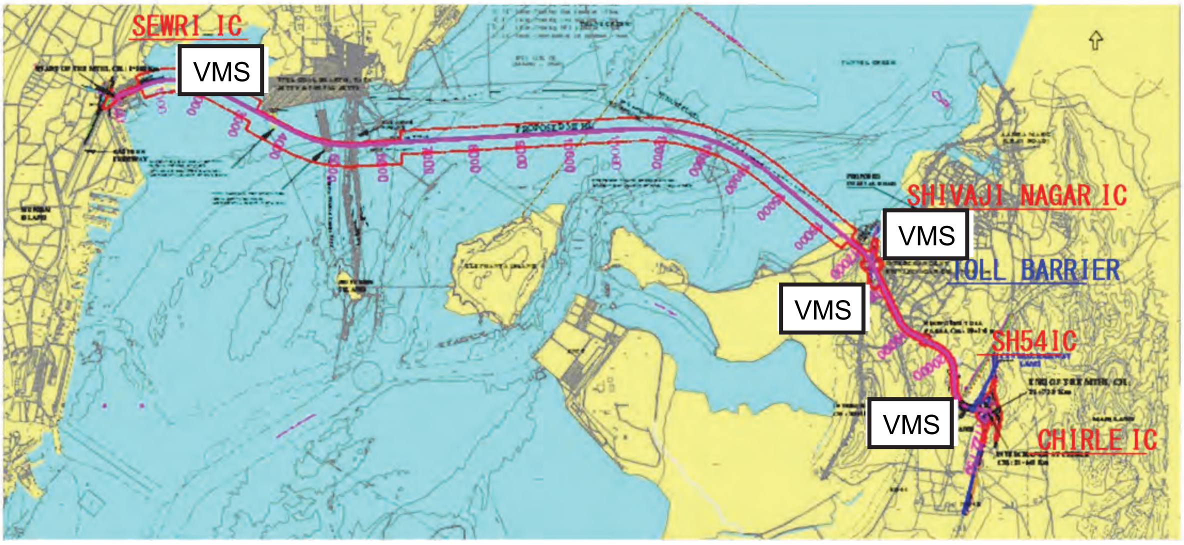
2) Facility Deployment Plan

The deployment plan of the road side facilities shall be planned based on the situation of similar roads mentioned in 6.6.2 and the discussion with MMRDA.

Table 6.6.12 Deployment Plan of Road Side Facilities

Facility	Quantity	Interval	Location
CCTV: on-road	132	Approx. 333 m	Road side
CCTV: under-girder	22	Approx. 1 km	Under slab of median
ECB	44	Approx. 1 km	Road side
VMS	4	—	Entrance of toll plaza After getting on toll road /Sewri side
MET	3	Approx. 7 km	Road side
ATCC	4	—	Between Sewri IC and Shivajinagar IC/each direction Between Shivajinagar IC and SH54 IC/each direction

VMSs shall be installed in the inflow section from Sewri side, Chirle side and Shivajinagar IC according to Figure 6.6.19, and disseminate the road information of MTHL. VMSs shall be planned not to be installed in the bridge intermediate section and the direction leaving outward from MTHL. This is because the information dissemination in the bridge intermediate section is to inform the drivers, and there is no information that can assist the drivers leaving outward from MTHL in making informed decisions regarding optimum route selection or driving pattern.

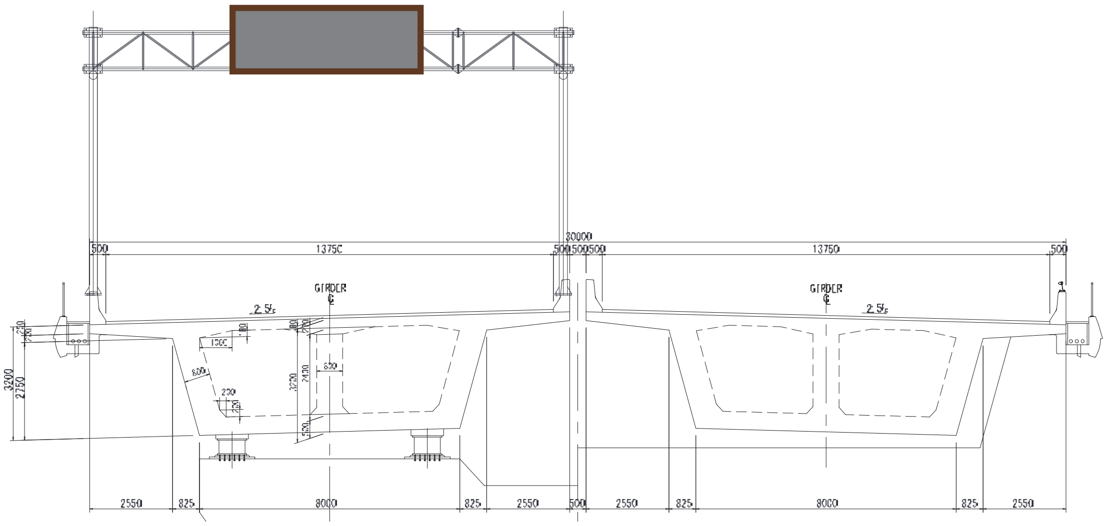


Source: JICA Study Team

Figure 6.6.19 Locations for the Installation of VMS (Recommended)

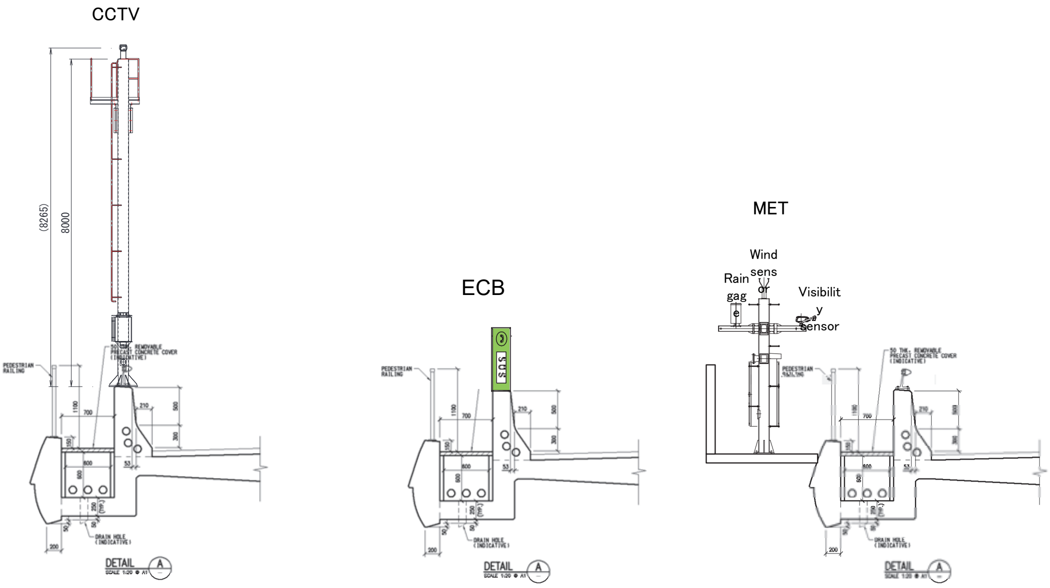
3) Installation

The installation images of each facility in the bridge part are shown below.



Source: JICA Study Team

Figure 6.6.20 Installation Image of VMS (Recommended)



Source: JICA Study Team

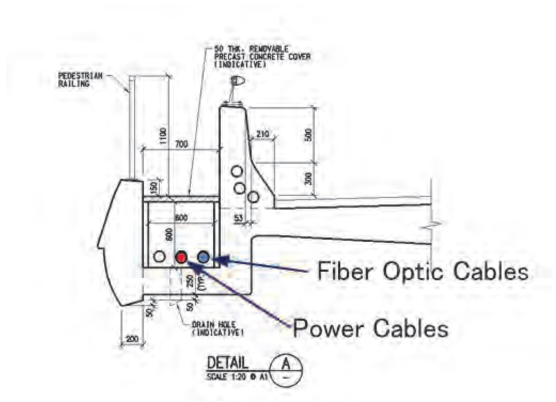
Figure 6.6.21 Installation Image of CCTV, ECB, MET (Recommended)

4) Optical Fibre Cable

MTHL's original communication line shall be installed by laying optical fibre cables on both sides of the road without using the communication carrier for the communication between the road side facilities and Traffic Control Centre, because nearly the entire line of MTHL consists of bridge structure over the Mumbai Bay.

5) Power Cable

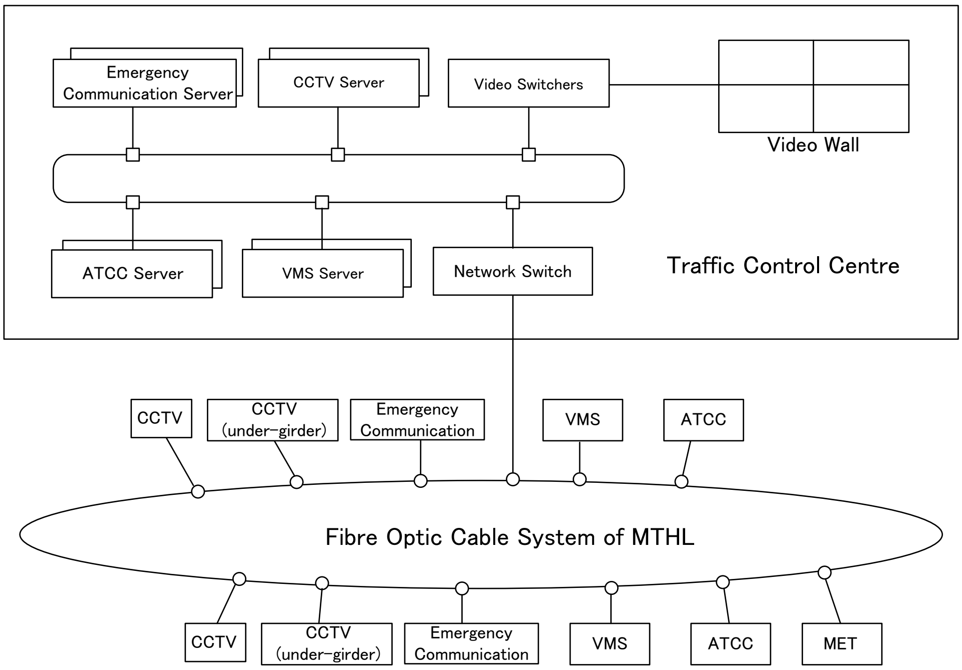
Electric power for the road facilities shall be supplied from the Mumbai side and the Navi Mumbai side because nearly the entire line of MTHL is bridge section as mentioned above. In addition, it is necessary to install generators in both the Mumbai side and Navi Mumbai side as the backup power source at the time of power failure.



Source: JICA Study Team

Figure 6.6.22 Laying Location of Cables (Recommended)

(3) System Configuration of Toll Management System



Source: JICA Study Team

Figure 6.6.23 Toll Management System Configuration

(4) Traffic Management System Cost Estimation

Table 6.6.13 shows the rough estimated cost of the Traffic Management System.

Table 6.6.13 Rough Estimated Cost of Traffic Management System

	Item	Estimated amount (in million INR)	Year of expenditure
1	Traffic Management System	475	The completion year of the construction and every 10 years thereafter for renewal

Source: JICA Study Team

6.7 Safety and security Considerations

6.7.1 Introduction

The purpose of this chapter is to review the vulnerability of the MTHL to threats, to consider how to provide a reasonable level of resilience.

This chapter considers the physical and operational vulnerability and risk mitigation measures to three types of threat such as terrorism, crime and civil disruption.

The chapter consists of the following three parts:

- Identify the likely threat to the project by carrying out a threat assessment.
- Review the resilience measures required to counteract the potential threat.
- Safety and Security measures to be installed in MTHL.

6.7.2 Threats assessment

(1) Terrorism

There is a high probability for terrorist attack in India with several incidents occurring in the recent past. Although there is no evidence that bridges are being targeted for terrorist attacks in India, the past international experience suggests that bridges are targeted for reasons of symbolism, disruption and significant impact to the national and local economies.

MTHL is a strategic linkage and plays an important role to connect to the new international airport and its importance for the future prosperity of greater Mumbai makes it a potential target. Any act of terrorism made against the bridge structure, buildings, operational systems and staff represents a high impact threat to the operation of the bridge. Countermeasures should be adopted to avoid the threat or militate against any consequences of an action.

(2) Crime

Bridges tend to be exposed to criminal threats. Those criminal threats likely to generate the highest levels of risk are indicated in the following table:

Table 6.7.1 Main Criminal Threats for MTHL

Criminal Threat	Threat Analysis
Graffiti / Petty Vandalism	Graffiti / Petty Vandalism represent a low-impact criminal threat but may place a continual management and maintenance burden on the bridge operators. Failure to rapidly repair the damage caused by graffiti and petty vandalism has been shown to act as a catalyst for further criminal damage and is likely to identify the MTHL as an attractive target or location for more serious criminal activities. Graffiti and petty vandalism may target the bridge structure and / or personal or commercial property located in and around the structure. Depending on the nature of the criminal damage, the health and safety of the offenders -as well as bridge users- may be threatened (e.g. an individual on the carriageway may present a danger to traffic)
Arson	It has the potential to represent a significant threat to the MTHL
Sabotage	It is possible that an individual intent on disrupting bridge security and safety operations could sabotage security and safety systems.
Theft	The MTHL will be exposed to a threat of acquisitive crime perpetrated by both opportunist and more organised offenders due to its potential accommodation of valuable items (including personal property, parked motor vehicles, office and IT equipment). The MTHL is likely to accommodate (in, for example, the substation compounds and maintenance zones) building and maintenance materials, metals, plant equipment and machinery. Such items are increasingly being targeted by criminals due to their residual value on the black market. While MTHL management may be able to transfer some of the financial implications of these threats through, for example, insurance, or by making contractors responsible for their own property, it is likely to retain a degree of management burden, indirect cost and operational disruption (e.g. delay in maintenance works)
Violence/ Against the Person	Although it is not envisaged that MTHL staff, visitors or contractors will be involved in any activities that would be likely to raise their exposure to violence above ambient levels, best practice measures commensurate with the local threat environment and those deployed at similar facilities are recommended to mitigate this threat.
Trespass	Trespass has the potential to represent an important threat to the MTHL and its operations. Trespass may be the precursor to more serious criminal offences, such as criminal damage or theft, or it may be the result of individuals loitering or attempting to, for example, walk across the bridge. Individuals trespassing on the carriageway may present a significant safety risk to passing traffic as well as themselves. Preventing trespass through access control and intruder detection and surveillance systems represents one of the principal mechanisms for mitigating criminal and terrorist threats.

Source: JICA Study Team

(3) Civil Disruption

There have been a number of cases of protests and civil unrest in India such as demonstrations. However, they have not specifically targeted bridge structures.

6.7.3 Requirements for Threats

The following show the general requirements for threats.

(1) Terrorism

Robust structures with solid piers shall be provided. Provide barriers to vehicle entry at abutment and substations. CCTV entry recorded.

(2) Crime

Deter entry and provide barriers to entry at toll plaza buildings, abutments and substations.

(3) Civil Disruption

Measures to prevent access to attractive areas of occupation for protests

6.7.4 Safety and Security measures to be installed

The Security Plan (safety and security measures) has been developed to mitigate the threats and risks identified in pevious sub-chapters.

(1) Access Management

CCTV cameras shall be installed at three locations at 1 km interval for each bound and Traffic Control Center will keep under surveillance aginst intruders or suspisous objects by using CCTV cameras. In addition, CCTV camaras are also to be installed under the bridge superstructure at 1km interval for surveillance. Depending the situations, both patrol vehicle and boat shall be sent to the site. Further details are indicated in Chapter 6.6.4.

Whereas inspection paths shall be installed around the pier tops for PC bridge secions, movable insptaction equipement for the steel bridge sections

(2) Installation of View Barriers

A view barrier shall be installed in order to prevent the view of Bhabha Atmic Research Center located in the northern side of MHTL from car users along the road, which ranges from CH4+000 to CH10+000, totalling of 6km in length.

(3) Installation of Safety Fence

A safety fence with 3m in hight shall be installed at navigation channels, crossing roads and railways in order to avoid unlawful damping from MTHL.

(4) Median Opening

A median opening shall be installed at the median at every 3km for dealing with vehicles in the emergency case.

(5) Consideration of Bridge Structure

Each bound of MTHL bridge is structurally separated to minimize the terrorist attack in case.

MTHL comprises PC box girder type and steel box one and the application of PC box type is superior to steel bridge in case of small scale of treats and terrorism. However, incae that the attack to PC bridge causes the break of PC cables, replacement of PC superstructure should be required and it is impossible to restore the bridge function with minor repairs. On the one hand, the attack to steel bridge sections may cause a minor damages and it is possible to restore the bridge function with minor repairs. Furthremore, although a simple superstructure system for bridge shall be superior to the continuous system of bridge in consideration of terroist attacks to MTHL, the continuous superstructure system was eventually applied from the viewponts of stability against earthquake, cosntructure cost and mainatence cost.

7. CONSTRUCTION PLANNING

7.1 Introduction

In this chapter, construction method, procurement plan, contract package, and a rough construction schedule are described. The point unlike the previous construction plan in 2012 is application of the large-block erection of the steel girders. The following advantages are gained by applying the large-block erection of the steel girders, which are lighter than concrete girders.

- Construction period can be shortened.
- Site safety can be improved. (It can decrease the period of construction at the site.)
- Quality control can be improved. (Steel girders will be fabricated at a factory.)

As for the construction period, it can be shortened by approximately 1.5 years in comparison with the previous study in 2012 by applying the steel box girder with steel slab for long span sections and reviewing the whole construction schedule.

The construction schedule is tight. Therefore, after the commencement of the construction it is necessary to carry out the following in parallel promptly.

- Detailed design
- Preparation work (material order, levelling and additional purchasing of construction yards, etc.)
- Obtain construction permissions from related authorities
- Establishment of construction plan
- Soil investigation at each pier location (confirmation of bearing layer)
- Confirmation of natural conditions
- Confirmation and obtaining permission for the crossing structures such as pipelines and ship navigation
- Detour plan during the construction on land
- Grasp of environmental impact on surroundings

As for the contract package, it will be recommended in consideration of various kinds of conditions to secure the smooth and effective construction and construction supervision.

7.2 Construction Methodology

7.2.1 Construction Overview

Summary of the construction is shown below.

Table 7.2.1 Summary of the Construction - 1/6: Main Alignment

Construction Environment	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Pier No.	Substructure Type Foundation Type
	Start	End			
Typical Marine Section	0+495	1+045	PC Box Girder (Span-by-Span)	MP1 (0+495) MP12 (1+045)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
	1+045	3+395		MP13 (1+095) MP58 (3+345)	
Special Marine Section	3+395	3+715	Steel Box Girder with Steel Slab (Large Block Erection)	MP59 (3+395) MP62 (3+715)	Wall Pier: Voided Rectangular Pile: ϕ2,400 (in situ)
Typical Marine Section	3+715	4+625	PC Box Girder (Span-by-Span)	MP63 (3+765) MP80 (4+585)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Special Marine Section	4+625	6+078	Steel Box Girder with Steel Slab (Large Block Erection)	MP81 (4+625) MP93 (6+078)	Wall Pier: Voided Rectangular Pile: ϕ2,400 (in situ)
Typical Marine Section	6+078	8+620	PC Box Girder (Span-by-Span)	MP94 (6+128) MP143 (8+574)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Special Marine Section	8+620	9+180	Steel Box Girder with Steel Slab (Large Block Erection)	MP144 (8+620) MP148 (9+180)	Wall Pier: Voided Rectangular Pile: ϕ2,400 (in situ)
Typical Marine Section	9+180	11+880	PC Box Girder (Span-by-Span)	MP149 (9+230) MP201 (11+830)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Special Marine Section	11+880L	13+610L	Steel Box Girder with Steel Slab (Large Block Erection)	MP202 (11+880)L MP217 (13+610)L	Wall Pier: Voided Rectangular Pile: ϕ2,400 (in situ)
	11+880R	13+610R		MP202 (11+880)R MP217 (13+610)R	
Typical Marine Section	13+610	16+610	PC Box Girder (Span-by-Span)	MP218 (13+660) MP276 (16+560)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Mangrove Section	16+610	16+840	PC Box Girder (Span-by-Span)	MP277 (16+610) MP281 (16+800)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Road Crossing Section	16+840	16+880	PC Box Girder (Span-by-Span)	MP282 (16+840) MP283 (16+880)	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
Mangrove Section	16+880L	17+320L	PC Box Girder (Span-by-Span)	MP284 (16+925)L MP292 (17+270)L	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
	16+880R	17+341R		MP284 (16+925)R MP293 (17+320)R	
Road Overbridge	17+320L	17+517L	PC Box Girder (Span-by-Span)	MP293 (17+320)L MP296 (17+471)L	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
	17+341R	17+517R		MP294 (17+341)R MP297 (17+482)R	
Mangrove Section	17+517L	18+087L	PC Box Girder (Crane Full Span)	MP298(17+517)L MP317(18+062)L	Column Pier: ϕ2,500 Pile: ϕ2,000 (in situ)
	17+517R	18+087R		MP298(17+517)R MP317(18+062)R	

Source: JICA Study Team

Table 7.2.2 Summary of the Construction - 2/6: Main Alignment

Construction Environment	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Pier No.	Substructure Type Foundation Type
	Start	End			
Road Overbridge	18+087	18+127	PC Box Girder (Full Staging)	MP318 (18+087) MP319 (18+127)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	18+127	18+187	PC Box Girder (Crane Full Span)	MP320 (18+157) MP321 (18+187)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	18+187	18+217	PC Box Girder (Crane Full Span)	MP322 (18+217)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	18+217	18+317	PC Box Girder (Crane Full Span)	MP323 (18+247) MP325 (18+297)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	18+317	18+357	PC Box Girder (Full Staging)	MP326 (18+317) MP327 (18+357)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	18+357	18+424	PC Box Girder (Full Staging)	MP328 (18+387)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Railway Overbridge	18+424	18+492	Steel Truss (Crane Full Span)	MP329 (18+424) MP330 (18+492)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	18+492L	18+574L	PC Box Girder (Full Staging)	MP331 (18+530)L MP332 (18+574)L	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
	18+492R	18+554R		MP331 (18+530)R MP332 (18+554)R	
Road Overbridge	18+574L	18+644L	PC Box Girder (Full Staging)	MP333 (18+610)L MP334 (18+644)L	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
	18+554R	18+644R		MP333 (18+595)R MP334 (18+644)R	
Typical Land Section	18+644	18+884	PC Box Girder (Crane Full Span)	MP335 (18+675) MP342 (18+884)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	18+884	18+929	PC Box Girder (Full Staging)	MA2(18+930)	Inverted T Abutment Pile: ϕ1,000 (in situ)
Earthworks Section	18+929	20+070			
Typical Land Section	20+070	20+225	PC Box Girder (Crane Full Span)	LA1 (20+070) LP4(20+190)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	20+225	20+260	PC Box Girder (Crane Full Span)	LP5(20+225) LP6(20+260)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	20+260	21+009	PC Box Girder (Crane Full Span)	LP7(20+295) LP30(20+085)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	21+009	21+079	PC Box Girder (Crane Full Span)	LP31(21+009) LP33(21+079)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	21+079	21+228	PC Box Girder (Crane Full Span)	LP34(21+109) LP37(21+199)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Railway Overbridge	21+228	21+423	Steel Truss (Crane Full Span)	LP38(21+228) LP41(21+423)	Column Pier: ϕ3,250 Pile: ϕ1,500 (in situ)
Typical Land Section	21+423	21+659	PC Box Girder (Crane Full Span)	LP42(21+449) LP49(21+659)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Road Overbridge	21+659	21+729	PC Box Girder (Crane Full Span)	LP50(21+695) LP51(21+729)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)
Typical Land Section	21+729	21+834	PC Box Girder (Crane Full Span)	LP52(21+764) LP54(21+834)	Column Pier: ϕ2,500 Pile: ϕ1,200 (in situ)

Source: JICA Study Team

Table 7.2.3 Summary of the Construction - 3/6: Sewri IC

Sewri Interchange	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Substructure Type	Foundation Type
	Start	End			
Ramp A	Sewri	0+495	PC Box Girder (Crane Full Span / Full Staging)	Hammer Head Pier	Pile: ϕ1,200; ϕ1,500 (in situ)
Ramp B				Hammer Head Pier	Pile: ϕ1,200 (in situ)
Ramp C1				Wall Pier	Pile: ϕ1,000; ϕ1,200 (in situ)
				Straddle Bent	Pile: ϕ1,200 (in situ)
Ramp E				Hammer Head Pier	Pile: ϕ1,200 (in situ)
Ramp C2					
Ramp F					
Ramp EW					

Source: JICA Study Team

Table 7.2.4 Summary of the Construction - 4/6: Shivaji Nagar IC

Shivaji Nagar Interchange	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Substructure Type	Foundation Type
	Start	End			
Ramp JM	17+105	---	RC Voided Slab (Full Staging)	Inverted T Abutment Column Pier: ϕ2,000	Pile: ϕ1,000 (in situ)
Ramp MA	17+125	---			
Ramp CA	17+320	---			
Ramp MJ	17+471	---			
Ramp AM	17+797	---			
Ramp AC	17+617	---			

Source: JICA Study Team

Table 7.2.5 Summary of the Construction - 5/6: SH54 IC

SH 54 Interchange	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Substructure Type	Foundation Type
	Start	End			
Ramp MP	20+355	---	PC Box Girder (Crane Full Span)	Inverted T Abutment Column Pier: ϕ2,500	Pile: ϕ1,000; ϕ1,200 (in situ)
Ramp JM	20+355	---			

Source: JICA Study Team

Table 7.2.6 Summary of the Construction - 6/6: Chirle IC

Chirle Interchange	Construction Overview				
	Chainage		Superstructure Type (Construction Method)	Substructure Type	Foundation Type
	Start	End			
Ramp MP	21+228	---	Steel Truss (Crane+Bent Constr.)	Column Pier: ϕ3,250	Pile: ϕ1,500 (in situ)
			RC Voided Slab (Full Staging)	Inverted T Abutment Column Pier: ϕ2,000	Pile: ϕ1,000 (in situ)
Ramp JM	21+228	---	Steel Truss (Crane+Bent Constr.)	Column Pier: ϕ3,250	Pile: ϕ1,500 (in situ)
			RC Voided Slab (Full Staging)	Inverted T Abutment Column Pier: ϕ2,000	Pile: ϕ1,000 (in situ)
Ramp MJ	21+834	---	RC Voided Slab (Full Staging)	Inverted T Abutment Column Pier: ϕ2,000	Pile: ϕ1,000 (in situ)
Ramp PM	21+834	---	RC Voided Slab (Full Staging)	Inverted T Abutment Column Pier: ϕ2,000	Pile: ϕ1,000 (in situ)

Source: JICA Study Team

7.2.2 Construction Method

For this project, general construction methods for earthworks, pavement and road facilities were considered. In this section, special construction methods are described briefly.

(1) Foundations

Cast in situ piles will be used on the bridge foundations. The geological strata in the project region can be roughly described as: cohesive soil in the surface, sand, gravel, weathered basalt and hard basalt (or breccia). In some regions the basalt layer thickness is greater than 10 m. For cast in situ pile construction an all-casing method is recommended.

1) Land Portion

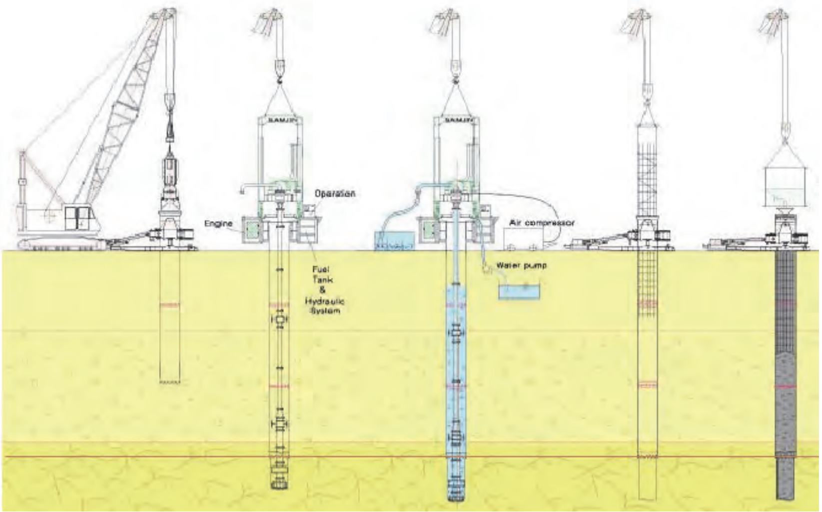


Figure 7.2.1 Steps for Cast in Situ Pile Construction on the Land Portion

For the land portion, the piles will be constructed using an all-casing method with rock bit drilling equipment, according to the following steps:

- Set the casing oscillator in the horizontal position ensuring that the centre of the steel casing matches the pile centre.
- Excavate the cohesive sand and gravel layer inside the casing pipe using a hammer grab. Rotators shall press down on the steel casing during the excavation to avoid hole collapse.
- Hammer grab is replaced by rock bit drilling equipment. Fresh water is used as the drilling fluid, while rock cuttings are brought to the surface using a vacuum pump system.
- After achieving the bearing layer capacity, socketing in rock according to the specified length.
- Lowering the reinforcement cage.
- Insert the tremie pipe.
- Pump the concrete while slowly removing the casing and the tremie pipe.

2) Marine Portion (over Temporary Jetty)

Figure 7.2.2 Example of Cast in Situ Pile Using a Temporary Jetty

For the temporary jetty portion, the piles will be constructed using an all-casing method with rock bit drilling equipment, according to the following steps:

- On the temporary jetty, set the crane with the installed vibro hammer in the horizontal position , ensuring that the centre of the steel casing matches the pile centre.
- Install the steel casing.
- Excavate the soft layers using a hammer grab.
- The next steps are the same as the land portion.

3) Marine Portion (over Barge)

Figure 7.2.3 Example of Cast in Situ Pile in the Marine Portion

For the marine portion, the piles will be constructed using an all-casing method with rock bit drilling equipment, according to the following steps:

- On a spud barge, set the crane with the installed vibro hammer in the horizontal position, ensuring that the centre of the steel casing matches the pile centre.
- Install the steel casing.
- Excavate the soft layers using a hammer grab.
- The next steps are the same as the land portion.

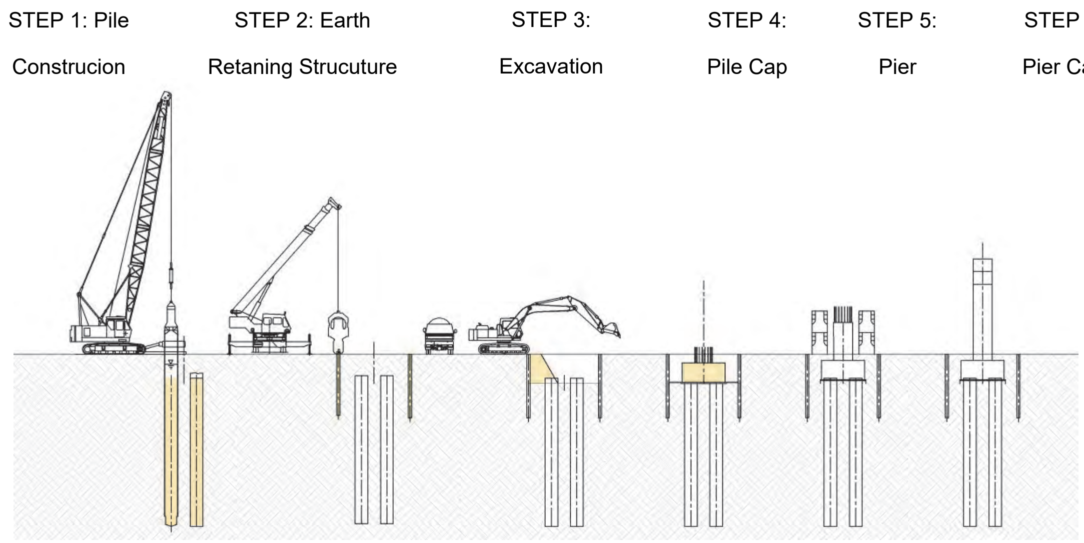
(2) Substructure

After completing the pile construction, the substructure will be constructed in the following order: pile cap (in the temporary jetty and marine portion a precast shell will be used), scaffolding, formwork & reinforcement assembling, and fresh concrete casting. After the concreting, remove the formwork. For abutments, the last step is backfill.

Ground improvement treatment is necessary in weak and compressible soil areas, the implemented method should be based on ground settlement measures and boring investigations. The abutment construction should only start after checking if the residual ground settlement and the ground strength measurements are according to the design specifications.

1) Land Portion

Manly, the open excavation method will be used in the land portion for building the pile cap. In the Serwi Interchange area it will be necessary to use sheet piles for the excavation due to the proximity of the existing road and other structures. Struts may be necessary if the excavation is deeper than 3 meters. The construction steps in the areas where earth retaining structures are necessary are shown in Figure 7.2.4.

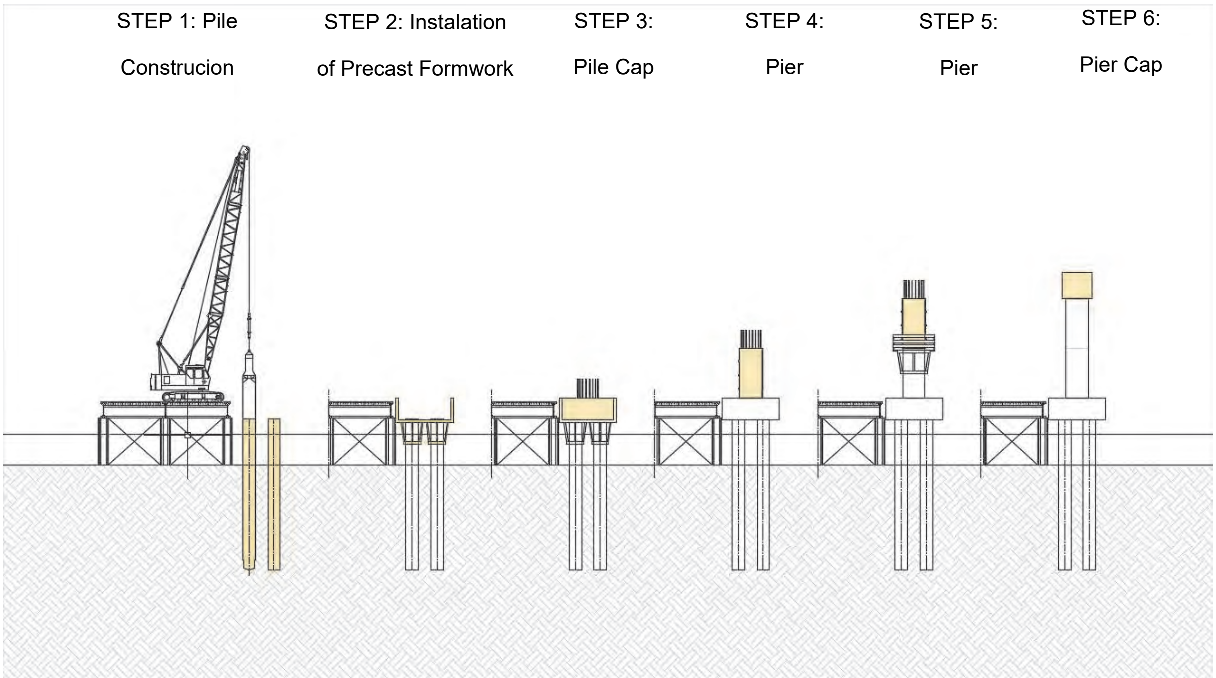


Source: JICA Study Team

Figure 7.2.4 Steps for Substructure Construction on the Land Portion

2) Marine Portion (over Temporary Jetty)

Materials necessary for construction of the substructure can be supplied from the land side (by trucks) or from the marine side (by barges). After the construction of the piles, the pile cap is constructed using a precast formwork. Then the scaffold is installed and the pier and pier cap are erected. Construction in the marine portion over the temporary jetty is shown in Figure 7.2.5.

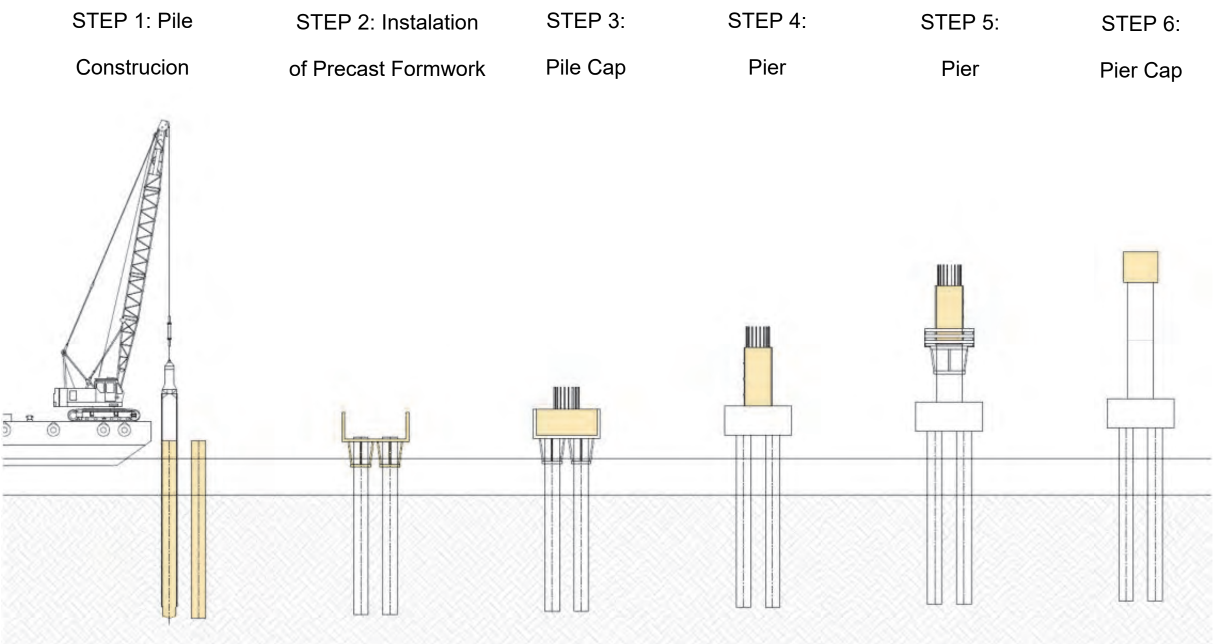


Source: JICA Study Team

Figure 7.2.5 Substructure Construction Step over Temporary Jetty (Pile Bent)

3) Marine Portion (over Barge)

In the marine portion, the construction will be executed mainly over barges. The construction steps are basically the same as the construction over the temporary jetty. The construction using a floating concrete plant and barges to transport the material need to be evaluated specially in the monsoon period. Construction in the marine portion over the barge is shown in Figure 7.2.6.



Source: JICA Study Team

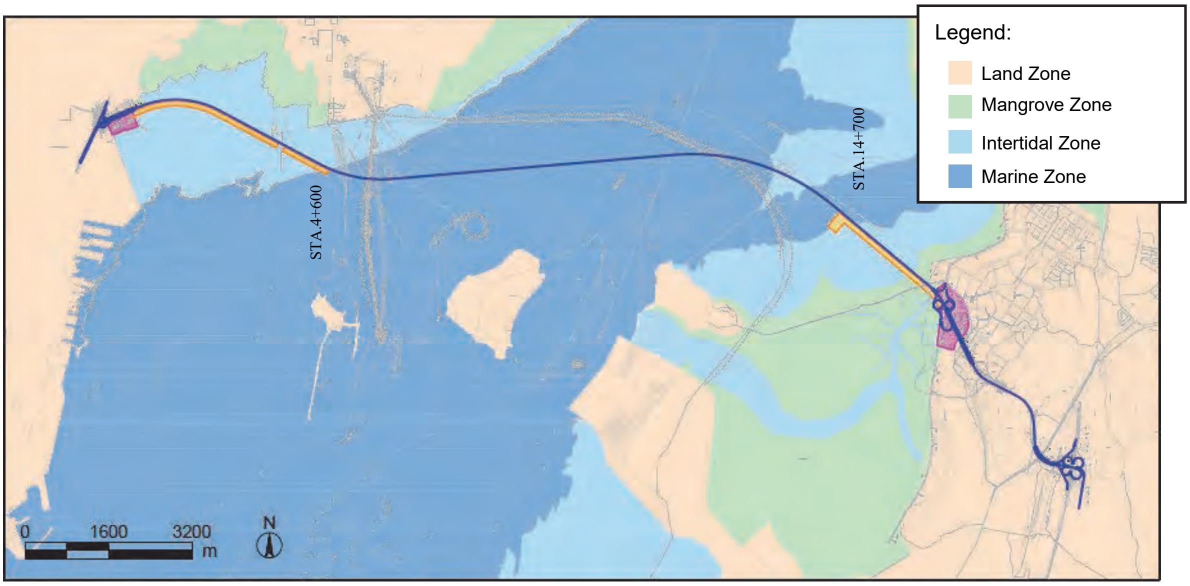
Figure 7.2.6 Substructure Construction Step over Barge (Pile Cap)

7.2.3 Temporary Jetty Plan

(1) Overall Plan

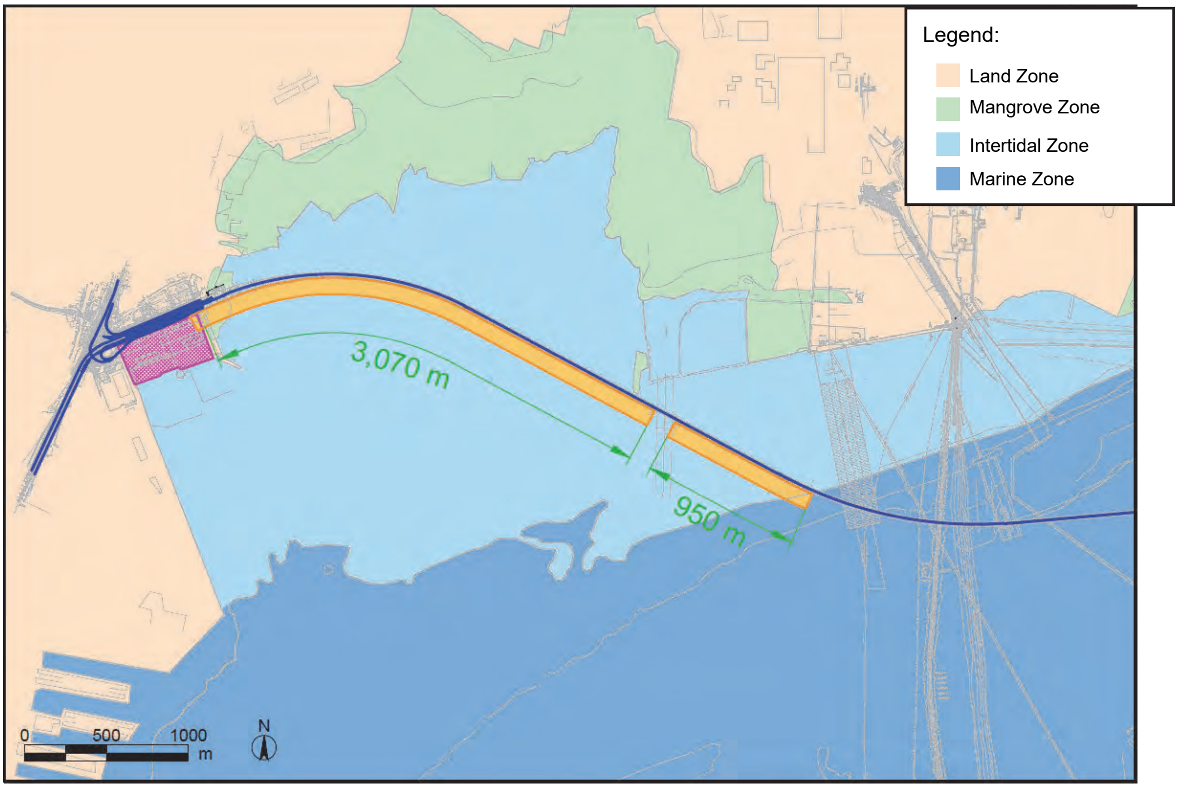
1) Outline

A temporary road shall be considered for the intertidal section on the Mumbai and Navi Mumbai sides. On the Mumbai side, a temporary jetty, which is approximately 4.0 km long, will be provided from Sewri shore up to CH.4+600 ; on the Navi Mumbai side, a temporary jetty, which is approximately 2.75 km long will be provided from CH.14+700 to Shivaji Nagar Interchange (CH.17+450). Considering the cost and construction time aspects is recommended that a temporary road on the embankment be provided. The area habited by flamingos is a sensitive mangrove ecosystem, so a temporary jetty is a more suitable alternative. Furthermore, the position of the jetty pile foundation should be carefully considered to allow the passage of small fishing boats. The temporary jetty outline plan is shown in the Figure 7.2.7 to Figure 7.2.9.



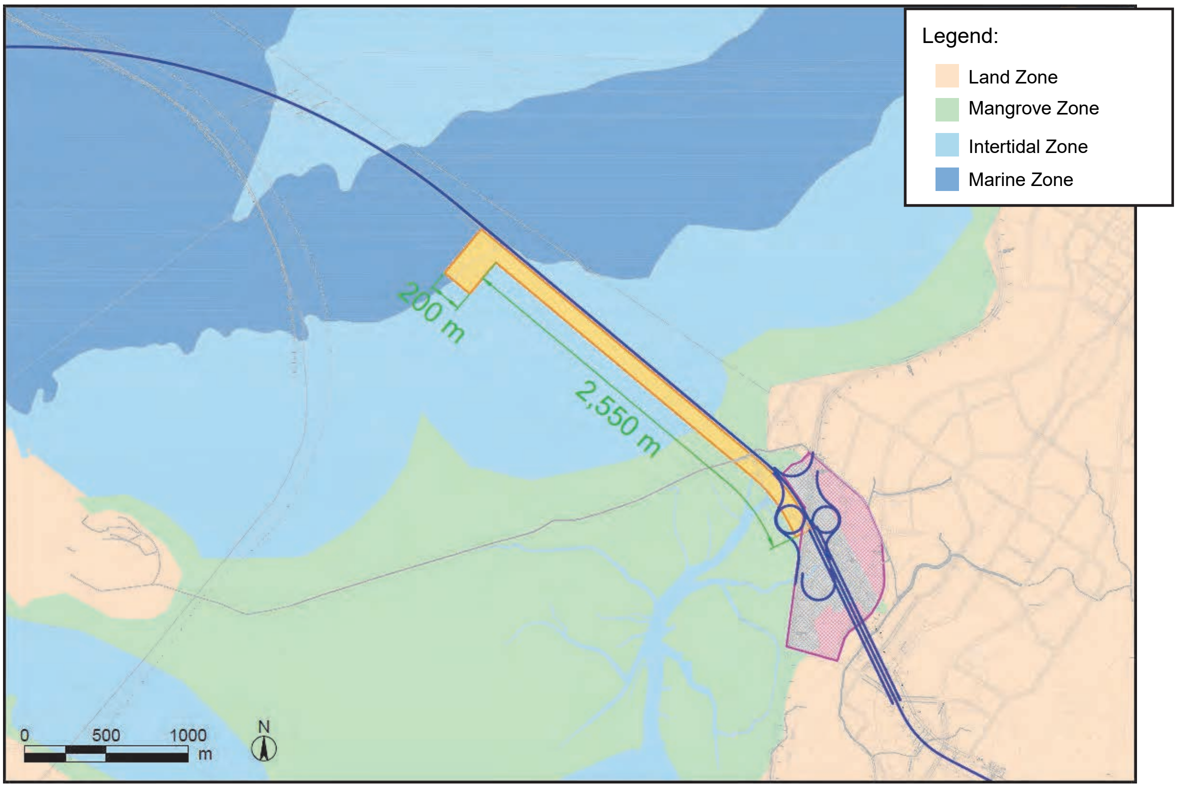
Source: JICA Study Team

Figure 7.2.7 Temporary Jetty (General View)



Source: JICA Study Team

Figure 7.2.8 Temporary Jetty (General View on the Mumbai Side)

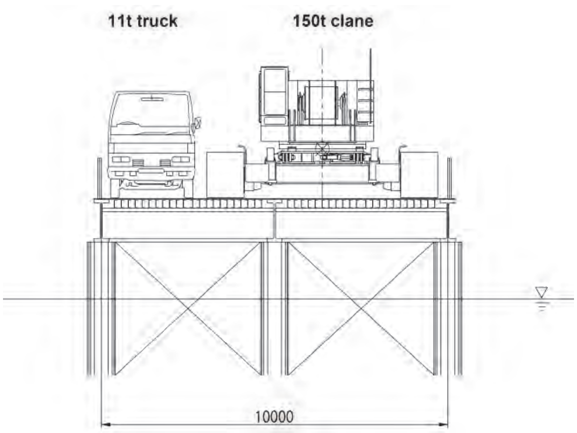


Source: JICA Study Team

Figure 7.2.9 Temporary Jetty (General View on the Navi Mumbai Side)

2) Temporary Jetty Width

Considering that the temporary jetty will be used for wide ranging activities, the proposed width is 10 m allowing the simultaneous passage of a 150 ton crawler crane and a large size truck. The temporary jetty width is shown in Figure 7.2.10.



Source: JICA Study Team

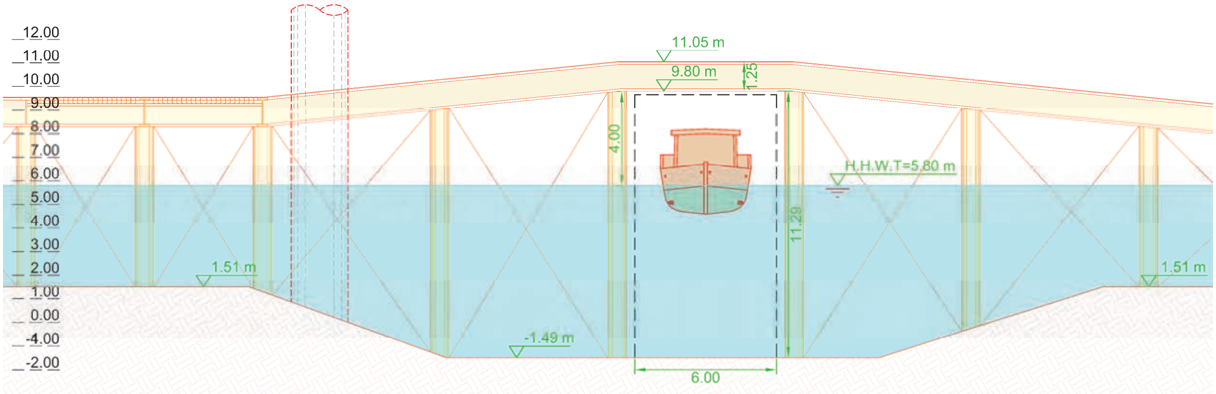
Figure 7.2.10 Temporary Jetty (Cross Section)

3) Passage for Small Boats

For general sections the temporary jetty surface level is proposed at H.H.W.L +1.00 m based on simulations of the sea level from Jan/2015 to 2023 (Max: 5.07 m / Min: -0.24 m). Also, an appropriate clearance was considered for the passage of small fishing boats.

Mumbai Side

There is a navigation route near STA.3+500 mainly used by fishing boats on the Mumbai side. The temporary jetty foundation piles shall be located to preserve the passage of small fishing boats. On the fishing boat navigation section a freeboard of 4m above the H.H.W.L was considered to allow the passage of those fishing boats. The cross section is shown in Figure 7.2.11.

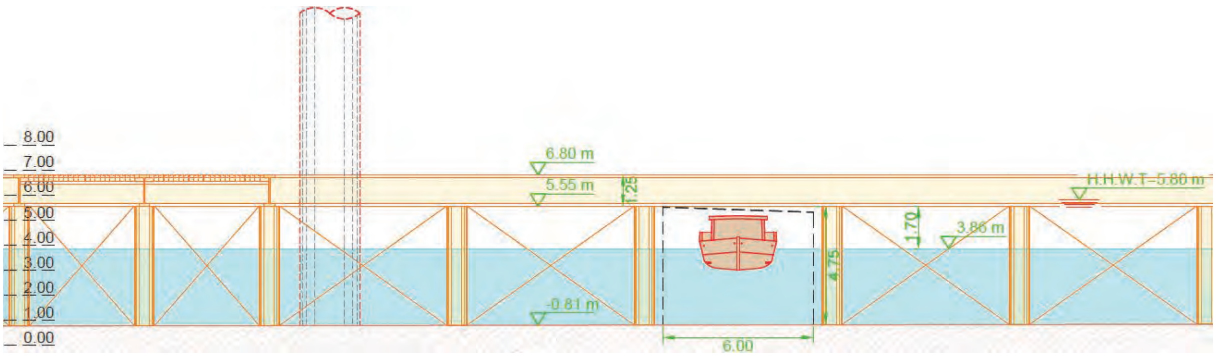


Source: JICA Study Team

Figure 7.2.11 Temporary Jetty (Fishing Boat Passage on the Mumbai Side)

Navi Mumbai Side

The temporary jetty surface level is proposed at H.H.W.L +1.00 m, the same as the Mumbai side. This makes it possible to guarantee an average tidal window of 18.0 hours per day considering that a typical boat can only cross if the sea level is higher than 0.5m and there is minimum freeboard of 1.5m. If the jetty surface is raised 1.0 m (H.H.W.L +2.00 m), it is possible to increase the tidal window to 20.0 hours per day. In this case, the temporary jetty will need a 3% gradient (~33 m length ramp), which is not a problem considering structural or constructive aspects. The fishing boat navigation channel cross section is shown in Figure 7.2.12.



Source: JICA Study Team

Figure 7.2.12 Temporary Jetty (Fishing Boat Passage on the Navi Mumbai Side)

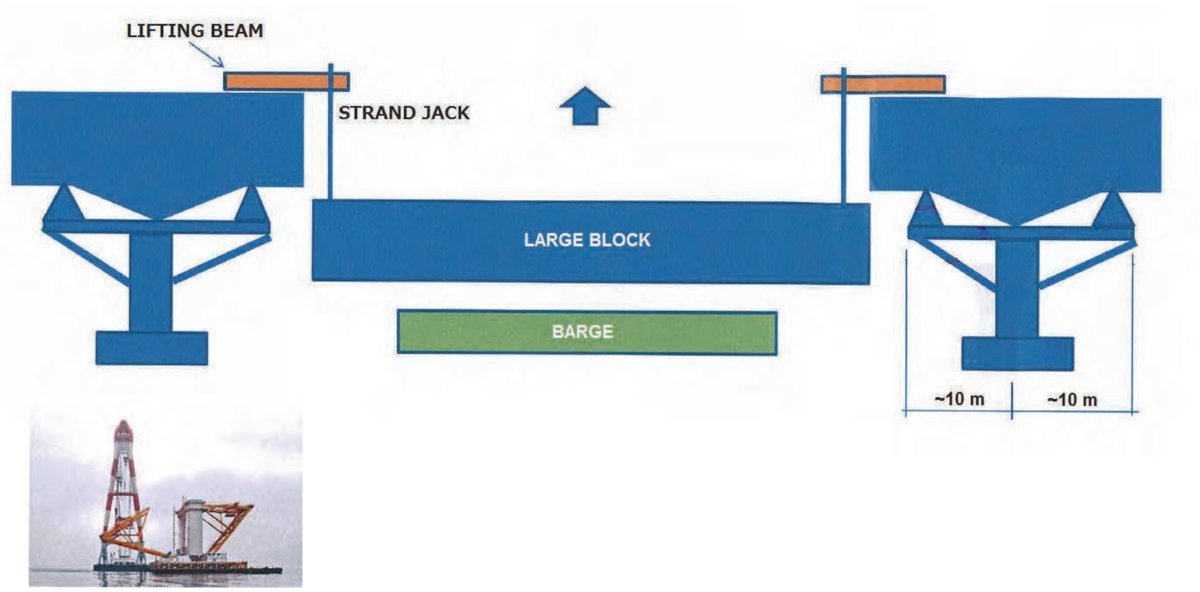
7.2.4 Superstructure

(1) Steel Slab Box Girder (Large Block Erection Method)

For construction of the steel slab box girder (4 sections) the large block erection method is proposed. In detail, transport the large blocks in a barge and jack up to the final position is one advantage this alternative for the 3 sections located in the marine portion. For the remaining sections located in a shallow area (STA.3+395 to STA.3+715), crane erection over the temporary jetty using temporary bents is proposed for construction of the side portion and a gantry crane erection is proposed for construction of the central portion. Also, floating crane erection can be considered, if leasing from overseas, mobilization costs, etc. can be handled.

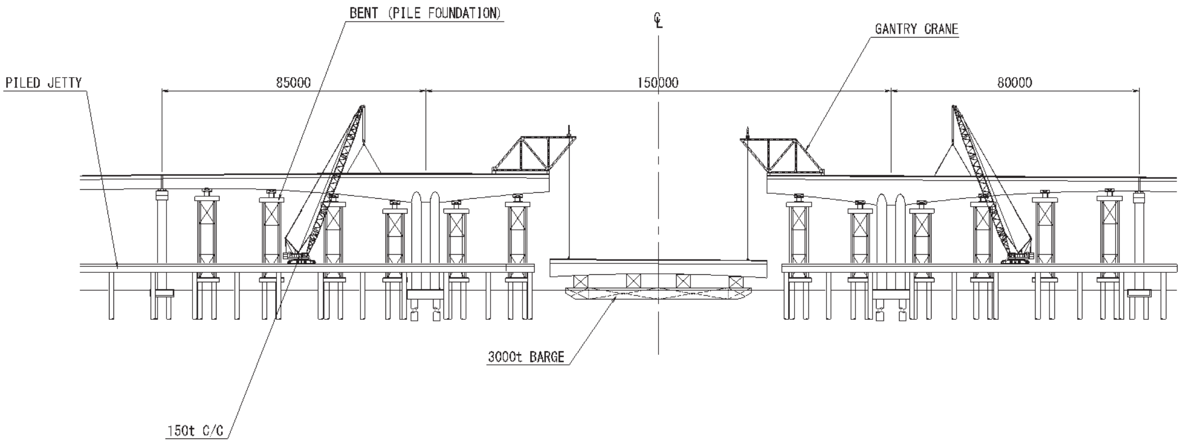
The steps of the jack up erection method are described below:

- Fabricate girder segments at the fabrication yard.
- Transport the girder segments from the fabrication yard to the assembling yard by multi-wheeled trailer or barge.
- Assemble girder segments into a large block.
- Transport the large block girder from the assembling yard to the site by barge.
- Lifting up the main girder (large block) with a floating crane.



Source: JICA Study Team

Figure 7.2.13 Large Block Erection Method Using Floating Crane



Source: JICA Study Team

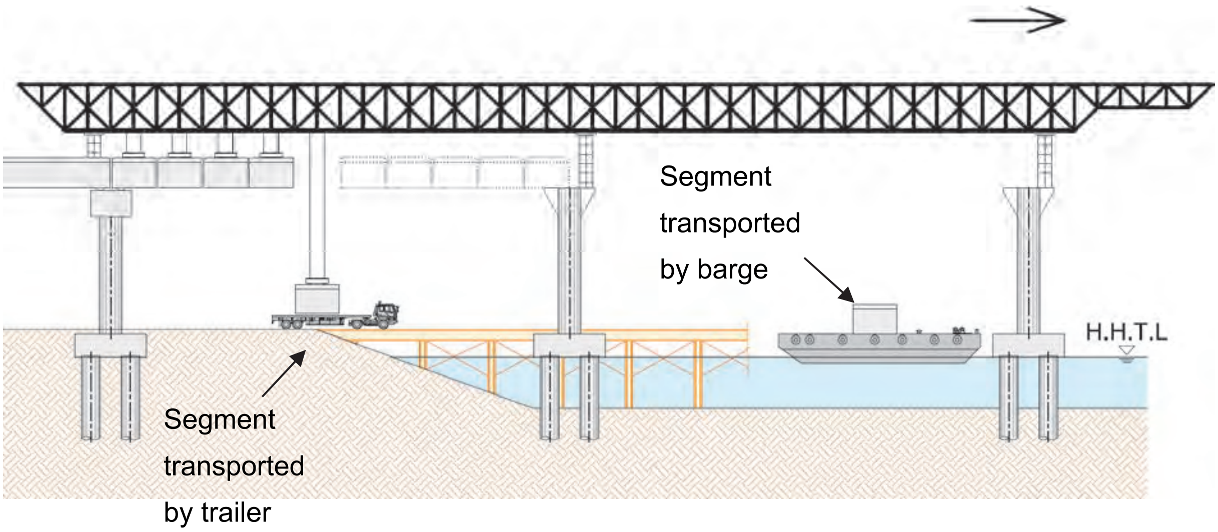
Figure 7.2.14 Central Span Erection Using Gantry Crane

Figure 7.2.15 Large Block Erection Method Using Floating Crane

(2) Span-By-Span Erection Method

The span-by-span erection method has been proposed by other studies aiming to reduce the construction period of the typical PC Box Girder (50 m span) section. The Study Team also recommends this alternative. Cranes used for the installation of the bent in the steel slab box girder sections can also be used for installation of the launching girder. The constructions steps are described below:

- Placing the launching girder over two piers.
- Transporting the girder segments from the precast yard to the site by multi-wheeled trailer (land and temporary jetty portion) or barge (marine portion).
- Placing each segment on the sliding pads and sliding into position.
- Applying epoxy in the joints, inserting the longitudinal prestressing tendons and prestressing the entire span.
- Moving the launching girder to the next span and repeat the cycle until the bridge is completed.



Source: JICA Study Team

Figure 7.2.16 Span-By-Span Erection Method

(3) Full Span Erection Method

The Full Span Erection Method is proposed for construction of PC Box Girder 30 m span section on the Navi Mumbai side. The basic construction sequence is described below:

- Placing the gantry cranes in position.
- Transporting the girder from the precast yard to the site by multi-wheeled trailer.
- Lifting the main girder into position.

Moving the gantry cranes to the next span and repeat the cycle until the bridge is completed.

Figure 7.2.17 Full Span Erection Method (Using Gantry Crane)

7.3 Procurement Plan

7.3.1 Procurement Plan for Major Materials

The procurement sources of the major materials for the bridge and road works are given in Table 7.3.1. Raw materials, such as cement, aggregate, sand, rebar, strand, etc. can be procured in the domestic market. Steel material, special bearing pads and expansion joints need to be procured in the overseas market.

Table 7.3.1 Procurement Source for Major Materials

Materials	Source		Remarks
	Domestic	Overseas	
Earth Works			
Borrow pit	○		
Aggregate	○		
Concrete			
Cement	○		
Course Aggregate	○		
Fine Aggregate	○		
Sand	○		
Fresh Concrete	○		
Rebar	○		
Epoxy rebar	○		
Steel Works			
Steel plate		○	Steel Box Girder with Steel Slab
H shape steel	○		
Bolts & Nuts	○	○	
Welding materials	○	○	
Coating		○	Anti-corrosion Coating
Temporary Works			
Deck panel	○		
H shaped steel	○		
Steel bent	○		
Bridge Accessories			
Bearing pad	○		P < 600 t
		○	P ≥ 600 t
Expansion joint	○		e < 300 mm
		○	e ≥ 300 mm
Anchor bar	○		
Waterproof sheet	○		
PC strand	○		
Road Accessories			
Light	○		
Guard rail	○		
Traffic light	○		
Drainage	○		
Ground improvement			
Drain materials	○		
Oil and Emulsion			
Fuel	○		
Asphalt	○		

Source: JICA Study Team

7.3.2 Procurement Plan for Major Equipment

General equipment for civil works can be procured in the Indian domestic market. However, large floating cranes need to be procured from the overseas market. The procurement sources for major equipment are shown in Table 7.3.2.

Table 7.3.2 Procurement Source for Major Equipment

Equipment	Procurement Source		Remarks
	Domestic	Overseas	
Backhoe	○		
Bulldozer	○		
Rough terrain crane	○		
Truck crane	○		
Crawler crane	○		
Tower crane	○		
Floating crane		○	
Jack up	○	○	In India: Max 250 t available
Concrete pump machine	○		
Concrete pump vehicle	○		
All casing powered jack rig	○		
Vibration hummer	○		
Vertical drain equipment	○		
Tire roller	○		
Vibration roller	○		
Road roller	○		
Asphalt paver	○		
Vibration compactor	○		
Form traveller	○		
Dump truck	○		
Semi-trailer	○		
Concrete Floating Plant	○		
Asphalt Floating Plant	○		

Source: JICA Study Team

7.3.3 Source of Materials

There are stone quarries in the project area and in the vicinity that can guarantee adequate aggregate quantity for this project as shown in Figure 7.3.1. Also, basalt stone from the cut sections in the land section could be used as aggregate. Regarding concrete and asphalt, there are many plants in the project area that could provide the necessary quantities. Natural river sand is banned in Maharashtra State (replaced by crushed sand) and trucks transporting aggregate can only enter Mumbai City at night.

Source: JICA Study Team

Figure 7.3.1 Quarry Locations

7.3.4 Construction Yard

This project has approximate 22 km total length and approximately 17 km are located in the marine portion. Considering construction logistics, construction yards on both the Mumbai and Navi Mumbai sides are necessary. The area near the Sewri IC on the Mumbai side has 15 ha that can be used for a construction yard. The area near the Shivaji IC has 16 ha and the area near Chirle IC has 8.75 ha that can be used for construction yards. The details of the construction yards are shown in Figure 7.3.2.

＊A casting yard of approximately 15 Ha near Serwi IC is guaranteed, however the other points indicated in the above figure are possible locations identified by the JICA Study Team.

Source: JICA Study Team

Figure 7.3.2 Yard Locations

7.4 Contract Packages

7.4.1 Civil Works

The project can be categorized by the characteristics of the topography. The project consists of construction of concrete bridges and steel bridges except for earth work section in section 5 of table below.

Table 7.4.1 Topographic Classifications in MTHL

Section	Topographic Classification	Depth of the Sea
Section-1 (Sta.0-0.5km)	Land	—
Section-2 (Sta.0.5-5.6km)	Mudflat	0.0 ～ 3.0m
Section-3(Sta.5.6-10.75km)	Sea	4.5 ～ 7.0m
Section-4 (Sta.10.75-16.75km)	Sea (partially Mudflat)	0.0 ～ 4.0m
Section-5 (Sta.16.75-21.84km)	Land	—

Source: JICA Study Team

The packaging of the project components should be carefully considered. There is no limitation regarding the construction contract scale. However, the packaging shall be decided in consideration of the contract scale of the civil work in past JICA projects and the contract price for which the bidder can prepare a performance bond.

Although the bidders can becomes able to prepare a large-scale performance bond by forming a joint venture consisting of several companies, this leads to many construction sections in a package and cooperation and adjustment between the construction sections may become difficult.

In another method, the packaging can be divided by the construction work items. The work items that require high technique in the project are fabrication and large-block erection of steel girders. However, the marine section is dotted with the steel bridges so that it is difficult to divide the contract package by the construction work item (concrete bridge and steel bridge).

Other considerable factors for dividing the contract package are topographic classification and securable construction yard. As for the construction yard, it will be secured by MMRDA with approximately 14 ha at Sewri and more than 15 ha near Shivaji Nagar IC. However, these face the shallow marine portion so that temporary jetties and an assembly base shall be provided up to the deep marine portion and fabrication of precast segments of PC girders and assembled steel girders can be carried out. Considering the above points, dividing the marine section in two contract packages is the most realistic option, and the line adopted to divide the packages was the border line of the two organizations (Mumbai Port and JNPT) that have jurisdiction in the Mumbai Bay. (Figure 7.4.2)

The comparative analysis for packaging of the contract is shown in Figure 7.4.1 and Table 7.4.2.

As a result of the analysis for each optional package, it is recommended that the project should be implemented with three contract packages in consideration of the contract scale, secured construction yards, increase of the bid participation opportunity and securing of smooth project implementation.

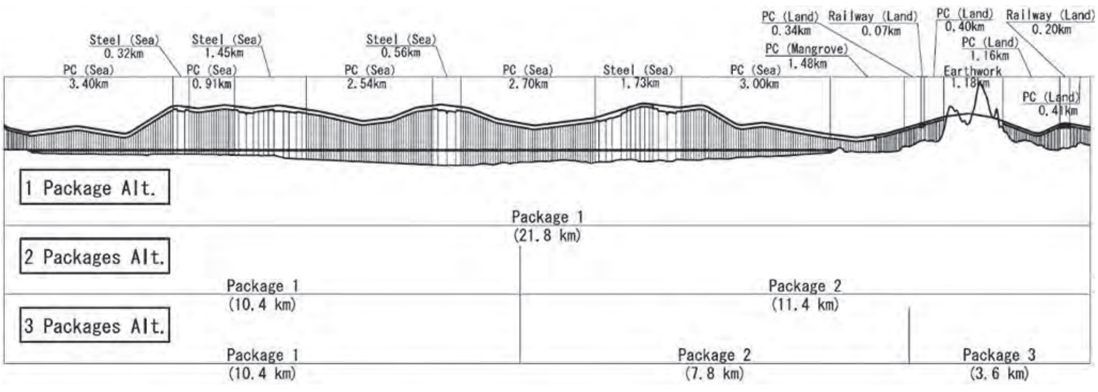


Figure 7.4.1 Options for Contract Package

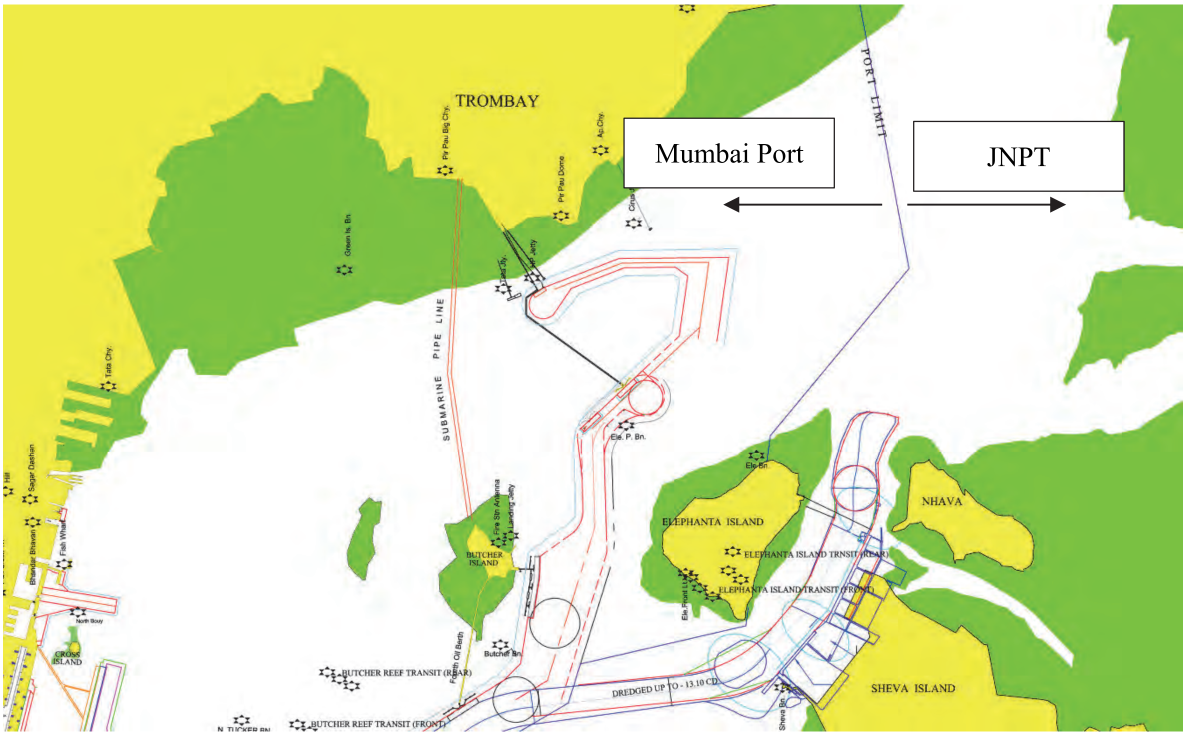


Figure 7.4.2 Border of Organization (Mumbai Port and JNPT)

Table 7.4.2 Analysis for Each Optional Package

Item	1 Package Alternative	2 Packages Alternative	3 Packages Alternative
Section	21.8km	Package 1 : 10.4km Package 2 : 11.4km	Package 1 : 10.4km Package 2 : 7.8km Package 3 : 3.6km
Features	- Integrated control is possible. - The largest scale in JICA funded bridge projects.	- Divided into two packages of the same scale each - Large scale in JICA funded bridge projects	- One package is the land section in Navi-Mumbai, and the marine section is divided into two packages. - Large scale in JICA funded bridge projects
Procurement of Contract	- Construction risks will be increased as the contract scale is large. - Shortest procurement period	- Opportunity for bid participation will be increased. - Longer procurement period than one package.	- Opportunity for bid participation will be increased. - Longest procurement period.
Construction Yard	Assumed construction yards will be available.	Assumed construction yards will be available.	Although an Additional construction yard will be required, it can be secured inside the ROW.
Work Management	Quality control is easier than others.	Coordination and unification of quality between packages will be required.	Coordination and unification of quality between packages will be required.
Evaluation	Bidders will be limited and the risks of the bidder will be higher than others since the contract scale is large.	- Opportunity for bid participation will be increased. Work management will not be complicated. - Packages can be divided at the border of organization.	-The variation of bids will be increased by making a package for the land portion. -Opportunity for bid participation will be increased. -Work management will not be complicated. - Packages can be divided at the border of organization. **“Recommended Alternative”**

Source: JICA Study Team

7.4.2 ITS

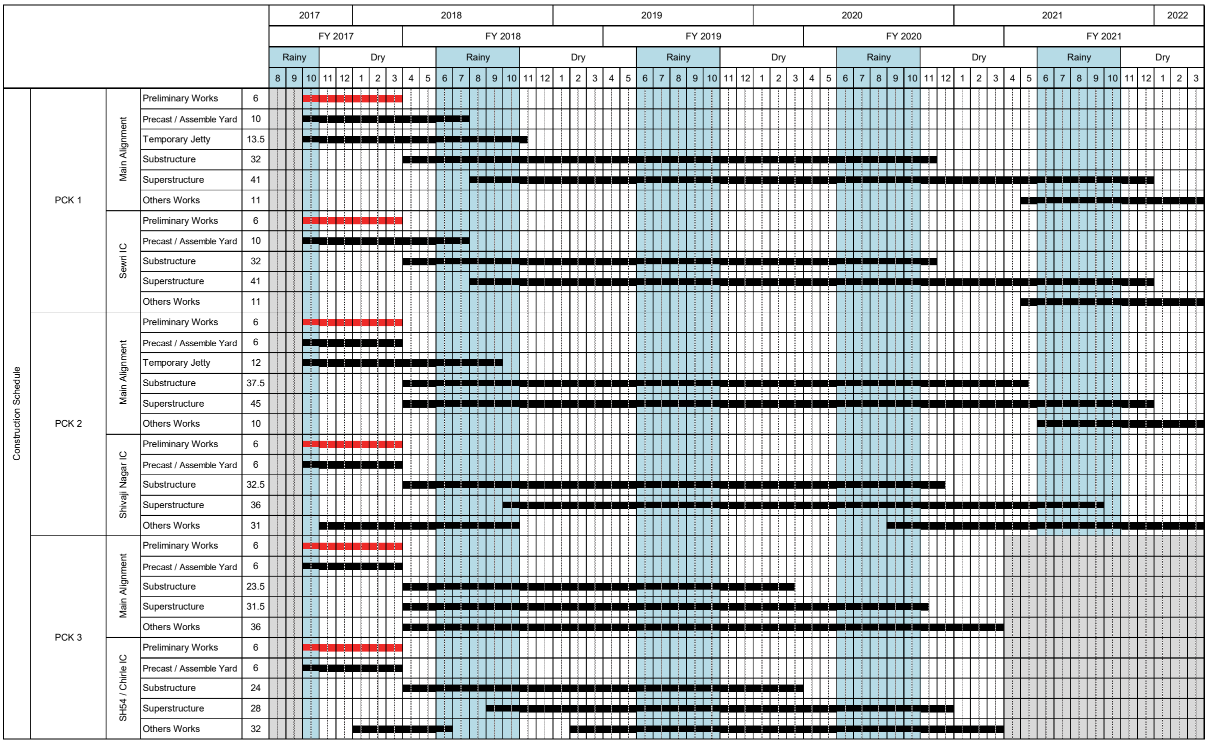
The ITS component is mainly to procure and install the ITS machinery and materials. Therefor the ITS is a separate package of the project components (refer to 6.6).

7.5 Construction Schedule

7.5.1 Construction Schedule

In India there are two defined seasons: Rainy (June to October) and Dry (November to May). In the monsoon season heavy rain falls, usually during a short space of time, also there are only few days that is not possible to work due continuous rains. However, the operation of the barges may be limited due the monsoon influence on tidal hydrodynamics. A coefficient of 1.35 was applied in the elaboration of the construction schedule to consider the loss of productivity during the rainy season. The construction schedules for all major works are shown below:

(1) Construction Schedule Resume

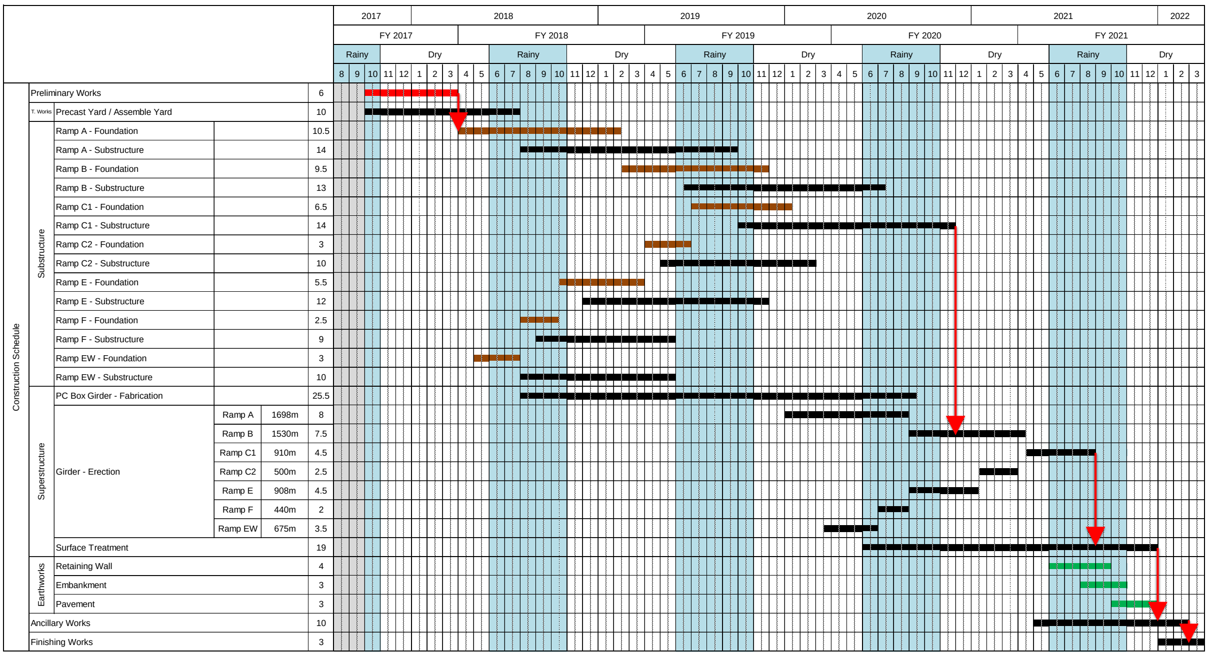


Source: JICA Study Team

Figure 7.5.1 Construction Schedule – Resume

(2) Package 1

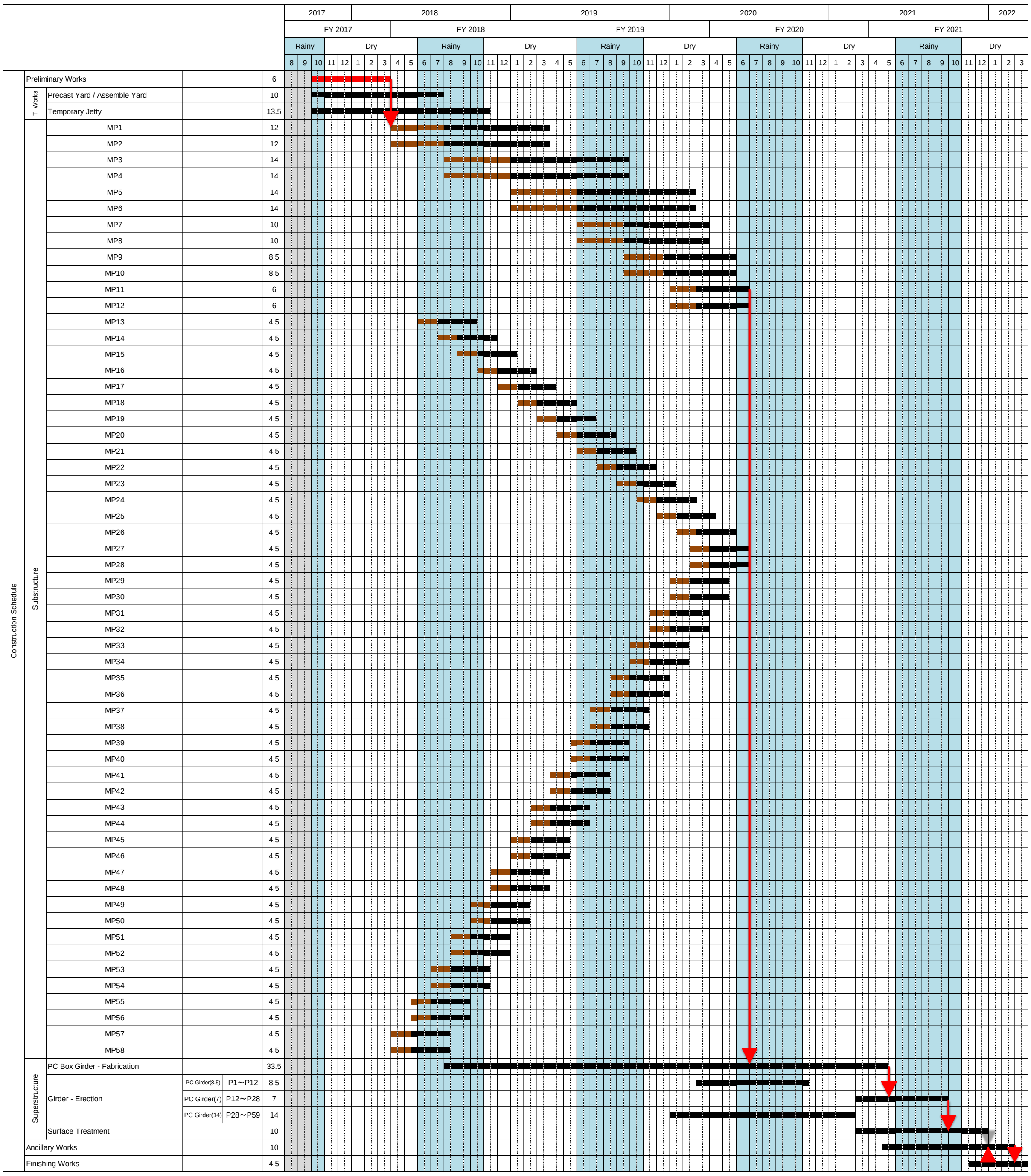
1) Sewri IC



Source: JICA Study Team

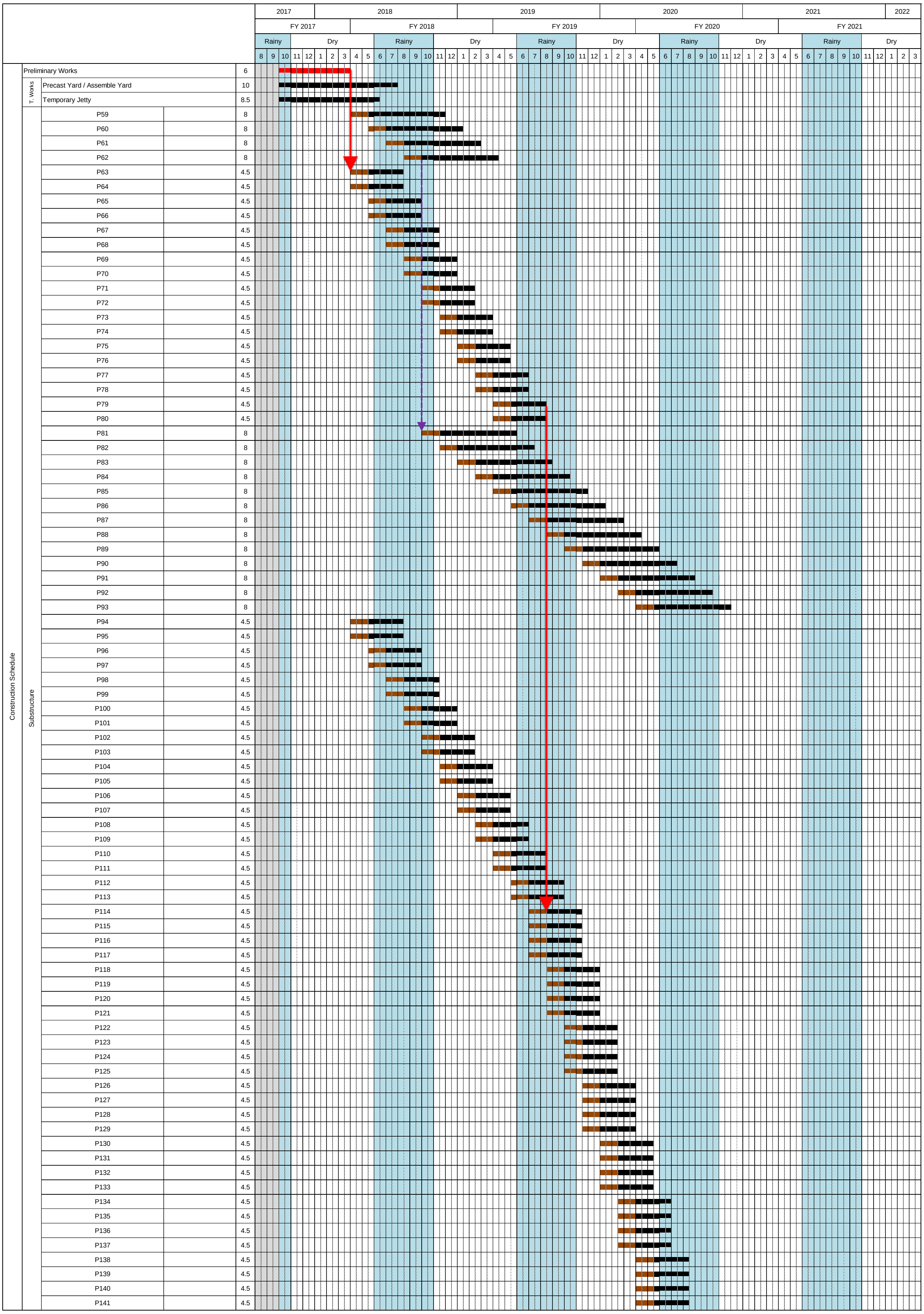
Figure 7.5.2 Construction Schedule – Sewri IC

2) Main Alignment (0+450~10+380)



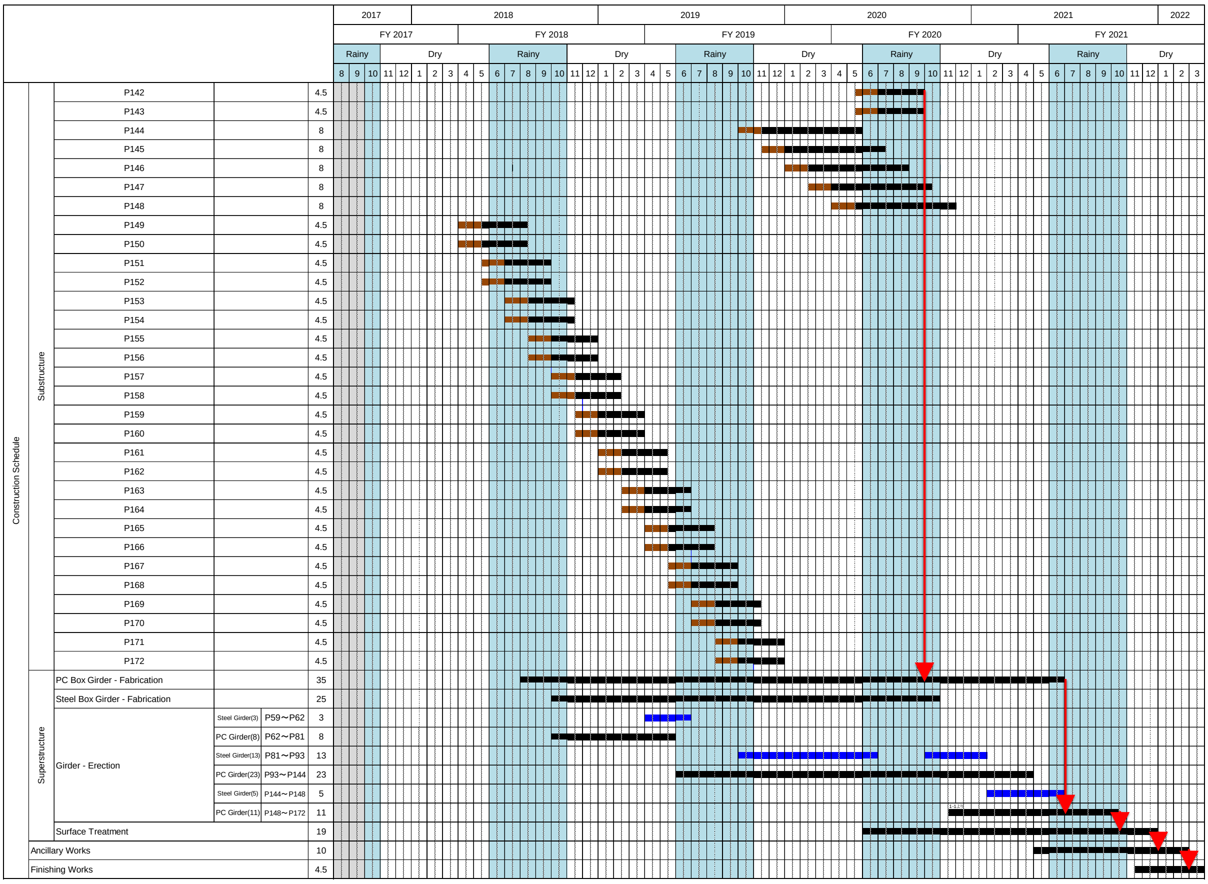
Source: JICA Study Team

Figure 7.5.3 Construction Schedule – Main Alignment (0+450~3+345)



Source: JICA Study Team

Figure 7.5.4 Construction Schedule – Main Alignment (3+345~8+474)

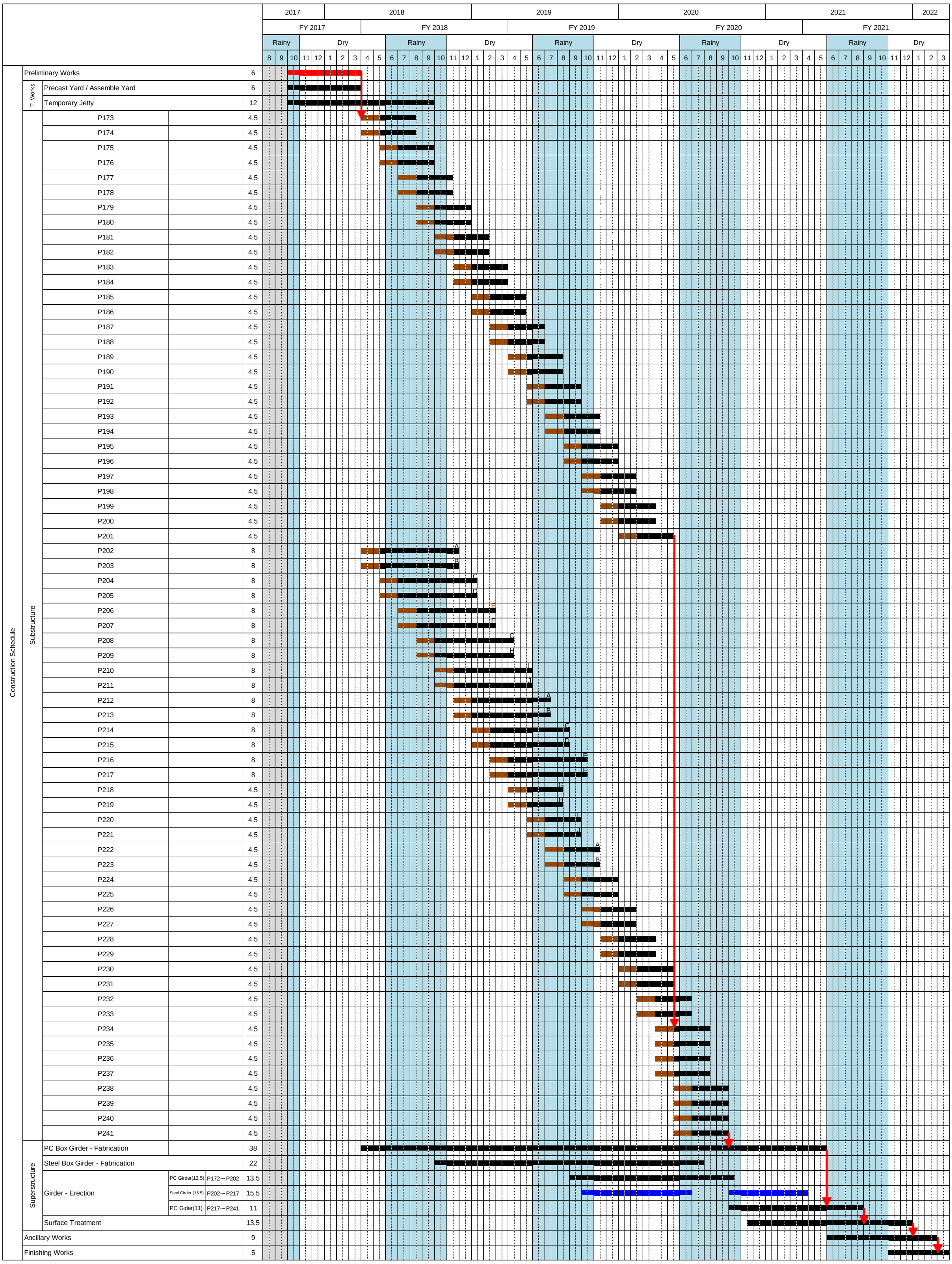


Source: JICA Study Team

Figure 7.5.5 Construction Schedule – Main Alignment (8+474~10+380)

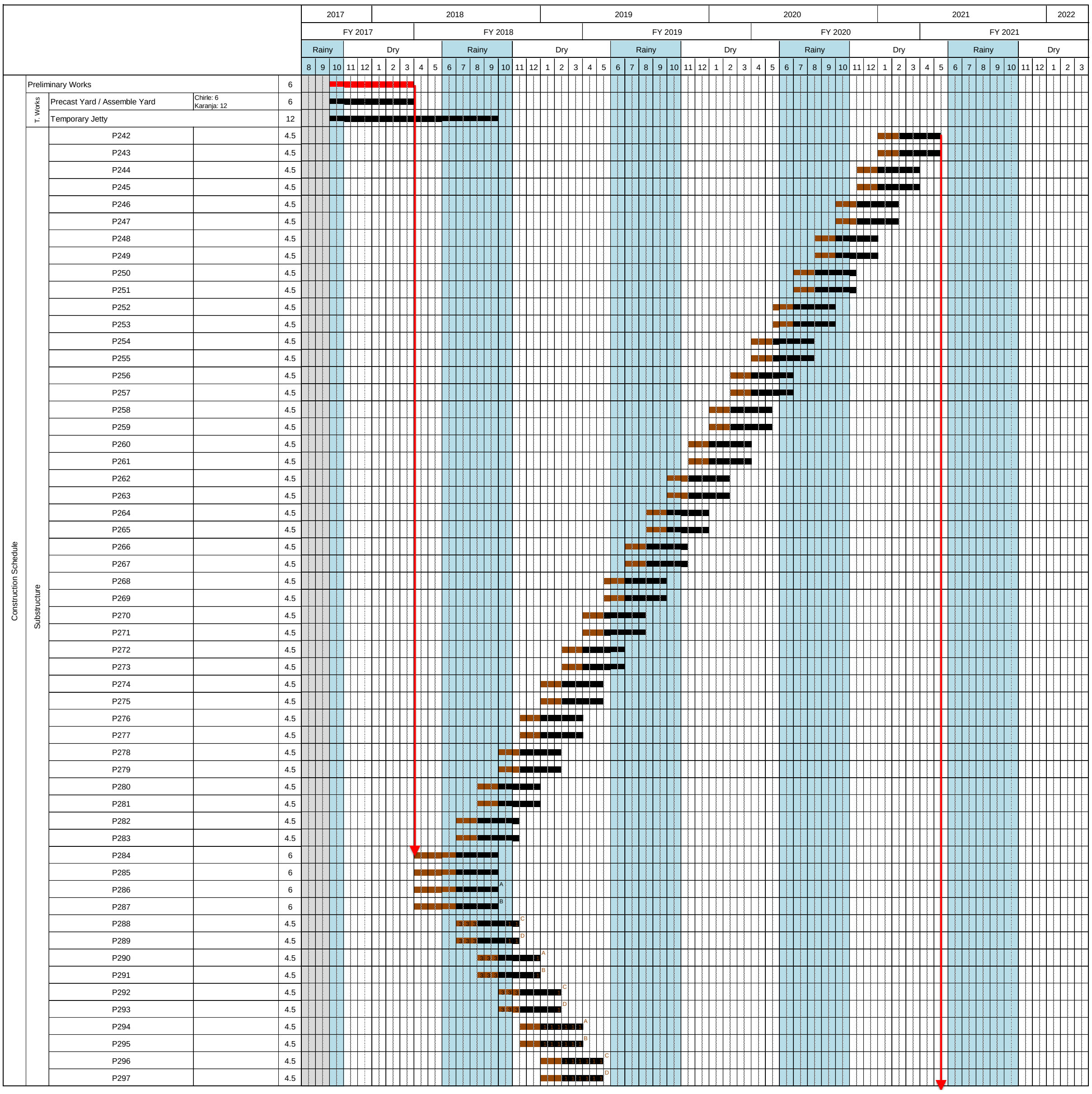
(3) Package 2

1) Main Alignment (10+380~18+187)



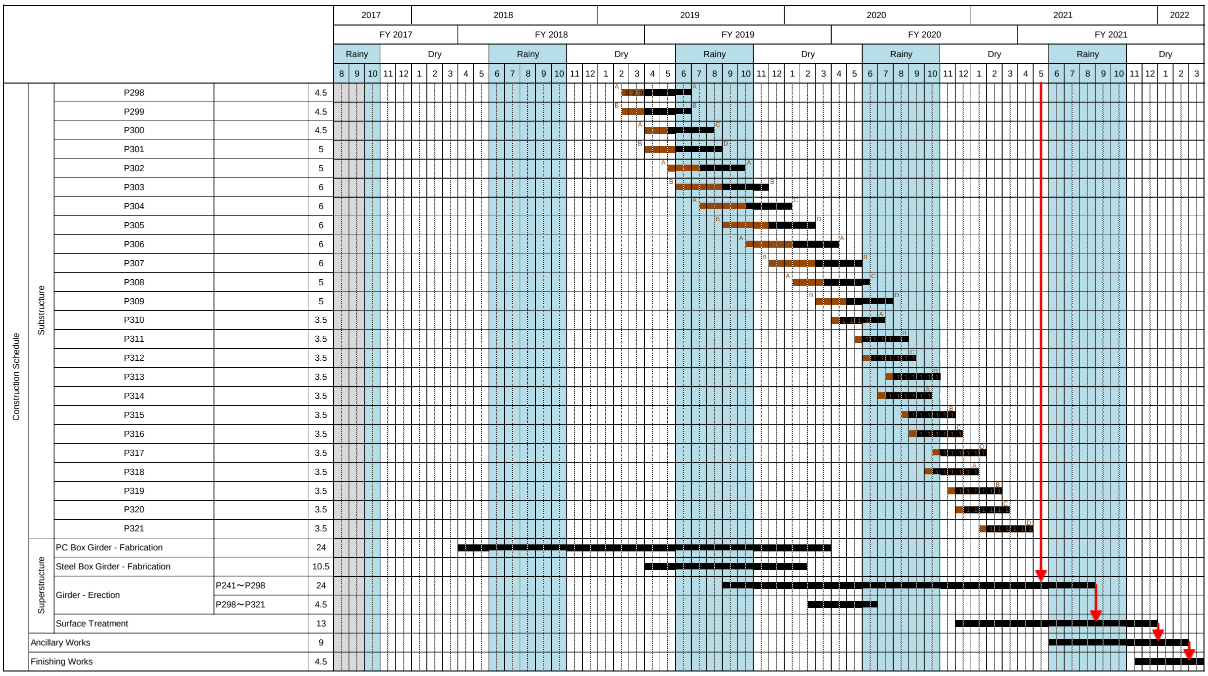
Source: JICA Study Team

Figure 7.5.6 Construction Schedule – Main Alignment (10+380~14+810)



Source: JICA Study Team

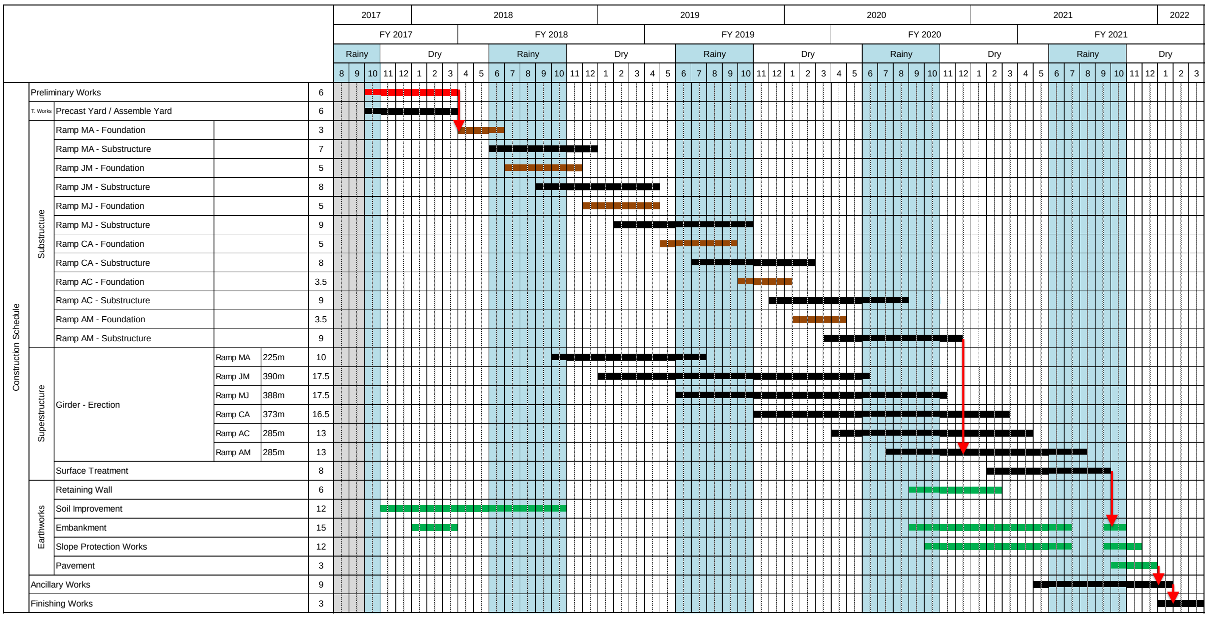
Figure 7.5.7 Construction Schedule – Main Alignment (14+810~17+482)



Source: JICA Study Team

Figure 7.5.8 Construction Schedule – Main Alignment (17+482~18+187)

2) Shivaji Nagar IC

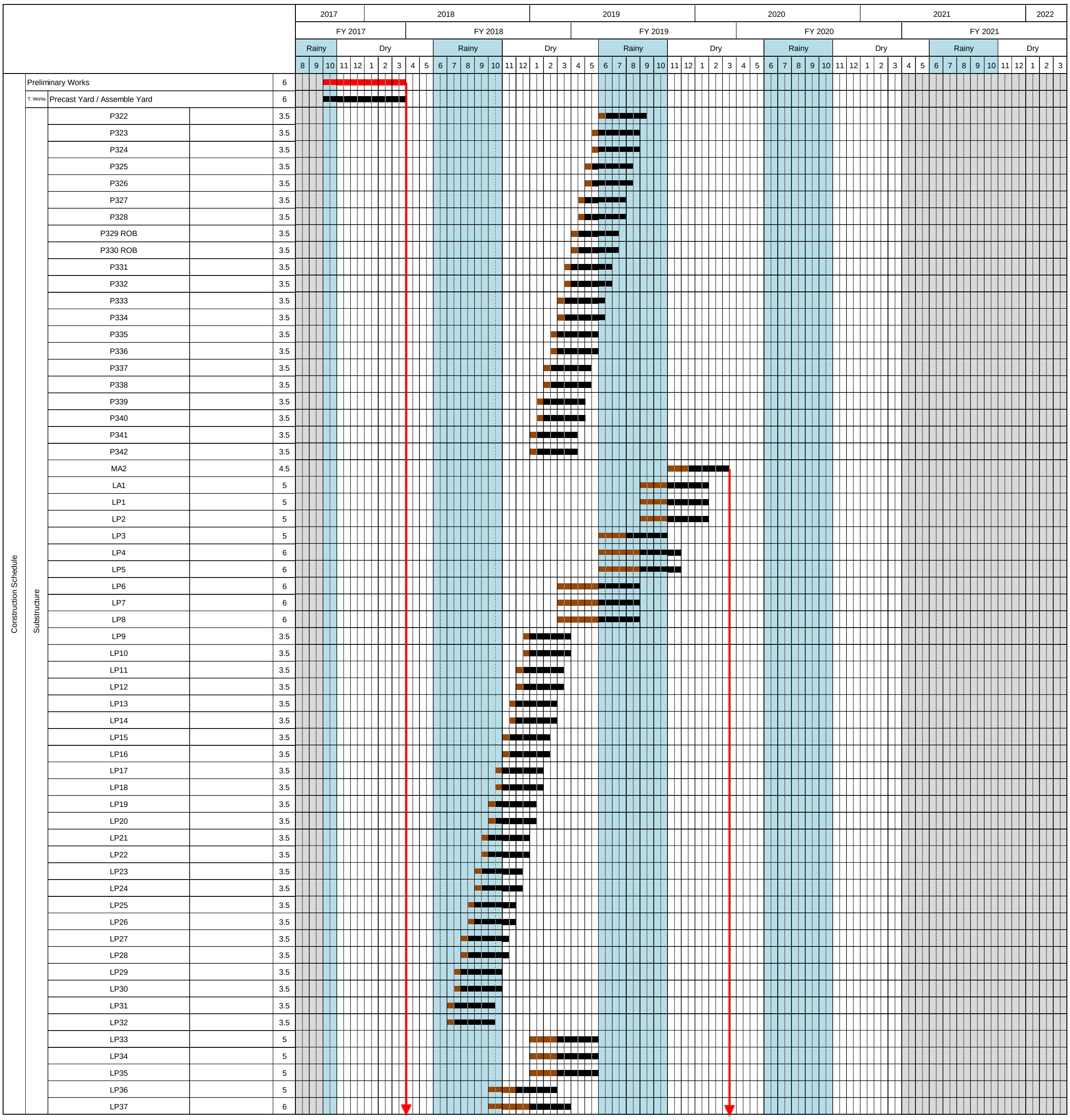


Source: JICA Study Team

Figure 7.5.9 Construction Schedule – Shivaji Nagar IC

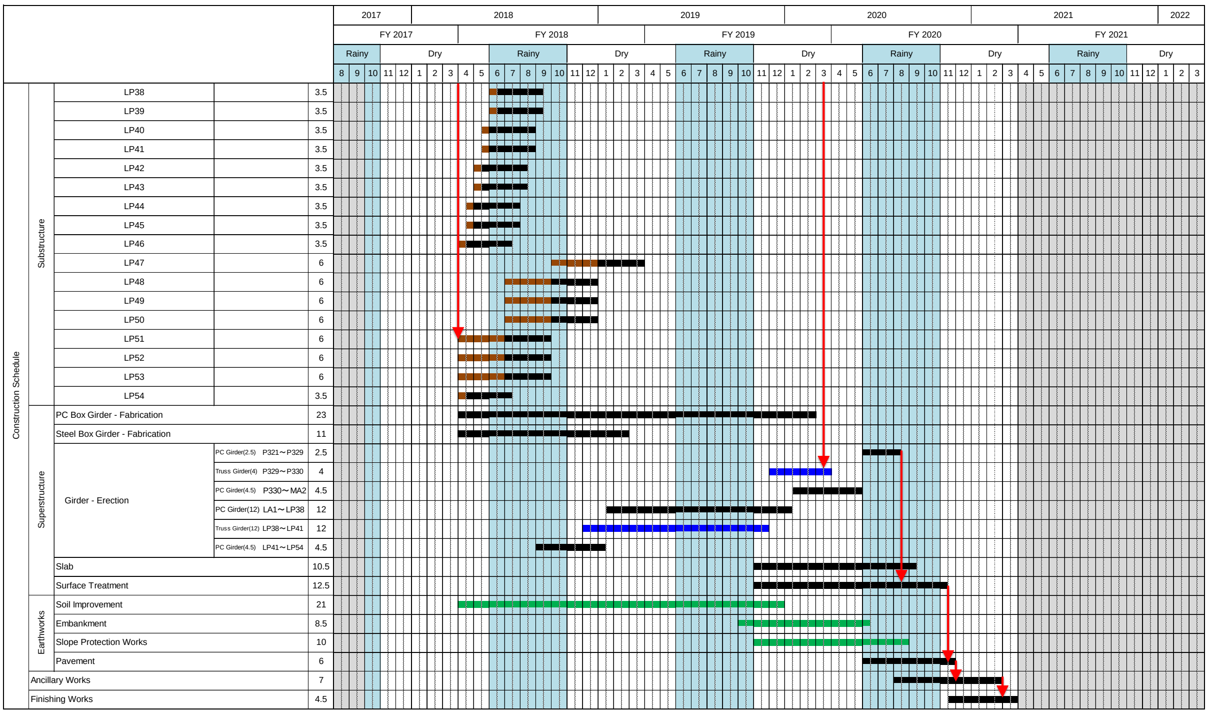
(4) Package 3

1) Main Alignment (18+187~21+834)



Source: JICA Study Team

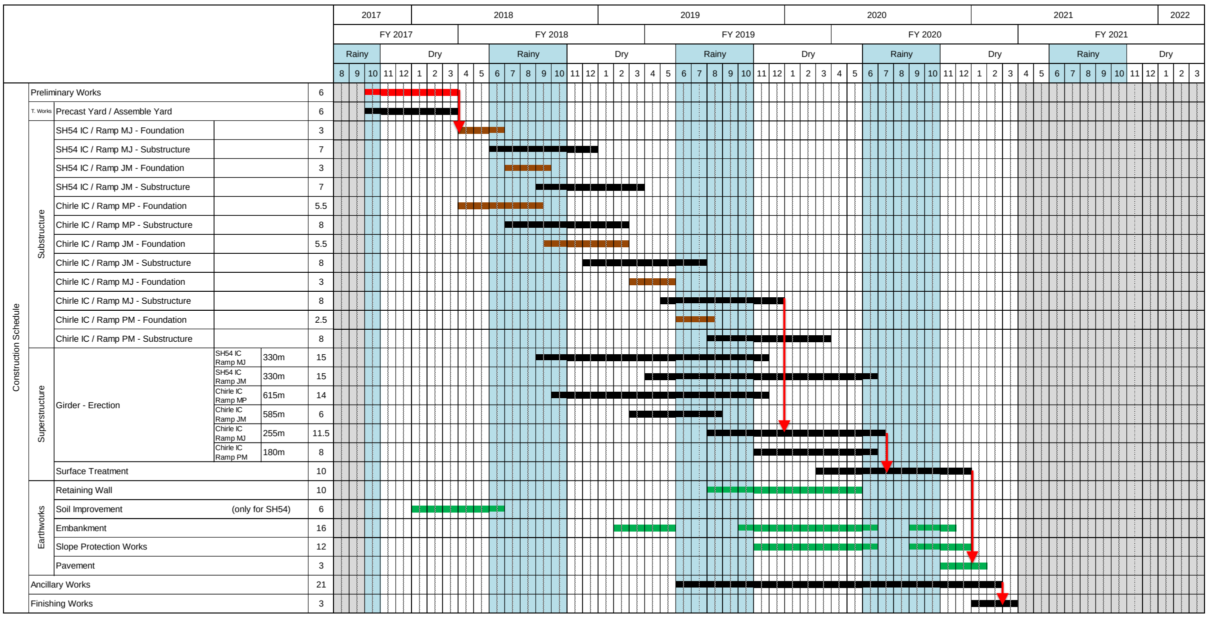
Figure 7.5.10 Construction Schedule – Main Alignment (18+187~21+199)



Source: JICA Study Team

Figure 7.5.11 Construction Schedule – Main Alignment (21+199~21+834)

2) SH54 / Chirle IC



Source: JICA Study Team

Figure 7.5.12 Construction Schedule – SH54 / Chirle IC

8. PROJECT COST ESTIMATE

8.1 Introduction

The project cost estimation is based on the rough quantities obtained from the preliminary design for each subproject. The eligible portions of this project are assumed to be funded through the JICA loan scheme. For other expenses, it is assumed that the government of India will allocate funds from the federal budget (and also from the state budget) thought MMRDA for the non-eligible portions of the project.

8.2 Condition for Cost Estimation

The conditions for cost estimation are shown in Table 8.2.1

Table 8.2.1 Conditions for Cost Estimation (Draft)

Item	Condition
Date of Estimate	Jan, 2016
Exchange Rate	1 US Dollar (USD) = 121.8 Japanese Yen (JPY) 1 US Dollar (USD) a= 66.6 Indian Rupee (INR)
Price Escalation Rate	Foreign Currency Portion: 1.8% Local Currency Portion: 1.3%
Physical Contingency	10% of Construction Cost / 5% of Consultant Fee
Interest During Construction	0.30% of Construction Cost 0.01% of Consultant Fee
Administration Cost	3% of Total Cost
Import Tax	30%
Commercial Tax	6%

Source: JICA Study Team

8.3 Result of Cost Estimates

8.3.1 Construction Cost (Base Cost)

Base construction cost is shown in Table 8.3.1.

Table 8.3.1 Construction Cost (Base Cost)

Packages	Subtotal		Total
	JPY (Million)	INR (Million)	JPY (Million)
Package 1	1,685	65,116	237,405
Package 2	923	48,556	
Package 3	127	13,005	
Package 4	- -	1,444	
Package 5	- -	196	

Source: JICA Study Team

8.3.2 Total Project Cost

The estimated total project cost is shown in Table 8.3.2.

The JICA Study Team originally estimated the project cost shown in Table 11.1.2 and Table 11.1.3 in Chapter 11 at the appraisal stage. However, after detailed working and discussions between JICA and MMRDA, the cost toward the price escalation, the consulting service, other administrative costs and taxes were updated, and the total project cost was finalized as indicated in Table 8.3.2.

Table 8.3.2 Total Project Cost

Items	Foreign Currency Portion (million JPY)			Local Currency Portion (millon INR)			Total (million JPY)		
	Total	JICA Portion	Others	Total	JICA Portion	Others	Total	JICA Portion	Others
Package-1 (Western Off-Shore)	1,685	1,685	0	65,116	65,116	0	120,772	120,772	0
Package-2 (Eastern Off-Shore)	923	923	0	48,556	48,556	0	89,723	89,723	0
Package-3 (Navi Mumbai)	127	127	0	13,005	13,005	0	23,911	23,911	0
Package-4 (ITS)	0	0	0	1,444	1,444	0	2,640	2,640	0
Package-5 (Geo-Technical Investigation)	0	0	0	196	0	196	359	0	359
Dispute Boads for Pkg-1/2/3/4	337	337	0	0	0	0	337	337	0
Price Escalation	138	138	0	4,051	4,051	0	7,546	7,546	0
Physical Contingency	321	321	0	13,237	13,217	20	24,529	24,493	36
Consulting Services	3,609	3,609	0	1,805	1,805	0	6,911	6,911	0
Land Acquisition	0	0	0	9,969	0	9,969	18,231	0	18,231
Administration Cost	0	0	0	4,838	0	4,838	8,849	0	8,849
VAT	0	0	0	9,079	0	9,079	16,604	0	16,604
Import Tax	0	0	0	579	0	579	1,059	0	1,059
Interest during Construction	4,507	0	4,507	0	0	0	4,507	0	4,507
Front End Fee	553	0	553	0	0	0	553	0	553
Project Cost	**12,201**	**7,140**	**5,060**	**171,875**	**147,194**	**24,681**	**326,531**	**276,333**	**50,198**

Source: JICA Study Team

8.3.3 Cost Breakdown

(1) Construction Cost

The breakdown of the project costs is shown in Table 8.3.3 to Table 8.3.7.

Table 8.3.3 Breakdown of Project Cost (Package-1)

Item	Unit	Quantity	Unit Price		Total
			Foreign	Local	
			JPY '000	INR '000	JPY '000
Investigation & Tests	L.Sum	1		554,254.8	1,013,637.1
Detailed Design	L.Sum	1		326,292.0	596,732.2
Existing Utilities Relocation	L.Sum	1		838,688.2	1,533,817.1
Temporary Jetty	m²	72,625		63.8	8,473,035.7
Earthworks		1			
Foundation	m	57,412		173.6	18,231,959.6
Substructure	m³	176,851		38.2	12,360,413.9
Superstructure (Concrete)	m²	235,920	7.1	64.0	29,293,613.0
Superstructure (Steel)	t	58,792	764.3		44,932,223.6
Dolphins	No	36		32,434.7	2,135,433.0
Pavement	m²	751,526		0.6	841,140.8
Road Furniture	L.Sum	1		743,648.2	1,360,005.3
Total					120,772,011.5

Source: JICA Study Team

Table 8.3.4 Breakdown of Project Cost (Package-2)

Item	Unit	Quantity	Unit Price		Total
			Foreign	Local	
			JPY '000	INR '000	JPY '000
Investigation & Tests	L.Sum	1		401,665.4	734,577.2
Detailed Design	L.Sum	1		234,190.5	428,294.4
Existing Utilities Relocation	L.Sum	1		607,100.0	1,110,282.0
Temporary Jetty	m²	65,761		88.1	10,591,552.0
Earthworks	L.Sum	1		3,590,652.9	6,566,689.5
Foundation	m	28,537		192.8	10,064,495.2
Substructure	m³	103,984		38.1	7,239,744.3
Superstructure (Concrete)	m²	140,798	6.6	61.4	16,730,351.1
Superstructure (Steel)	t	43,596	768.6		33,507,312.7
Dolphins	No	16		57,129.6	1,671,683.5
Pavement	m²	494,964		0.6	556,700.7
Road Furniture	L.Sum	1		285,261.1	521,693.7
Total					89,723,376.3

Source: JICA Study Team

Table 8.3.5 Break down of Project Cost (Package-3)

Item	Unit	Quantity	Unit Price		Total
			Foreign	Local	
			JPY '000	INR '000	JPY '000
Investigation & Tests	L.Sum	1		126,309.5	230,998.4
Detailed Design	L.Sum	1		58,255.4	106,539.1
Existing Utilities Relocation	L.Sum	1		178,066.6	325,653.4
Temporary Jetty	m²				
Earthworks	L.Sum	1		2,933,803.7	5,365,424.9
Foundation	m	33,271		95.3	5,797,254.7
Substructure	m³	44,766		35.7	2,923,909.3
Superstructure (Concrete)	m²	58,482	2.2	62.4	6,802,970.9
Superstructure (Steel)	t	3,198		315.0	1,842,108.2
Dolphins	No				
Pavement	m²	186,996		0.6	205,190.2
Road Furniture	L.Sum	1		169,990.0	310,882.5
Total					23,910,931.5

Source: JICA Study Team

Table 8.3.6 Break down of Project Cost (Package-4)

Item	Unit	Quantity	Unit Price		Total
			Foreign	Local	
			JPY '000	INR '000	JPY '000
Investigation & Tests	L.Sum	1		8,021.7	14,670.3
Toll Gate & ITS Facilities	L.Sum	1		1,435,691.3	2,625,633.6
Total					2,640,303.9

Source: JICA Study Team

Table 8.3.7 Break down of Project Cost (Package-5)

Item	Unit	Quantity	Unit Price		Total
			Foreign	Local	
			JPY '000	INR '000	JPY '000
Geo-Tech. Investigation & Tests	L.Sum	1		196,196.0	358,808.9
Total					358,808.9

Source: JICA Study Team

(2) Quantity

The breakdown of the quantities is shown in Table 8.3.8 to Table 8.3.10.

Table 8.3.8 Breakdown of Quantities (Package-1)

Package 1 (CH. 0+000 to CH. 10+380)

Foundation (Pile)

Diameter of Piles *1	Number of Piers (A)	Number of Piles per Pier (B)	Average Length per Pile (m) (C)	Total Pile Length (m) (=AxBxC)
φ1000	14	8	17.848	1,999
φ1200	174	4	18.869	13,133
φ1500	34	2	19.397	1,319
φ2000	319	4	28.120	35,881
φ2400	44	4	28.864	5,080
				57,412

*1 Pile diameters according to the preliminary design: 1000/1200/1500mm (Sewri IC) and 2000/2400mm (marine area).

Substructure

Number of Pier (A)	Average Concrete Volume/Pier (m3) (B)	Total Concrete Volume (m3) (=AxB)
585	302.309	176,851

Superstructure (Concrete)

Bridge Length of Concrete (m) (A)	Average Area of Cross Section (m2) (B)	Number of Bridge (C) *1	Total Concrete Volume (m3) (=AxBxC)	
7,552	12.175	2	183,885	* Main Alignment
6,441	8.079	1	52,035	* Ramps
			235,920	

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Superstructure (Steel Box Girder Bridge)

Bridge Length of Steel (m) (A)	Average Weight of Steel (kg/m) (B)	Number of Bridge (C) *1	Total Steel Weight (kg) (=AxBxC)	
2,333	12,600	2	58,792,000	* Main Alignment

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Dolphins (Ship collision protection)

Number of Dolphin/Pier (A)	Number of Pier (B)	Total Dolphin Number (=AxB)
4	4	16
5	4	20
		36

Dolphins were considered only on piers adjacent to navegation channel.

Pavement

Pavement Length along Bridge (m) (A) *1	Average Pavement Width (m) (B) *2	Layers (C) *3	Total Pavement Area (m2) (=AxBxC)
16,326	23.016	2	751,526

*1 Total pavement length considering main alignment and ramps.
*2 Average pavement width considering main alignmnet and ramps.
*3 The pavement shall be executed in 2 layers (2 stages)

Noise Barrier

Noise Barrier Length along Bridge (m) (A) *1	Barrier Height (m) (B)	Number of Noise Barrier (C) *2	Total Noise Barrier Area (m2) (=AxBxC)
1,700	2	2	6,800

*1 Considered in the intertidal area to protect Flamingo in Mumbai side.
*2 Considered on both sides of the structure (north and south).

Concrete Barrier

Concrete Barrier Length along Bridge (m) (A)	Average Number of Concrete Barrier (B) *1	Total Concrete Barrier Length (m) (=AxB)
16,326	3.21	52,422

*1 The number shown is an average considerering 4 barriers in the main alignment and 2 barriers in the ramps.

Source: JICA Study Team

Table 8.3.9 Breakdown of Quantities (Package-2)

Package 2 (CH. 10+380 to CH. 18+187)

Earthworks

	Cross Section Area (m2) (A)	Average Height (m) (B)	Length (m) (C)	Total Volume (m3) (=AxB, AxC)
Excavation	69.90		1,490	104,151
Soft Soil Improvement	35,015.14	3.5		122,553

Values based on a typical cross section

	Height (m) (A)	Length (m) (B)	Total Area (m2) (=AxB)
Retaining Wall	6.00	308	1,848

Values based on a typical cross section

Foundation (Pile)

Diameter of Piles *1	Number of Piers (A)	Number of Piles per Pier (B)	Average Length per Pile (m) (C)	Total Pile Length (m) (=AxBxC)
φ1000	133	4	7.141	3,799
φ1200	62	6	7.357	2,737
φ2000	217	4	22.502	19,532
φ2400	32	4	19.289	2,469
				28,537

*1 Pile diameters according to the preliminary design: 1000/1200mm (Shivajinagar IC) and 1200/2000/2400mm (main alignment).

Substructure

Number of Pier (A)	Average Concrete Volume/Pier (m3) (B)	Total Concrete Volume (m3) (=AxB)
444	234.198	103,984

Superstructure (Concrete)

Bridge Length of Concrete (m) (A)	Average Area of Cross Section (m2) (B)	Number of Bridge (C) *1	Total Concrete Volume (m3) (=AxBxC)	
6,077	10.609	2	128,942	* Main Alignment
1,383	8.576	1	11,856	* Ramps
			140,798	

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Superstructure (Steel Box Girder Bridge)

Bridge Length of Steel (m) (A)	Average Weight of Steel (kg/m) (B)	Number of Bridge (C) *1	Total Steel Weight (kg) (=AxBxC)	
1,730	12,600	2	43,596,000	* Main Alignment

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Dolphins (Ship collision protection)

Number of Dolphin/Pier (A)	Number of Pier (B)	Total Dolphin Number (=AxB)
4	4	16

Dolphins were considered only on piers adjacent to navegation channel.

Pavement

Pavement Length along Bridge (m) (A) *1	Average Pavement Width (m) (B) *2	Layers (C) *3	Total Pavement Area (m2) (=AxBxC)
9,190	26.929	2	494,964

*1 Total pavement length considering main alignment and ramps.
*2 Average pavement width considering main alignmnet and ramps.
*3 The pavement shall be executed in 2 layers (2 stages)

Noise Barrier

Noise Barrier Length along Bridge (m) (A) *1	Barrier Height (m) (B)	Number of Noise Barrier (C) *2	Total Noise Barrier Area (m2) (=AxBxC)
627	2	2	2,508

*1 Considered in the intertidal area to protect Flamingo in Navi Mumbai side.
*2 Considered on both sides of the structure (north and south).

Concrete Barrier

Concrete Barrier Length along Bridge (m) (A)	Average Number of Concrete Barrier (B) *1	Total Concrete Barrier Length (m) (=AxB)
9,190	3.673	33,757

*1 The number shown is an average considerering 4 barriers in the main alignment and 2 barriers in the ramps.

Source: JICA Study Team

Table 8.3.10 Breakdown of Quantities (Package-3)

Package 3 (CH. 18+187 to CH. 21+800)

Earthworks

	Cross Section Area (m2) (A)	Average Height (m) (B)	Length (m) (C)	Total Volume (m3) (=AxB, AxC)
Excavation	225.4		3,217.0	725,189
Soft Soil Improvement	19,505.1	3.5		68,268

Values based on a typical cross section

	Height (m) (A)	Length (m) (B)	Total Area (m2) (=AxB)
Retaining Wall	6.0	1,000.0	6,000

Values based on a typical cross section

Foundation (Pile)

Diameter of Piles *1	Number of Piers (A)	Number of Piles per Pier (B)	Average Length per Pile (m) (C)	Total Pile Length (m) (=AxBxC)
φ1000	116	5	18.515	10,739
φ1200	181	6	18.820	20,438
φ1500	18	6	19.389	2,094
				33,271

*1 Pile diameters according to the preliminary design: 1000/1200mm (Interchange) and 1200/1500mm (main alignment).

Substructure

Number of Pier (A)	Average Concrete Volume/Pier (m3) (B)	Total Concrete Volume (m3) (=AxB)
315	142.114	44,766

Superstructure (Concrete)

Bridge Length of Concrete (m) (A)	Average Area of Cross Section (m2) (B)	Number of Bridge (C) *1	Total Concrete Volume (m3) (=AxBxC)	
2,284	10.014	2	45,746	* Main Alignment
1,650	7.719	1	12,736	* Ramps
			58,482	

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Superstructure (Steel Truss)

Bridge Length of Steel (m) (A)	Average Weight of Steel (kg/m) (B)	Number of Bridge (C) *1	Total Steel Weight (kg) (=AxBxC)	
326	4,900	2	3,198,000	* Main Alignment

*1 There are 2 bridges in the main alignment: inbound lane (Chirle to Sewri) and outbound lane (Sewri to Chirle).

Pavement

Pavement Length along Bridge (m) (A) *1	Average Pavement Width (m) (B) *2	Layers (C) *3	Total Pavement Area (m2) (=AxBxC)
4,260	21.95	2	186,996

*1 Total pavement length considering main alignment and ramps.

*2 Average pavement width considering main alignmnet and ramps.

*3 The pavement shall be executed in 2 layers (2 stages)

Concrete Barrier

Concrete Barrier Length along Bridge (m) (A)	Average Number of Concrete Barrier (B) *1	Total Concrete Barrier Length (m) (=AxB)
4,260	3.15	13,438

*1 The number shown is an average considerering 4 barriers in the main alignment and 2 barriers in the ramps.

Source: JICA Study Team

8.4 Cost Estimate Results for MoUD and MoRTH

Since the scale of the MTHL project is very large, the MoUD carried out the approval of the MTHL project cost. Thus, the MoUD requested the latest project cost reflecting latest information (not to the project cost at the appraisal stage of the project in January, 2016) from JICA Study Team. The result of the latest project cost update is shown in Appendix-20.

9. OPERATION AND MAINTENANCE OF MTHL

9.1 Introduction

The Government of Maharashtra appointed the Mumbai Metropolitan Region Development Authority (MMRDA) as the implementing agency of MTHL based on the Resolution dated 4 Feb, 2009 and decided that necessary funds will be raised by MMRDA.

In Chapter 9, the existing implementation structure and capability of MMRDA as the implementation agency of MTHL is confirmed and an effective Operation & Maintenance plan is prepared. Technical cooperation for the capacity development of Operation & Maintenance of MTHL is proposed, as necessary.

9.2 Organization and Capacity of Agencies Responsible for Road and Bridge Maintenance and Operation

9.2.1 The Organization and Responsibilities of MMRDA

MMRDA was established on 26th January, 1975 in accordance with the Mumbai Metropolitan Development Act, 1974 to make Mumbai Metropolitan Region (MMR) a destination for economic activity by promoting infrastructure.

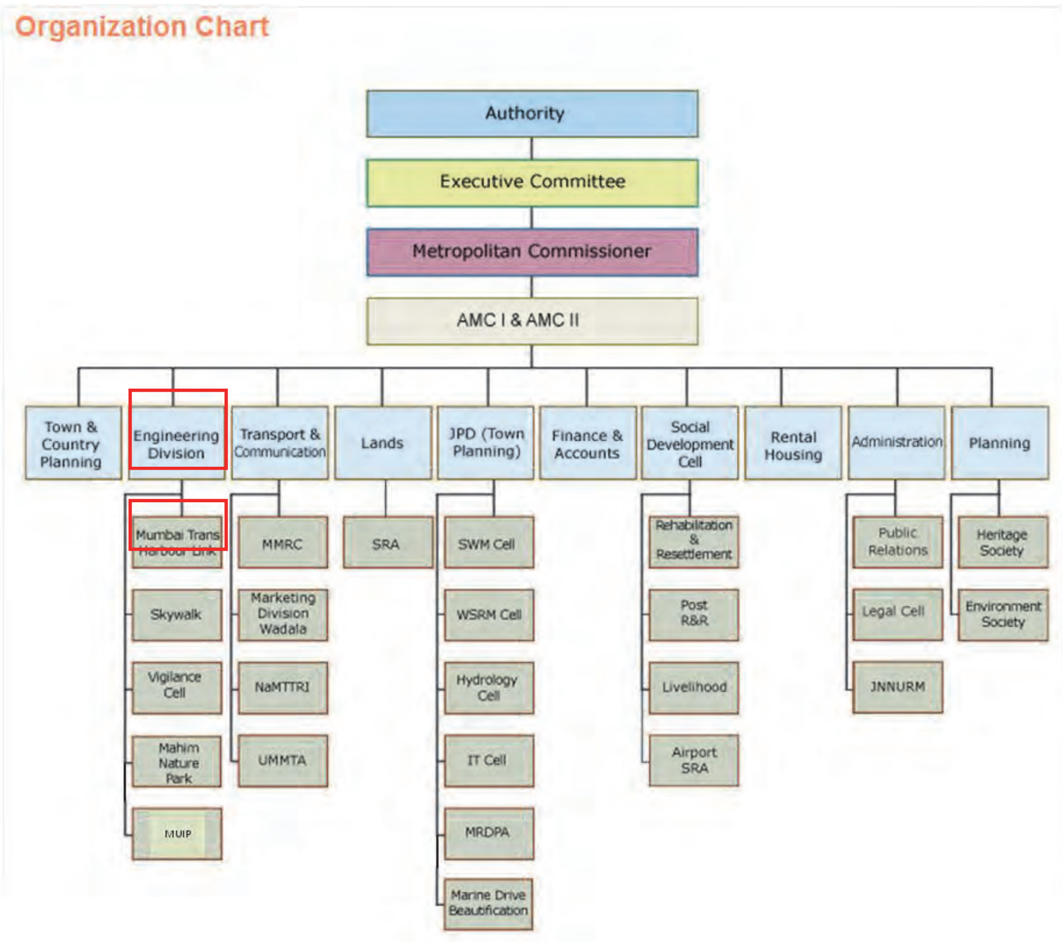
Since its establishment, MMRDA has been engaged in long term planning, promotion of new growth centres, implementation of strategic projects and financing infrastructure development.

The following are the responsibilities of MMRDA,

- Preparation of Regional Development Plans
- Providing financial assistance for significant regional projects
- Providing help to local authorities and their infrastructure projects
- Coordinating execution of projects and/or schemes in MMR
- Restricting any activity that could adversely affect appropriate development of MMR, etc.

In particular, it conceives, promotes and monitors the key projects for developing new growth centres and brings about improvement in sectors like transport, housing, water supply and the environment in the Region. MTHL contributes to the improvement of connectivity in MMR to deal with the geographical limitation that is a big obstacle for continuing development of new growth centres. MMRDA takes responsibility for MTHL directly, and carries it out.

The Organization Chart of MMRDA is shown in Figure 9.2.1. The Authority, headed by the Chief Minister, Government of Maharashtra, is the highest policy making body of MMRDA which supervises and controls all the activities of MMRDA. The Executive Committee, headed by the Chief Secretary, Government of Maharashtra, provides technical guidance to MMRDA. The implementation structure consists of ten Divisions under the Metropolitan Commissioner. The project section of MTHL is established in the Engineering Division. The number of the engineers of the whole MMRDA Engineering Division who are in charge of MTHL are shown in Table 9.2.1. The implementation structure in the Construction phase of MTHL, which is proposed by MMRDA, is shown in Table 9.2.2, and the officers classes and numbers of engineers in the Engineering Division in the Construction phase and the Operation and Maintenance phase of MTHL, which is proposed by MMRDA, is shown in Table 9.2.3.



Source: MMRDA

Figure 9.2.1 Organization Chart of MMRDA

Table 9.2.1 Number of Engineers

Organization/Division/Unit	Number (Person)	
	Engineers	Outsourced engineers
MMRDA (Total)	66	0
Engineering Division (Total)	54	0
MTHL Unit	5	0

Source: MMRDA

Table 9.2.2 Number of Officers of Project Implementation Unit (Proposed by MMRDA)

Division	Number (Person)	
	Key personnel	Support Staff
Engineering	26	4
Finance & Accounts	4	2
Social Development Cell	2	2
Lands	3	1
Administration	3	9
Environmental	2	0
Total	40	18

Source: MMRDA

Table 9.2.3 Officers Class and Numbers of Engineers in Engineering Division (Proposed by MMRDA)

Position Name	Number of Engineers (person)	
	Construction Stage	O / M Stage
Chief Engineer	1	1
Superintending Engineer	2	1
Executive Engineer	6 (civil), 2 (electric)	2
Deputy Engineer	6 (civil), 2 (electric)	4
Assistant Engineer	6 (civil), 2 (electric)	4
Total	27	12

Source: MMRDA

9.2.2 Financial Situation of MMRDA

The trend of allocated budget and expenditure for MMRDA Roads for the past 5 years are shown in Table 9.2.4.

Table 9.2.4 Allocated Budget and Expenditure for MMRDA Roads (Million INR)

Items	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
Budget	8,250	9,900	4,380	6,700	7,230
Expenditure	6,280	9,040	7,760	7,020	7,000

Source: MMRDA

9.2.3 Implementation Capability of MMRDA

The Engineering division of MMRDA, which is responsible for MTHL, undertakes various projects to provide better urban infrastructure and improve the traffic and transportation scenario in MMR. The following are the major projects implemented by the Engineering Division.

Mumbai Urban Infrastructure Project：MUIP

In consideration of the increasing population in Mumbai and future travel demand, this project is aimed at improving the road network for a total of over 450 km in length consisting of elevated roads, flyovers, subways and footpaths. MUIP is estimated to cost approximately 37,400 million INR. This project period was 2005 through 2011.

Mumbai Urban Transport Project：MUTP

This project aimed to improve the transport infrastructure and services in Mumbai through investment in suburban railway projects, local bus transport, new roads, bridges, pedestrian subways and traffic management activities. MUTP is estimated to cost approximately 8,620 million INR. This project period is 2005 through 2015.

Eastern Freeway

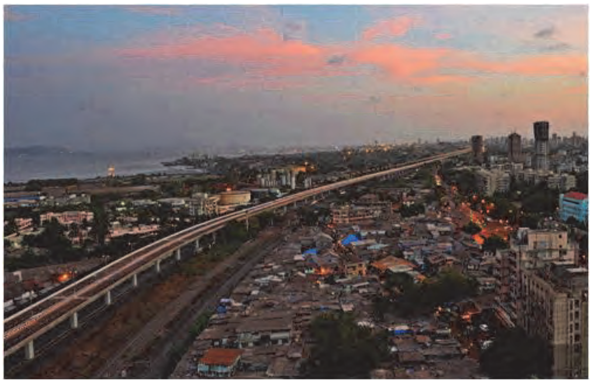
In consideration of the present situation, future traffic and other transportation demands, this project aims to help smooth traffic and reduce traffic congestion in Mumbai. This project is to construct a freeway of 16km in length consisting of an elevated corridor, bridges, flyovers, over bridge and twin tunnel, which is first of its kind in Mumbai. This project is estimated to cost approximately 8,690 million INR. In addition, MTHL shall be connected to the freeway on the Mumbai side.

Source: MMRDA

Figure 9.2.2 Mumbai Urban Infrastructure Project (MUIP)

Source: MMRDA

Figure 9.2.3 Mumbai Urban Transport Project（MUTP）



Source: MMRDA, Study Team

Figure 9.2.4 Eastern Freeway

MMRDA has various experiences with major road projects, and it is considered that MMRDA can perform the appropriate correspondence as the implementation agency in the implementation of MTHL. However, MMRDA does not have any experience in the Operation and Maintenance of roads so far, because MMRDA handed over the roads developed by them to Municipal Corporations. It is necessary to examine the appropriate organization structure to maintain the marine bridge and operate the toll road, in consideration of the special features of MTHL, which are long span marine bridges and access controlled toll road. An appropriate plan for Operation and Maintenance structure of MMRDA should be examined based on the organization of MSRDC which is an implementing agency of the toll road business in Maharashtra.

9.2.4 Maharashtra State Road Development Corporation Ltd. (MSRDC)

MSRDC is a corporation established and fully owned by the Government of Maharashtra and has been incorporated as a limited liability company under the Companies Act 1956 as of 2nd August 1996. MSRDC mainly deals with the properties and assets comprising movables and immovables including land, road projects, flyover projects, toll collection rights and works under construction which vested with the State Government and were under the control of the Public Works Department.

MSRDC was the contracting agency of MTHL at the time of the bid before and responsible for the study of MTHL in 2004. According to the interview survey, MSRDC has jurisdiction over road projects of the BOT method, and MMRDA has jurisdiction over projects not involving BOT. Therefore MSRDC does not seem to have a possibility of operating MTHL in the future due to the change of the project scheme from BOT method to EPC method.

One of the achievements of MSRDC is “Bandra Worli Sea Link (BWSL)” which is the link road connecting the western suburbs with the island city of Mumbai. This project is similar to MTHL containing marine bridges and a toll road. Hence the administration of BWSL will be useful for the examination of the Operation & Maintenance Plan of MTHL. For the description of BWSL, see section 6.6.2.

9.3 Operation and Maintenance Plan

9.3.1 General Situation of Operation and Maintenance

(1) Divisions in Charge of Operation and Maintenance

The Engineering Division, MMRDA, will be in charge of Operation and Maintenance of MTHL after the completion of its construction. In the interviews with MMRDA, MMRDA indicated that it intends to outsource the Operation and Maintenance of MTHL. In addition, Concessionaires generally under take Operation and Maintenance of toll roads in MMR.

(2) General Situation of Operation and Maintenance Works

In an effort to describe the general situation of Operation and Maintenance works of toll roads in MMR, the situation of MSRDC's Project, "Bandra Worli Sea Link (BWSL)" and "Mumbai Pune Expressway" are mentioned below. For the description of these projects, see section 6.6.2.

1) Inspection and Maintenance

In the interviews with MSRDC and MEP Infrastructure Developers Ltd. (the Concessionaire), which are operating and maintaining BWSL, the inspection and maintenance of road structures are conducted following the Operation and Maintenance Manuals of BWSL made by the Concessionaire based on the relevant laws and regulations of India and the IRC guidelines.

In the Operation and Maintenance Manual of BWSL, which has similar conditions with MTHL such as a marine bridge, inspection can be categorized into three classes: Routine, Extended and Special inspection. Besides these categorized inspections there are casual and cursory observations made by users of the structure or by people who happen to be in the vicinity. This information can be of major importance when reporting accidents and acts of vandalism.

(a) Routine Inspections

Routine Inspections by the concerned Bridge Maintenance Department should be carried out methodically at regular intervals (1 year, 3 years, and 5 years: middle intervals of Extended Inspection). The inspector should work through a checklist that was prepared based on this maintenance manual and take into account the local operating and environmental conditions of the bridge.

The inspection should be carried out by a trained inspector under the supervision of an experienced bridge engineer. The result should be compared with the results of previous inspections. A written report should be made of the condition of the structure and its various parts. The inspection is primarily a visual inspection and, in general, special access, plant or equipment other than those already provided in the design should not be necessary.

(b) Extended Inspections

Extended Inspections should be carried out in place of the second routine inspection (regular intervals: 2 years, 6 years, and 10 years). The aim of Extended Inspections is to carry out a closer and more intensive examination of all elements of the structure. This may require special access platforms or mounted vehicles such as cherry pickers, remote viewing techniques, taking core and samples, and in-situ non-destructive testing. In addition to the Checklist of Routine Inspection, special instructions applicable to the different parts of the bridge should be considered.

(c) Special Inspections

A number of circumstances may arise in between Routine Inspections and Extended Inspections that warrant additional inspections to be carried out. These include:

- Exceptionally high winds or storms that may have caused bridge damage, including vibration of the stay cables.
- Abnormally heavy loads passing over the bridge.
- Collision with bridge piers, parapets, pylons, stay cables or abutments by errant vehicles or marine vessels.
- Accidents on the bridge involving spillage of toxic, flammable or corrosive material.
- An earthquake of sufficient magnitude to have caused damage to parts of the bridge.
- Acts of vandalism or unlawful violence serious enough to have damaged parts of the bridge.
- Exceptionally high waves that may have caused damage to bridge piers.

As Maintenance works, measures of Correction and Prevention for the assumed Problems of each component (Piles, Pile Cap, Piers, Pylons, Bridge Bearings, Bridge Deck, Stay Cables, Stay Anchorages, Abutments, Concrete Kerb, Metal crash barrier, Hand Rail, Bituminous wearing course, Bridge Drainage System, etc.) are covered in Operation and Maintenance Manual. In addition, the improvement works are not included in the concession agreement and MSRDC places a separate order for these works to specialized companies.

In the case of Mumbai Pune Expressway, the 94.5km total length is divided into 3 sections (about 30km/ section), and Inspection and Maintenance works are carried out by each Maintenance Office.

2) Traffic Management

(a) Traffic Patrol

In the case of BWSL, the road patrol by motorcycle is always conducted for 24 hours a day in 3 shifts by 2 people in each shift. In addition, it is not aimed for traffic management, but security guards are arranged every 500 m in median.

In the case of Mumbai Pune Expressway, an Accident Management Team, Incident Management Team, Medical Team and Recovery Team are in place 24 hours a day in 3 shifts in each Maintenance Office of the 3 sections like the inspection and maintenance works.

(b) Road side facilities and Traffic Control Centre

In the case of BWSL, the road side facilities such as CCTV (Closed-Circuit Television), ECB (Emergency Call Box), ATCC (Automatic Traffic Counter–cum-Classifier Detection Systems) and VMS (Variable Message Signs) are installed, and 2 operators always monitor the road facilities of BWSL for 24 hours a day in 3 shifts in a traffic control room.

In the case of Mumbai Pune Expressway, ECB and ATCC are installed, and an operator is always arranged for 24 hours a day in 3 shifts in a call centre.

For further descriptions of the Road side facilities and Traffic Control Centre of BWSL and Mumbai Pune Expressway, see section 6.6.2.

(c) Vehicles for Traffic Management

It is common in toll roads in India that following the concession agreement, the Concessionaire should assign 1) road patrol vehicles, 2) ambulances and 3) towing vehicles to the section of road that it manages and operate them. In fact, IRB Infrastructure Developers Ltd., the Concessionaire of Mumbai Pune Expressway, has assigned these vehicles to the sections and other crane trucks used together with other sections, and they manage and have been operating them there.

In the case of BWSL, an ambulance is not assigned because there are emergency facilities near.

Source: JICA Study Team

Figure 9.3.1 Vehicles for Traffic Management (Mumbai Pune Expressway)

3) Toll Management

For the Toll Management, an Electronic Toll Collection system (ETC) is installed together with the manual toll collection by toll collectors at each toll plaza. For further description of the Toll Management System, see section 6.6.2.

At the toll plaza of BWSL, 4 lanes among the total 16 lanes are only for ETC, and the 12 remaining lanes are for manual toll collection. In each toll booth, the members are comprised of a Toll collector in the toll booth, a Lane assistant who delivers the receipt showing the rate and the change out of the toll booth and a Security guard. Under the instruction of a Supervisor, the members conduct the manual toll collection for 24 hours a day in 3 shifts. The placement system of the staff in the toll plaza is similar in the Mumbai-Pune Expressway.

9.3.2 Operation and Maintenance Plan

(1) Outline of Operation and Maintenance

An appropriate plan for the Operation and Maintenance of MTHL after the completion of its construction is prepared. In general, the O/M of a toll road on which vehicles can be driven at a high speed (100km/h), such as MTHL, is divided into four major components: 1) Inspection, 2) Maintenance, 3) Traffic Management and 4) Toll Management. Table 9.3.1 shows the outline of each of the four components mentioned above and the general supervision.

Table 9.3.1 Overview of Road Operation and Maintenance

Component	Outline of the work
General supervision	- Preparation of an overall project plan and a budgetary management plan - Supervision of budget allocation and work execution - Preparation of required standards and manuals - Supervision of the contracts for the maintenance work - Coordination with relevant organizations - Supervision and monitoring of the execution of the Inspection, Maintenance, Toll Management and Traffic Management
Inspection	- Preparation of an inspection plan - Execution of the inspection work (including emergency inspections) - Compilation of results of inspections and evaluation of structural soundness - Prioritization of the need for repair of damage - Preparation of a medium- to long-term maintenance plan - Preparation of a road improvement plan and a disaster management plan - Monitoring and evaluation of completed repair and improvement works
Maintenance	- Preparation of a maintenance plan - Execution of the maintenance work - Emergency work (repairing of road surface, accident restoration and disaster restoration, etc.) - Execution of improvement and maintenance works - Monitoring and evaluation of completed maintenance and repair works
Toll Management	- Preparation of a plan for the toll collection including the number of lanes (toll booths) at the tollgate, assignment and work shifts of toll collectors, toll collection method and toll collection facilities - Toll collection - Counting, verification, storing and depositing of collected tolls - Responses to inquiries from road users
Traffic Management	- Collection of traffic information from relevant organizations and road users - Regular road patrols and road patrols at the time of emergency - Collection of traffic and road information from the road patrols and the roadside facilities (including CCTV cameras and emergency telephones etc.) - Provision of road and traffic information on variable-message signs (VMS), radio and the Internet - Initial responses (including traffic regulation and notification to the traffic police and fire services) to incidents (including accidents, objects on the road and stalled vehicles) - Warning and enforcement of regulations to traffic violators in cooperation with the traffic police

(2) Inspection and Maintenance Plan

1) Inspection Plan

MTHL will be characterized by its large proportion of bridge structures. In order to maintain MTHL in the condition which ensures safe and comfortable driving for a long term, damage to the structures shall have to be detected at an early stage with regular inspection and repair.

The types and frequency of the inspection works are planned in Table 9.3.2, in reference to the Operation and Maintenance Manual of BWSL and inspection works conducted on expressways in Japan.

Table 9.3.2 Types of Inspection for MTHL (recommended)

Items	Interval	Type of inspection
Initial Inspection	After completion of the construction and /or Before opening the road	Short range visual
Regular Inspection	5 every 2 weeks *	On board visual
Routine Inspection	1 every year	Distant visual Short range visual, if necessary
Detailed Inspection	1 every 5 years	Short range visual Examination by touch Hammering inspection Non-destructive inspection
Special Inspection	As needed	Short range visual

* If the traffic volume is more than 25,000 /day and less than 50,000 /day

(a) Initial Inspection

Initial Inspection is the inspection by short range visual and hammering, etc. to grasp the initial situation after the completion of the structure. The inspection is conducted before commencing service. The records such as defects, disasters and repairs under construction are gathered and it is necessary to arrange basic data about the initial situation of the structure to utilize it for the later maintenance.

(b) Regular Inspection

Regular Inspection is to detect the conditions of the structure on a daily basis to secure safe road traffic, and to prevent damage to third parties. And to detect damage and changes in the conditions at an early stage and decide whether or not it is necessary to take appropriate measures against the damage and changes to maintain roads in the ordinary sound condition.

The inspection is conducted in the range capable of confirmation from the carriage way mainly by looking from the car and feeling while driving, and the condition is identified by getting out of the car as needed.

(c) Routine Inspection

Routine Inspection is to examine general conditions of structures in the entire section on a regular basis concerned with focus on damages at locations such as intersections and road sides where damage to third parties is expected to occur.

The inspection is conducted in the entire section mainly by distant visual observation from the outside of the carriage way and short range visual observation as needed.

(d) Detailed Inspection

Detailed Inspection is to examine each member of the structures in detail on a regular basis, and evaluate/diagnose the condition of the structures with occurrence or progress of damages, to grasp structural soundness, to ensure safe road traffic and to prevent damage to third parties.

The inspection is conducted basically by short range visual observation with palpation, hammering and non-destructive inspection as needed.

(e) Special Inspection

Special Inspection is conducted when the need for the inspection arises, e.g. when a problem which cannot be solved with the regular inspection has been detected, when severe damage has been detected on a structure, at the time of an extreme weather condition or a traffic accident or a natural calamity.

2) Maintenance Plan

Routine Maintenance includes cleaning, vegetation and minor pavement repair, etc. In general, Maintenance Requirements are set for maintenance of National Highways by Concession agreement in India. In MTHL, the maintenance work that is equal to other Indian toll roads is demanded. For reference, Maintenance Requirements are shown in Table 9.3.3 and Table 9.3.4.

Table 9.3.3 Maintenance Requirements for Roads (Reference)

Nature of defect or deficiency	Time limit for repair / rectification
■Carriageway and paved shoulders	
Breach and blockade	Temporary restoration of traffic within 24 hours Permanent restoration within 15 days
Roughness value exceeding 2,750 mm in a stretch of 1 km	180 days
Pot holes	48 hours
Cracking in more than 5% of road surface in a stretch of 1 km	30 days
Rutting exceeding 10 mm in more than 2% of road surface in a stretch of 1 km	30 days
Bleeding / Skidding	7 days
Ravelling / Stripping of bitumen surface exceeding 10 m^2	15 days
Damage to pavement edges exceeding 10 cm	15 days
Removal of debris	6 hours
■Hard / earth shoulders, side slopes, drains and culverts	
Variation by more than 2% in the prescribed slope of camber / cross fall	30 days
Edge drop at shoulders exceeding 40 mm	7 days
Variation by more than 15% in the prescribed side (embankment) slopes	30 days
Rain cuts / gullies in slopes	7 days
Damage to or silting of culverts and side drains during and immediately preceding the rainy season	7 days
Desilting of drains in urban / semi-urban areas	48 hours
■Road side furniture including road signs and pavement marking	
Damage to shape or position; poor visibility or loss of retro-reflectivity	48 hours
■Street lighting and telecom (ATMS)	
Any major failure of the system	24 hours
Faults and minor failures	8 hours
■Trees and plantation	
Obstruction in a minimum head-room of 5 m above carriageway or obstruction in visibility of road signs	24 hours
Deterioration in health of trees and bushes	Timely watering and treatment
Replacement of trees and bushes	90 days
Removal of vegetation affecting sight line and road structures	15 days
■Rest areas	
Cleaning of toilets	Every 4 hours
Defects in electrical, water and sanitary installations	24 hours
■Toll plaza(s)	
Failure of toll collection equipment or lighting	8 hours
Damage to toll plaza	7 days
■Other Project Facilities and Approach roads	
Damage or deterioration in Approach Roads, (pedestrian facilities, truck lay-bys, bus-bays, bus-shelters, cattle crossings, traffic aid posts, medical aid posts and other works)	15 days

Table 9.3.4 Maintenance Requirements for Bridges (Reference)

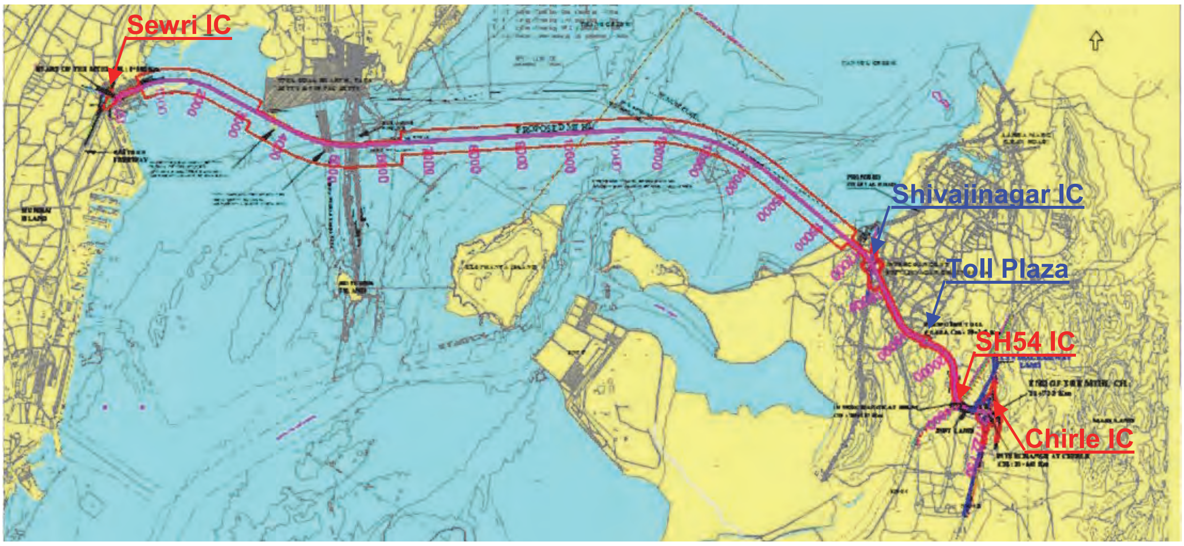
Nature of defect or deficiency	Time limit for repair / rectification
■Super structure of bridges	
Cracks	Temporary measures within 48 hours Permanent measures within 45 days
Spalling / scaling	15 days
■Foundations of bridges	
Scouring and/or cavitation	15 days
■Piers, abutments, return walls and wing walls of bridges	
Cracks and damages including settlement and tilting	30 days
■Bearings (metallic) of bridges	
Deformation	15 days
■Joints in bridges	
Loosening and malfunctioning of joints	15 days
■Other items relating to bridges	
Deformation of pads in elastomeric bearing	7 days
Gathering of dirt in bearings and joints; or clogging of spouts, weep holes and vent-holes	3 days
Damage or deterioration in parapets and handrails	3 days
Rain-cuts or erosion of banks of side slopes of approaches	15 days
Damage to wearing coat	15 days
Damage or deterioration in approach slabs, pitching, apron, toes, floor or guide bunds	30 days
Growth of vegetation affecting the structure or obstructing the waterway	15 days

(3) Toll Management Plan

1) Location of Toll Plazas

The interchanges connecting with MTHL are planned in one place (Sewri IC) on the Mumbai side and three places (Shivajinagar IC, SH54 IC, Chirle IC) on the Navi Mumbai side, so four places in total.

The toll plazas of MTHL are planned in Shivajinagar IC toll plaza (CH:17+342) and the main toll plaza (CH:19+370; main line between Shivajinagar IC and SH54 IC). Both toll plazas shall be located on the Navi Mumbai side.



Source: JICA Study Team

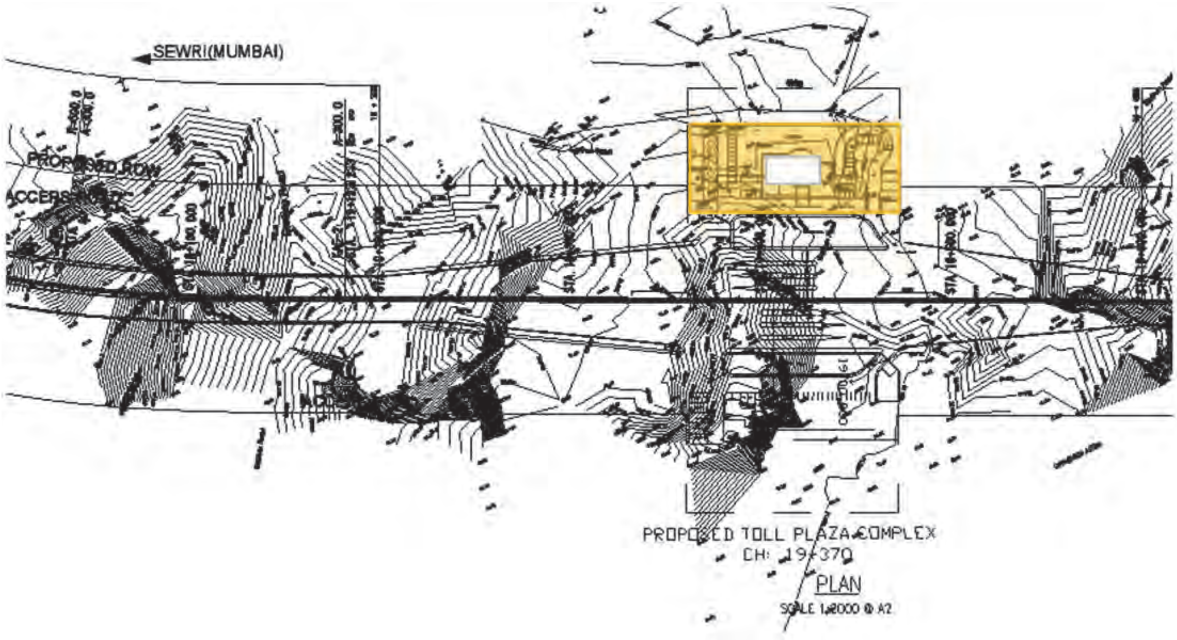
Figure 9.3.2 Location of IC and Toll Plaza

2) Layout Plan for the Toll Plaza

The Main Toll Plaza shall be located in the main line (CH:19+370). And the layout plan and points of concern of Shivajinagar IC Toll Plaza are shown in 6.6.3.

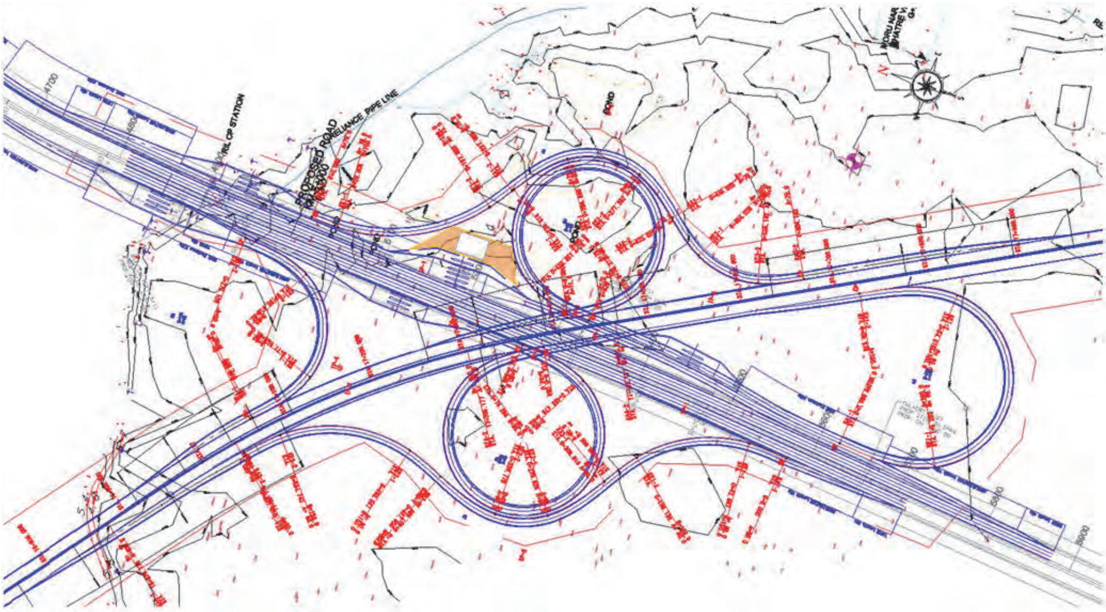
Facilities in the Toll Office are mainly for its functions of the monitoring of the toll collection, the management of the collected toll, as a rest place for toll collectors and as a place for customer care. As these functions do not require a large-scale facility, the operation office of the MTHL is designed to be established at the same location and in the same building as the toll office. The recommended layout plan of the Main Toll Office is shown in 9.4.1 along with the Maintenance Office.

The Shivajinagar IC Toll Office should be located near Shivajinagar IC Toll Plaza within the ROW considering accessibility to the Toll Plaza, conditions in CRZ clearance and the mangrove area. Therefore, detailed location plan and drawings of the Toll Office need to be prepared in next stage. The recommended layout plan of Shivajinagar IC Toll Office is shown in Figure 9.3.5.



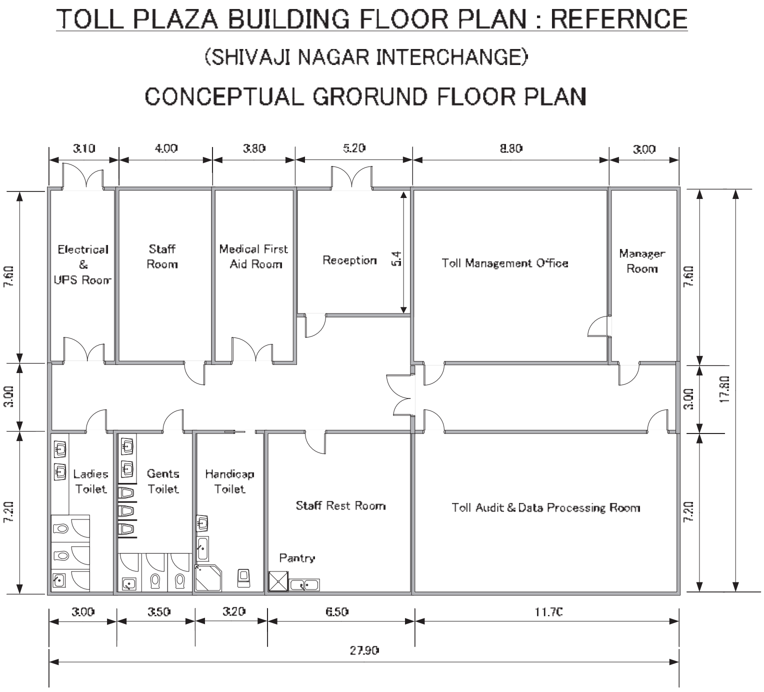
Source: JICA Study Team

Figure 9.3.3 Location of IC and Main Toll Office (in Operation Office) (Reference)



Source: JICA Study Team

Figure 9.3.4 Location of Shivejinagar IC Toll Office (Reference)



Source: JICA Study Team

Figure 9.3.5 Layout Plan for the Toll Plaza (Recommended)

3) Facilities and Equipment in Toll Plaza

CCTV cameras shall be installed at each lane in the Toll Plaza and CCTV images shall be monitored in the Toll Office in order to monitor the situations of traffic and toll collection at the tollgates. Vehicle types shall be identified and checked by toll collectors and vehicle type identifiers installed at the tollgates. The Toll Management System configuration, Manual lane equipment, ETC lane equipment and Toll Plaza Computer System are shown in 6.6.4.

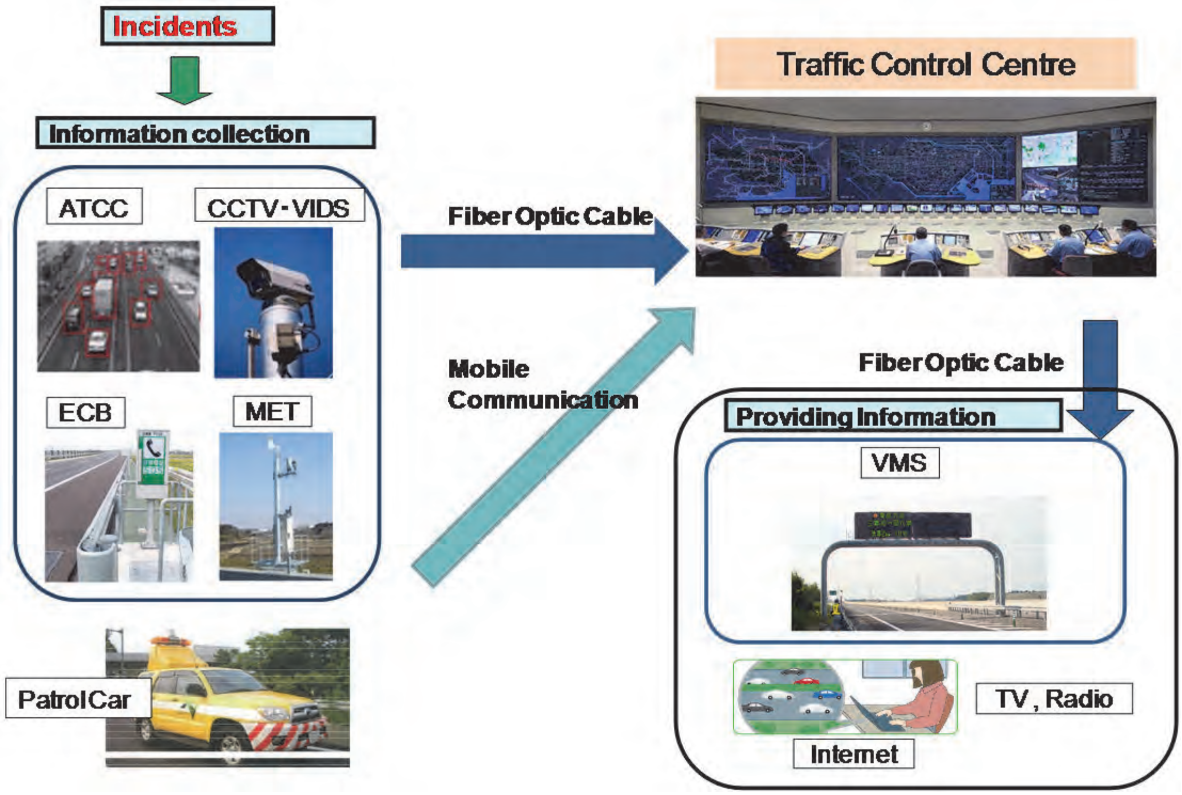
(4) Traffic Management Plan

The major services generally required in the Traffic Management are as follows:

- Collection of 1) traffic information including congestion, 2) road information including objects on the road and 3) weather information from the road patrols and the roadside facilities (including CCTV cameras, traffic counters and emergency telephones) and implementation of appropriate measures against the situation
- Warning to and enforcement of laws and rules on traffic violators (speeding, overloading, etc.) in cooperation with the traffic police
- Accumulation and analysis of the traffic, road and weather information collected from the road patrols and the roadside facilities (hereinafter referred to as “the Road Traffic Information”)
- Provision of the Road Traffic Information to road users on variable-message signs

(VMS) and the Internet.

The outline of workflow of the Traffic Management is shown in Figure 9.3.6 as reference.



Source: JICA Study Team

Figure 9.3.6 Outline of the Workflow of the Traffic Control (Reference)

1) Field Work (including Road Patrols)

In order to secure the level of services for the toll road to be maintained on MTHL, services such as regular road patrols and assignment and emergency dispatch of an ambulance and a tow vehicle will have to be provided on it.

2) Collection of the Road Traffic Information

Road information and traffic information will be collected from the road patrols, the data of traffic volumes at the toll plaza and from Road side facilities including Automatic Traffic Counter–cum-Classifiers (ATCC), CCTV and Emergency Call Boxes (ECB). The weather information will be obtained from Meteorological Sensors (MET) including rain gauges anemometers and visibility meters, in addition to TV programmes and other information sources. Information collection systems are shown in 6.6.4.

3) Provision of the Road Traffic Information

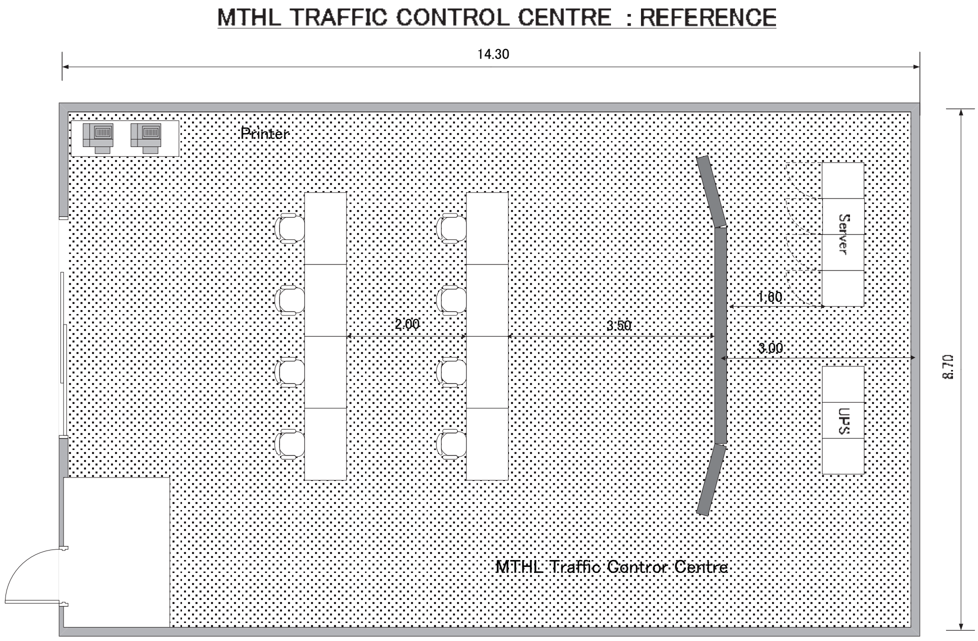
VMSs shall be installed for the provision of road information, traffic information and whether information to road users. The recommended location of VMSs is shown in 6.6.4.

4) Traffic Control Centre

The traffic control centre shall be planned to secure the safe and smooth traffic flow of MTHL and to operate the road facilities appropriately. The main roles of the Traffic control centre are as follows;

- Collection of the Road Traffic Information from the roadside equipment and traffic patrols
- Analysis and accumulation of the Road Traffic Information
- Provision of the Road Traffic Information to road users
- Monitoring of the road and traffic conditions and responses to abnormal and emergency situations

Traffic Management System configuration is shown in 6.6.4. And the layout plan of the Traffic control centre is shown in Figure 9.3.7 as reference.



Source: JICA Study Team

Figure 9.3.7 Traffic Control Center

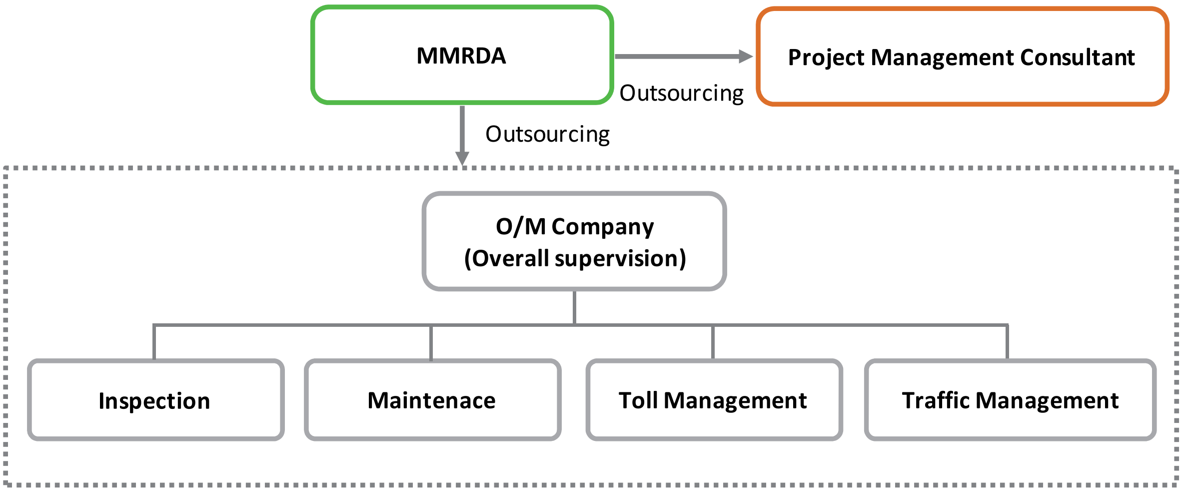
9.4 Operation and Maintenance Organization

9.4.1 Proposed Operation and Maintenance Organization

(1) Overall Organizational Structure

MMRDA intends to outsource the Operation and Maintenance (O/M) of MTHL after the completion of its construction. And the supervision of the outsourced Operation and Maintenance works shall be planned to be conducted by Project Management Consultants because it seems difficult for MMRDA to supervise the Operational and Maintenance works directly. In the case of tolled roads of a BOT scheme implemented by MSRDC, an Independent Engineer supervises Operation and Maintenance works in place of MSRDC.

Efficient and effective road maintenance requires not only the functions and the works mentioned in Table 9.3.1, but also coordinated implementation of the works. The coordinated implementation requires establishment of an organizational structure which enables efficient and effective performance of individual functions and works under the supervision of a superior organization of the O/M Company (parent company). Figure 9.4.1 shows the recommended overall organizational structure for O/M for MTHL.



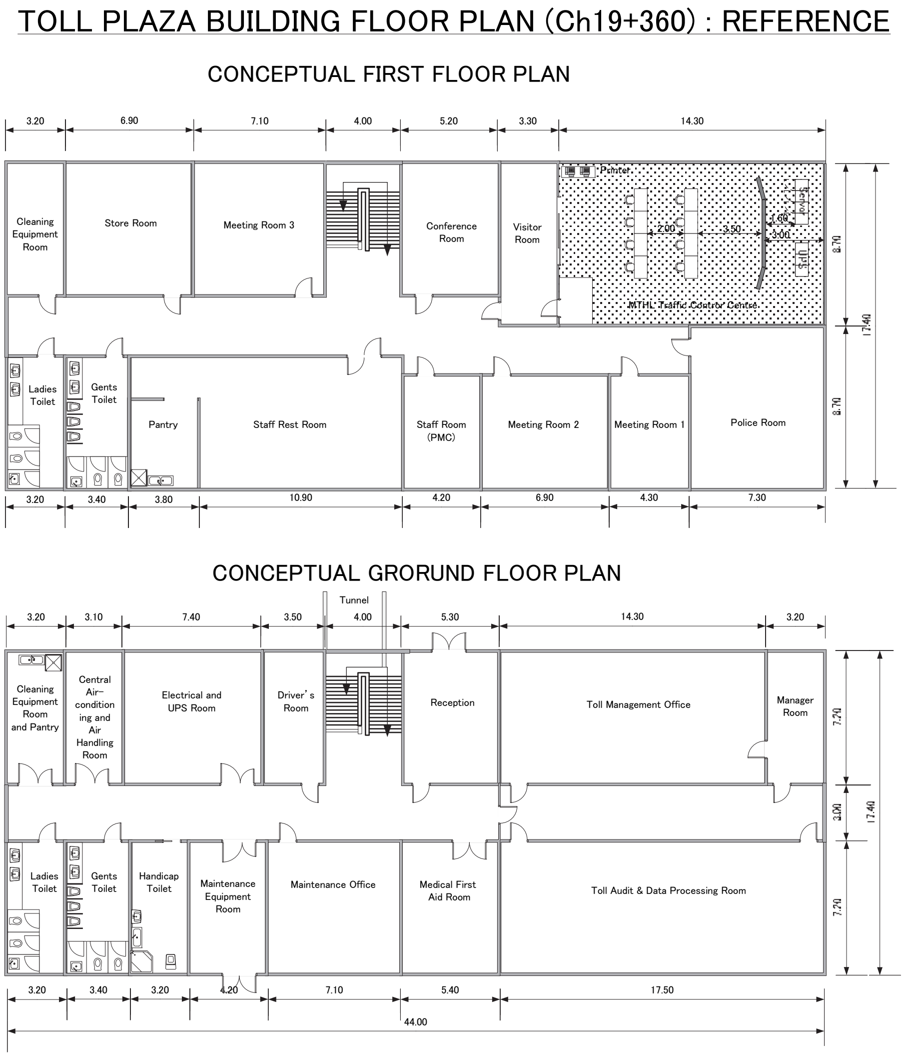
Source: JICA Study Team

Figure 9.4.1 Overall Organizational Structure for O / M (Recommended)

(2) Overall Facility Plan

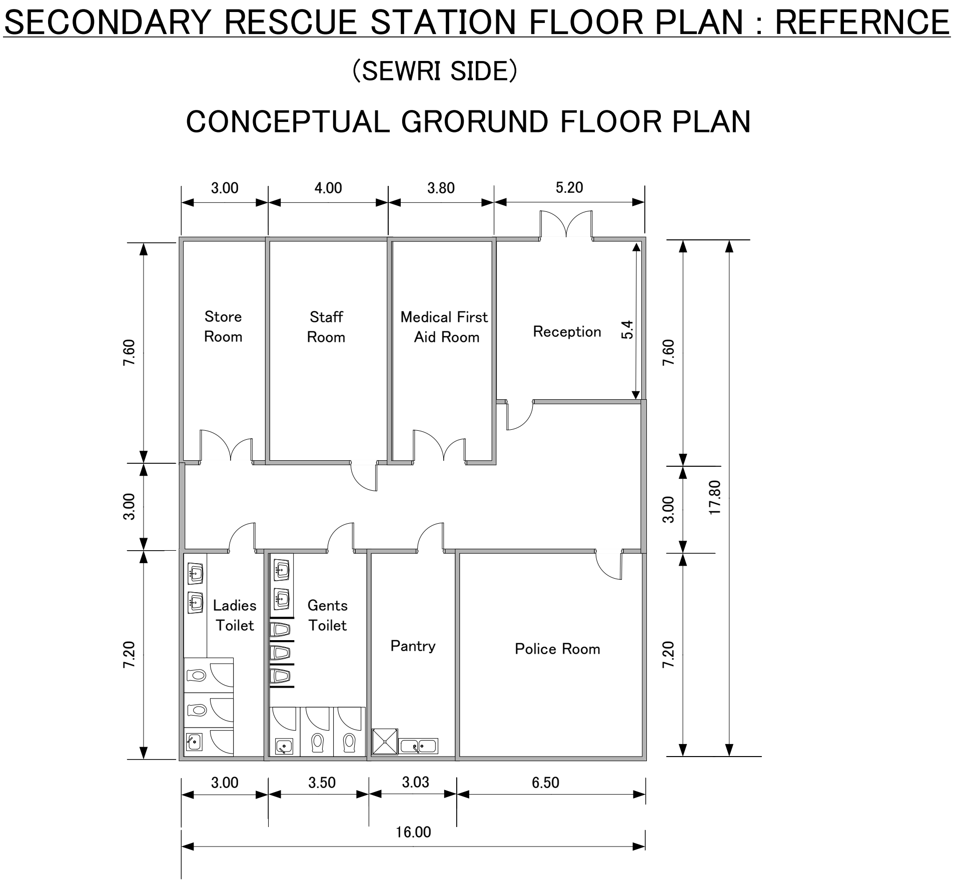
Appropriate road Operation and Maintenance requires a Maintenance Office for its implementation. Maintenance Offices are located on each toll road in MMR. Considering the management length per one Maintenance Office of Mumbai Pune Expressway being an average of around 30 km and the management length of MTHL, a main Maintenance Office is planned at a location facing the main Toll Plaza on MTHL. The office includes the Toll Office, Traffic Control Centre, Medical room and Police room, etc. The proposed floor plan of the main Maintenance Office is shown in Figure 9.4.2 as reference.

And considering requests from traffic police, a Secondary Office including Staff room, Medical room and Police room is planned at a location on the Mumbai side within the ROW. The proposed floor plan of the Secondary Office is shown in Figure 9.4.3 as reference.



Source: JICA Study Team

Figure 9.4.2 Floor Plan of the Main Maintenance Office (Reference)

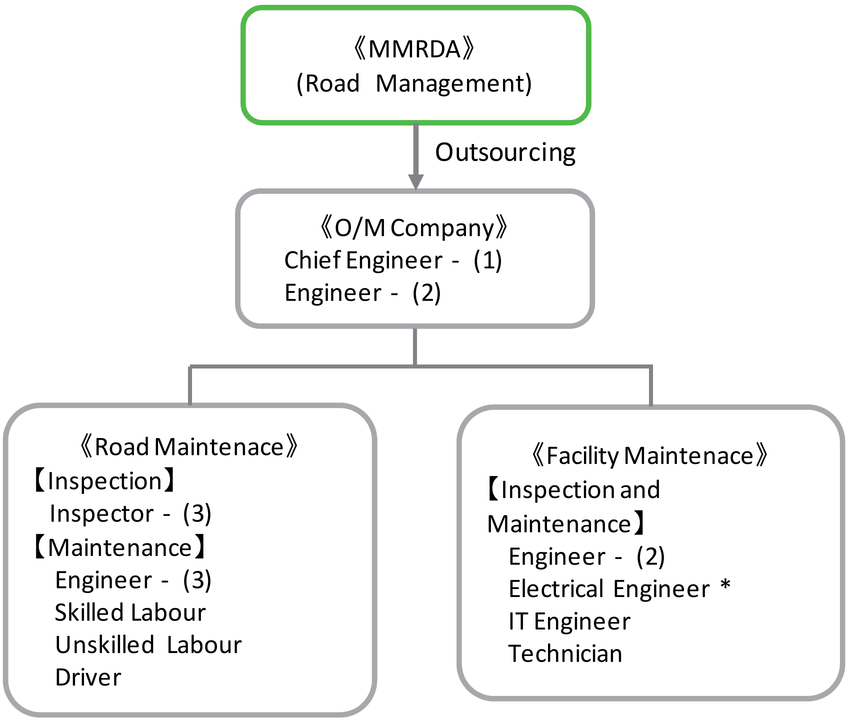


Source: JICA Study Team

Figure 9.4.3 Floor Plan of the Secondary Office (Reference)

(3) Organizational Structure for Inspection and Maintenance

Figure 9.4.4 and Table 9.4.1 show the recommended organizational structure and the main duties by job type, respectively, for the inspection and maintenance of MTHL. As seen in Figure 9.4.4, engineers shall be appointed to develop plans and supervise the inspection and maintenance and the actual inspection and maintenance services shall be conducted by the Road maintenance team and Facility maintenance team. The number of labourers changes depending on the work contents.



* 8 hours a day in 3 shifts

Source: JICA Study Team

Figure 9.4.4 Organizational Structure for Inspection and Maintenance (Recommended)

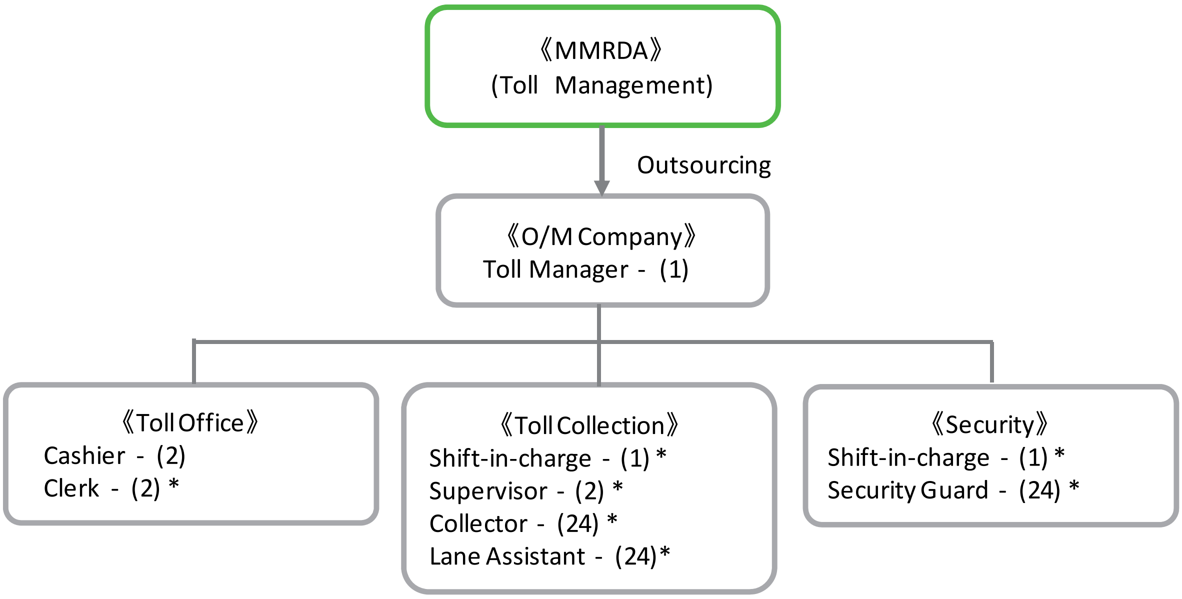
Table 9.4.1 Main Duties in the Inspection and Maintenance Dept. by Job Type (Recommended)

Job title	Main duties
Chief Engineer	- Head of the department responsible for the road inspection and maintenance - Responsible for all the inspection and maintenance work, coordinator of the overall operation - Reporting to and coordination with the relevant organizations on the results of the inspection and maintenance - Special inspection when serious damage has been detected on road structures - Education and training of the engineers
Engineer	- Supervision of the inspection and maintenance works - Preparation of a maintenance/repair plan - Reporting to and coordination with the chief engineer on the results of the inspection - Special inspection when serious damage has been detected on road structures, preparation of special inspection reports
Inspector (Road Maintenance)	- Implementation of the regular, routine, detailed and special inspections - Preparation of inspection reports - Compilation and creation of databases of the inspection results - Preparation of inspection reports - Reporting to and coordination with the engineer on the results of the inspection
Engineer (Road Maintenance)	- Supervision of the actual road maintenance works - Labor management of the actual road maintenance works - Safety management of the actual road maintenance works - Reporting to and coordination with the engineers
Engineer (Facility Maintenance)	- Implementation of the inspection for facilities (Road side facilities, Toll plaza facilities and Traffic control centre facilities, etc.) - Supervision of the actual facility maintenance works - Labor management of the actual facility maintenance works - Safety management of the actual facility maintenance works - Reporting to and coordination with the engineers

Source: JICA Study Team

(4) Organizational Structure for Toll Management

The recommended organizational structure and the details of the duties by job type are shown in Figure 9.4.4 and Table 9.4.2 respectively, designed by reference to other toll roads in India,. As shown in Figure 9.4.4, the toll management is to be implemented with a structure consisting of eight job types. As the toll collection has to be performed 24 hours a day/365 days a year, a design of four teams working eight-hours a day in 3 shifts has been adopted as the standard work shift system.



* 8 hours a day in 3 shifts

Source: JICA Study Team

Figure 9.4.5 Organization Structure for Toll Collection (Recommended)

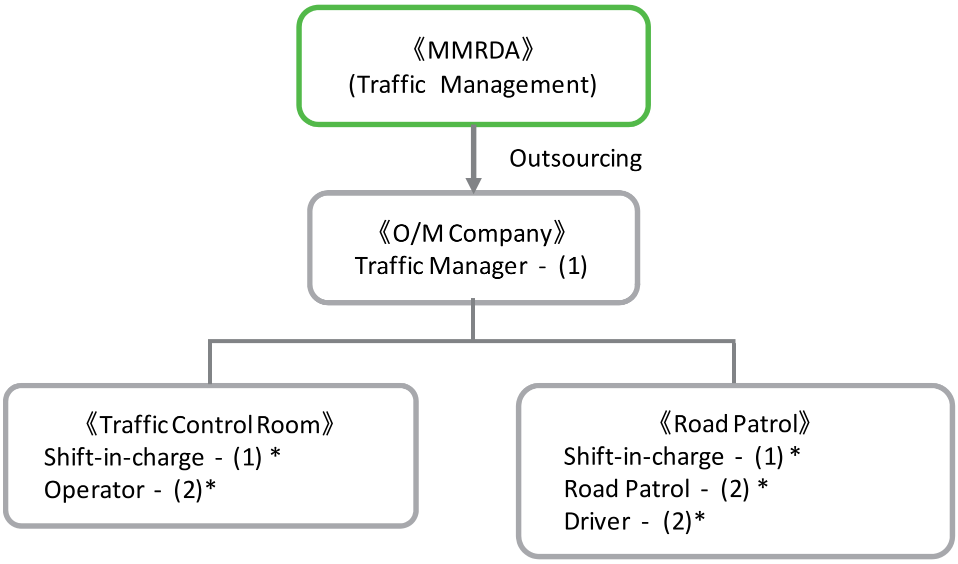
Table 9.4.2 Main Duties in the Toll Management by Job Type (Recommended)

Job title	Main duties
Toll Manager	- Supervision of the overall toll management - Coordination with the client and the relevant organizations
Cashier	- Counting the amount of the collected tolls and comparing the counted and calculated amounts - Verification of the amount of tolls collected in a day and depositing of the collected tolls in a bank account - Ensuring availability of small change and transporting it to the toll booths
Clerk	- Clerical works including attendance management and management of consumables and office supplies - Entry of management data in the system - Sales of special passes including season passes - Reception of reports on the collected and calculated amounts of the tolls (during the night) - On duty 24 hours a day/365 days a year
Shift in charge	- Head of the toll collection section - Preparation of work shift schedules - Monitoring of the performance and responses of the toll collectors and supervisors - Verification of vehicle type when a toll collector and a vehicle type identifier have identified the same vehicle differently - Education and training of the toll collectors and supervisors - On duty 24 hours a day/365 days a year
Supervisor	- Supervision of the performance of the toll collectors - Receives reports from toll collectors in the event of a special incident, such as the passing of an emergency vehicle - Responds to non-payment of a toll - Responds to inquiries from road users - Verification of the amount of tolls collected by a toll collector after her/his shift - On duty 24 hours a day/365 days a year
Collector	- Stationed in a booth to identify types of vehicles and collect tolls from road users - Reporting to the supervisor of occurrence of a special incident such as passing of an emergency vehicle - Calculation of the amount of the collected tolls and reporting of the amount to the Head Cashier Banking (or the clerk on duty during the night) at the end of the shift - Closing of the tollgates and notification to road users in the case of a road closure - On duty 24 hours a day/365 days a year
Lane Assistant	- Stationed outside of the booths to assist delivering tolls/change between road users and collectors - On duty 24 hours a day/365 days a year
Security Shift In charge	- Head of the security section and in charge of the security - Preparation of work shift schedules of the security guards - On duty 24 hours a day/365 days a year
Security Guards	Monitoring and protection of the tollgate, lanes, staff members, collected money and facilities On duty 24 hours a day/365 days a year

Source: JICA Study Team

(5) Organizational Structure for Traffic Management

Figure 9.4.5 and Table 9.4.3 show the recommended organizational structure and main duties by job type, respectively, for the implementation of the traffic management of MTHL. As shown in Figure 9.4.5, the traffic management is to be implemented with a structure consisting of six job types. As the traffic control has to be performed 24 hours a day/365 days a year, a design of four teams taking eight-hour shifts in turns has been adopted as the standard work shift system.



*: 8 hours a day in 3 shifts

Source: JICA Study Team

Figure 9.4.6 Organizational Structure for Traffic Management (Recommended)

Table 9.4.3 Main Duties in the Traffic Management by Job Type (Recommended)

Job title	Main duties
Traffic Manager	- Head of the traffic management - Coordinator of the overall operation of the traffic management with the responsibility for the whole operation - Education and training of the operators and the road patrol officers
Operator shift in charge	- Preparation of work shift schedules of Operators - Monitoring and management of the performance of the Operators - Making decisions on appropriate measures to be taken, including a road closure and provision of information to road users, after receiving information on the occurrence of an extraordinary incident, such as a fire, an accident or an abnormal weather condition, from an Operator - Responses to inquiries from road users - Cooperation and coordination with public organizations including the police and fire services and relevant organizations including the state government - Handover of the duties to the Operator Shift in Charge of the next shift, preparation of daily reports - On duty 24 hours a day/365 days a year
Operators	- Collection of the Road Traffic Information - Collection of information required for the traffic control, including road construction work, from relevant organizations - Reporting incidents occurred and measures taken against them to the Operator shift in charge and making required initial responses (including a request for dispatch of the patrol team and notification to relevant organizations including the police) - Provision of the information on any incidents that occurred and measures taken against them on the VMSs to road users - Verifying the state of a roadside facility when it's experiencing an abnormality or a breakdown has been detected and taking measures, such as sending a request for the dispatch of the maintenance team - Preparation of daily reports on incidents, road conditions and measures taken - Making required responses in accordance with the instruction of the Operator shift in charge - On duty 24 hours a day/365 days a year
Patrol shift in charge	- Preparation of work shift schedules of the Road Patrols - Monitoring and management of the performance of the Road Patrols - Reporting to and coordination with the Traffic Control Centre - Instruction of an emergency dispatch and initial responses (including road closures and preventive measures against rear-end collision) to Road Patrols against an extraordinary/emergency situation - Handover of the duties to the Patrol shift in charge of the next shift, preparation of daily reports - On duty 24 hours a day/365 days a year
Road Patrol	- Regular road patrols - Driving an ambulance and/or a towing vehicle quickly to a scene of an extraordinary/emergency situation - Reporting such an incident as a fire, an accident or an abnormal weather condition to the Traffic Control Centre and making initial responses (including road closures, and preventive measures against rear-end collision) at the scene of the incident - Preparation of daily reports on the patrol and reporting to the Patrol shift in charge - Notification of an abnormality or breakdown of a road facility to the Traffic Control Centre - On duty 24 hours a day/365 days a year
Driver	- Driving the patrol cars and emergency vehicles - On duty 24 hours a day/365 days a year

Source: JICA Study Team

(6) Operation of the Maintenance Office

In the Maintenance Office, it is necessary to perform general affairs so that the staffs can carry out their duties smoothly. For the main types of job, Office Manager, Accountants, Clerks, Office boys, Cleaners, and Security guards are necessary.

(7) Vehicles for Operation and Maintenance

Table 9.4.4 shows the recommended vehicles for Operation and Maintenance of MTHL.

In addition to the vehicles deployed normally in the maintenance company of toll roads, a Bridge inspection vehicle and a Motorized patrol boat shall be deployed in consideration of the characteristics of MTHL.

Table 9.4.4 Vehicles for O/M (Recommended)

Type	Quantity	Remarks
Road patrol vehicle	8	Road / Facility Maintenance Traffic Management
Towing vehicle	2	Traffic Management
Vehicle mounted crane	1	Traffic Management
Ambulance	1	Traffic Management
Bridge inspection vehicle	1	Road Maintenance
Motorized patrol boat	1	Road Maintenance
Road sweeper	1	Road Maintenance

Source: JICA Study Team

Source: JICA Study Team

Figure 9.4.7 Bridge Inspection Vehicle

9.4.2 Operation and Maintenance Cost Estimation

The Operation and Maintenance Cost for MTHL shall be estimated based on the recommended Operation and Maintenance Plan in 9.3.2 and recommended Operation and Maintenance Organizational Structure in 9.4.1. and the Periodic Maintenance Cost shall be estimated as well.

(1) Routine Operation and Maintenance

Table 9.4.5 shows the rough estimated cost of Routine Operation and Maintenance.

Table 9.4.5 Rough Estimated Cost of Routine Operation and Maintenance

	Item	Estimated Amount (in million INR)	Interval
1	Project Management Consultant	16	Every year
2	Inspection & Maintenance	95	Every year
3	Toll Management	101	Every year
4	Traffic Management	40	Every year
5	Maintenance Office	10	Every year
6	Others (Electricity)	10	Every year

Source: JICA Study Team

(2) Periodic Maintenance

Table 9.4.6 shows the rough estimated cost of Periodic Maintenance.

Table 9.4.6 Rough Estimated Cost of Periodic Maintenance

	Item	Estimated Amount (in million INR)	Interval
1	Pavement	427	15 years (5 years)
2	Road marking	42	10 years (5 years)
3	Touch-up painting	121	15 years (10 years)
4	Repainting	455	25 years (15 years)
5	Expansion device	163	20 years (5 years)
6	Bridge inspection passage	119	20 years (5 years)
7	Noise barrier	128	20 years
8	Traffic Management system	448	10 years
9	Toll Management system	200	10 years

( ): Implementation period as reference

Source: JICA Study Team

9.5 Proposal for Technical and Institutional Support to O/M Agency

As mentioned in 9.4, MMRDA will outsource the supervision of the outsourced Operation and Maintenance works, planned to be conducted by Project Management Consultants because MMRDA have no experience in the Operation and Maintenance of roads.

MMRDA has an adequate capacity for contract management in consideration of their achievements of major projects.

Therefore, MMRDA can be assumed to be able to carry out Operation and Maintenance of MTHL with utilization of the outsourcing, after the completion of its construction.

In the business frame mentioned above, the items of technical cooperation for MMRDA are proposed as follows;

9.5.1 To Support the development of Operation and Maintenance Manuals of MTHL

Manuals for Operation and Maintenance will be required to implement Operation and Maintenance works adequately in MTHL by Project Management Consultant and Operation and Maintenance Company. In the stage of Detailed Design and Construction, Manuals should be developed depending on which structures and facilities are to be adopted.

The examples of Manuals supposed to be required are given as follow;

- Inspection and maintenance manual
- Traffic management manual
- Toll management manual
- Traffic control system maintenance manual
- Toll collection system maintenance manual
- Training in Japan / Third country (Operation and Maintenance of expressway)

9.5.2 Training in Japan/Third Country

The objective of the training in Japan/Third country is that MMRDA will deepen its understanding of the Operation and Maintenance works for marine bridges and toll road before the commencement of the Operation and Maintenance of MTHL. And MMRDA will come to be able to utilize the knowledge regarding the O/M of MTHL.

10. PROJECT IMPLEMENTATION PLAN

10.1 Implementation Organization

The project organization will be organized so that the MMRDA can implement the Project smoothly and effectively as well as coordinate with project stakeholders. It is recommended that the Project Management Office (PMO) for the Project will be organized under MMRDA. The PMO will be established before the commencement of tender. All tasks to be carried out for the Project will be managed by the PMO. The Project is divided into the following two stages.

- Tender stage (1st stage)
- Detailed design and construction stage (2nd stage)

Tender procedure and compensation work including the relocation will be carried out in the 1st stage. Construction management will be carried out in the 2nd stage.

10.2 Implementation Scheme

The Navi-Mumbai airport connection to MTHL is going to open partially in 2019. In addition, distributing and sharing the city functions of Mumbai with Navi-Mumbai and relaxation of the traffic congestion in Mumbai and on Vashi Bridge are urgent issues to be solved. From the above, MMRDA strongly hoped for early commencement of construction work. Therefore JICA decided the adoption of the Design Build (DB) scheme unlike the traditional scheme (separate ordering of detailed design and construction) under Japan ODA civil work projects. DB is the implementation scheme that will utilize the know-how of the contractor. Advantages of DB are as follows:

<u>Advantages</u>

➢ Efficient and rational design and construction can be carried out.

  - The rational detailed design that utilized the contractor's prudent construction technology is enabled.
  - Tendering procedure is reduced and preparation for construction is enabled while designing.

- Construction quality is increased.
  - Reliable construction method by the contractor is utilized and its quality is also increased.

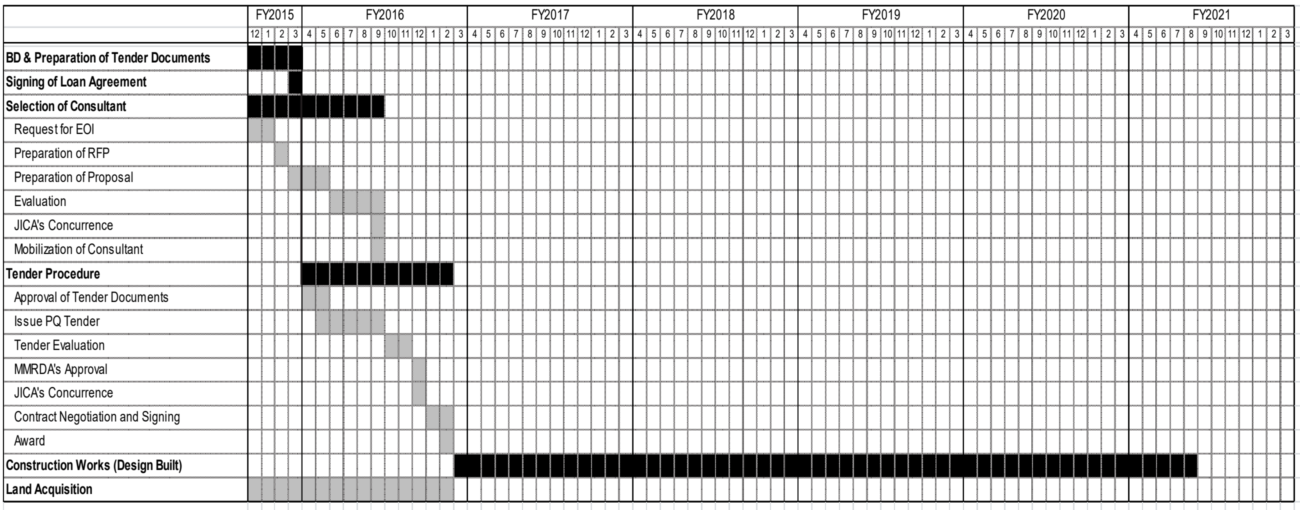
Basic conditions such as bridge span length, cross section, bridge form (substructure and superstructure) and pavement structure are decided in the preliminary design. Therefore, the contractor shall carry out the detailed design based on the preliminary design results which were shown by the client. At the same time a construction plan and required temporary facilities for the construction shall be proposed by the contractor. The Contractor may increase the span lengths while maintaining the statutory vertical and horizontal clearances required.

10.3 Implementation Schedule

The implementation plan is established based on the month/year for the milestones of key events of the project. The DB scheme has already been planned by discussion between MMRDA and JICA. The plan includes the stage of tender procedure, detailed design and construction work. The construction period is estimated as 4.5 years. It is assumed that International Competitive Bidding (ICB) will be applied for procurement of the contractor and the consultant for the project. The time required for the procurement is assumed based on the procedures for a financial scheme of Japanese ODA Loan. The milestones for the implementation of the project undertaken by Japanese ODA Loan are formulated as follows:
This implementation schedule was decided by discussion between MMRDA and JICA on 6 August 2015.

- The Loan Agreement (L/A) will be signed in March 2016.
- Seven months will be required for the selection of the consultant for tender assistance and construction supervision.
- Nine months will be required for the procurement of the contractor.
- The construction period will be 54 months in a DB scheme.

The total implementation schedule will begin with L/A in March 2016, and the construction will be completed in September 2021. In addition, securing the Right of Way (ROW) for the project has already been conducted in this study and 70% of it has already been completed. MMRDA will be able to commence the remaining land acquisition and compensation procedure soon, and the procedure will be completed by the commencement of the construction. The implementation schedule for the project is shown in Figure 10.3.1



Source: JICA Study Team (based on the discussion between MMRDA and JICA on 6 August 2015)

Figure 10.3.1 Implementation Schedule