Joint Feasibility Study for Mumbai-Ahmedabad High Speed Railway Corridor

Final Report
Volume 3

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Japan International Cooperation Agency(JICA)
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Abbreviations

Abbreviations	Formal Name
A	Articulated
AC	Alternative Current
ADB	Asian Development Bank
AGV	Automotrice à Grande Vitesse
AP	Affected Person
ASI	Archaeological Survey of India
AT	Auto Transformer Feeding
ATC	Automatic Train Control System
ATP	Auto Transformer Post
AUDA	Ahmedabad Urban Development Authority
AVE	Alta Velocidad Española
BIS	Bureau of Indian Standards
BLT	Build, Lease & Transfer
BOT	Build, Operate & Transfer
BT	Booster Transformer Feeding
BT	Build & Transfer
BTO	Build, Transfer & Operate
CAI	computer-aided instruction
CAM	Cement Asphalt Mortar
CAPEX	Capital Expenditure
CB	Circuit Breaker
CBA	Cost Benefit Analysis
CD	Compact Disc
CDM	Clean Development Mechanism
CDP	City Development Plan
CER	Certified Emission Reductions
CIDCO	City and Industrial Development Corporation of Maharashtra Limited
CMDA	Chennai Metropolitan Development Authority
CMP	Comprehensive Mobility Plans
CMS	Centralized Information Monitoring System
COMTRAC	Computer Aided Traffic Control
CPCB	Central Pollution Control Board, India, India
CRIC	China Rail Investment Corporation
CRT	Cathode-Ray Tube display
CRZ	Coastal Regulation Zone
CTC	Centralized Traffic Control
CVC	Classified Volume Count
CVCF	Constant Voltage Constant Frequency
DB	Deutsche Bahn
DC	Direct Current
DCF	Discounted Cash Flow
DEA	Department of Economic Affairs
DFC	Dedicated Freight Corridor
DMIC	Delhi Mumbai Industrial Corridor development
DMRC	Delhi Metro Rail Corporation Ltd.
DNA-CDM	Designated National Authority-Clean Development Mechanism
DPR	Detailed Project Report
DSCR	Debt Service Coverage Ratio
EAC	Environmental Appraisal Committee, India
EC	Environmental Clearance
ECBs	External Commercial Borrowings
EIA/ESIA	Environmental Impact Assessment/Environmental and Social Impact

Abbreviations	Formal Name
	Assessment
EM&MP	Environmental Management & Monitoring Plan
EMP	Environmental Management Plan
EMU	Electric Multiple Unit
EPA	Environmental Protection Act
EPCS	Electric Power Control System
ERP	Electronic Road Pricing
ES	Executive Summary
EVT	Earthed Voltage Transformer
FEM	Finite Element Method
FMS	Facility Management System
FSI	Forest Survey of India
FSI	Floor Space Index
FTr	Feeding Transformer
GC	General Consultant
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIDC	Gujarat Industrial Development Corporation
GOI	Government of India
GRDP	Gross Regional Domestic Product
GUDC	Gujarat Urban Development Corporation
HDFC	Housing Development Finance Corporation Limited
HSR	High Speed Rail
HSRA	High Speed Rail Authority
HSRC	High Speed Rail Corporation of India Limited
HUDCO	Housing & Urban Development Corporation
ICC	Integrated Circuit Card
ICE	Inter City Express
ICT	Information & Communication Technology
IDC	Interest During Construction
IDFC	Infrastructure Development Finance Company
IEIA	Initial Environment Impact Assessment
IFCs	Infrastructure Finance Companies
IIFCL	India Infrastructure Finance Company Limited
IL&FS	Infrastructure Leasing & Financial Services Limited
IMF	International Monetary Fund
INR	Indian National Rupees
IOCC	Integrated Operations Control Center
IR	Indian Railway
IR	Involuntary Resettlement
IRFC	Indian Rail Finance Corporation Ltd.
IS	Indian Standard
JETRO	Japan External Trade Organization
JICA	Japan International Cooperation Agency
JNR	Japanese National Railways
JR	Japan Railways
JRTT	Japan Railway Construction, Transport and Technology Agency
LA	Land Acquisition
LA	Lightning Arrester
LAN	Local Area Network
LARAP	Land Acquisition and Resettlement Action Plans
LBS	Load-Break Switch
LCC	Life Cycle Cost
LCX	Leaky Coaxial Cable

Abbreviations	Formal Name
LGV	Ligne à Grande Vitesse
MAP	Million Annual Passengers
METI	Ministry of Economy, Trade and Industry, Japan
MEGA	Metro Link for Gandhinagar and Ahmedabad
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MMDA	Madras Metropolitan Development Authority
MMRDA	Mumbai Metropolitan Region Development Authority
MMTS	Multi Modal Transport System
MOEF	Ministry of Environment and Forest, India
MOR	Ministry of Railways, India
MOU	Memorandum of Understanding
MOUD	Ministry of Urban Development
MPSEZ	Mundra Port and Special Economic Zone Ltd
MSK	Minimum Shift Keying
MTC	Metropolitan Transport Corporation
MWCS	Maintenance Work Control System
MoEF	Ministry of Environment and Forest, India
NA	Not Articulated
NATM	New Austrian Tunneling Method
NBFIs	Non-Banking Finance Institutions
NEAA	National Environmental Appellate Authority, India
NH	National Highway
NHAI	National Highways Authority of India
NHSRA	National High Speed Rail Authority
NOC	None Objection Certificate
NRSC	National Remote Sensing Centre
NUDP	National Urban Development Policy
NW-4	National Waterway
O&M	Operation & Maintenance
OCC	Operation Control Center
OCS	Overhead Catenary System
OD	Origin-Destination
ODA	Official Development Assistance
OFC	Optical Fiber Cable
OPEX	Operating Expenses
PAP	Project Affected Person
PAX	Passengers
PC	Power Concentration
PC	Pre-stressed Concrete
PCCP	Power Concentration Concentrated Power
PD	Power Distribution
PDDP	Power Distribution Distributed Power
PDL	Passenger Designated Lines
PE	Private Equity
PH	Public Hearing
PHC	Pre Hardened Copper
PIAs	Project Influenced Areas
PNB	Punjab National Bank
PPDPD	Person Per Day Per Direction
PPM	Post-Project Monitoring
PPP	Public Private Partnership
PPP	Purchasing Power Parity
PRC	Programmed Route Control

Abbreviations	Formal Name
PRIDe	Peninsular Region Industrial Development Corridor
PSU	Public Sector Unit
QC	Quality Control
RBI	Reserve Bank of India (Central Bank)
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
RDSO	Research Design & Standards Organization, India
RFF	Réseau Ferré de France
RFP	Request for Proposal
RLDA	Rail Land Development Authority
RO	Regional Office
ROB	Road Over Bridge
ROC	Republic of China
ROW	Right of Way
RP	Resettlement Plan
RPC	Railway static unbalanced Power Compensator
RS	Rolling Stock
RSCS	Rolling Stock Control System
RTRI	Railway Technical Research Institute
RVNL	Rail Vikas Nigam Limited
RUB	Road Under Bridge
RYWMS	Railway Yard Work Management System
SBI	State Bank of India
SCADA	Supervisory Control and Data Acquisition
SDH	Synchronous Digital Hierarchy
SEA	Strategic Environmental Assessment
SEAC	State Level Expert Appraisal Committee, India
SEIAA	State Environmental Impact Assessment Agency, India
SFC	Single phase Feeding unbalanced power Conditioner
SHM	Stake Holder Meeting
SNCF	Société Nationale des Chemins de Fer Français
SOD	Schedule of Dimensions
SP	Sectioning Post
SPC	Special Purpose Company
SPCB	State Pollution Control Board, India
SS	Substation
SSB	Single Side Band
SSO	Single Sign-on
SSP	Sub Sectioning Post
SUICA	Super Intelligent Card
TAZ	Traffic Analysis Zone
TBM	Tunnel Boring Machine
TEU	Twenty-foot Equivalent Unit
TGV	Train à Grande Vitesse
THSRC	Taiwan High Speed Rail Corporation
TIFS	Tax Increment Financing Schemes
TOD	Transport Oriented Development
TPS	Transportation Plan System
TSC	Taiwan Shinkansen Consortium
TSI	Technical Specification for Interoperability
TSS	Traction Substation
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
UPS	Uninterruptible Power Supply

Abbreviations	Formal Name
USD	United States Dollar
UTI1	Unit Trust of India
UTPCC	Union Territory Pollution Control Committee, India
VA	Volt Ampere
VCT	Voltage and Current Transformer
VFM	Value For Money
VGF	Viability Gap Funding
WACC	Weighted Average Cost of Capital
WPI	Whole Price Index
WTP	Willingness to Pay

Chapter 8 Train Operation Plan

8.1 Basic Conditions for the Train Operation Plan

8.1.1 Basic Concept

The basic concept of the train operation plan is as follows.

(1) To set maximum operation speed at 320 km/h to shorten the traveling time. (Maximum design speed for the future is 350km/h)

In view of the fact that the maximum operation speed of HSR currently engaged in revenue service constantly and stably in the world is 320 km/h, the maximum operation speed of the this project should be set at 320 km/h to shorten the traveling time.

(2) To adopt the average passenger load factor of 70% for setting operation plan.

An average passenger load factor should be 70%, taking into account the fluctuation of the number of passengers. For reference, Passengers in Japan usualy can book seats on particular trains optionally when trains are set with an average passenger load factor of approximately 70% assumed.

(3) To set 2 types stop-patterns of train.

In view of the diverse needs of passengers, a vriety of origin and destination and a need to shorten the travelling time, two types (rapid train and each stop train) should be planned: a rapid train that will only stop at major stations and a each stop train that will stop at every station. The stations where “rapid service trains” stop shall be determined based on an OD Table.

(4) To separate operation time zone and maintenance time zone.

To ensure safety operation is the top pripority for HSR. The maintenance work for facilities should be carried out properly by separating the operation time zone and the maintenance time zone comlpetely. From the view point of securing safety operation and avoiding confusion of operation troubles, which may sometimes causes serious accident, it is recommended Bi-direction operation sould not be adopted when traffic density is fairly thick.

The train operation time zone and the maintenance time zone is as follows

- Train operation time zone: 6:00-24:00 (0:00)
- Maintenance service time zone: 0:00-6:00

8.1.2 Route Length and Stations

Table 8.1-1 shows the station names and locations proposed in this study.

Table 8.1-1 Station Names and Locations

No.	Name of Station	Distance
1	Mumbai (B.K.C)	0 k 000
2	Thane	27 k 950
3	Virar	65 k 170
4	Boisar	104 k 260
5	Vapi	167 k 940
6	Bilimora	216 k 580
7	Surat	264 k 580
8	Bharuch	323 k 110
9	Vadodara	397 k 060
10	Anand/Nadiad	447 k 380
11	Ahmedabad	500 k 190
12	Sabarmati	505 k 750

8.1.3 Restricted Train Speed (Curve and Down-gradient Sections)

Table 8.1-2 shows the restricted train speed on curve sections.

Table 8.1-2 Restricted Train Speed on Curve Section

Curve radius	Speed (km/h)
6000 m or above	320 *
4000 m 〃 under 6000 m	310
3500 m 〃 under 4000 m	275
3000 m 〃 under 3500 m	260
2800 m 〃 under 3000 m	250
2500 m 〃 under 2800 m	235
2200 m 〃 under 2500 m	220
2000 m 〃 under 2200 m	210
1800 m 〃 under 2000 m	200
1500 m 〃 under 1800 m	185
1200 m 〃 under 1500 m	165
1000 m 〃 under 1200 m	150
900 m 〃 under 1000 m	140
800 m 〃 under 900 m	135
700 m 〃 under 800 m	125
600 m 〃 under 700 m	115
500 m 〃 under 600 m	105
400 m 〃 under 500 m	95

*320km/h is the maximum operation speed in this study. 350km/h is possible in the future.

Table 8.1-3 shows the restricted train speed on down-gradient sections.

Table 8.1-3 Restricted Train Speed on Down- Gradient Section

Down-gradient	Maximum speed Train set configured to operate at 320 km/h
Less than 15‰	320 km/h*
More than 15‰ and less than 25‰	260 km/h
More than 25‰ and less than 30‰	260 km/h

*320km/h is the maximum operation speed in this study. It depends on rolling stock performance whether 320km/h or more are possible.

8.2 Train Operation Plan

8.2.1 Demand Forecast

The study team implemented demand forecast for 2023, 2033, 2043 and 2053 as referred to in Chapter 5.

At that time, for the purpose of evaluationg how the train fares changed the demand forecast, three fares for the high-speed railway had been set: same level as the 1A class of the existing railway, 1.5 times and 2.0 times so that the fares will be higher than the 1A class and lower than the airfare.

After forecasting the total fare revenue of high-speed railway for each case, the study team found that the fare revenue in the case of 1.5 times of the 1A class of the existing railway would be the highest.

Therefore, the train operation plan is formulated based on the demand forecast of train fare at 1.5 times of the 1A class.

8.2.2 Stop Pattern

As explained in Clause 8.1.1, two types (rapid train and each stop train) of trains are planned: a rapid train that will only stop at major stations and an each stop train that will stop at every station.

As the stations where “rapid trains” shall stop, Surat, Vadodara and Ahmedabad stations are proposed, while taking into account the fact that the number of passengers is overwhelming large between Mumbai and Ahmedabad, between Mumbai and Surat and between Mumbai and Vadodara, based on the results of the demand forecasting for 2023 shown in Figure 8.2-1, and obtained agreement thereon from MOR.

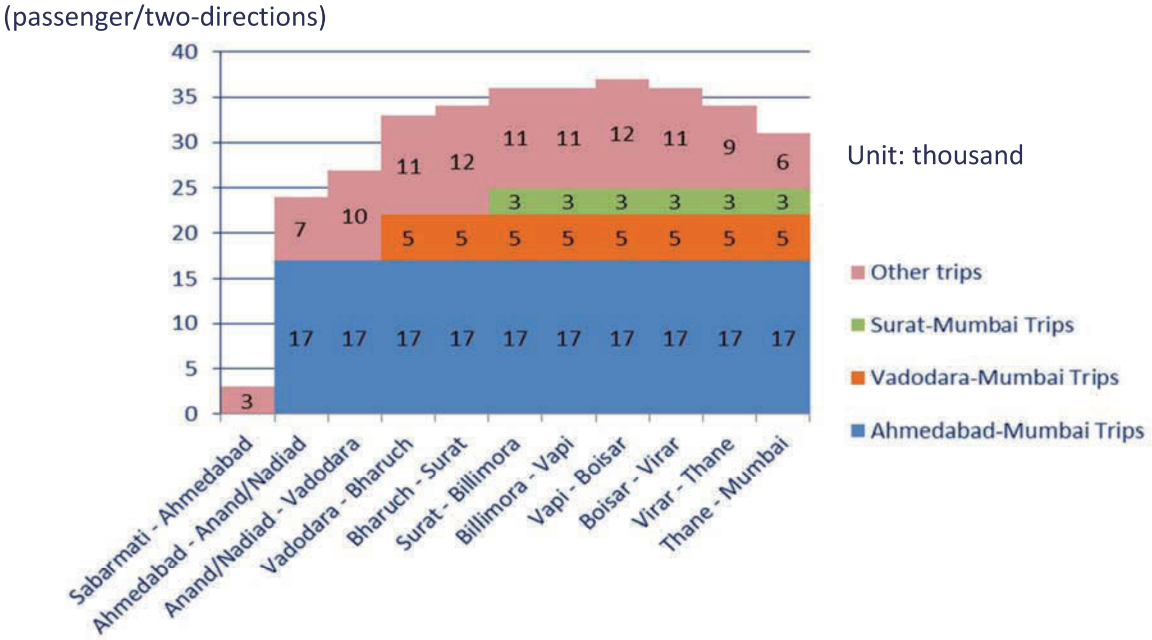


Figure 8.2-1 Demand Forecast in 2023

Table 8.2-1 shows stopping station by train type.

Table 8.2-1 Stopping Station by Train Type

Station	Distance (km)	Stopping Station	
		Rapid train	Each stop train
Mumbai (B.K.C.)	0 k 000	○	○
Thane	27 k 950	-	○
Virar	65 k 170	-	○
Boisar	104 k 260	-	○
Vapi	167 k 940	-	○
Bilimora	216 k 580	-	○
Surat	264 k 580	○	○
Bharuch	323 k 110	-	○
Vadodara	397 k 060	○	○
Anand/Nadiad	447 k 380	-	○
Ahmedabad	500 k 190	○	○
Sabarmati	505 k 750	○	○

(○: Stopping, -: Passing)

8.2.3 Traveling Time

The traveling time of the two type trains, the rapid type train that will stop at major stations and the each stop type train, are examined.
Table 8.2-2 shows Traveling time by train type.

Table 8.2-2 Traveling Time by Train Type

Station	Distance (km)	Stopping station	
		Rapid train	Each stop train
Mumbai(B.K.C.)	0 k 000	0:00	0:00
Thane	27 k 950	-	0:10
Virar	65 k 170	-	0:24
Boisar	104 k 260	-	0:39
Vapi	167 k 940	-	0:59
Bilimora	216 k 580	-	1:15
Surat	264 k 580	0:58	1:32
Bharuch	323 k 110	-	1:52
Vadodara	397 k 060	1:32	2:14
Anand/Nadiad	447 k 380	-	2:32
Ahmedabad	500 k 190	1:59	2:50
Sabarmati	505 k 750	2:07	2:58

* Stopping time at Surat, Vadodara and Ahmedabad: 2 minutes
Other stations: 1 minute

** Stopping time at Ahmedabad may be required about 5 minutes when there are a lot of passengers getting on/off at Ahmedabad

The traveling time shown in Table 8.2-2 is based on the present track profiles.
The traveling time of rapid train is one hour and 59 minutes (one minutes less than two hours) between Mumbai and Ahmedabad, with the train assumed to dwell for two minutes each at the Surat, Vadodara and Ahmedabad stations, and two hours and seven minutes between Mumbai and Sabarmati, with the train assumed to dwell for two minutes at the Ahmedabad station.
The traveling time of each stop train is two hours and 58 minutes (two minutes less than three hours) between Mumbai and Sabarmati.

8.2.4 Train Capacity

The train capacity is one of the most important factors in the planning of a train operation plan. Based on demand forecast, the train capacity per train determines the number of trains.
The train capacity is significantly affected by seat types and the number of cars per train-set. Therefore these factors had been discussed sometimes between study team and MOR as summarized below.

(1) Seat Type

By referring to the case of Shinkansen in Japan, features and merits/demerits of introducing four types of seat arrangement, first class (seat arrangement 1+2), business class (seat arrangement 2+2), second class (seat arrangement 2+3) and convenience class (seat arrangement 3+3), had been examined.
Figure 8.2-2 shows the seat arrangement of each type.


First class (1+2 seat)


Business class (2+2 seat)


Standard class (2+3 seat)


Convenience class (3+3 seat)

Figure 8.2-2 Seat Type

(a) First class seat arrangement

This seat arrangement features comfort equivalent to that of the first class seat arrangement of airplanes. Because of the reasons as follows,

- Traveling time from Mumbai to Ahmedabad is only about 2 hours.
- Domestic air line, a competitor, also doesn't have first class seats.
- The fare of first class seat is very high.

It shoud be recommended that the first class seat is not adopted and agreeded.

(b) Business class and standard class seat arrangements

These seat arrangements are already adopted for express trains on existing railways in India. As they are usual arrangements in other countries as well, introduction of them into this project was reccomended and obtained agreement thereupon.

(c) Convenience class seat arrangement

While this type of seat arrangement is less comfortable than others because of narrower width of seat and aisle, it can increase train capacity and cope with demand of low-fare seat, which is mentioned in the 3rd Joint Monitoring Committee (JMC).

Thereof this type has been examined and recommended as an optional plan, which is explained later, to create a wide range of passenger, resulting in greater rider ship.

To summarize the above descriptions, it is recommended that two seat arrangements, business class and standard class, shoul be set in the train operation plan. In addition, Convenience class (3+3 seat) should be considered as an option plan to meet a need of low-fare seat train.

(2) Number of cars in train configuration

The train capacity changes according to a train configuration and influence the number of trains setted in an operation plan.

Regarding the ratios of seat aarangement, the cases where the number of the cars in train configuration is 6, 10 and 16 at inauguration (2023), with two seat arrangements, business class and standard class are examined and discussed in detail between concerned departments of MOR.
The results of examination about train capacity, train configuration and number of trains in 2023 are as shown in Table 8.2-3.

Table 8.2-3 Train Capacity, Train Configuration and Number of trains in 2023

Train configuration	Business (2+2)	Standard (2+3)	Total	Number of trains (train/one-direction/day)
6 cars	1 car (55 seats)	5 seats (325 seats)	6 cars (380 seats)	68
10 cars	1 car (55 seats)	9 cars (695 seats)	10 cars (750 seats)	35
16cars	2 cars (120 seats)	14 cars (1130 seats)	16 cars (1250 seats)	21

* The number of seats is an approximate number at present, which is subject to change according to the detailed design of floor layout.

To determine the number of trains, three cases, 6-, 10- and 16-car train configuration were compared (number of the trains in operation, frequency of train operation in peak and off-peak hours), train capacity, rolling stock cost and operating cost and heard the opinion of concerned experts in MOR. The results of comparison/discussion are explained below.

Adopting 16-car trains at the inauguration of business, there is little number of train operation and as a result, the time zone during which only one train is operated per hour becomes wider. Given the fact that high-frequency train operation is a matter of great concern in India, operation of 16-car trains doesn't satisfy this requirement. Therefore, the operation of 16-car train should not be recommended at the inauguration phase.

1) Case studies

(a) 6-car train

Figure 8.2-3 illustrates a diagram image of the operation of 6-car trains at inauguration.

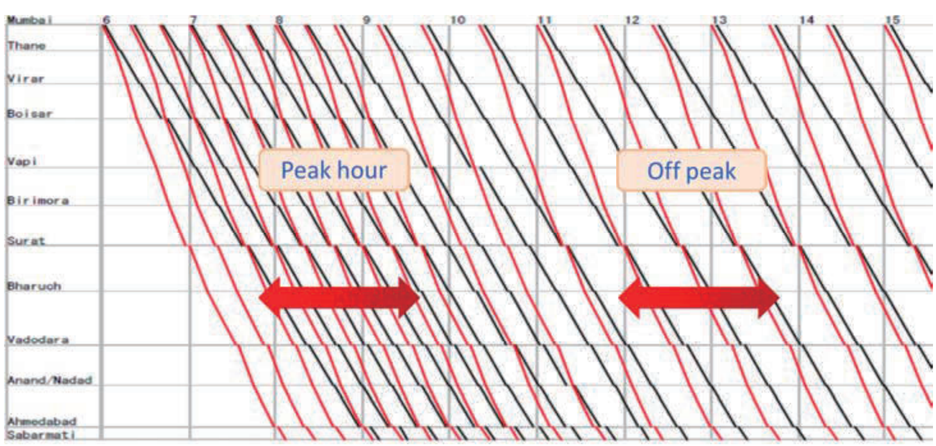


Figure 8.2-3 Diagram Image (6 cars)

Rapid train
Each stop train

In this case, 68 trains will run per direction per day at inauguration in 2023 or approximately six trains per direction per hour in peak hours and approximately three trains per direction per hour in off-peak hours.

(b) 10-car train-set

Figure 8.2-4 shows a diagram image of the operation of 10-car trains at inauguration.

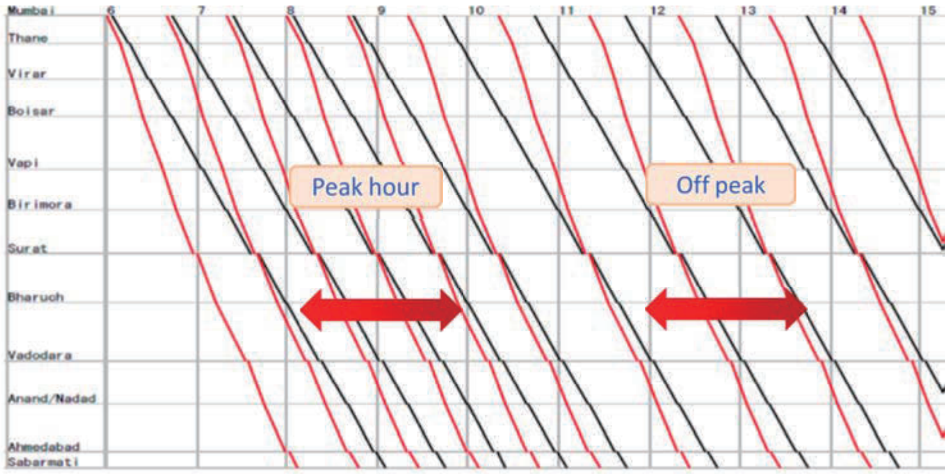


Figure 8.2-4 Diagram Image (10 cars)

In this case, 35 trains will run per direction per day at inauguration in 2023 or approximately three trains per direction per hour in peak hours and approximately two trains per direction per hour in off-peak hours.

(c) Comparison

Compared the number of trains, frequency of train operation (in peak hours and off-peak hours), train capacity per train and costs of rolling stock between two cases where 6-car train and 10-car train are operated, at inauguration phase. Table 8.2-4 shows the results thereof,

Table 8.2-4 Comparison between 6 Cars Train and 10 Cars Train

Item	6 cars train	10 cars train
Frequency	Peak hour: 6 trains/h Off peak: 3 trains/h Train frequency is high	Peak hour: 3 trains/h Off peak: 2 trains/h
Capacity/train	380 seats/train	750 seats/train
Rolling stock cost	Number of Train sets: 46 Number of Cars: 276 Rolling stock cost increases.	Number of Train sets: 24 Number of Cars: 240
Operation cost	Number of operation staff (driver, etc) increases. Operation cost increases.	

2) Recommendation

Repeating discussion between MOR and the study team it had been eventually reached a consensus that operation of approximately three trains in peak hours and approximately two trains in off-peak hours is the most appropriate.
In view of the fact that eight to nine express trains per day are running at present on an existing railway between Mumbai and Ahmedabad, even the frequency of train operation in the case where 10-car train run on the HSR will substantially improve the convenience of passengers, which will be realized by the operation of 10-car train formation (35 trains per direction per day) at inauguration. Therefore, it is recommended that 10-car train formation should be adopted into the train operation plan at inauguration phase.

8.2.5 Train Operation Plan

As explained in Clause 8.2.4, 10-car train will be operated at the inauguration of business, and it enables to guarantee operation of two trains per hour, such as one rapid service train and one each stop train, during off-peak hours.
Later on, as demand rises, the number of trains and the number of cars per train-set will be increased.
When the number of cars per train-set is increased, the maximum number of cars per train-set will be adopted 16-car train-set for the following reasons.

- Although technically train-sets composed of more than 16 cars could be adopted, the corresponding stations and rolling stock depots, which are designed to accommodate train-sets, require to be enlarged and modification of equipment/facilities
- Even the Tokaido Shinkansen in Japan relies on 16-car train-set for passenger transport, despite that it claims the largest HSR passenger service in the world.

Despite that it is possible to introduce eight-car train sets at inauguration and convert them into 16-car train sets in the future by connecting each two eight-car train sets into one, this idea is not chosen for the following reasons.

- The necessity of 16-car train-sets will become a reality 10 years from now, when it is desirable from the viewpoint of passenger service to introduce new 16-car train armored with the latest technologies. Furthermore, connecting two train-sets into one produces a coupling section in the new train-set that is unavailable and inefficient for passenger service.

Increasing the number of trains and the number of cars per train-set, the durable years (life) of cars should be taken into consideration. Therefore, 10-car train-sets and 16-car train-sets coexist for some time in the transient period as shown in the Table 8.2-5.
Since the result of demand forecast showed that there is no section with big difference in cross sectional traffic volume, Almost all trains are set to operate mainly from Mumbai to Sabarmati and the number of trains will meet the maximum cross sectional traffic volume.

The numbers of the trains in 2023, 2033, 2043 and 2053 based on the maximum cross sectional traffic volume between Mumbai and Sabarmati are as follows. The frequency of train operation during peak hours, which is a matter of great concern on the HSR, is reviewed . Table 8.2-5 shows the number of trains and the number of the cars in train configuration in 2023, 2033, 2043 and 2053.

Table 8.2-5 Train Configuration, Number of Trains and Traffic Volume
(In 2023, 2033, 2043 and 2053)

Year	2023	2033	2043	2053
Train configuration	10	10・16	16	16
Train capacity	Approx. 750	Approx. 750, 1,250	Approx. 1,250	Approx. 1,250
Trafficvolume (day/one-direction)	17,900	31,700	56,800	92,900
Number of trains (day/one-direction)	35	51	64	105
Number of trains (train/hour/one-direction) Peak hour Off peak	Peak hour: about 3 Off peak: about 2	Peak hour: about 4 Off peak: about 3	Peak hour: about 6 Off peak: about 3	Peak hour: about 8 Off peak: about 6

Figures 8.2-5 and 8.2-6 show an image of train operation diagram in 2023 and 2053, respectively.
In 2053, 105 trains per direction will run, or approximately eight trains per hour during peak hours.
Regarding maximum number of train operation(/hour/one-direction), 15 has been realized in Japanese Shinkansen.
When there are more trains in operation, the cleaning time during the turn back of trains at terminal stations will become an important factor. The turn back, including the cleaning time, must be completed within 30 minutes given the current track layout at the Mumbai station. It is necessary to find methods to shorten the cleaning time as much as possible during the turn back operation, such as by increasing the number of cleaning staff and improving the cleaning equipment, and so on.

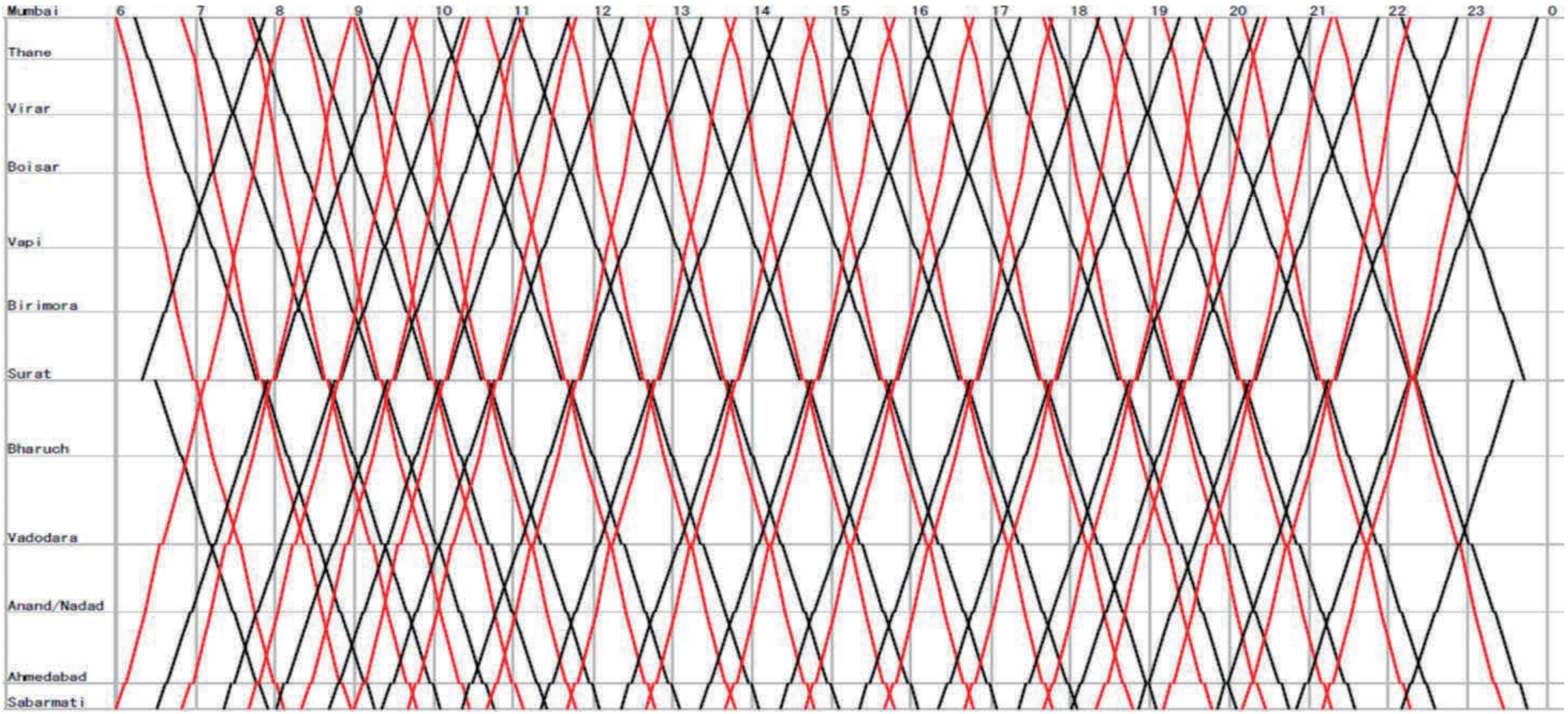


Figure 8.2-5 Image of Diagram in 2023

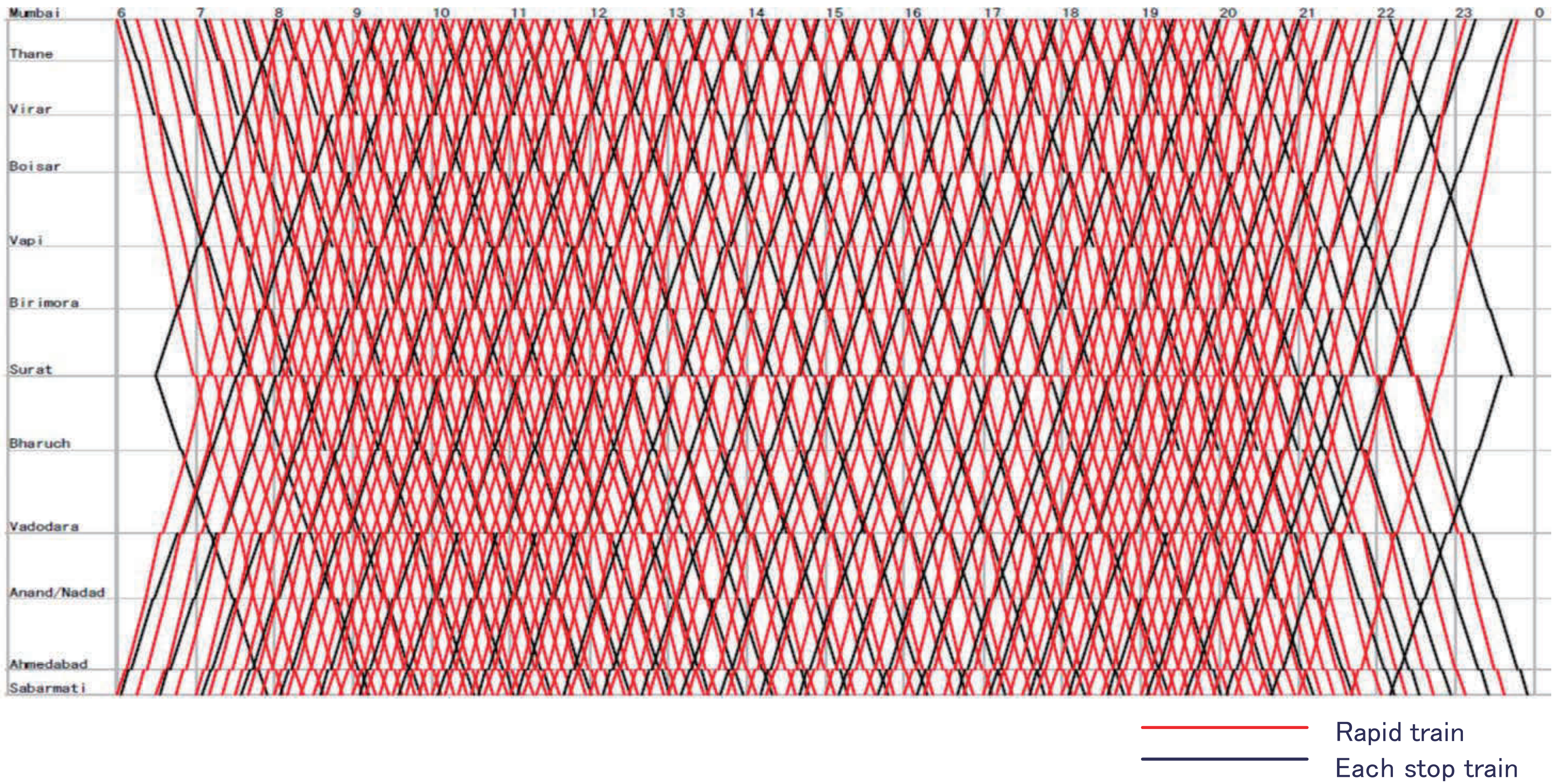


Figure 8.2-6 Image of Diagram in 2053

Figure 8.2-7 shows image view of increasing the train-sets and the number of cars in the train-set.

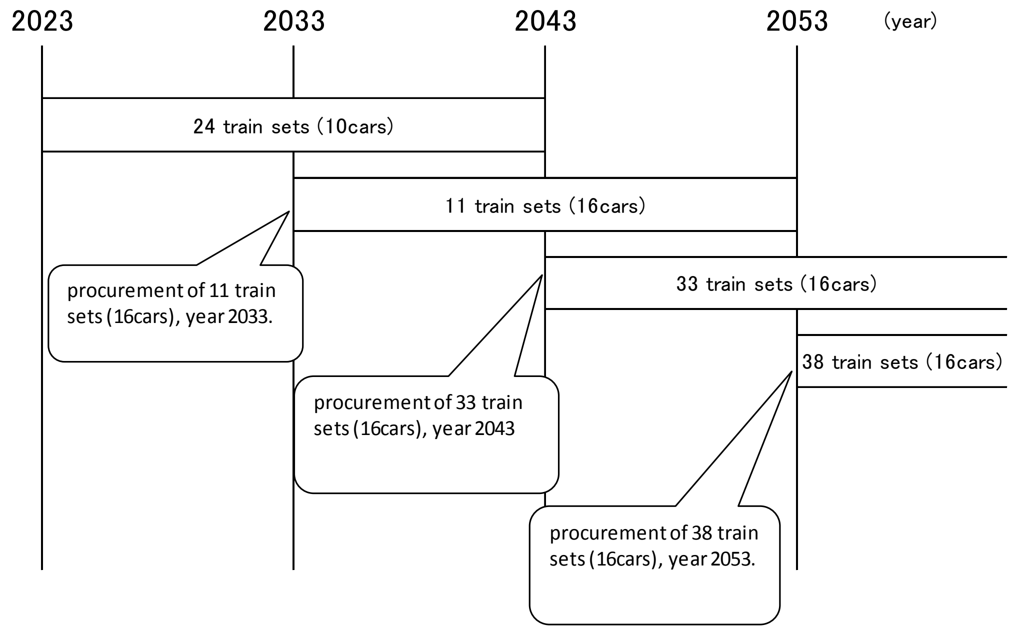


Figure 8.2-7 Image of procurement plan for rolling stock

8.3 Number of Required Train-Sets (Number of Cars) and Storage Locations

The equipment plan of the storage locations and the number of stabling tracks are affected significiantly by the number of required train-sets (cars).
As demand rises, the number of train-sets and the number of cars per train set will be increased.
From 2033, 10-car trains and 16-car trains coexist.
While taking into account those factors, the numbers of required train-sets are examined at 10-years intervals.
The number of required train-sets are calculated, reffering to the train kilometers per day (1,500km/day) of the Tohoku Shinkansen in Japan, the condition of which is simmililar to this project.

8.3.1 Number of Required Train-Sets (Number of Cars)

Table 8.3-1 shows the train-kilometers calculated based on the number of trains in Table 8.2-5 at 10-year intervals.

Table 8.3-1 Train Kilometers

Year	Train configuration	Number of trains (train/one-direction/day)	Train kilometers(km/day)	Remarks
2023	10 cars	35	35364.0	
2033	10,16 cars	51	51530.4	
2043	16 cars	64	64665.6	
2053	16 cars	105	106092.0	

Table 8.3-2 shows the number of required train-sets in 2023, 2033, 2043 and 2053 calculated with running kilometers per day per car taken as 1,500 km.

Table 8.3-2 Number of Required Train-sets (Number of Cars)

Year		2023	2033	2043	2053	Remarks
Number of trains (train/one-direction/day)		35	51	64	105	
Number of train sets	10 cars	24	24	-	-	
	16 cars	-	11	44	71	
Number of cars		240 cars	416 cars	704 cars	1136 cars	

At inauguration in 2023, 24 train-sets (240 cars) are required. Later on, as demand rises, the number of train-sets and the number of cars per train-set will be increased. By 2053, seventy one train-sets of 16-car (1136 cars) will be needed.

8.3.2 Storage Locations

Table 8.3-3 shows the storage locations and the numbers of train-sets in 2023, 2033, 2043 and 2053.

Table 8.3-3 Storage Locations and Number of Train Sets

Location	2023			2033			2043			2053		
	Operation	Reserve	Total	Operation	Reserve	Total	Operation	Reserve	Total	Operation	Reserve	Total
Mumbai St	2	0	2	3	0	3	3	0	3	3	0	3
Thane Depot	9	2	11	13	3	16	17	3	20	28	5	33
Surat St	2	0	2	2	0	2	2	0	2	2	0	2
Sabarmati Depot	8	1	9	12	2	14	16	3	19	28	5	33
Total	21	3	24	30	5	35	38	6	44	61	10	71
Train Configuration	10 cars			10 cars, 16 cars			16 cars			16 cars		

The Surat station has been selected as an intermediate storage location in order to operate an earlier train than those from terminals, Mumbai and Sabarmati.

8.4 Option plan for Low-fare Passengers

8.4.1 Introduction of Low-fare Seat Trains

MOR keenly requires introduction of low-fare seats, with the necessity thereof referred to also at the 3rd JMC.
MOR said that it is necessary to provide the transport service corresponding to the wide fare

from a low fare to a high fare considering actual demand in proper timing.
Therefore, the introduction of low-fare seats (convenience class seat) is examined, assuming the following conditions.

(1) Train capacity

(a) Seat type

As low-fare seats, which is called a convenience class seat arrangement (3-row + 3-row) are introduced, the image of which is shown in Figure 8.4-1.

Figure 8.4-1 Convenience class (3+3 seats)

(b) Train configuration and train capacity

Regarding 10-car train-sets, as explained in Cause 8.2.4, Table 8.4-1 shows the train capacity with and without low-fare seats introduced, it means the train configuration of standard/convenience and business/standard and business/standard/convenience class cars, changing the ratios of the standard class cars and convenience class cars. For reference, train capacity of 16-car train-set is shown in Table 8.4-1.

Table 8.4-1 Comparison of Train Capacity

Train Configuration	Business (2＋2)	Standard (2＋3)	Convenience (3＋3)	Total
10 cars	1 car 55 seats	9 cars 695 seats	-	10 cars 750 seats
	1 car 55 seats	4 cars 325 seats	5 cars 440 seats	10 cars 820 seats
	-	5 cars 390 seats	5 cars 440 seats	10 cars 830 seats
	-	-	10 920 seats	10 cars 920 seats
16 cars	2 car 120 seats	14 cars 1130 seats	-	16 cars 1250 seats
	2 car 120 seats	6 cars 450 seats	8 810 seats	16 cars 1380 seats
	-	-	16 1580 seats	16 cars 1580 seats

(c) Train operation plan

The concept of the train operation plan is as follows.

- As the basic operation trains, business/standard class trains shall be adopted.
- To effectively utilize the off-peak hours and respond to the demand for low-fare seats, standard/convenience class trains with low-fare seats shall be operated only during off-peak hours.
- As seat arrangements differ between business/standard and standard/convenience,

dedicated train-sets with low-fare seats are required. To operate low-fare seat trains for three round trips, three dedicated train-sets are necessary (two for operation and one for spare).

However, in case of dedicated train-set for low-fare train, it is necessary to consider following points.

- Separated operation between basic and low-fare train-sets is required.
- More difficulties are in recovering from confusion of train operation, because of necessity of consideration for each train type respectively.

Figure 8.4-2 shows an example of train operation diagram drawn based on that concept.

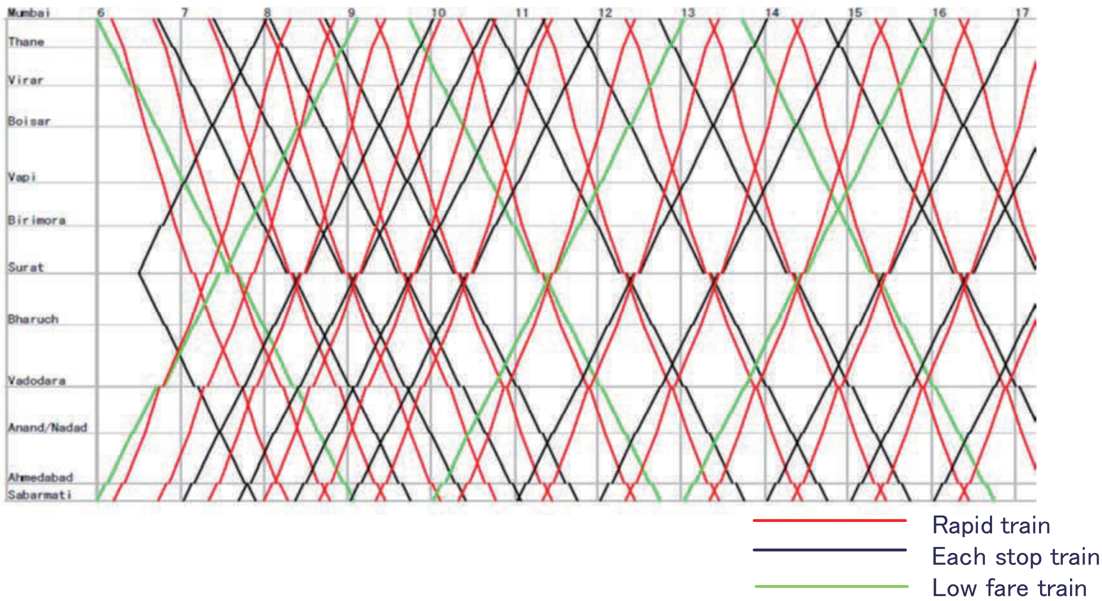


Figure 8.4-2 Image of Diagram of Low-fare train (In 2023)

In addition, as operation methods for low-fare seat train, it is thought that the low-fare seat trains shall be operated as each stop trains or during off-season.

Operation of low-fare seat train is subject to detailed discussion in the future.

8.4.2 Others

There is another view in MOR regarding the stations to stop rapid train than those discussed in the section 8.2.2.

In this context, therefore, it is shown how long the traveling time is increasing when rapid train stops at more stations. As an example, Table 8.4-2 shows the traveling time when rapid trains stop additionally at the Virar station.

Table 8.4-2 Traveling Time of Rapid train in case of Stopping Virar Station

Station	Distance (km)	Stopping station		
		Rapid train	Rapid Train (+Virar St.)	Each stop train
Mumbai(B.K.C.)	0 k 000	0:00	0:00	0:00
Thane	27 k 950	-	-	0:10
Virar	65 k 170	-	0:20	0:24
Boisar	104 k 260	-	-	0:39
Vapi	167 k 940	-	-	0:59
Bilimora	216 k 580	-	-	1:15
Surat	264 k 580	0:58	1:06	1:32
Bharuch	323 k 110	-	-	1:52
Vadodara	397 k 060	1:32	1:39	2:14
Anand/Nadiad	447 k 380	-	-	2:32
Ahmedabad	500 k 190	1:59	2:06	2:50
Sabarmati	505 k 750	2:07	2:14	2:58

Table 8.4-2 proves that, when rapid trains stop at one more station, the traveling time increases approximately seven minutes. If rapid trains stop more frequently, the traveling time will become further longer. What stations rapid train stops at should be determined, therefore, by duly taking into consideration the time-value of HSR.

Chapter 9 High Speed Railway Construction Plan

9.1 Basic Specification and Track Layout of the High Speed Railway for HSR1 Construction Plan

9.1.1 Basic Track Layout

Figure 9.1-1 shows a schematic drawing of the distribution of stations, depots, workshops and maintenance depots for rolling stock along the whole HSR1 line.

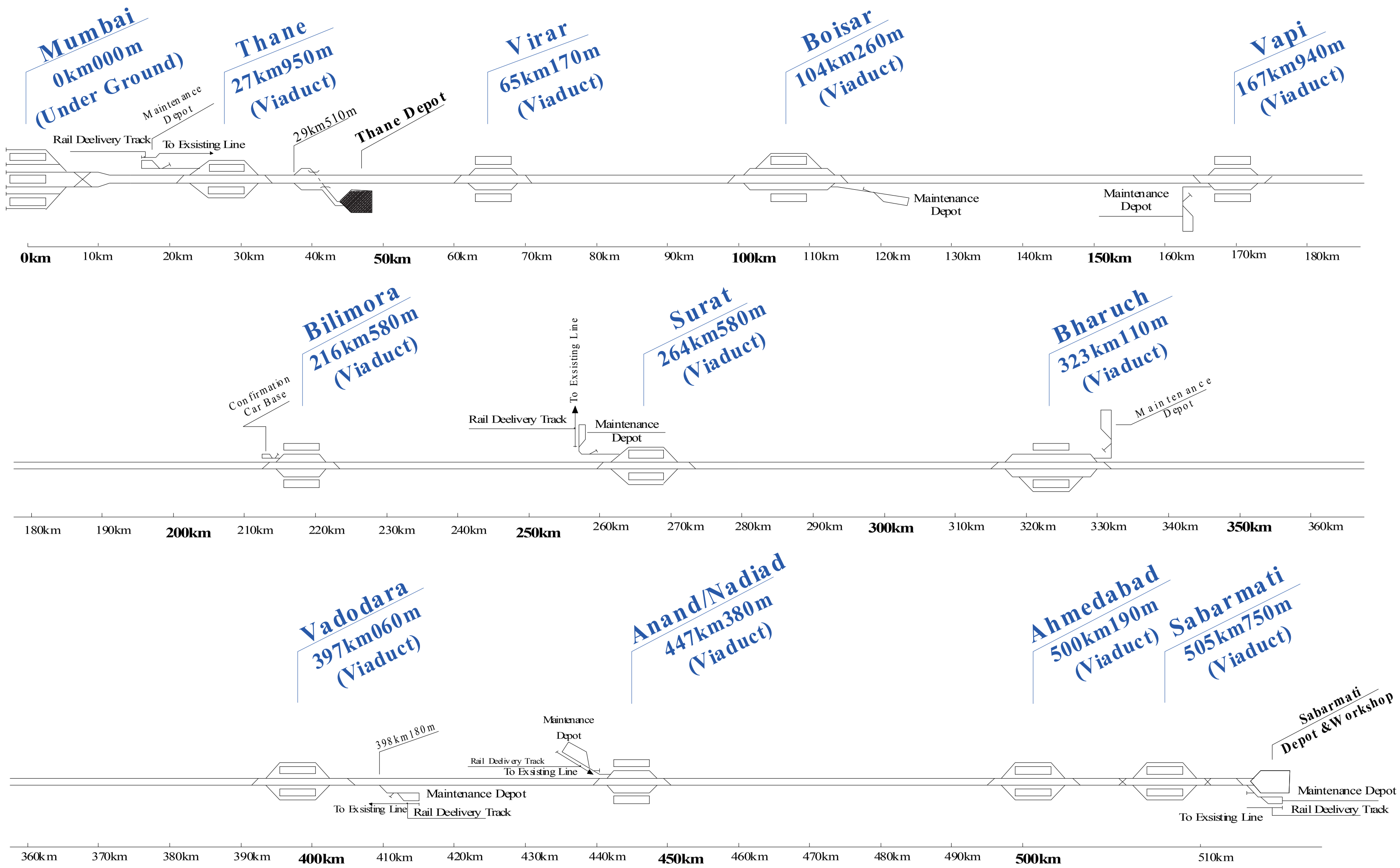


Figure 9.1-1 Distribution of Stations, Depots, Workshops and Maintenance Depots for Rolling Stock along the Whole HSR1 Line

(1) Station track layout

Table 9.1-1 summarizes the locations and functions of the stations shown in the train operation plan based on the alignment plan and demand forecasting.

Table 9.1-1 List of Stations

Station Name	km	Structure Type	Operation Type	Remarks
Mumbai	0 km 000 m	Dead-end type 3-platform for 6-track	Starting/arriving terminal	
Thane	27 km 950 m	Island type 2-platform for 4-track	All-train handling station	Connected to maintenance depot
Virar	65 km 170 m	Separated type 2-platform for 4-track	Non-stop trains handling station	
Boisar	104 km 260 m	Island type for down-trains, separate type for up-trains, 2-platform for 5-track	Non-stop trains handling station	Connected to maintenance depot
Vapi	167 km 940 m	Separated type 2-platform for 4-track	Non-stop trains handling station	Connected to maintenance depot
Bilimora	216 km 580 m	Separated type 2-platform for 4-track	Non-stop trains handling station	With pilot car shed
Surat	264 km 580 m	Island type 2-platform for 4-track	All-train handling station	
Bharuch	323 km 110 m	Separated type for down-trains, island type for up-trains, 2-platform for 5-track	Non-stop trains handling station	Connected to maintenance depot
Vadodara	397 km 060 m	Island type 2-platform for 4-track	All-train handling station	
Anand/Nadiad	447 km 380 m	Separated type 2-platform for 4-track	Non-stop trains handling station	Connected to maintenance depot
Ahmedabad	500 km 190 m	Island type 2-platform for 4-track	All-train handling station	
Sabarmati	505 km 750 m	Island type 2-platform for 4-track	Starting/arriving terminal	

The fundamental conditions to determine the station width and length in the station track layout plan shall be as per the following:

- Width of platform
  Where both sides of an island type platform are used: 10 m or over at the center and 5 m or over at the ends.
  Where one side of a separated type platform is used: 8 m or over at the center and 3 m or over at the ends.
- Safety fence of platform
  To prevent passengers' falling onto the track or train-touching accidents on passenger platforms, a 1.3 m-high fence shall be installed (1) along a line 0.68 m-distant from the platform edge at the ends of platform at stations other than non-stop train handling stations or (2) along a line 2.0 m-distant from the edge of platform, together with platform doors at each train door position at non-stop train handing stations. In the latter case, the platform width shall be 11.32 m or over in consideration of the 1.32 m smaller width of platform than at other stations.
- Distance between tracks
  The track-to track distance shall be 4.6 m or over between stop train handling tracks and 5 m or

over between a stop train handling track and a non-stop train handling track.

- The distance between the track center and the edge of platform in straight sections
  1.76 m for platforms handling stop trains alone
  1.80 m for platforms handling non-stop trains
- Height of platform
  The edge of platform height shall be 1.25 m high (1) from the track plane in straight sections and (2) from the track plane inclined due to the cant in curved sections. The distance between the track center line and the edge of platform, (1) distance of 1.76 m shall be guaranteed for platforms handling stop trains alone and (2) distance of 1.80 m added with the extra distance extended to cope with the curve for platforms handling both stop trains and non-stop trains.
- Length of platform
  Maximum length of train (25 m x 16 cars) + 10 m (margin) = 410 m
- Effective track length
  410 m (length of platform) + 50 m (absolute stop control section) + 20 m (margin) = 480 m

The following are the track layout at each station based on the above conditions:

1) Mumbai station (0 km 000 m)

All trains shall turn back at the Mumbai station, a dead-end type departure and arrival terminal. On the mainline of high-speed railways, maximum 12 trains can run per hour at 5-minute intervals. As it takes 10 minutes, each for passenger alighting, preparatory services for departure and passenger boarding (total 30 minutes from arrival to departure), two trains can arrive and depart per hour per track. To handle 12 trains per hour, therefore, three island type platforms to serve six tracks are required.

As development is active in and around Mumbai, it was difficult to prepare ground-level lands for the station. As a result, we had no choice to construct the Mumbai station underground. As the volume of ground excavation significantly affects the cost in constructing an underground station, we designed the platforms to have the minimum practical end widths at the Mumbai station. See Fig.9.1-2 for a schematic drawing of the track layout and a cross section of the track-floor center, Mumbai station.

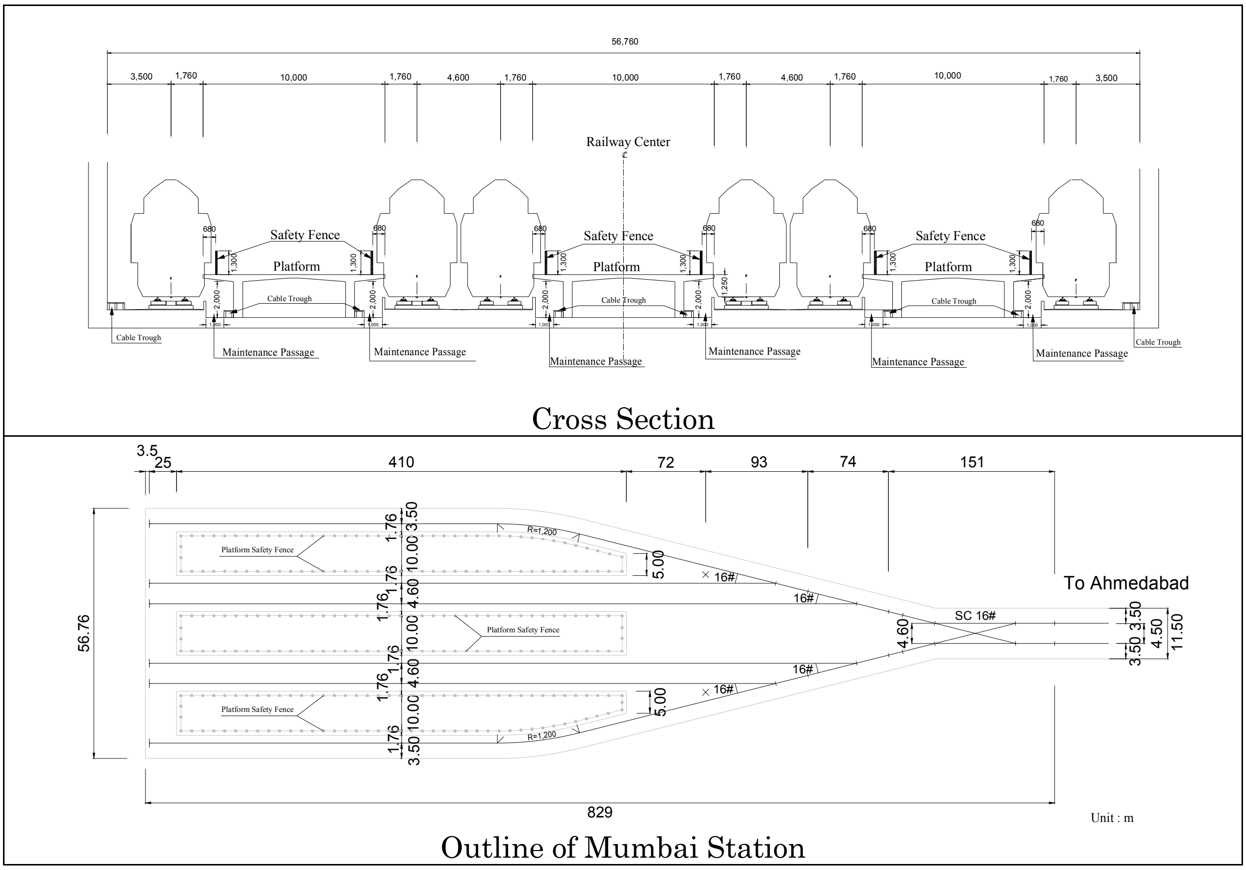


Figure 9.1-2 A Cross-section and a Schematic Drawing of the Track Layout, Mumbai Station

2) All-train handling station

We will equip all-train handling stations with two island-type inside-mainline platforms to serve four tracks, having a distance of 1.8 m between the track center and the edge of platform to allow handling non-stop trains.

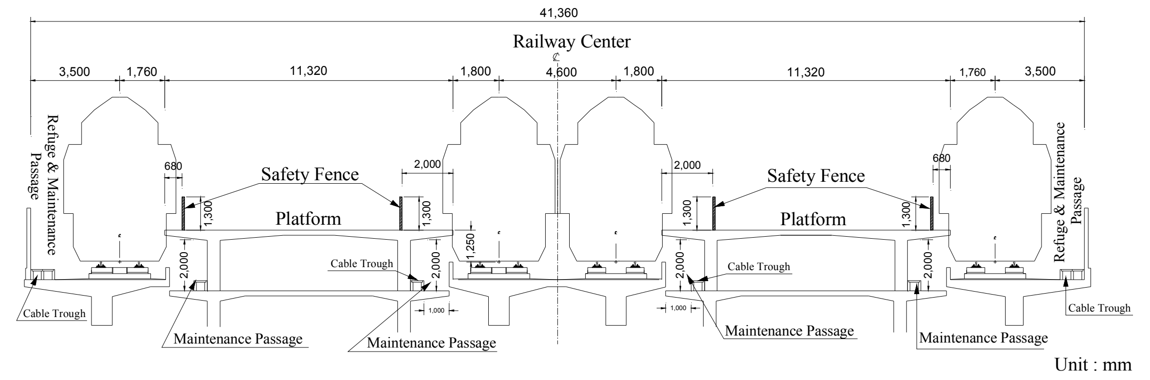
The Thane station (27 km 950 m) will be located at an intersection with the existing line to enable changing trains in between. The track layout at the station will be designed to allow connection between the sub-mainline and a railway maintenance depot.

We will locate the Surat station (264 km 580 m) at an approximate midpoint of the route, equipped with two island type platforms for four tracks to accommodate all trains and for changing trains to/from trains running ahead or behind, as a number of passengers expected to change trains toward Mumbai and Ahmedabad. The track layout will be designed to allow connection between the sub-mainline and a railway maintenance depot.

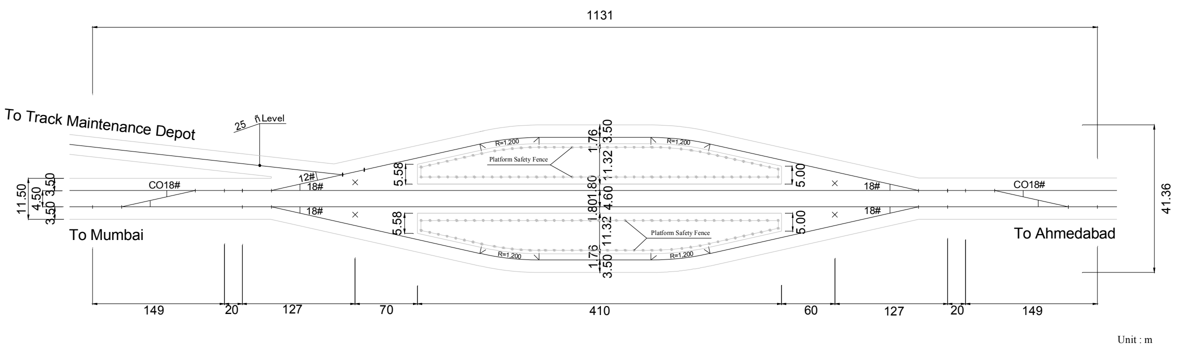
We will plan to construct the Vadodara station (397 km 060 m) side by side with the existing station that has rails running to/from Delhi, to facilitate changing trains to/from the high-speed railway. As the existing station stands on a curve, the constructing work of an HSR station on the viaduct in the station yard would substantially obstruct the operation of existing line and make the period of construction work longer. Therefore, a straight line will be constructed inward of the curve equipped with two island type platforms for four lines and a passenger passage connecting to the existing station.

The HSR Ahmedabad station will be constructed on a viaduct over the existing station. The area on the main station building side is used for through-lines and platforms for major existing lines. The eastern side is used for a platform for departing trains on meter-gauge suburban lines. As meter-gauge lines are little affected by the construction work, a 2-platform 4-track HSR station will be constructed above the meter-gauge lines, with tracks laid on the third layer from the ground-level and passage to change trains to/from existing lines, ticket offices, ticket barriers, passenger accommodations and other facilities required for HSR distributed on the second layer.

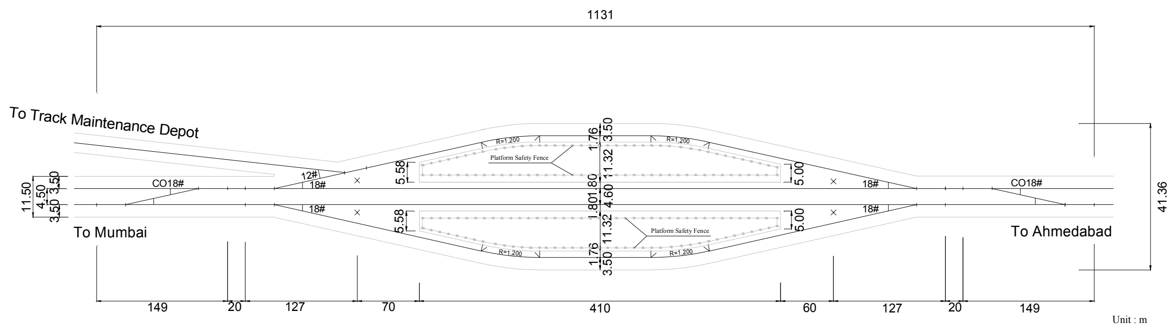
We will locate a 2-platform 4-track Sabarmati station in a major Western Railway rolling stock depot, on a viaduct over a group of storage tracks sandwiched between an existing trunk line and a suburban line and equip it with a passenger passage to/from these two existing lines. As the Sabarmati station is an arrival terminal having a rolling stock depot in back, trains arrived at the station will retreat once to the depot after completion of passenger alighting, though some turn back, and show up later as a departure train from the station. As it is constructed in an existing rolling stock depot, the station will take shape of a station on a curve to reflect the layout of existing facilities and land profile.
See Figure 9.1-3 for cross section at the center and schematic drawing of the track layout of these stations.



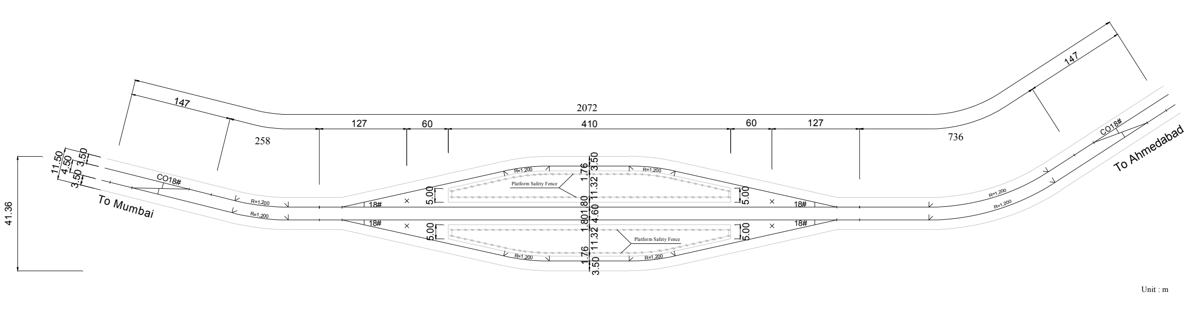
Cross Section



Thane Station



Surat Station



Vadodara Station

Figure 9.1-3 (1) Drawings of the Cross-section at the Center
and Schematic Drawing of the Track Layout of Different Stations

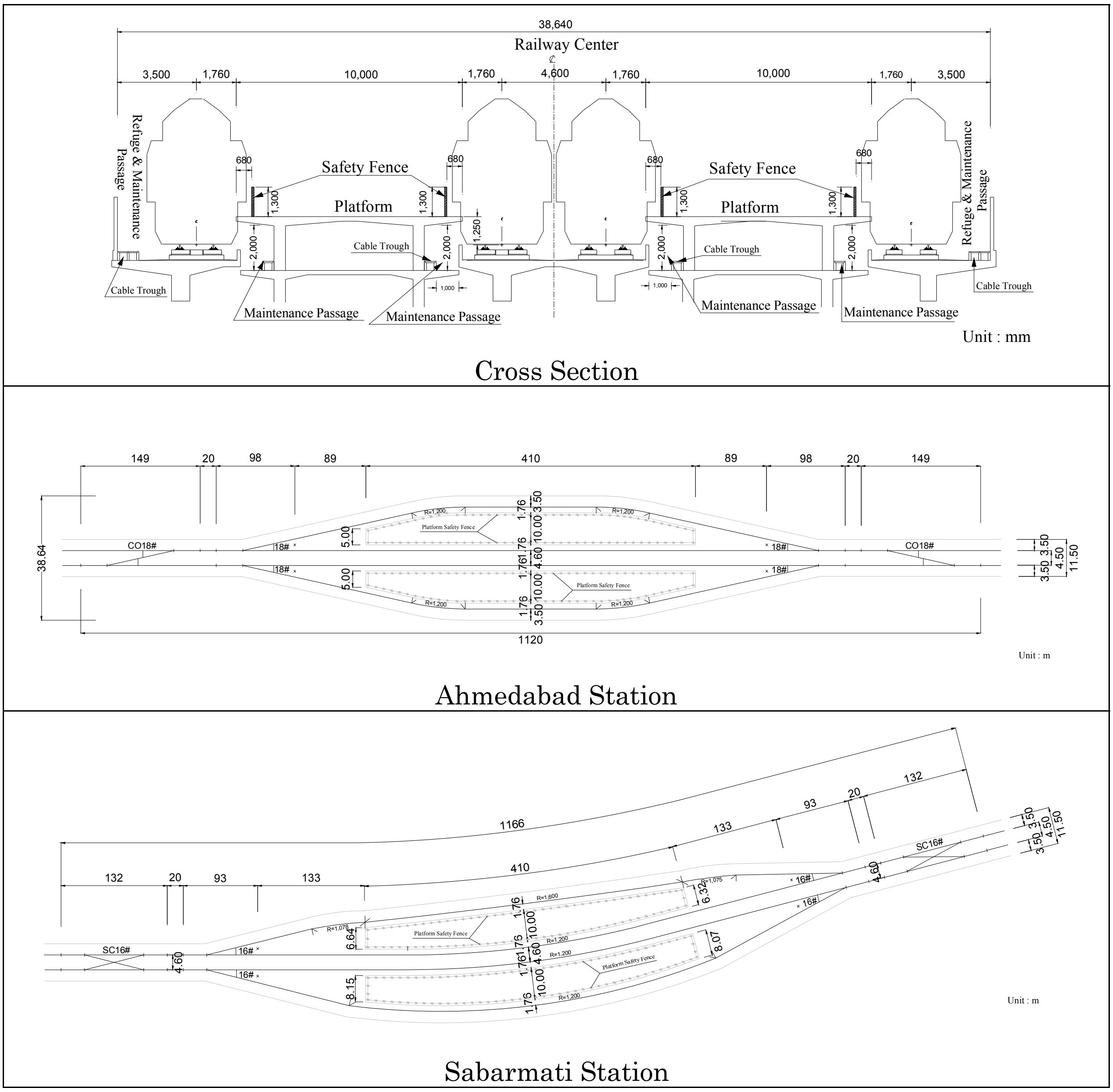


Figure 9.1-3 (2) Drawings of the Cross-section at the Center
and Schematic Drawing of the Track Layout of Different Stations

3) Non-stop train handling station

Non-stop train handling stations shall be equipped with two separated type inside-mainline platforms for four lines, except the island type platforms for the down-track at the Boisar station and for the up-track at the Bharuch stations, with the secondary sub-mainline used, without implementing passenger boarding services, as a storage track for test-run cars subjected to maintenance at the Thane and Sabarmati depots. See Figure 9.1-4 for the drawings of cross-section at the center and schematic drawing of the track layout of different stations.

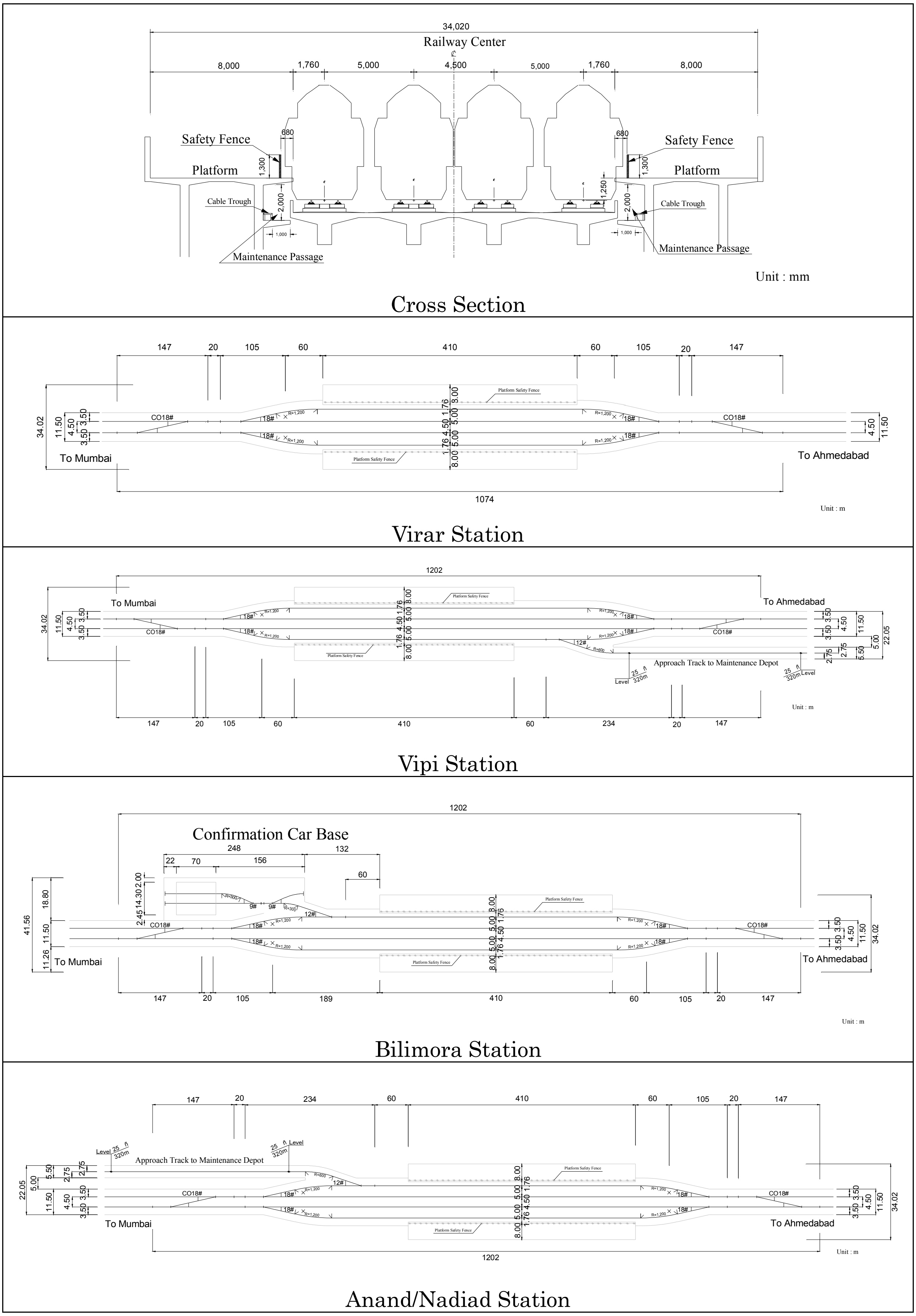


Figure 9.1-4 (1) Drawings of the Cross-section at the Center and Schematic Drawing of the Track Layout of Different Stations

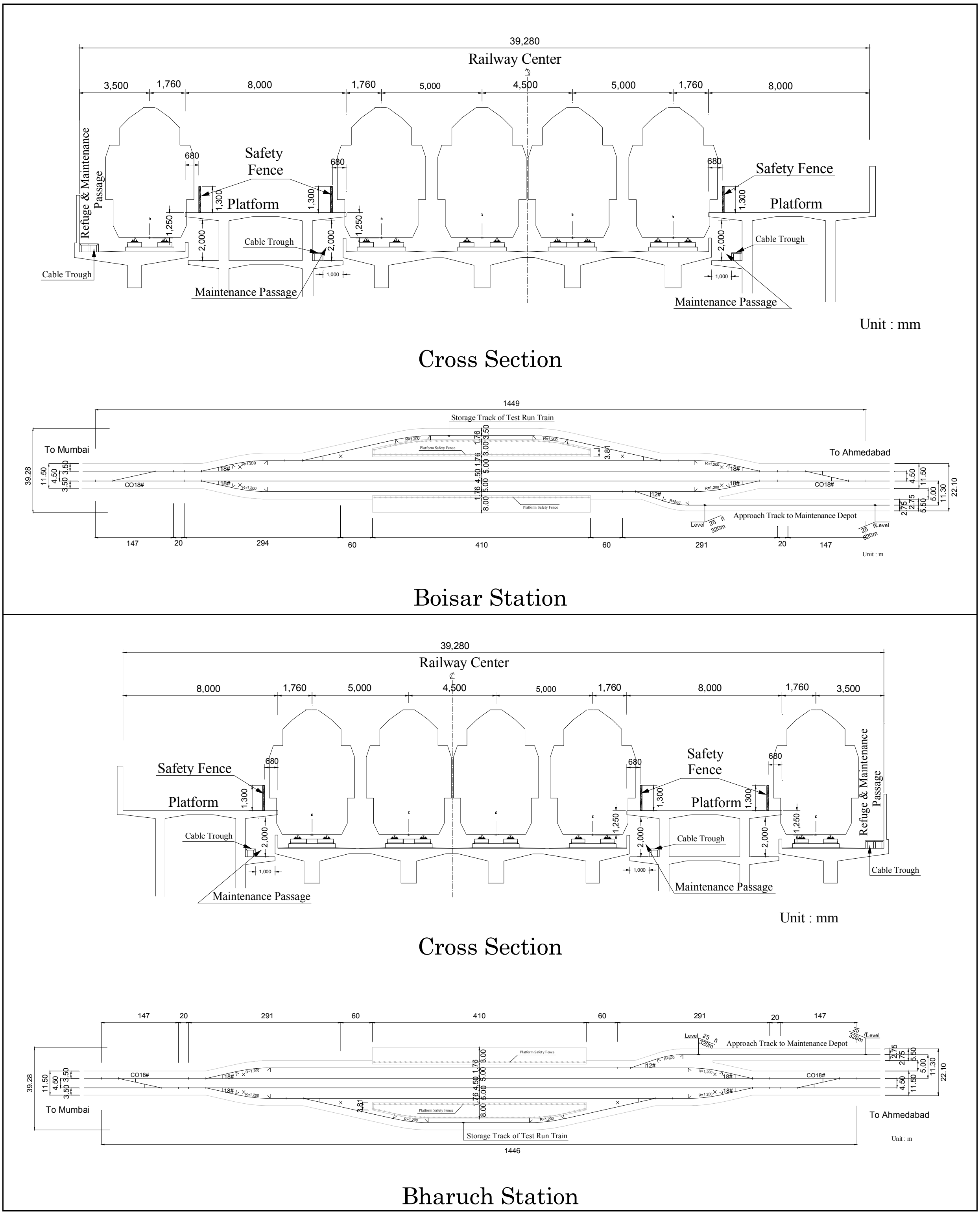


Figure 9.1-4 (2) Drawings of the Cross-section at the Center
and Schematic Drawing of the Track Layout of Different Stations

(2) Rolling stock depot and workshop

We construct two rolling stock depots, one each in the suburbs of Mumbai and Ahmedabad, or two terminals of the HSR line. Although it was difficult to secure the land for a depot around Mumbai, we found one in the suburbs of the adjacent Thane station. In the suburbs of Ahmedabad in contrast, a large-size land owned by Western Railway was available for a rolling stock depot, where we planned to construct a depot and a workshop for HSR. See Table 9.1-2 for the scales of the workshops, Thane and Sabarmati, from fiscal 2023 through 2053.

Table 9.1-2 List of Rolling Stock Workshops and Their Scales

Items \ Year	2023		2033		2043		2053		Remarks
	Thane	Sabarmati	Thane	Sabarmati	Thane	Sabarmati	Thane	Sabarmati	
Depot									
Storage Tracks	13	11	15	13	23	22	29	29	L=480 m
Daily Inspection Tracks	2	2	3	3	3	3	6	6	
Regular Inspection Tracks	2	2	3	2	2	2	3	3	
Special Inspection & Repair Track	1	1	1	1	1	1	1	1	
Wheel Re-profiling Track	1	1	1	1	1	1	1	1	
Car Washing Track	1	1	1	1	1	1	1	1	
Drill Track (L=400m)		1		1		1		1	
Workshop									
Overhaul Tracks		2		2		2		2	
Bogie Exchange Track		1		1		1		1	
Assembly Tracks		2		2		2		2	
Bogie Repair Shop (W×Lm)		88m ×460m		88m ×460m		88m ×460m		88m ×460m	
Rigging Shop (W×Lm)		130m ×180m		130m ×180m		130m ×180m		130m ×180m	
Paint Shop (W×Lm)		130m ×140m		130m ×140m		130m ×140m		130m ×140m	
Traverser (Set)		4		4		4		4	
Drill & Test Track (L=1,000m)		1		1		1		1	

Branching downward at 25‰ to the ground-level from up- and down-tracks at the 29 km 590 m point between Thane and Virar station, the Thane rolling stock depot is equipped with a maintenance/repair shed and a group of storage tracks arranged in series. In the final year of the plan, there will be 29 storage tracks, though the capacity is designed to accommodate 32 tracks. An effective length of 480 m is required for each storage track as they are put under the ATC system. We will prepare maintenance/repair tracks and building areas as required as well as a ring road surrounding the depot. The area required is approx. 8,880 m^2 for approach tracks and approximately 324,420 m^2 for the depot.

We construct the Sabarmati rolling stock depot side by side with a rolling stock workshop approximately 2.3 km behind the Sabarmati station, a group of storage tracks, a maintenance/repair shed and a building to house workshop equipment/facilities in parallel according to the site profile. Transfer of cars between storage tracks will be done through drill tracks. The drill track mainly used by the workshop will be 1,000 m long to allow test running. In the final year of the plan, there will be 29 storage tracks, though the capacity is designed to accommodate 32 tracks, in the same way as for the Thane base. An effective length of 480 m is required for each storage track under the ATC system. We will secure an area required for the rolling stock depot to accommodate maintenance/repair tracks as required and a shed built side by side and surrounded by a ring road. The area required is approximately 36,510 m^2 for approach tracks and approximately 673,260 m^2 for the base.

See Figure 9.1-5 and 9.1-6 for the schematic drawings of the track layouts of the Thane and Sabarmati rolling stock depots, respectively.

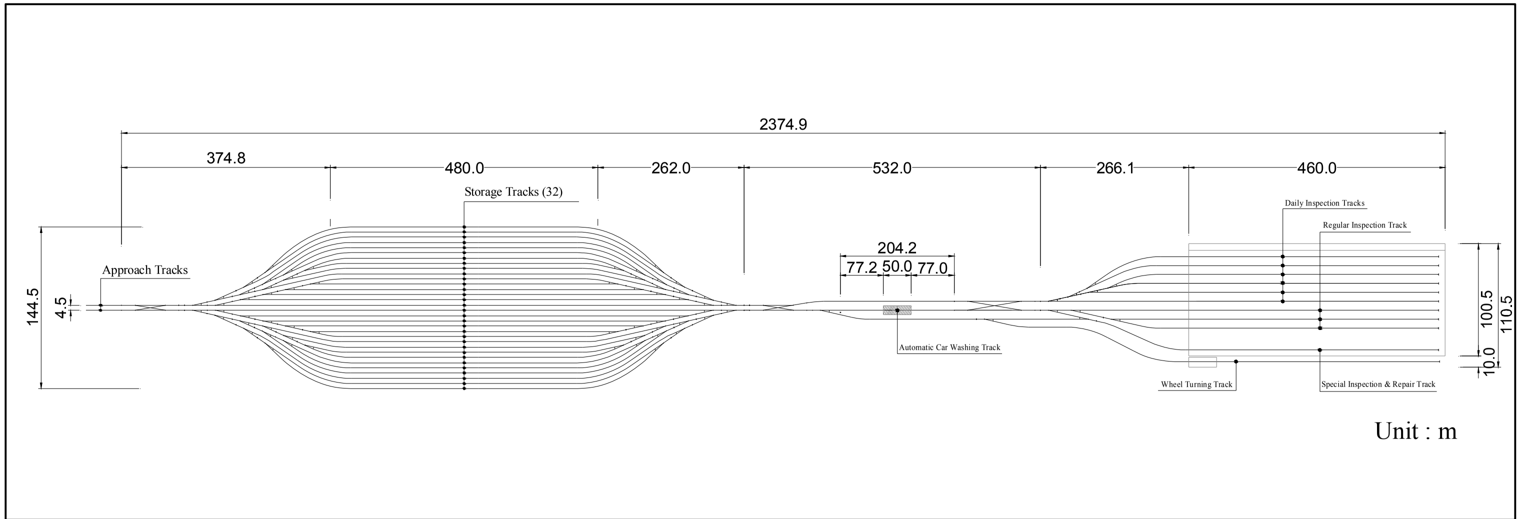


Figure 9.1-5 (1) Schematic Drawing of the Track Layout, Thane Rolling Stock Depot

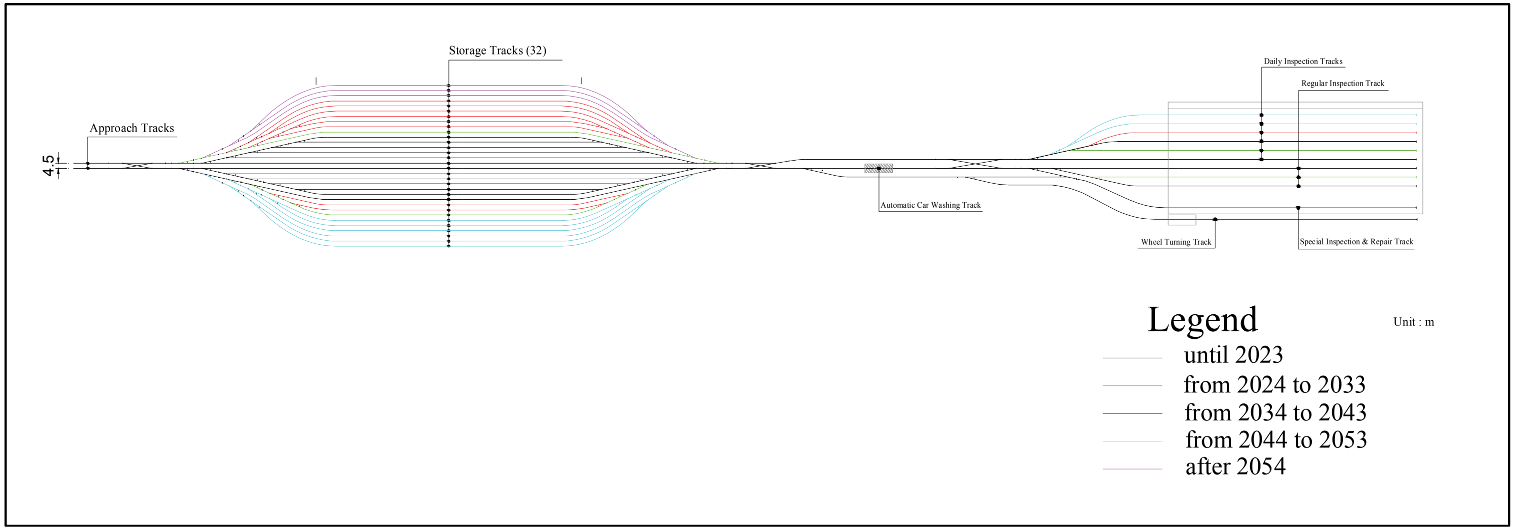


Figure 9.1-5 (2) Track Layout of the Thane Rolling Stock Depot in Different Fiscal Years

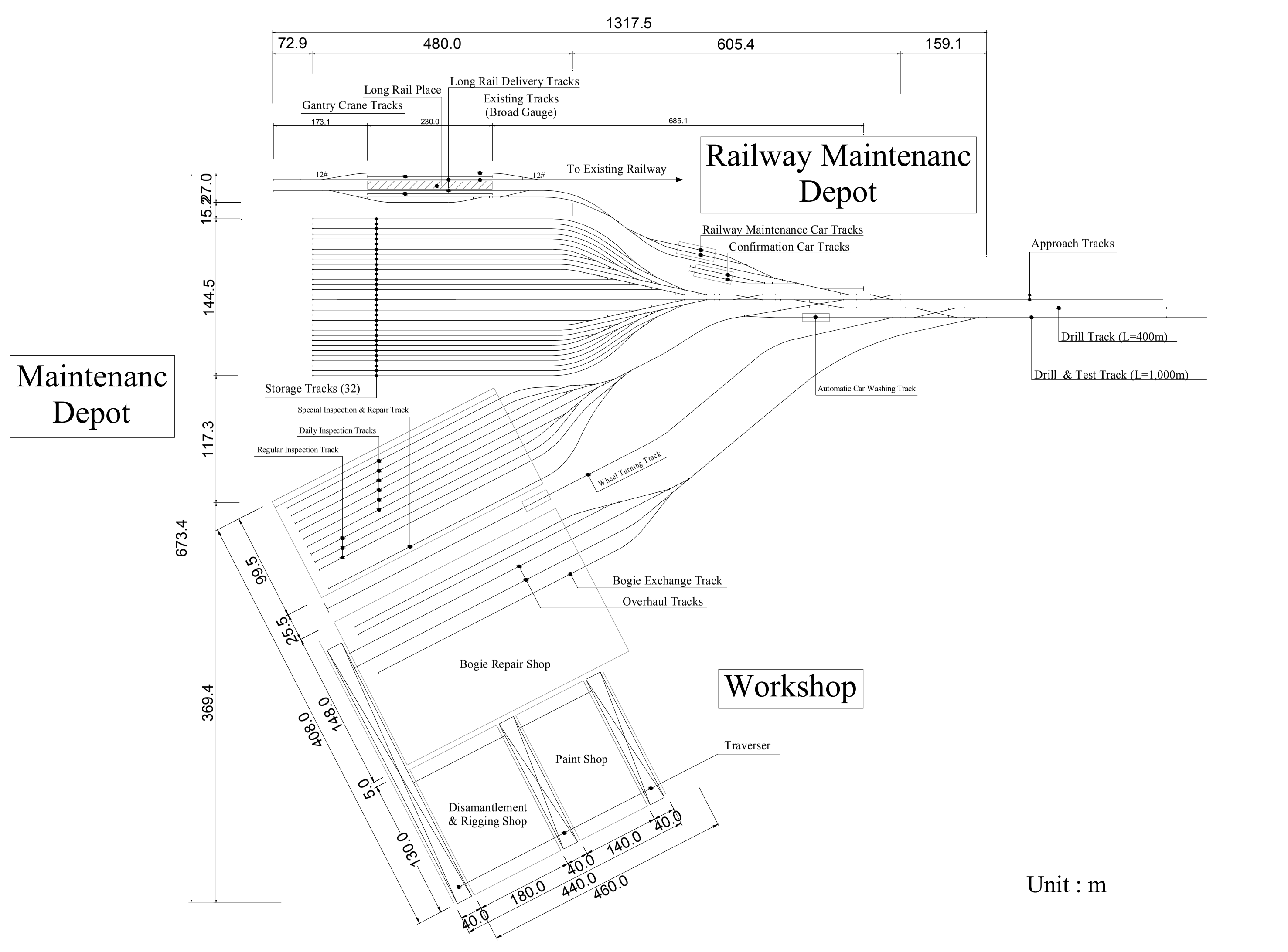


Figure 9.1-6 (1) Schematic Drawing of the Track Layout Sabarmati Rolling Stock Depot and Workshop

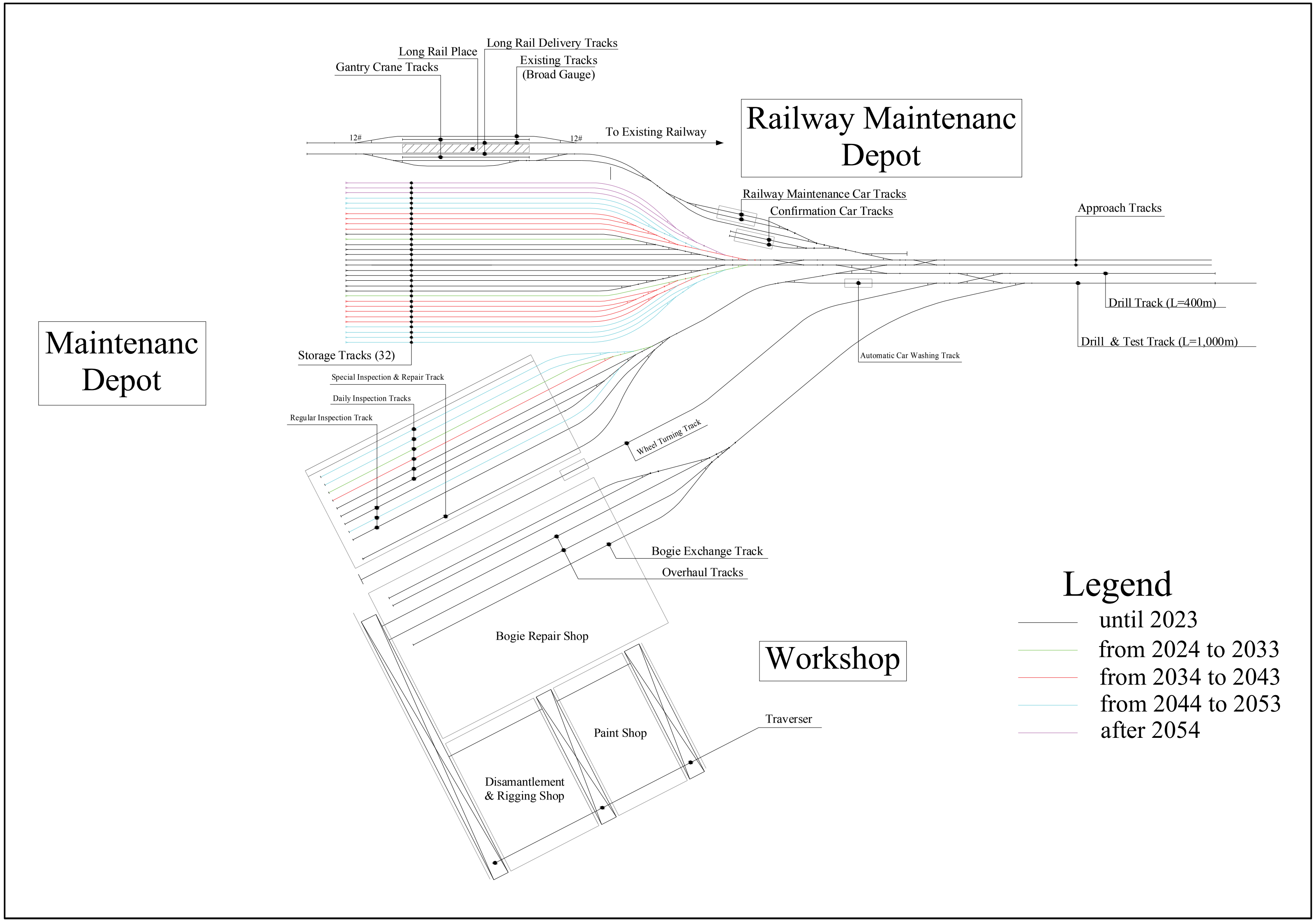


Figure 9.1-6 (2) Chronological Changes in the Track Layout, Sabarmati Rolling Stock Depot and Workshop

(3) Track maintenance depot

The track maintenance work of high-speed railways is carried out in the time zone from 24:00 when train operation of the day has completed to 6:00 next morning. To quickly provide tracks with various maintenance services, large-size maintenance machines and material/machine transport cars move on the mainline to the work site and return to the maintenance depot after maintenance services have been completed. At the end of the working time zone, a new train operation time zone starts to run revenue service trains. In this working time zone included is the operation of confirmation car to confirm the completion of track maintenance services. Taking into account this six-hour working time zone, we will distribute track maintenance depots at intervals of 50 to 80 km.

Track maintenance depots shall organically arrange track maintenance work maneuvering cars, material/maintenance transporting cars, workers deploying cars, a material/machine storage shed and a maintenance car servicing shed. Regarding the treatment of rails, a weighty and lengthy track work article, 200 m-long welded rails of the basic specifications for this category of rails, can be transported from iron mills directly to the work site through existing railway lines in India. Therefore, we will install track maintenance depots where the high-speed railway crosses or contacts an existing railway line and equipped them with rail receiving/dispatching tracks.

(Note: In the case of road transport, eight pieces of at most 25 m-long rails transported by road are welded at the track maintenance depot to produce a 200 m-long rail. The 200 m-long rails thus produced are sent to the construction work site, again welded to a specified length and laid on the track. When compared with this method, therefore, track construction work to lay rails transported through existing railway lines can eliminate seven welding points per 200 m-long rail. This means that seven weak points (welded points) per 200 m can also be eliminated on the mainline track.)

There are five points along the route where the high-speed railway crosses or runs close to an existing railway line. They are the Thane station, Surat station, Vadodara station, Anand/Nadiad station and the Sabarmati rolling stock depot. In the track maintenance depot connected to these stations, we will place a rail receiving/dispatching track in parallel with the existing railway line.

Other track maintenance depots are connected to the Boisar station, Vapi station and Bharuch station. Other than these eight track maintenance depots, we construct a confirmation car accommodation depot side by side with the Bilimora station.

See Figure 9.1-7 for schematic drawings of track layout of these track maintenance depots, Figure 9.1-6 (1) for a schematic drawing of the Sabarmati track maintenance depot and Figure 9.1-4 (1) for the Bilimora confirmation car depot.

Each track maintenance depot can be reached from the corresponding station branching from the station subsidiary track through a 25‰ down-gradient ramp to the ground-level. See Table 9.1-3 for the area required for each track maintenance depot.

Table 9.1-3 Areas Required for Track Maintenance Depots (m^2)

Name of Depot	Main part of Depot	Approach	Total	Remarks
Thane	33,000	2,470	35,470	Connected to an existing line
Boisar	32,220	2,530	34,750	
Vapi	32,220	2,530	34,750	
Bilimora	17,900	—	17,900	Confirmation car shed
Surat	31,230	5,030	36,260	Connected to an existing line
Bharuch	32,200	2,780	34,980	
Vadodara	31,380	6,390	37,770	
Anand/Nadiad	33,000	2,140	35,140	Connected to an existing line
Sabarmati	Within Car Depot & Workshop			Connected to an existing line
Total	243,150	23,870	267,020	

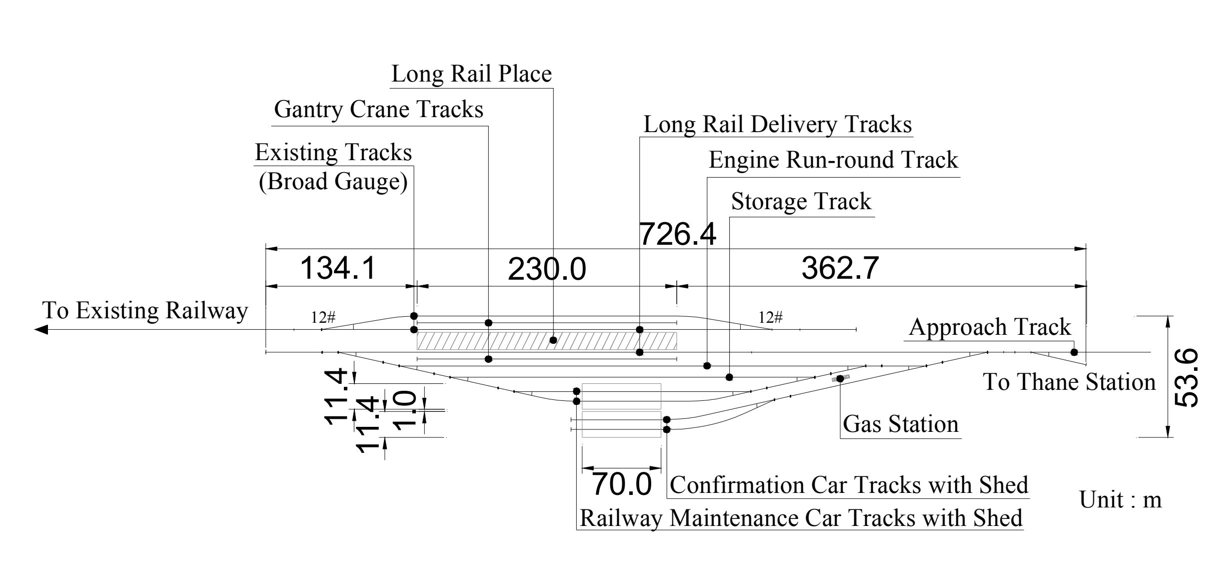


Figure 9.1-7 (1) Schematic Drawing of Track Layout, Thane Track Maintenance Depot

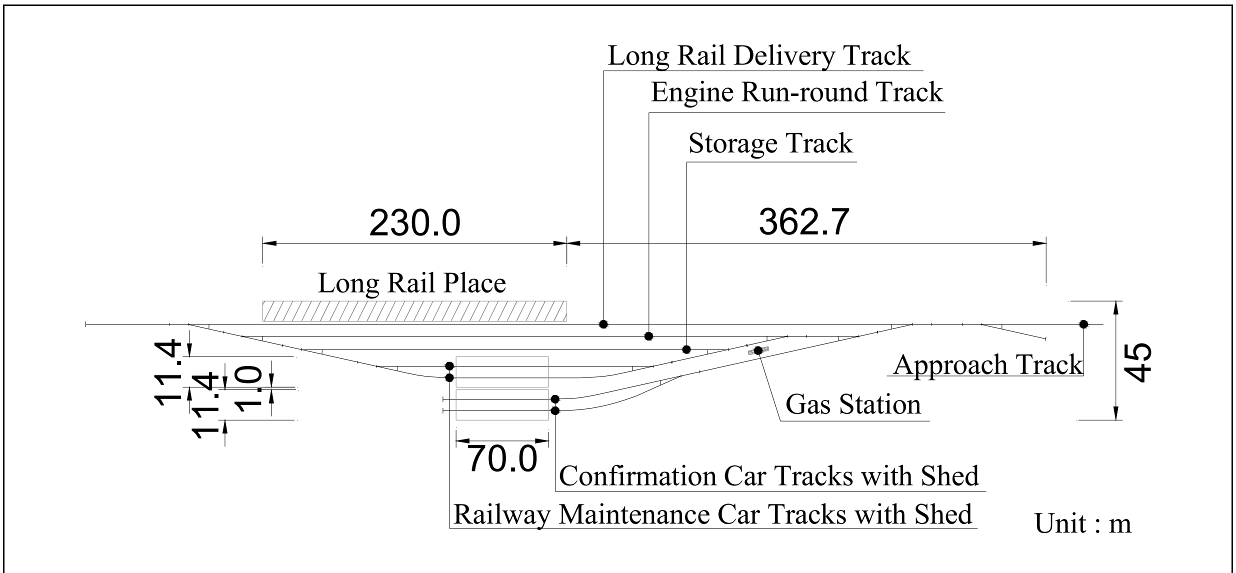


Figure 9.1-7 (2) Schematic Drawings of Track Layout,
Boisar, Vapi and Thane Track Maintenance Depots

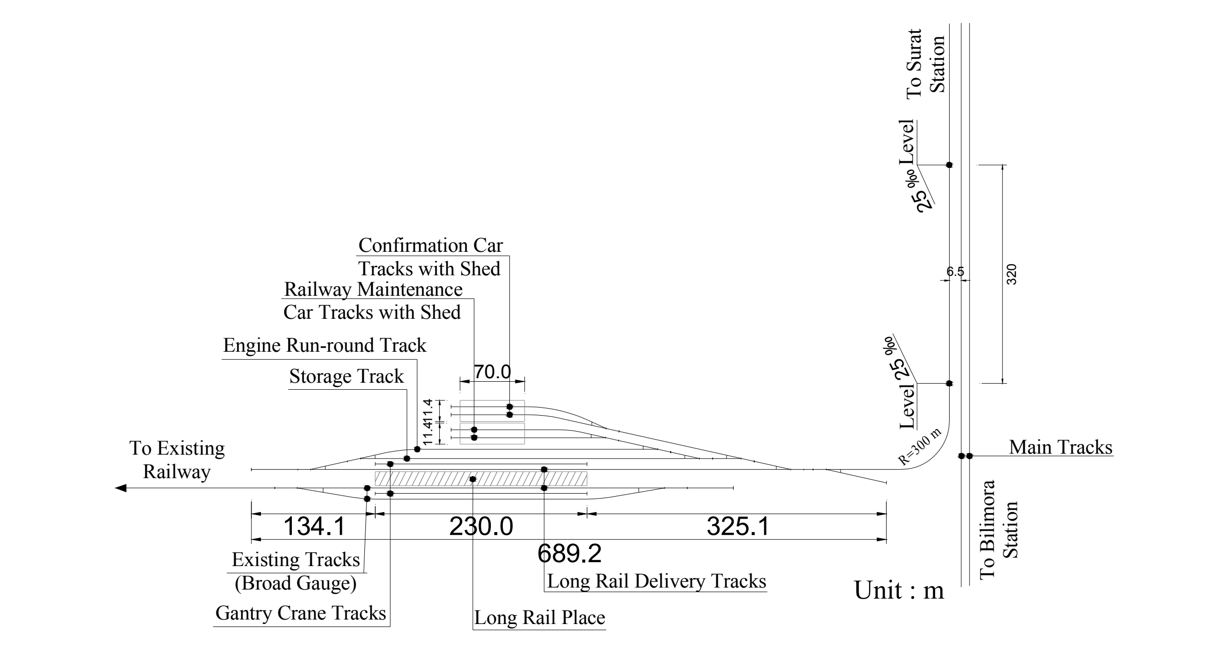


Figure 9.1-7 (3) Schematic Drawing of Track Layout, Surat Track Maintenance Depot

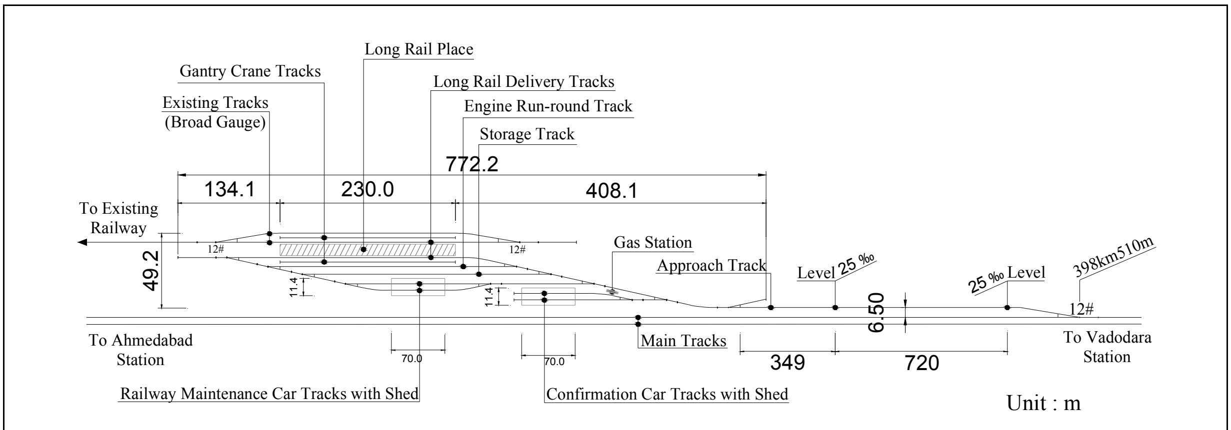


Figure 9.1-7 (4) Schematic Drawing of Track Layout, Vadodara Track Maintenance Depot

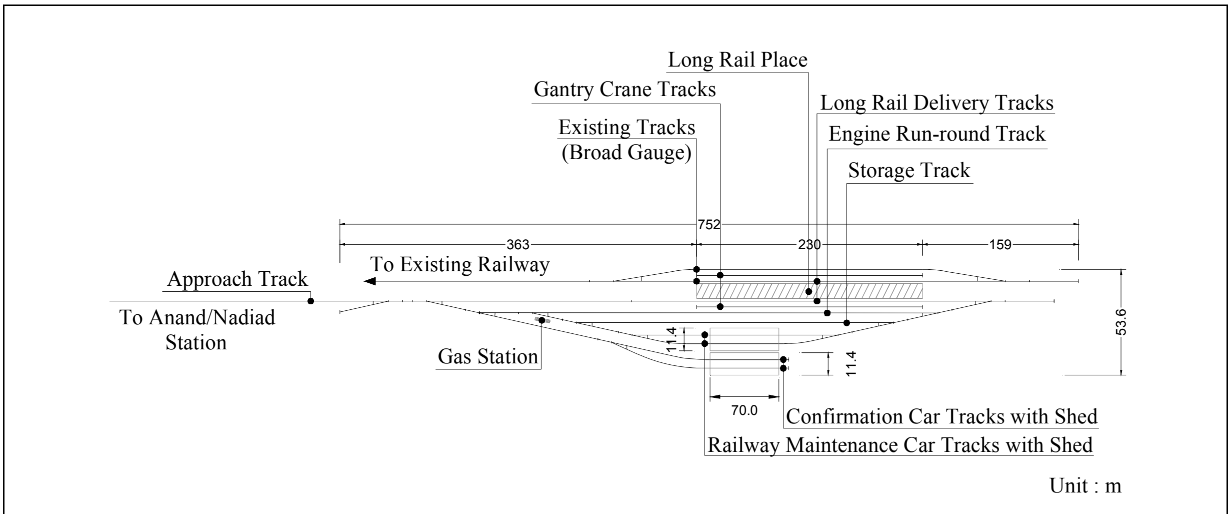


Figure 9.1-7 (5) Schematic Drawing of Track Layout,
Anand/Nadiad Track Maintenance Depot

9.1.2 Basic Policy for Designing Civil Structures

Study team discussed carefully about basic policy for designing civil structures and decided policies as below.

➢ Adopting safety-first and high-speed operation
- All civil structure was planned for HSR train (Maximum speed: 350km/h) load, another types of train load are not considered.
- All crossing of railways, roads, rivers and waterway was planned to have grade separation (No level crossing).

➢ Consideration of the construction cost reduction.
- Adopting the embankment structure for large part of alignment.
- Structure type and construction method were taken priority to choose usual types in India, not choose unusual types and methods in India with exceptions.
- Structure type and dimensions was standardized to make designing and constructing efficient.

➢ Consideration of the life cycle cost reduction.
- Adopting the reinforcement embankment and concrete structures to work saving at the time of maintenance.

➢ Harmonizing with urban planning
- Adopting viaduct structure in urban areas in order not to interfere with land use and disrupt the daily communication of residents.

➢ Environmental considerations
- Adopting the tunneling method for environmental protection.

➢ Countermeasures for natural disasters and long-term durability.

Although there are some issues about civil structures to be solved by the time design starts. The Study team has reviewed some of them as below.

(1) Seismic design

Seismic Design is one of major factors for choosing the type and size of civil structures. In this paragraph, we compare the seismic design methods in India and Japan, and reveal about the difference.

Table 9.1-4 Seismic Design Method in India (Outline)

	India
Characteristics of the Seismic Standard	■ The acknowledgement of the importance of plastic behavior of structure, when a higher earthquake occur causing seismic forces higher than the design forces adopted for elastic design. ■ Types of earthquake, Maximum Considered Earthquake (MCE), and Design Basis Earthquake (DBE) are adopted. ■ Response Reduction Factor is adopted.
Design Earthquake Motions (DBE)	■ DBE (Design Basis Earthquake) Reasonably be expected to occur at least once during the design life of structure. The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression. $A_h = (Z \cdot I \cdot S_a) / (2 \cdot R \cdot g)$ Z = Zone factor for the Maximum Considered Earthquake (MCE). I = Importance factor, depending upon the functional use of the structures. R = Response reduction factor, depending on the perceived seismic damage performance of the structure. S_a / g = Average response acceleration coefficient for rock or soil sites.

Design Earthquake Motions (MCE)	MCE (Maximum Considered Earthquake) The most severe earthquake effects. $A_h = (Z \cdot I \cdot S_a) / (R \cdot g)$
Set of the Damage Level of Members	■ For DBE (Design Basis Earthquake) Structure would undergo deformation beyond its yield limit. ■ For MCE (Maximum Considered Earthquake) The structure might undergo severe damage but total collapse could be avoided with judicious design of the bridge system.

Table 9.1-5 Seismic Design Method in Japan (Outline)

Japan	
Characteristics of the Seismic Standard	■ Two levels of design earthquake motion, Level-1 and Level-2 earthquake are adopted. Level-2 includes earthquake motion caused "by near-land-large-scale interpolate earthquake" and "by an inland near-field earthquake". ■ The concept of allowing damage but preventing collapse at the Level-2 earthquake is adopted, which is available through the appropriate evaluation of the ductility of members and foundations. So, the endurable extent of damage is prescribed and represented by "seismic performance" based on the viewpoint of damage control. ■ Dynamic analysis that completely models the foundation and the superstructure are mainly used to compute the response value of structures.
Design Earthquake Motions (Level-1)	■ Level-1 Level-1 earthquake motion has a probability of occurring several times within the service period of the structure. The intensity of earthquake motion is prescribed based on the acceleration response spectrum determined for firm ground classified in the conventional allowable stress design method, and is determined referring to an earthquake risk analysis of return period of 50 years. The maximum value is taken as 250gal (damping ratio 5%)(bedrock).
Design Earthquake Motions (Level-2)	■ Level-2 Level-2 earthquake motion is strong earthquake motion that has a low probability of occurring within the service period, such as earthquake motion caused "by a near-land-large-scale interpolate earthquake" or "by an inland near-field earthquake". ・Spectrum I targeting near-land interpolate earthquakes (Magnitude 8 level, distance to epicenter of 30 to 40 km). ・Spectrum II determined according to statistical analysis based on past earthquake observation records targeting earthquake produced by inland active faults.
Summary of Seismic Design	■ For Level-1 This level of earthquake motion has been used in combination with the elastic design method. As well as being presented as static loads (for the seismic coefficient method), also is provided as a seismic wave form for dynamic analysis. ■ For Level-2 The concept of allowing damage but preventing collapse is adopted, which is available through the appropriate evaluation of the ductility of members and foundations. So, the endurable extent of damage is prescribed and represented by "seismic performance" based on the viewpoint of damage control.

From table 9.1-4 and 9.1-5, there are 2 types of earthquake motion in both countries.
DBE in India is almost same meaning as Level-1 Earthquake in Japan. For DBE and Level-1 earthquake motions, all members must be within the range of longitudinal reinforcement yield. MCE is similar to Level-2 earthquake in Japan. For MCE and Level-2 earthquake motions, Structure must be within the specific displacement.

On the one hand, there are large differences in the size of earthquake motions between in India and in Japan, because sizes of earthquake motions for seismic design are set by reference to historical earthquake motions in each country.
Structures for HSR must be designed safety and economically, hence the seismic design method for HSR in India will have to be developed cautiously in the next stage.

(2) Dynamic effect and impact factor for girder

Dynamic effect (impact factor) is one of major factors for choosing the type and size of girder.
From table 9.2-3, Dynamic Effect Augment (CDA) in India is the same meaning as Impact factor in Japan.
In India, CDA is composed of only one factor "L (length of span)". On the other hand, impact factor in Japan is composed many factors (Length of span, train speed, length of vehicle), and train speed is a large factor.
CDA (India) is applicable for conventional railway structure, but not for HSR structures, for such occasions, impact factor (Japan) is recommended for designing HSR structures, but it will have to be developed cautiously in the next stage.

Table 9.1-6 Comparison of Dynamic Effect and Impact Factor

India	
Coefficient Multiplied by the Train Load	■ The augmentation ofload due to dynamic effects should be considered by adding a load Equivalent to a Coefficient of Dynamic Augment (CDA) multiplied by the live load giving the maximum stress in the member under consideration. ■ The CDA should be obtained as follows and shall be applicable upto 160km/h on broad gauge. ■ For single track spans, $CDA = 0.15 + 8 / (6 + L)$ Where L is the loaded length of span in meters for the position of the train giving the maximum stress in the member under consideration.
Japan	
Coefficient Multiplied by the Train Load	■ The running of a train induces dynamic response to structure. The ratio between dynamic response to the increase in static response of stress or deflection caused by dynamic response is called "impact factor." In design, the design impact factor is configured as shown in equation is multiplied by the train load. ■ $i = (1 + i_\alpha)(1 + i_c) - 1$ where, i_α : impact factor of speed effect i_c : impact factor of vehicle motion i_α is presented using numerical table, that was computed using the speed parameter $\alpha(=V/(7.2nL_b)$ and L_b/L_v V = maximum velocity of train (km/h) N = fundamental natural frequency of members, L_b = span of members L_v = length of a vehicle $I_c = 10 / (65 + L_b)$

(3) Deflection of girder

Deflection is one of major factors for choosing the type and size of girder.
HSR structures must support high speed trains safety in every condition, therefore deflection and displacement are restricted smaller than conventional train structures.
There are not design limit values of HSR girders in India, design limit values in Japan are recommended for designing HSR structures in India, but it will have to be developed cautiously in the next stage.

9.2 Embankment and Cut Structure

9.2.1 Embankment

Study team selected embankment sections in consideration of the following conditions.
There are a great variety of factors as the preconditions on the selection of structures in structure planning. They are topographical and geological conditions of mountains, hills and plains, status of land utilization in urban areas, outskirts, suburbs of cities and rural districts, intersections between railways and rivers/roads and longitudinal section.
In the structure planning for high-speed railways in particular, Study team shall also pay attention to track structures, location of turnouts, and civil engineering structures supporting these facilities. Depending on the topological, geological and surrounding environmental conditions, engineering structures between stations are classified into earth structures (embankments and cuts), viaduct, bridges and tunnels. Study team summarize below the scope of application of embankments.

(1) Scope and principles to select embankment sections

As the civil engineering structures between stations, earth structures (embankments and cuts) featuring superb economy and easiness of construction are selected in principle.
However, embankment structures before and after major stations tend to break the continuity of urbanity and disturb communication between citizens in the area. Furthermore, soft surface ground or flood plain areas are subject to slope collapse and liquefaction of track bed due to settlement, heavy rains or earthquakes after inauguration or apprehended to pose other problems in upkeep and control.
Therefore, Study team adopts viaducts but not embankments for the following sections:

- Urban areas surrounding major stations
- Soft surface ground or flood plain areas

Table 9.2-1 list of the embankment structures lengrh between stations.

Table 9.2-1 List of Embankment Structures

No.	Station	Length (km)	Embankment Structures(km)	Rate (%)
1	Mumbai st. – Thane st.	27.8	2.8	10
2	Thane st. – Virar st.	37.0	4.8	13
3	Virar st. - Boisar st,	39.4	23.8	61
4	Boisar st. – Vapi st.	64.7	48.0	76
5	Vapi st. – Bilimor st.	48.2	43.8	93
6	Bilimor st. – Surat st.	47.3	33.0	71
7	Surat st. – Bharuch st.	58.6	38.0	66
8	Bharuch st. – Vadodara st.	74.0	60.4	83
9	Vadodara st. - Anand/Nadiad st.	50.0	35.1	71
10	Anand/Nadiad st – Ahmedabad st.	52.7	23.3	45
11	Ahmedabad st. - Sabarmati Depot.	8.8	0.0	0
	TOTAL	508.5	313.0	63

Source: Study Team

(2) Subjects of embankment structures

As this project uses slab tracks, Study team don't adopt the normal embankment structure but a different version normally used where restriction of displacement and other conditions are severer. As an area of black cotton soil (hereinafter referred to as "BCS") having special geological properties spreads extensively along the Indian HSR railway, there are following problems. See the section 6.2 for the geological properties of BCS:

- As BCS cannot be used for the base embankment structure, Study team shall establish

methods to procure appropriate embankment soil and construct reinforced embankments.
- Study team shall establish a method to deal with BCS at the embankment foundation bed.

Study team decided, therefore, to collect materials/information on the above subjects and have discussions based on the opinions of leaned people about BCS:

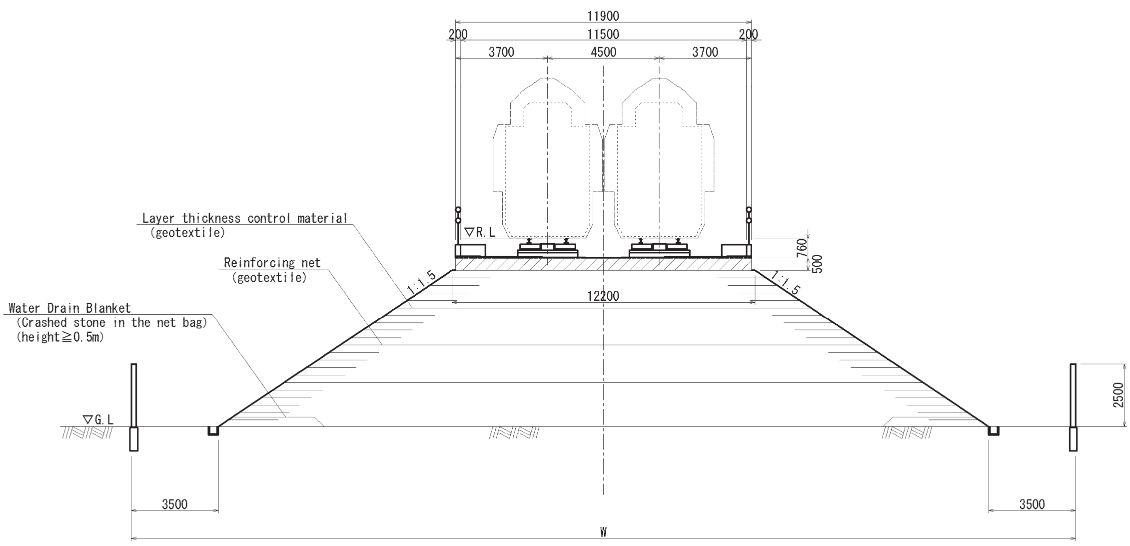
(3) Embankment structure related to the characteristics of BCS.

The black cotton soil in India is extremely hard when it is dry and softens when the water content has saturated. Changes in the water content are governed by the lengths of the dry and rainy seasons rather than by the volume of rain water penetrating the ground.
Physical property values of BCS are liquid limit: 46-97, plasticity index: 21-63 and shrinkage limit: 7-30%. Depending on grading, BCS is classified as cohesive soil and loamy soil (Reference material: Black cotton soil in India, Nov. 1978)
If an embankment were constructed on BCS without particular measures taken, uneven settlement or other adverse displacements would potentially take place in the rainy season. According to the views of knowledgeable people, ground conditions will be satisfied, if measures are taken to prevent penetration of water in the rainy season.

(4) Basic embankment cross-section

1) Embankment base structure

The embankment base structure is used to lay slab tracks thereon, with extremely small displacements allowed for track structural reasons. Therefore, Study team propose a structure in principle reinforced with reinforcement materials (geotextile, etc.) proven in the high-speed railways in Japan and matches Indian geological conditions.
The reinforced embankment structure to be adopted for Indian HSR as a standard has a slope gradient of 1:1.5 and a standard height of H = 6 m. See Figure 9.2-1 for the standard basic cross-section of the embankment of Indian HSR.

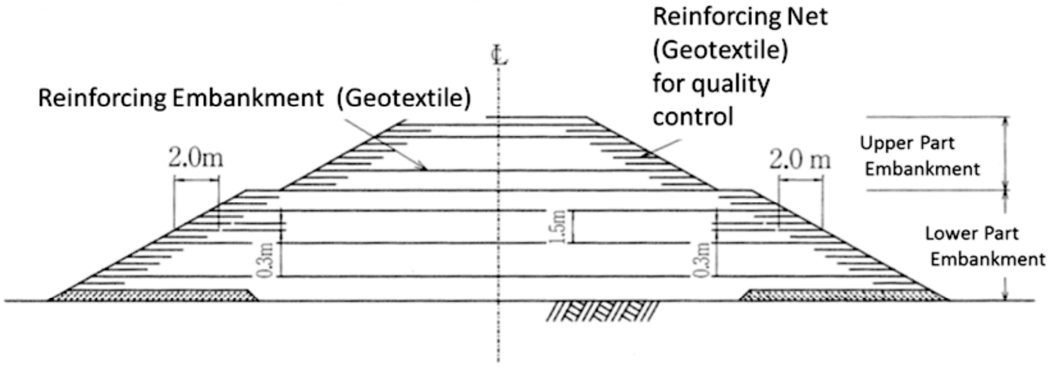


Source: Study Team

Figure 9.2-1 Standard Basic Cross-section of Embankment

2) Method of reinforced embankment construction

The reinforced embankment base structure shall be constructed under the following conditions : See Figure 9.2-2 for the Reinforced embankment.



Source: Study Team

Figure 9.2-2 Reinforced Embankment

a) Lay a layer thickness control material on the finished surface of each layer (0.3 m thick) after completing rolling compaction (a standard procedure).
b) Lay geotextile on each of the planes 1.5 m-spaced into the vertical direction from the embankment base (a standard procedure).
c) Construct 1.5 m wide berms on the boundary between the upper and lower parts and at 6 m intervals thereunder.

3) Conditions of the embankment supporting ground

Embankments shall be constructed on a supporting ground to safely support them and free from settlement problems.
A yardstick against the conditions of the embankment supporting ground: Cohesive soil (N-value 4 or over) or sandy soil (N-value 20 or over) (requiring confirmation of the properties free from liquefaction).
The limit of settlement of the embankment supporting ground to bear slab tracks shall be as per the following after completion of embankment supporting work:

・Limit of settlement	Settlement 10 mm for 10 years or less
・Limit of the displacement of the roadbed	Final settlement amount 30mm

4) Embankment materials

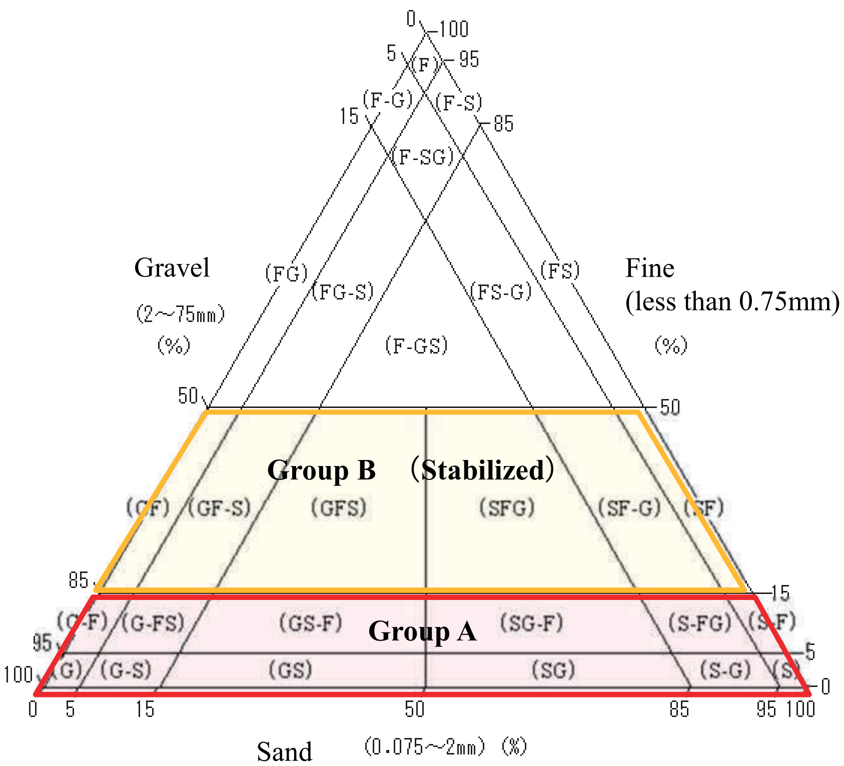
Embankment materials shall satisfy the conditions that (1) compacting is easy; (2) stability is ensured against external forces and (3) embankment shall be free from harmful settlement.
In concrete terms, embankment materials shall be of high-quality to readily guarantee K30 value ≧110 MN/m3 and present extremely small values of (1) compressive settlement due to self-weight, (2) residual settlement by repeated loading and (3) elastic displacement.
Although Study team apprehended at the initial stage whether borrow-pits exist where materials for reinforced embankments that satisfy the above conditions are available out of the BCS area, Study team hear that an appropriate borrow-pit was found in a site survey approx. 20 to 30 km east of the route in this project on the mountain side. Therefore, Study team determined to calculate the unit cost of embankment on the assumption that the soil excavated at this borrow-pit be used for embankment construction, though transporting distance is rather long.
Embankment having a height of 6 m or over is separated into the upper part embankment and lower part embankment. For the materials to construct upper/lower embankments, see Table 9.2-2.

Table 9.2-2 Materials Used to Construct Upper/Lower Embankments

Embankment	Material	Compaction
Upper	Group A, Stabilized Group B	Average density ratio of compaction ≧95% (lower limit : 92 %) And Average K30 value ≧ 110MN/m^3 (lower limit :70 MN/m^3)
Lower	Group A, Stabilized Group B	Average density ratio of compaction for gravel ≧90% (lower limit: 87%) for sand ≧95% (lower limit: 92%)

Source: Study Team

The classification of Group A and group B is according to the small classification for coarse grain soil in Figure 9.2-3 and the triangular coordinates for coarse grain soil sub-classification.



Source: Study Team

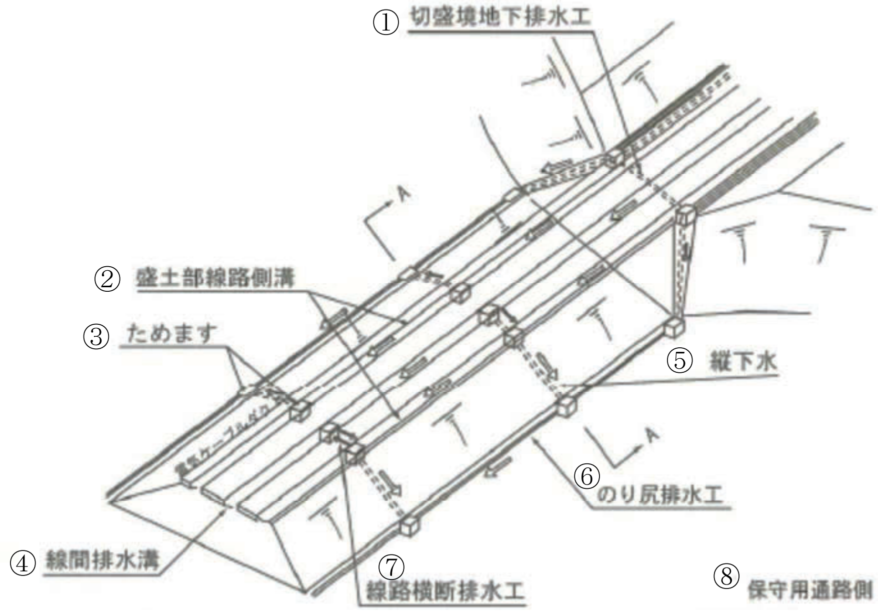
Figure 9.2-3 The Small Classification for Coarse Grain Soil and the Triangular Coordinates for Coarse Grain Soil Sub-classification

5) Slop surface protection work and drainage ditches

a) Slope surface protection work

To prevent surface erosion, strengthen the surface layer soil and preserve the environment by greening, Study team propose sodding planting that suit the climates of the Gujarat and Maharashtra states and has been adopted for the embankments of existing railways.

b) Drainage ditches
The distance between a drainage ditch and the longitudinal ditch shall be at 50 m intervals.
Guarantee drainage gradients of 0.3% or over.
The minimum cross-section shall be 0.3 x 0.3 m, subject to change later in consideration of the amounts of rainfall in the Gujarat and Maharashtra states.
See Figure 9.2-4 for a case of embankment drainage ditches.



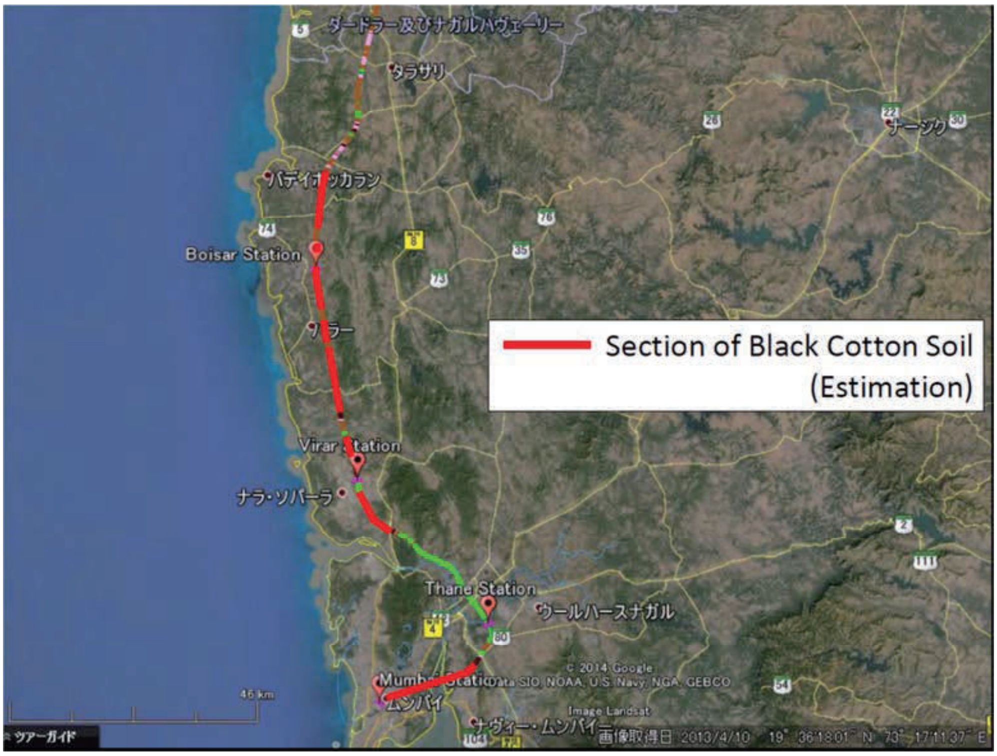
① Boundary of cutting and filling underground drainage work
② Embankment track side drainage
③ Catch basin
④ Drainage ditch between tracks
⑤ Longitudinal sewage
⑥ Slope toe drainage work
⑦ Track crossing drainage work
⑧ Maintenance passage side

Source: Study Team

Figure 9.2-4 Layout of Embankment Drainage Ditches

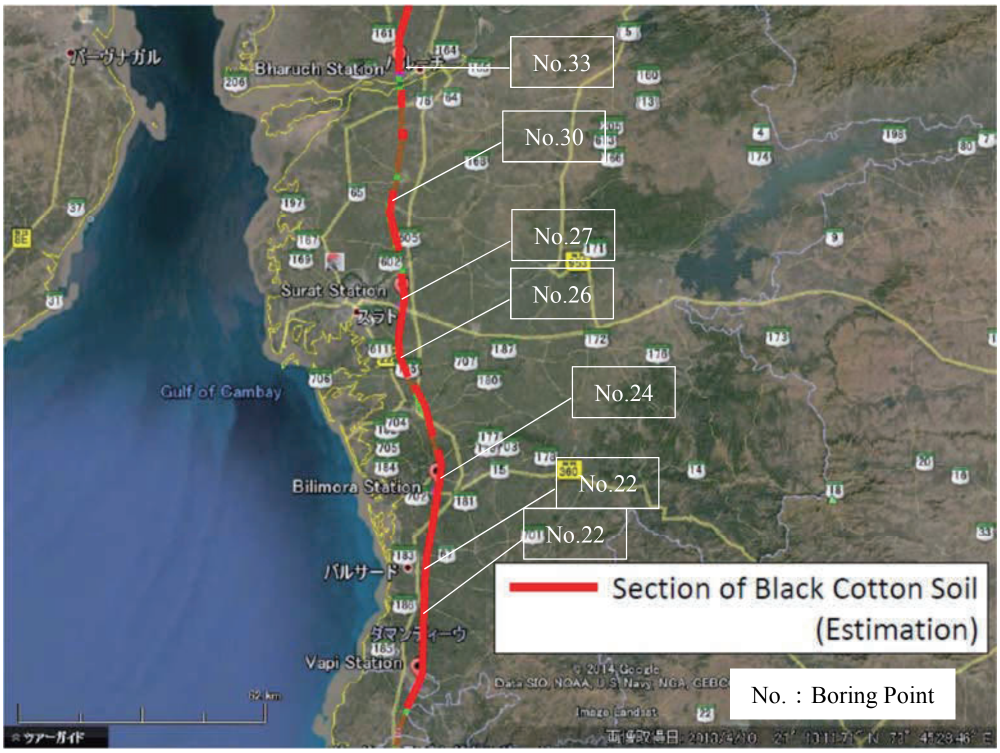
(5) Relation between the embankment structure and geology (BCS)

As extensile cohesive soil called the black cotton soil distributes in the north of Vapi (Figure. 9.2-5～7: BCS distribution map) along the route of this project, measures against such special grounds are required. Below explained are the measures against BCS based on the information obtained from a literature survey on BCS (Reference material: Black cotton soil India, November 1978, D. Mohan and R.K. Bhandari).



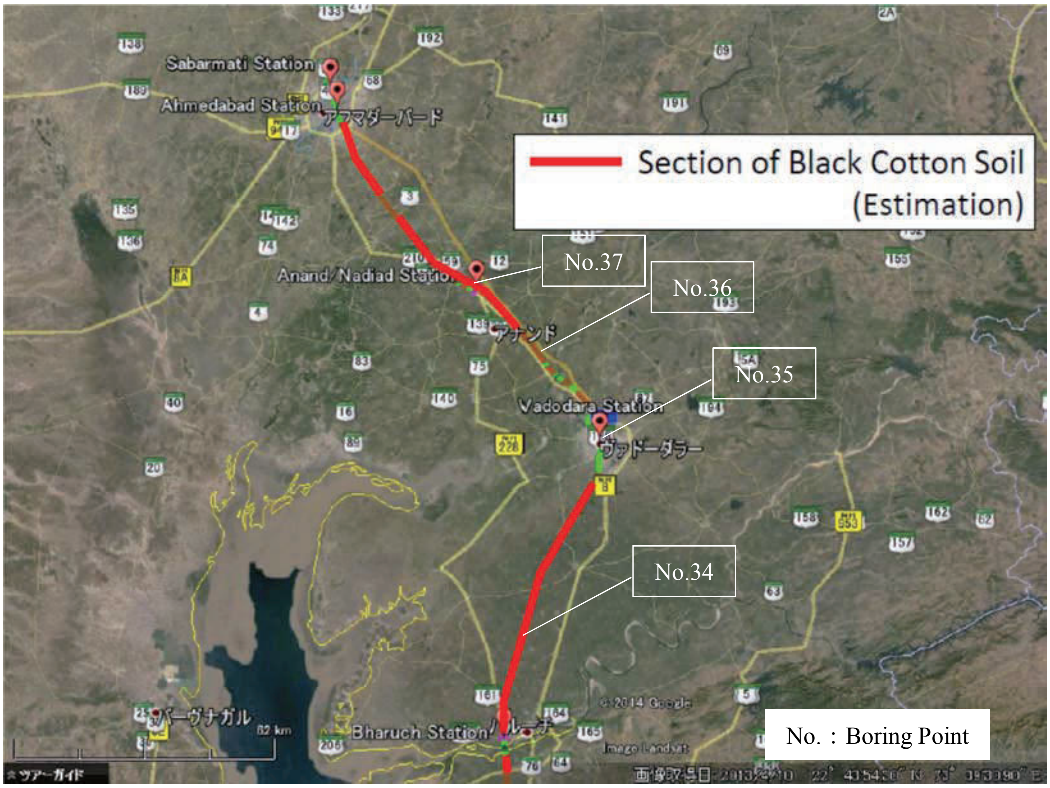
Source: Study Team

Figure 9.2-5 Distribution Area of BCS 1



Source: Study Team

Figure 9.2-6 Distribution Area of BCS 2

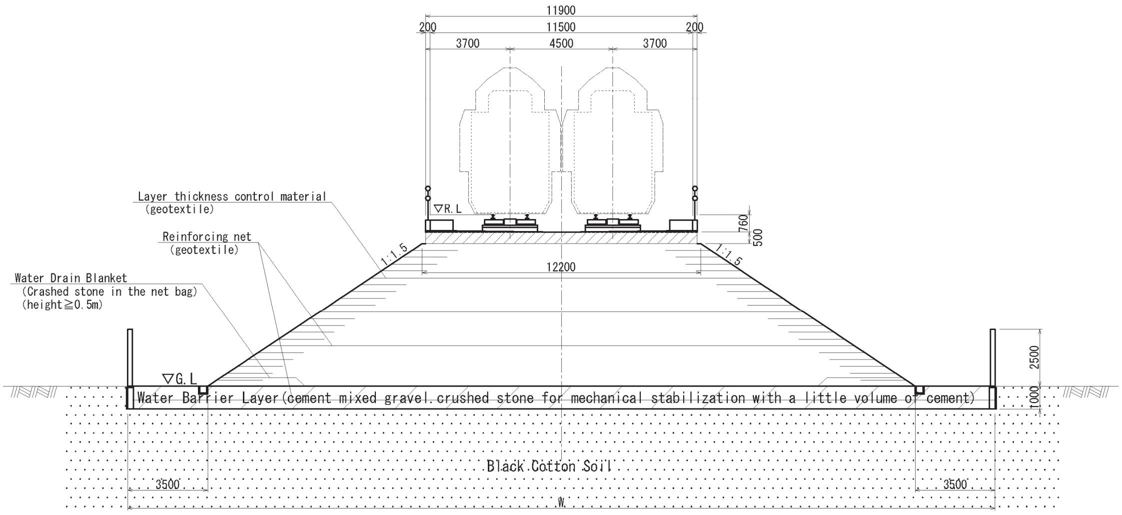


Source: Study Team

Figure 9.2-7 Distribution Area of BCS 3

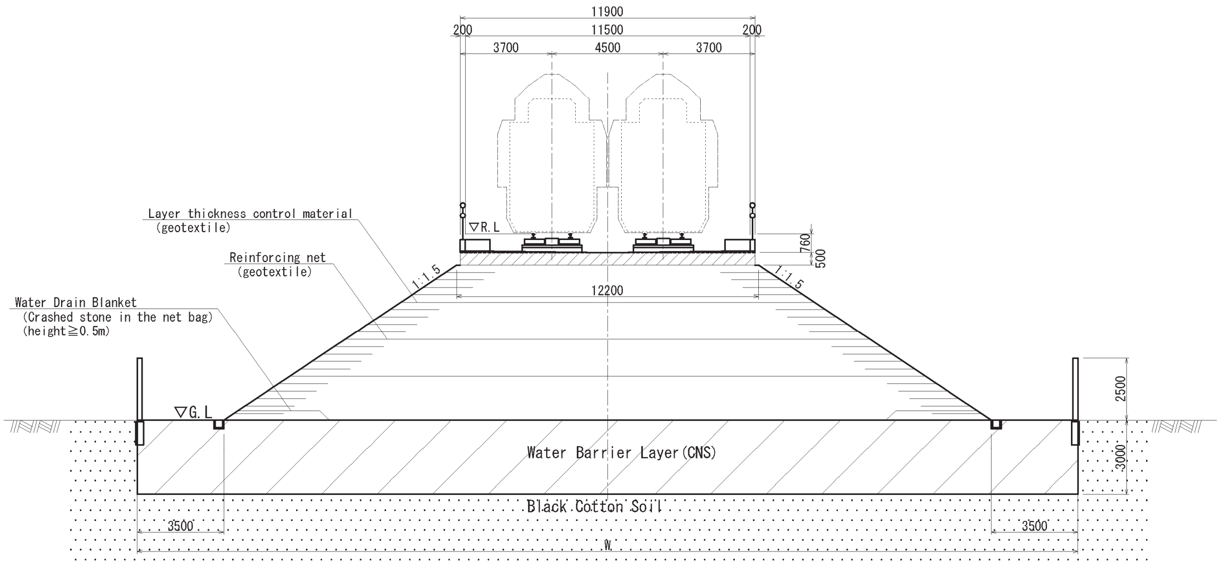
BCS is significantly extensile under wet conditions and contractile under dry conditions. The ground surface may crack to a width of approx. 15 cm in the dry season and depths reportedly within a range 2 to 3 m from the surface.
According to a reference material (literature), BCS often has an N-value of 4 or over to cut the penetration of rail water from the surface, thereby satisfying the embankment supporting ground conditions.
From the geological survey results, for No. 24, 27, 35, 36, 37 Boring, N-value was, clay 4 or more, sandy soil more than 20.
Whether there is the presence of the BCS, it is confirmed that a very low swelling BCS is present; it was a no-measures.

Figure 9.2-8, 9 shows the basic cross-section of an embankment having a standard height H = 6m as a measure against BCS in a BCS section.



Source: Study Team

Figure 9.2-8 A standard Basic Cross-section of Reinforced Embankments (Cement-improved Gravelly Soil + Geotextile)



Source: Study Team

Figure 9.2-9 A standard Basic Cross-section of Reinforced Embankments (CNS Layer)

(6) Measures against BCS foundation ground

From the geological survey results, for No.22,23,33,38 boring, N-values of clay is 4 or more, N-value of the sandy soil is more than 20. BCS low swelling is present, measures are required.
For No.26,30,34 Boring, N-values of clay is 4 or more, N-values of the sandy soil is more than 20, but more value swelling of BCS is high, strong measures are necessary.
In performing the measures of the BCS, are described in the following specific measures:

Study team discuss measures against the settlement and displacement of the embankment formed on the BCS ground based on the following ideas a, b and c.
Out of these ideas, Study team select a measure against the BCS foundation ground, by taking into account imperviousness, easiness of application and economy and also by referring to the opinion of learned and knowledgeable people.

a) Remove the BCS foundation ground downward for approx. 1.5 m from the surface and replace it with non-extensile soil (used as a measure for the slab track embankment ground).

b) Set an impervious layer at the embankment base to prevent rain water from penetrating BCS.

c) In case the measures in the above paragraphs a) and b) don't work, improve the rigidity of the foundation ground by piling or other means (implementation of ground improving work) or adopt a viaduct structure.

Study team discuss measures in the paragraphs a) and b) including the costs and easiness of application thereof.

As the learned and knowledgeable people remark that "the supporting ground conditions will be satisfied in the dry season, if the BCS water content doesn't increase in the rainy season. To prevent the BCS water content from increasing, therefore, cut rain water at the base and on each side of the embankment up to a width of 3 m. By referring to this advice, Study team decided to discuss the methods to cope with the adverse effect of BCS.

The following①,②,③-1,③-2 are concrete measures to reflect the ideas:

① Set an impervious layer in the lower part of the embankment.

② Set an impervious layer spaced by a distance "an embankment width + 3 m x 2" to prevent rain water to come from the left and right sides.

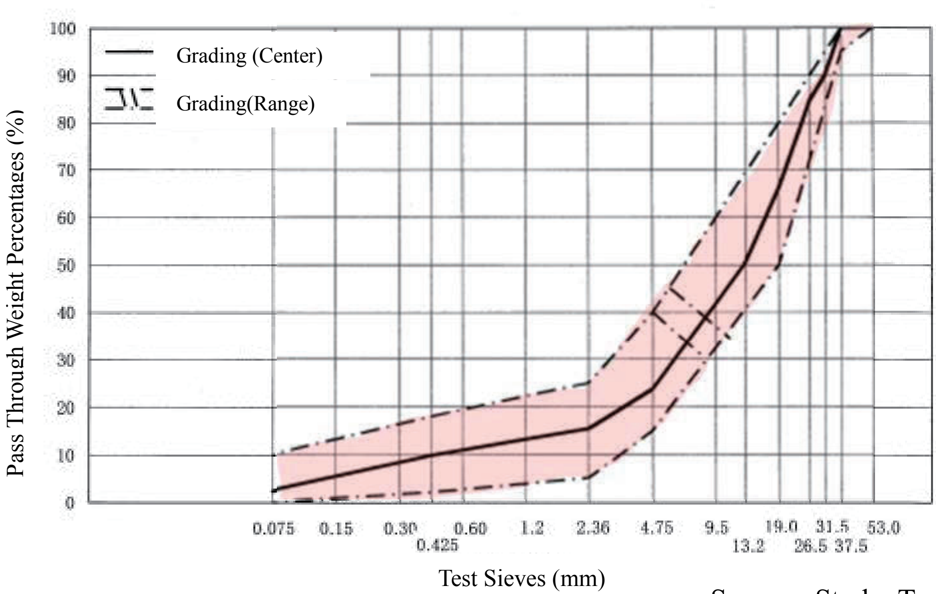
③-1 For highly extensile BCS, form the impervious layer with cement-improve gravelly soil and high-quality crushed stone (M-40)/geotextile to a cement improvement ratio of 4% (at least).

Table 9.2-3 and Figure 9.2-10 shows the Crushed stone (M-40).

Table 9.2-3 Crushed Stone (M-40) Used for Cement-improve Gravelly Soil

Designation	Grain size (mm)	Sieve name (mm) / Percentage in weight of the sieve passing grains (%)									
		50	40	30	25	20	13	5	2.5	0.4	0.074
M-40	40-0	100	95-100	-	-	60-90	-	30-60	20-50	10-30	2-10

Source: Study Team



Source: Study Team

Figure 9.2-10 M-40 Percentage in Weight of the Sieve Passing Grains of the Crushed Stone in a Cement-improved Gravelly Soil Sieving Test

③-2 For less extensile BCS, adopt impervious layers of cohesive soil.
Lay up to 3 m CNS featuring impervious performance (cohesive non-swelling soil), which is available along the planned route.

BCS's condition is very bad ,and not in the above measures①,②,③-1,③-2, Study team select viaducts in the same way as for soft grounds.

From the viewpoint of properties and allowable values, BCS don't satisfy the performance required for embankment base unit and materials for the foundation bed. Therefore, BCS cannot be used.

(7) Intersections between HSR embankments and railways/roads

At the intersections between HSR embankments and railways/roads, Study team will adopt RUBs to make roads pass under the HSR foundation level in principle and install abutments, girder bridges or box culverts depending on the size of intersection structures and robust fences on both sides of the embankment slope toe to prevent invasion of people and livestock. While taking into account local conditions, the box culvert type RUB shall be as per the contents of the application of box culvert items.

(8) Cost comparison between Embankment and Viaduct

Embankment structure needs wider land than Viaduct structure. Study team compares the cost between the Embankment and Viaduct as the construction cost plus land cost. Average of Land Cost for each structure and Turning Point for land cost is shown as below.

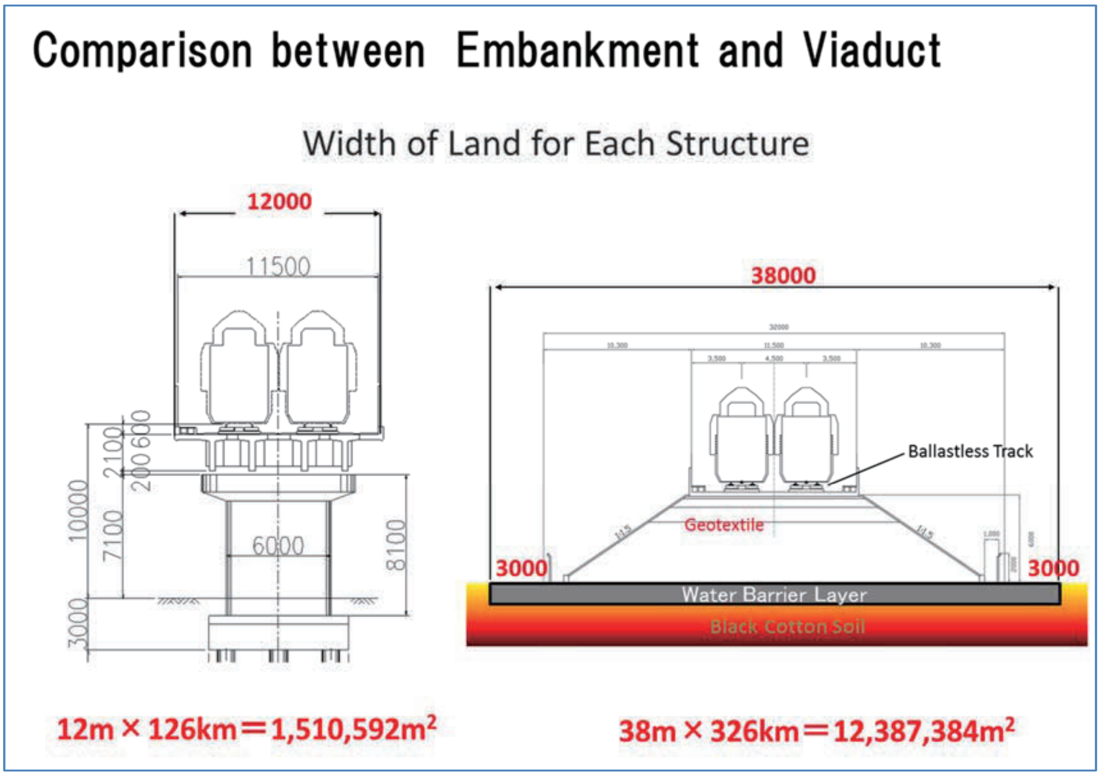


Figure 9.2-11(1) Comparison between Embankment and Viaduct

Source: Study Team

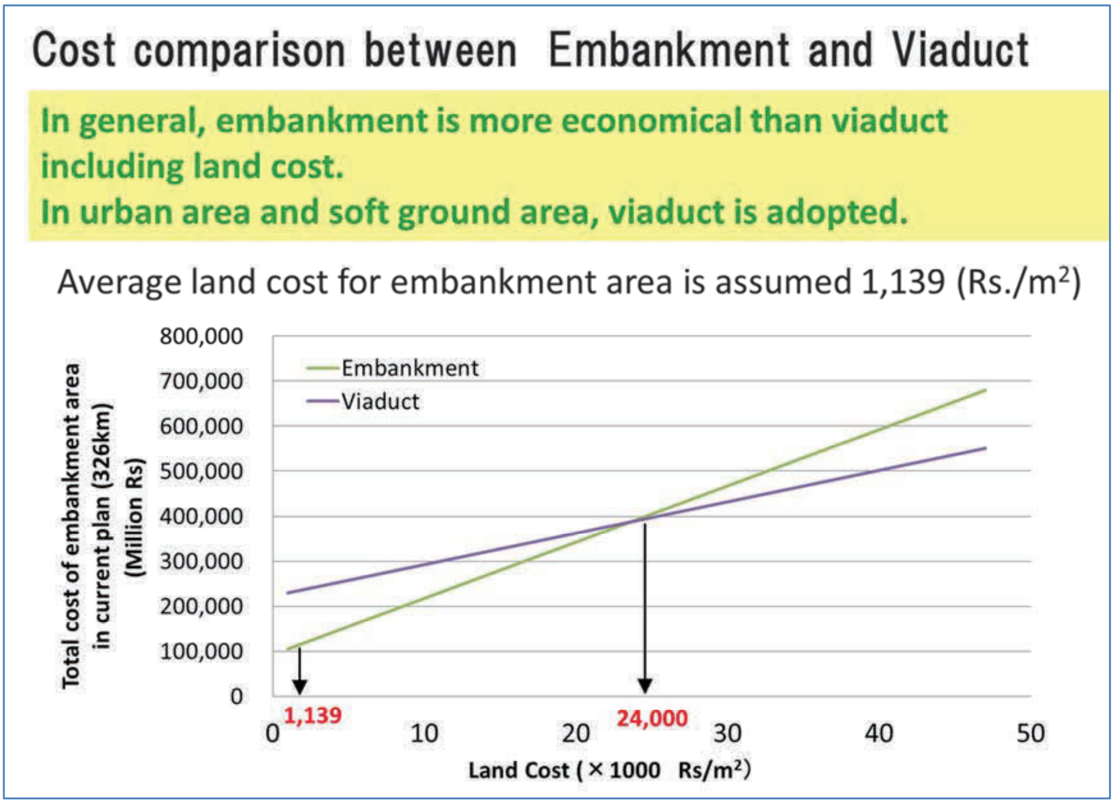


Figure 9.2-11(2) Cost comparison between Embankment and Viaduct

Source: Study Team

(9) Japanese experience of the Reinforced Embankment structure.
Study team shows the Japanese experience of Reinforced Embankment Structure.

Table 9.2-4 Japanese Reinforced Embankment Structure

HSR	Embankment Structures	Length(Km)
Hokuriku Shinkansen	Takasaki st. - Nagano st.	5.4
	Nagano st. - Kanazawa st.	3.9
Touhoku Shinkansen	Morioka st. - Hachinohe st.	10.9
	Hachinohe st. - Shin-Aomori st.	11.8
Kyusyu Shinkansen	Shin-Yatushiro st. - Kagoshimatyuou st.	13.5
	Hakata st. - Shin-Yatushiro st.	6.3
Hokkaido Shinkansen	Shin-Aomori st. - Shin-Hakodatehokuto st.	6.3
Total Length		58.1

Figure9.2-12 Japanese Experience of the Reinforced Embankment Structure

Source: Study Team

(10) Correspondence of settlement.

①Application Standard

➤ Shape, materials, supporting ground are set based on Japanese standard.

➤ Japanese standard is formulated considered many results of analysis, demonstration experiments and previous constructions.

②Consideration of Applicable Section

➤ At the Planning Stage

・Embankment is adopted to the section that the height (RL – GL) are under 9.00m.

・Embankment is not adopted to the area around the main stations and its surrounding urban areas.

・Embankment is not adopted in the submergence area. (Viaduct is adopted)

➤ At the Investigation and Design Stage

・”Boring investigations” will be conducted to check the conditions of supporting ground.
Supporting ground : N value ≧ 4 (Cohesive) , N value ≧ 20 (Sandy)

・Requiring confirmation of the properties free from liquefaction.

・ “Consolidation Settlement Analysis” will be conducted to predict the settlement.
The limit of settlement of the supporting ground shall be as Table 9.2-5.

Table 9.2-5 Limit of Settlement of Supporting Ground

Limit of Settlement	Settlement 10mm for 10 year or less
Limit of the Displacement of the Roadbed	Final Settlement Amount 30mm

➤ At the Construction Stage

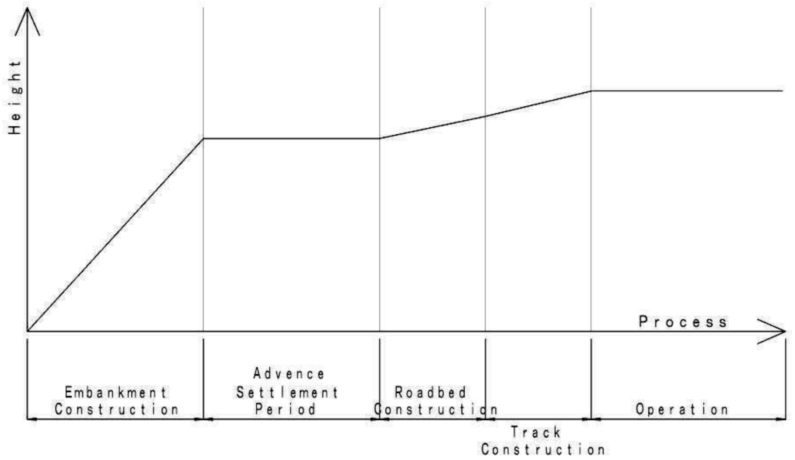


Figure9.2-13 Process of the Construction Stage

・ “Advance settlement period” is set before construction of roadbed.

・Train operation will start after the major part of settlement (refer to Figure 9.2-13).

(11) Point of additional study

Study team need to be clarified at the next stage as below.

・Detail information of slope surface protection work and drainage ditches.

・Composition of supporting ground around the BCS area.

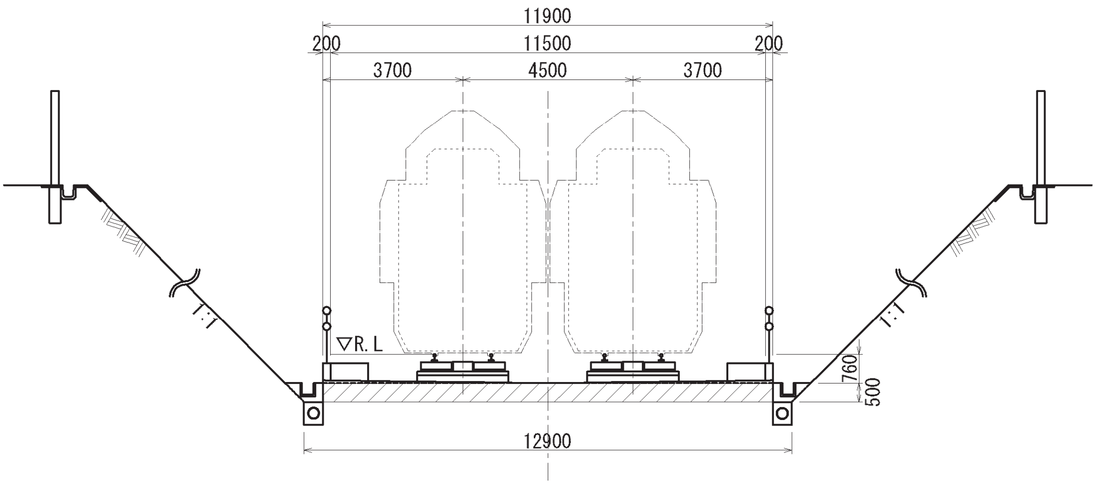
9.2.2 Cut Structure

(1) Standard cut structure

In hilly areas where topographical conditions don't require adoption of tunnels, Study team will adopt cut structures in principle. Study team will set a cut having a slope gradient 1:0.8 to 1.5 as a typical cut structure in this study and define its cross-section as the cut structure standard cross-section.

In the structure planning of this study, Study team adopts the cut (RC slab track sections) in Figure 9.2-14 as a typical structure. Robust fences shall be set on both sides to prevent invasion of people and livestock. Cuts shall satisfy the following two conditions simultaneously:

- Cuts shall support track beds safely and be free from harmful settlements or insertion of soft clay layers within 3 m from the foundation level.
- K30 value ≧ 110 MN/m^3 at the subgrade surface.

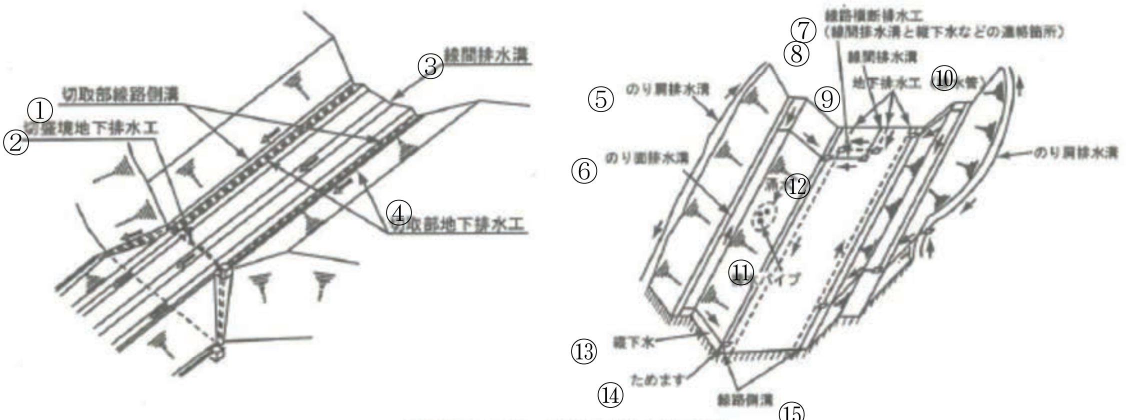


Source: Study Team

Figure 9.2-14 Standard Cross-section of the Cut for Slab Tracks.

(2) Slop surface protection work and drainage ditches

- Cut slope protection work
  Slop protection work in non-BCS sections shall be sodding planting.
- Cut drainage ditch
  The drainage gradient shall be 0.3% or over.
  The minimum cross-section of drainage ditch shall be 0.3.x 0.3 or over.



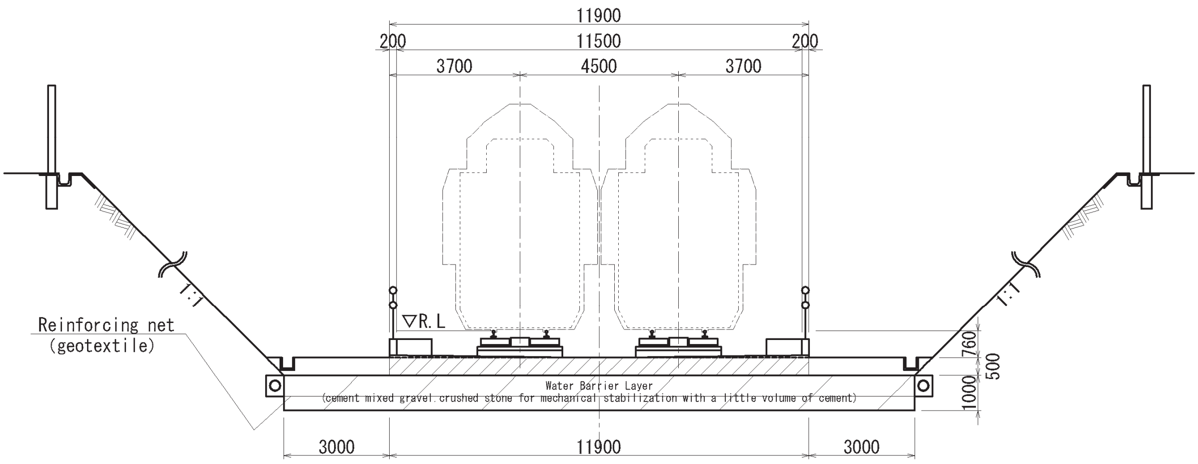
解説図 6.3.2 切取の排水系統の例

① Cut section track side ditch
② Boundary of cutting and filling underground drainage work
③ Drainage ditch between tracks
④ Cut section underground drainage work
⑤ Slope top drainage work
⑥ Slope drainage work
⑦ Track crossing drainage work
⑧ Joint between underground sewage and drainage between tracks
⑨ Underground drainage work
⑩ Drainage piping
⑪ Drainage pipe
⑫ Spring water
⑬ Longitudinal sewage
⑭ Catch basin
⑮ Track side ditch

Source: Study Team

Figure 9.2-15 Drawings of Cut Ditch

When BCS is observed in the surface of the track laying ground, take the same measures as those for embankment structures. Figure.9.2-16 shows a BCS cut section.
In Cut structure area, if within 3m from the the ground surface, BCS exists, as well as the embankment construction, and water measures and barrier.
Cut of 3m or deeper, is BCS is that it has sufficient strength from the the earth's surface.
Track surface is covered with concrete, since the structure of water does not enters to the bottom, and that it does not measure the BCS. Table 9.2-6 shows List of Cut Structures. Figure 9.2-16 shows the Average Hight of Cutting.



Source: Study Team

Figure 9.2-16 Average Hight of Cutting.

Table 9.2-6 List of Cut Structures

No.	Station	Length (km)	Cut Structures(km)	Rate (%)
1	Mumbai st. – Thane st.	27.8	0.1	0.4
2	Thane st. – Virar st.	37.0	1.8	4.9
3	Virar st. - Boisar st,	39.4	2.1	5.3
4	Boisar st. – Vapi st.	64.7	4.9	7.5
5	Vapi st. – Bilimor st.	48.2	0	0
6	Bilimor st. – Surat st.	47.3	0	0
7	Surat st. – Bharuch st.	58.6	0	0
8	Bharuch st. – Vadodara st.	74.0	0	0
9	Vadodara st. - Anand/Nadiad st.	50.0	0	0
10	Anand/Nadiad st – Ahmedabad st.	52.7	0	0
11	Ahmedabad st. - Sabarmati Depot.	8.8	0	0
	TOTAL	508.5	8.9	1.8

Source: Study Team

Figure 9.2-17 picture to give an Image of Cut Section

Source: Study Team

Figure 9.2-17 An Image of Cut Section

9.2.3 Box Culvert

Based on the convention in India and the results of site surveys, Study team determined to use box culverts (having a span of 10m or less) for small road RUBs, small rivers (Nala), canals, small canals (dams) in farm villages and farm roads. The dimensions/quantities of culvert boxes actually to be used are as follows:

(1) Small road RUBs

As a result of site surveys, Study team adopt box culverts for the RUBs of mall roads having a width of approx. 10m (such as those belonging to towns and villages). Their inner space dimensions are as per Table 9.2-7.

Table 9.2-7 Box Culverts Applied to Small RUBs

Box Culvert	Type	GL-RL (m)	Reason of application	Quantity (No. of places of application)
	H 3.6-4.8×W 10 m	6.0-7.0	Results of site surveys	189

Source: Study Team

(2) Application in farm villages

As embankments separate small canals (dams) and farm roads in agricultural villages, Study team determined to use box culverts for farm roads and canals having the dimensions in Table 9.2-7 to the quantity shown in the Table, based on the results of site surveys and hearing from Google Earth and local consultants. The total length of embankments is approx. 320 km. In this section, three farm road box culvers and two small canal (dam) box culvers will be used per 1 km on an average. Therefore, the total quantity of box culverts is as per Table 9.2-8.

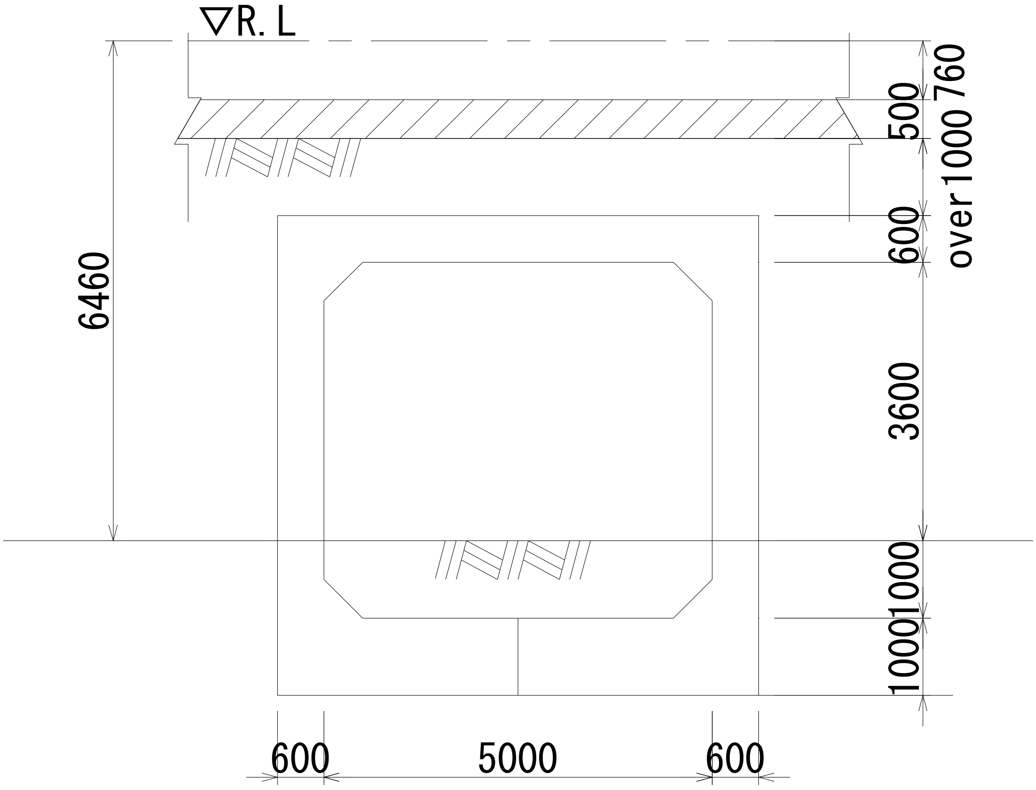
Table 9.2-8 Box Culvert Quantity

Box Culvert	Dimensions	Quantity
Farm road	H 3.6 m W 5.0 m	939
Small canal	H 1.5 m W 1.5 m	626

Source: Study Team

(3) Concept of the minimum height

As the minimum height of embankments used for vertical alignment is determined by the box culverts used for farm roads in embankment section, its height becomes GL-RL 6.46 m, by taking into consideration the minimum protection embankment height of 1 m, which Study team round to GL-RL 6.5m taking into consideration low-level precision at the site.
Figure 9.2-18 shows Box culvert for the minimum embankment height.



Source: Study Team
Figure 9.2-18 Box Culvert for the Minimum Embankment Height (GL-RL)

Figure 9.2-19 shows the image of box culvert RUB

Source: Study Team
Figure 9.2-19 An Image of Box Culvert RUB

(4) Small rivers (Nala) and canals

Study team adopt box culverts for small rivers (Nala) and canals having a width of approx. 10m. Their inner space dimensions are as per Table 9.2-9. Study team set height at 3.6m and width at 10m according to the results of site survey.

Table 9.2-9 Box Culverts to be Applied to Nala and Canals.

Box Culvert	Type	GL～RL（m)	Reason of application
	H3.6×W10m	6.0	Results of site surveys

Source: Study Team

The location and quantity of the Box Culvert to be applied to Canal and Nala is as per Table 9.2-10.

Table 9.2-10 Lists of Box Culvert Sections (Canal, Nala)

Box Culvert Length 10m (Inner space)

No.	Chainage (km)	RL-GL (m)	Canal or Nala
1	110.35	6.0	Canal
2	232.40	6.8	Canal
3	237.50	7.1	Canal
4	245.05	7.7	Canal
5	247.85	6.4	Canal
6	258.15	6.9	Canal
7	262.75	8.4	Canal
8	299.30	8.3	Canal
9	305.05	8.0	Canal
10	307.35	8.2	RUB
11	313.15	6.0	RUB
12	316.20	8.1	Nala
13	324.55	6.1	Nala
14	330.20	6.0	Canal
15	332.70	6.8	Nala
16	354.15	6.2	Canal
17	356.05	6.0	RUB
18	357.75	6.5	Nala
19	366.60	6.4	Canal
20	386.30	7.3	Nala
21	387.15	6.0	Nala
22	388.05	6.0	Nala
23	436.60	7.6	Nala
24	459.75	6.0	Canal
25	461.80	7.4	Canal
26	465.55	6.7	Canal
27	484.60	7.1	Nala

Source: Study Team

9.3 Viaduct

(1) Standard Type of Structure for Viaduct

Viaduct structure will be adopted for where “Areas around the main station and its surrounding urban areas”, “Where surface layer has soft ground or flooding area”, and “Where the height of R.L. (Rail Level) is more than 9 meters”.

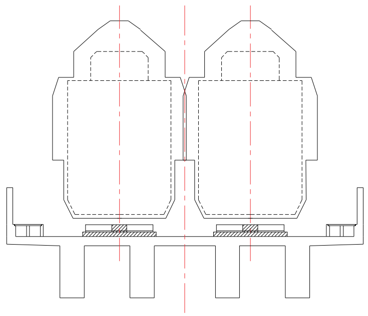
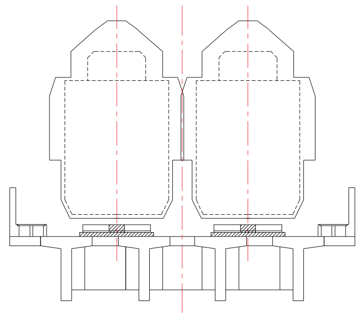
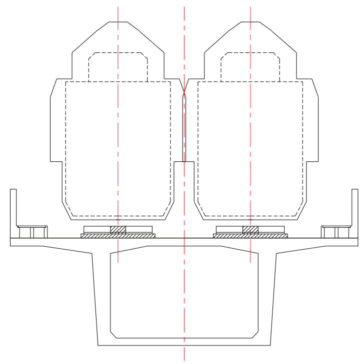
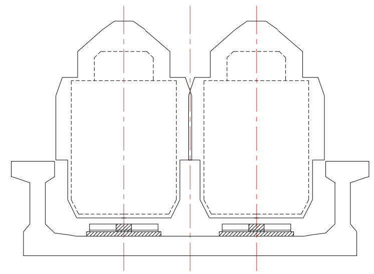
In this study, earth structures (embankment and cutting) which are relatively easy to construct and economical will be used as a basic civil structures for the section between stations.

However, during maintenance work, these earth structures may encounter some difficulties such as land subsidence, slope failures due to heavy rain and earthquake, and mud pumping from roadbed which will occur after the start of train operation. In addition, the shape of earth structures will interfere with land use and will disrupt the daily life of residents in the community.

In this case, the viaduct structure which has an advantage on maintenance (requiring less maintenance) may be used where the surface layer has soft ground or is a flooding area. The viaduct structure may also be applied to the main station and its surrounding urban areas resulting in not to interfere with land use.

Structure type of viaduct shall be determined based on the applicable span length, girder erection method, sectional form and local conditions of construction technology. The structures for HSR shall possess adequate safety against all loads during both the service and construction stage. Therefore, structures that have relatively strong rigidity, less joint gap and less permissible limits to secure the safety of train operations and riding quality of passengers on high-speed train operations shall be selected as a standard type. Table 9.3-1 shows the main structure types for viaduct for HSR.

Table 9.3-1 Main Structure Types for Viaduct and Bridge

Items / Structures (Project referred from)	RC Girder (Kyushu-Shinkansen)	PC T-shaped Girder (Kyushu-Shinkansen)	PC Box Girder (Kyushu-Shinkansen)	PC U-shaped Girder (Kyusyu-Shinkansen)
General Sections				
Applicable Span	L = 0 – 20 (m)	L = 20 – 45 (m)	L = 45 – 60 (m)	L = 10 – 60 (m)
Span / Girder Height	1/9.5	1/13.9	1/15.3	1/12.2
Applicable Construction Method	Cast - in - place Pre – cast	Cast - in - place Pre – cast	Cast - in – place Pre - cast	Cast - in – place Pre – cast (segmental)
Note	Construction cost is the lowest but applicable span is shorter.	PC-T Girder can be applied to various construction methods and has relatively strong rigidity to support HSR.	PC-Box Girder can be applied to various construction methods and has relatively strong rigidity to support HSR.	Used only where under clearance is limited

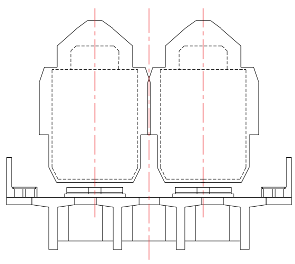
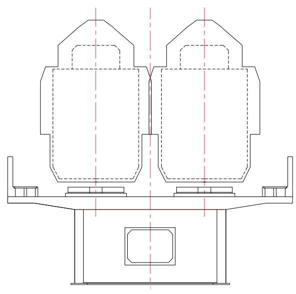
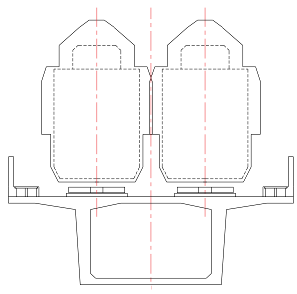
(2) Selection of Standard Type of Structure for Viaduct

PC simple T-shaped (I-shaped) and Box-girder, which can be applied to various construction methods and has relatively strong rigidity to support HSR is considered as the standard structure type for viaduct.

In places where an adequate construction yard is secured (such as suburbs and rural areas), the PC T-shaped (I-shaped) girder will be manufactured using the cast-in-place method and the girder will be erected at once using a crane. In places where securing a construction yard is not easy, a combination of the pre-cast method and girder erection using the erection girder will be used.
On the other hand, PC Box-girder will be manufactured by pre-cast method and erected using erection girder or mobile formwork method.
Figure 9.3-1 and Figure 9.3-2 show the viaduct of a PC T-shaped (I-shaped) girder and its girder erection.

On another note, the "Twin I Girder Steel Composite" is usually used as a standard type for viaducts in Europe. Table 9.3-2 shows a comparison chart of viaduct structures.

Table 9.3-2 Comparison Chart for Standard Structure Type of Viaduct

	Study Team's Recommendation	Typical Viaduct in European HSR	
Structure Type	PC T-shaped Girder	Twin I Girder Steel Composite	PC Box Type Girder
Typical Section			
Applicable Span Length	20 – 45(m)	45 – 60(m)	30 – 50(m)
Applicable Girder Erection Method	● Crane ● Erection Girder ● Cast-in-Place	● Crane ● Incremental Launching	● Full Pre-cast Spans ● Incremental Launching ● Cast-in-Place
Note	● Both slab and ballast track can be applicable ● Have relatively strong rigidity to support HSR	● Both slab and ballast track can be applicable ● The economical use of steel structures depends on the market conditions of the steel	● Both slab and ballast track can be applicable ● Have relatively strong rigidity to support HSR ● Equipment for "Full Pre-cast Spans" method is relatively high and it is generally considered that a minimum 6-7km of viaduct is necessary for investment ● Pre-cast segmental method is not usually used for HSR(*)

(*) It is noted that the PC-Box girder using the pre-cast segmental method which is applied to the Delhi Metro is not usually used in the HSR structures due to the lack of knowledge of behaviour (particularly the joints and the external pre-stressing vibrations, if used) under high-speed rail dynamic loading.

Source: Study Team, Source: http://www.pcken.or.jp

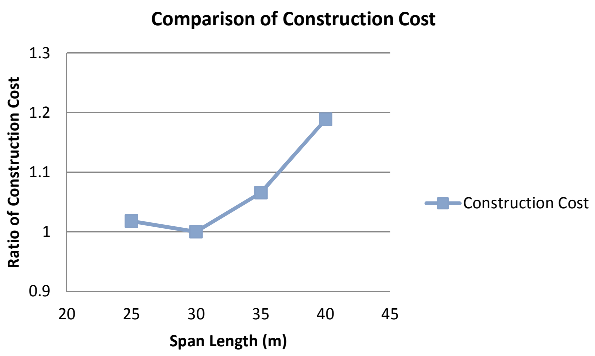
Figure 9.3-1 Viaduct (PC T-shaped Girder)

Source: http://www.pcken.or.jp

Figure 9.3-2 Girder Erection (Crane / Erection Girder)

(3) Study of Optimum Span Length

In this study, a study of optimum span length of Viaduct (PC T-shaped (I-shaped) Girder) has been made. As a result, it seems that the span length L = 30m is lower construction cost option among the applicable span lengths. Therefore optimum span length of Viaduct is set as 30m in this study. The summary of the study condition and result is shown in the Figure 9.3-3.



Conditions for Case Study:

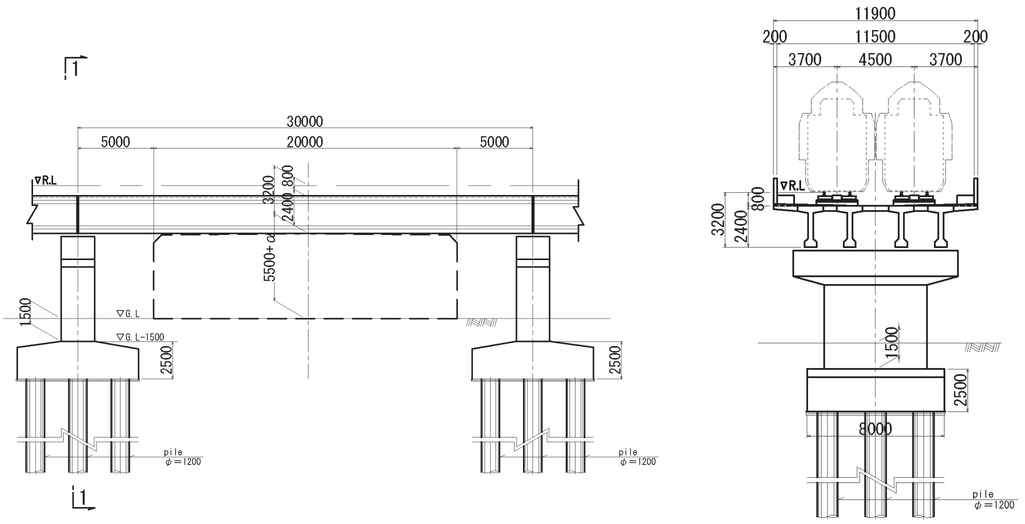
- Four options as L=25(m), 30(m), 35(m), 40(m) are compared,
- These options are compared under the same situation of girder erection method, height of R.L. and soil condition,
- Bridge length for case study is 1050 (m). (L=25m with 42-spans, L=30m with 36-spans, L=35m with 31-spans, and L=40m with 26-spans).

Figure 9.3-3 Summary of the Study Condition and Result

(4) Drawing for Standard Structure Type of Viaduct

Figure 9.3-4 shows a drawing for standard structure type of viaduct.

PC I-shaped girder is showed in this drawing, but there is a possibility for applying PC Box girder depending on the site condition.



Dimensions are assumptions.

Figure 9.3-4 Drawing for Standard Structure Type of Viaduct (1)

(5) GAD for Standard Structure

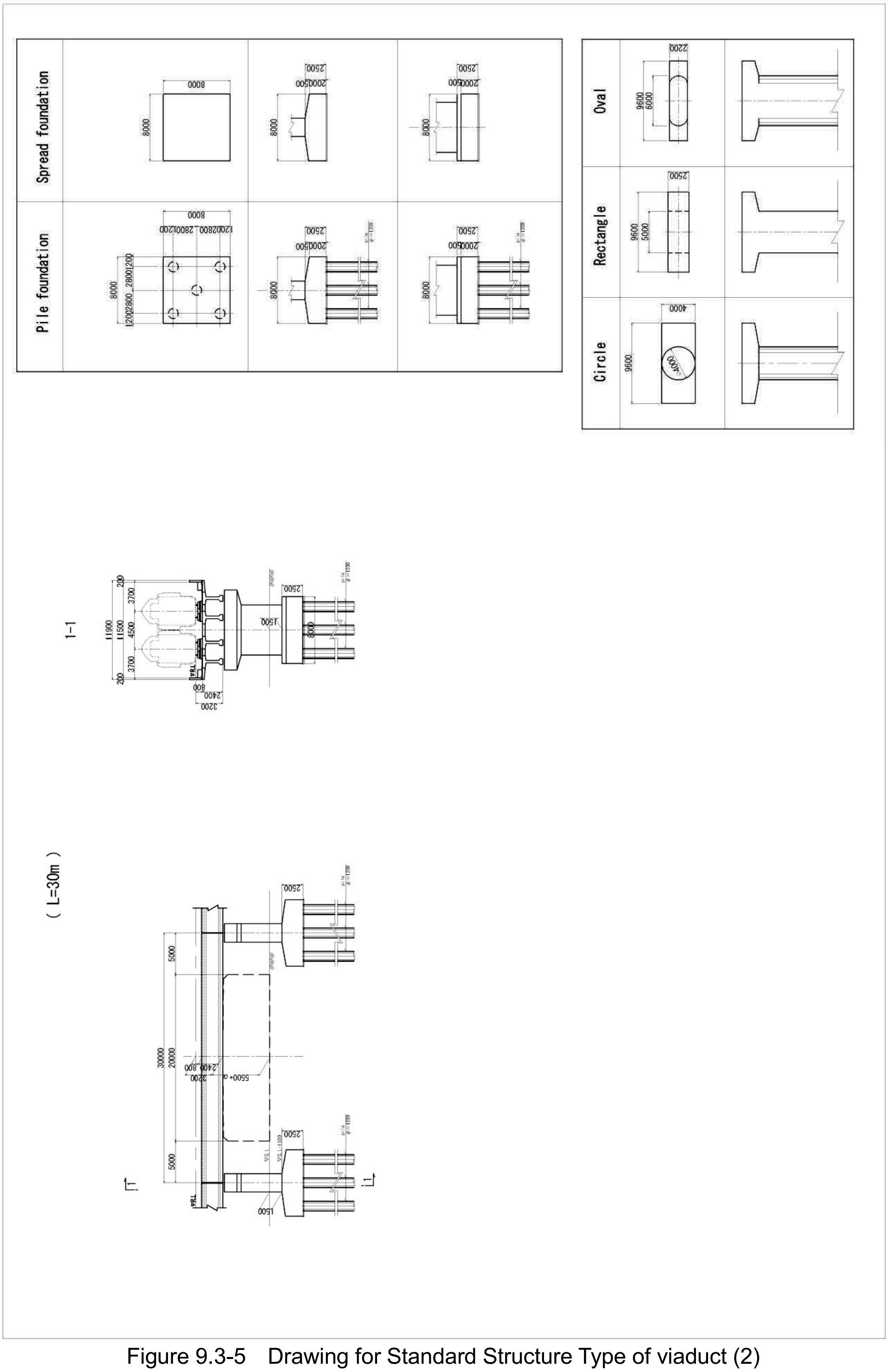


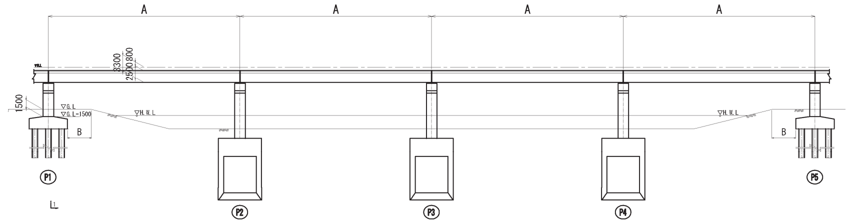
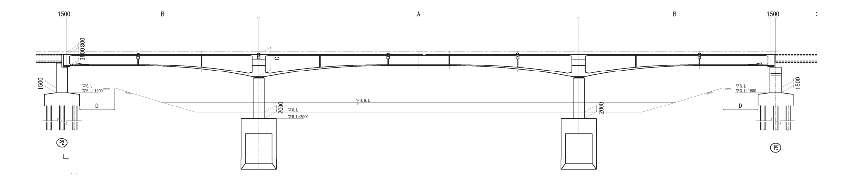
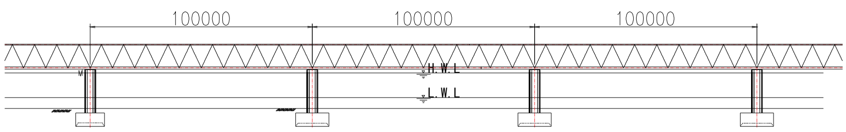
Figure 9.3-5 Drawing for Standard Structure Type of viaduct (2)

9.4 Bridge

(1) Standard Structure Type for Major-sized River Bridge

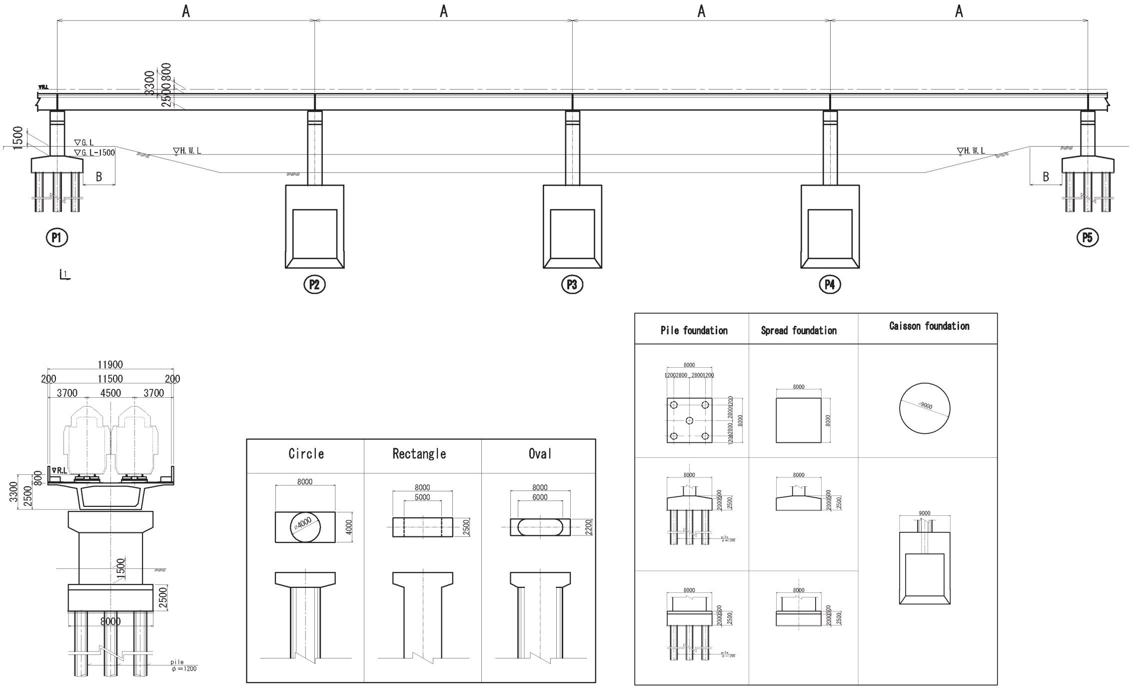
In river areas, a relatively long span bridge needs to be arranged so as not to avoid interfering with the flow of the river and to prevent the risk of scouring. The following three options as “1) Continuous Bridge of PC Simple I-shaped or Box Girders”, “2) Continuous Bridge of PC – Box Girder using Cantilever Method”, and “3) Continuous Bridge of Steel through Truss Girder” are proposed for standard structure type of River Bridge. (See Table 9.4-1).

Table 9.4-1 Major Structure Types for River Bridge

Structure Type	Side View / Note
Continuous Bridge of PC Simple I-shaped or Box Girders	
	● Have good flexibility with the construction methodology, such as Cast-in-Place / Supporting, Pre-cast girder / Girder Erection Method, etc. ● Flow of river will be affected by piers.
Continuous Bridge of PC – Box Girder	
	● Widely used for a River Bridge not only for the Japanese Shinkansen but also for the European HSR. ● This type is adapted to the place that the simple-girder is not able to be adopted due to the construction limits. ● Have good flexibility with the construction methodology, such as Cast-in-Place / Cantilever, Incremental Launching, Cast-in-Place / Supporting, etc. ● Flow of river will be affected by piers but less impact than continuous bridge of PC Simple I-shaped girders.
Continuous Bridge of Steel Through Truss Girder	
	● The economical use of steel structures depends on the market conditions of the steel. ● Has good flexibility with the construction methodology of the Traveller Crane Method, Track Crane/Bent, Incremental Launching. ● Flow of river will be affected by piers but less impact than continuous bridge of PC Simple I -shaped girders.

1) Bridge for River without construction limits

Regarding the bridge for river without construction limits, the Continuous Bridge of PC Simple I-shaped or Box Girders has been selected as a standard structure type. Shortening the construction period can also contribute to the reduction of construction cost. Figure 9.4-1 shows a drawing of a standard structure type, Multi-span Bridge of PC Simple Box Girders.



Dimensions are assumptions.

Figure 9.4-1 Drawing of Standard Structure Type for Bridge, Continuous Bridge of PC Simple Box Girders.

2) Bridge for River with construction limits

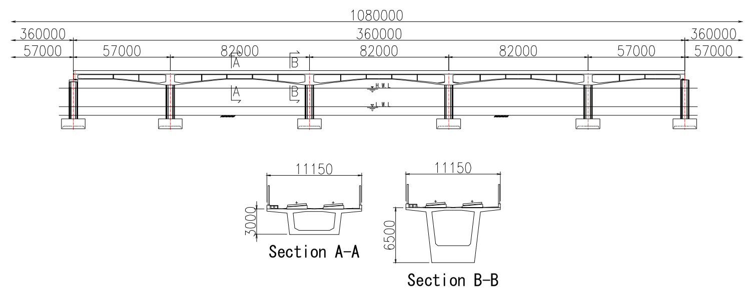
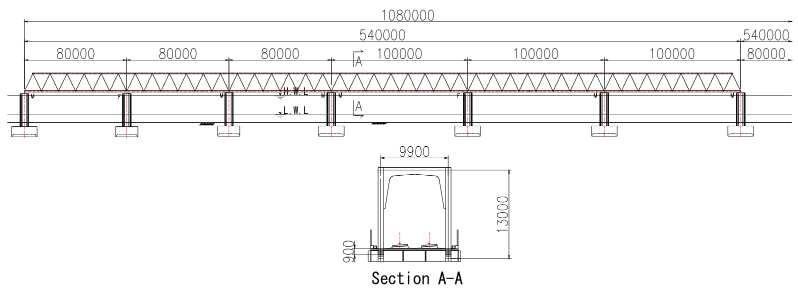
Regarding the bridge for river with construction limits, two options of "Continuous Bridge of PC - Box Girder using Cantilever Method" and "Continuous Bridge of Steel Through Truss Girder" can be adopted. In this study, the two options have been compared from the view point of construction cost, construction method (constructability), construction schedule, maintenance ability, applicability in India and environmental impact.

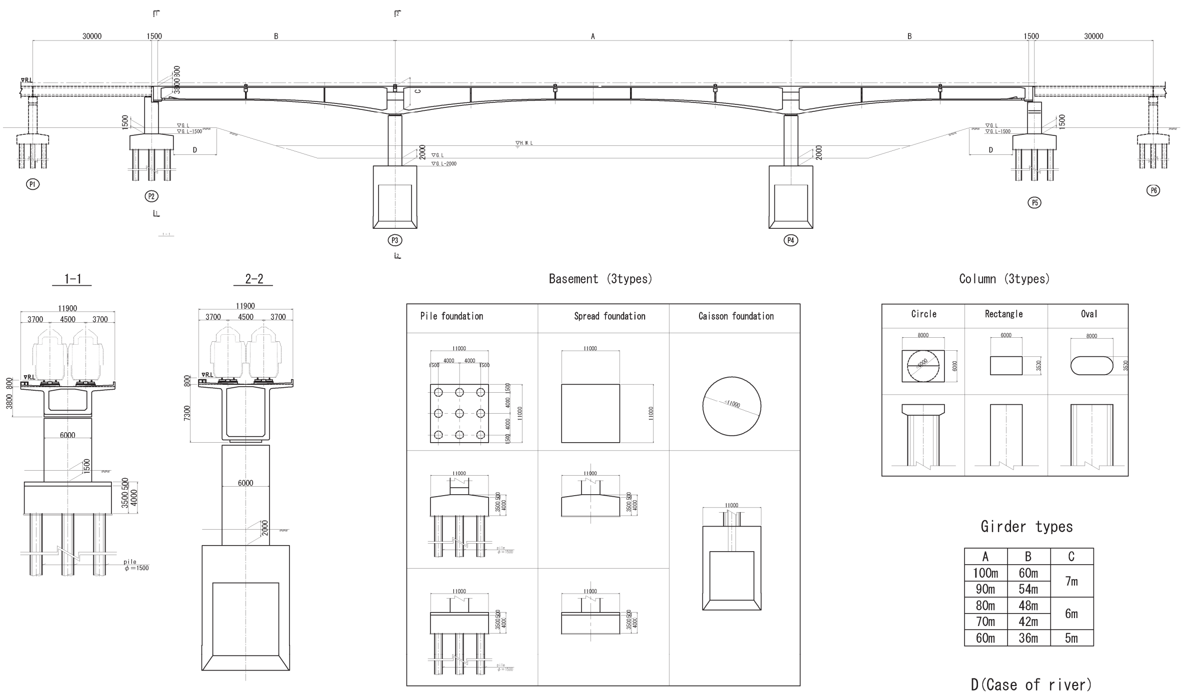
As a result of the study, the study team has selected the "Continuous Bridge of PC – Box Girder using Cantilever Method" which has an advantage on the construction cost as well as being a popular structure type in India. Table 9.4-2 shows a summary of the comparison and its result.

If base is free from the possibility of settlement, it is possible to choose rigid frame bridge with PC-Box girder. It has an advantage in structural mechanism and is economical.

Figure 9.4-2 Continuous Bridge of PC – Box Girder using Cantilever Method
Source: http://www.pcken.or.jp

Table 9.4-2 Comparison Table Between Continuous Bridge of PC
– Box Girder using Cantilever Method and Continuous Bridge of Steel Through Truss Girder with Concrete Slab

Case	Case - 1	Case - 2
Structure Type	Continuous Bridge of PC – Box Girder using Cantilever Method	Continuous Bridge of Steel Through Truss Girder with Concrete Slab
Side and Cross Section View (with Sample Span)		
Quantity of Main Materials	Superstructure Concrete (m3) : 15,100 Steel (t): 7,200 PC – Steel (main, lateral, shear force) (t): 2,300 Substructure Concrete (Pier and Foundation) (m3): 21,100 Caisson (13m) (sets): 16	Superstructure Steel (Truss, Weathering Steel) (t): 5,750 Slab Concrete (Light-weight concrete) (m3): 4,800 Substructure Concrete (Pier and Foundation) (m3): 17,800 Caisson(13m) (sets): 13
Cost	1.00	1.12
Construction Method	Cast-in-Place / Cantilever	Traveller Crane Method, Track Crane/Bent, Incremental Launching.
Schedule	Approximately 24 (months)	Approximately 30 (months) (The schedule may change based on conditions of river)
Maintenance	Less Maintenance(concrete bridge)	Less Maintenance (weathering steel with concrete slab)
Applicability in India	Popular (many of experiences for railway project)	Seldom (no experience on the through truss girder with concrete slab)
Environmental impact	Less noise impact	Noise from steel bridge is bigger than the concrete bridge
Evaluation	○	△



Girder types

A	B	C
100m	60m	7m
90m	54m	
80m	48m	6m
70m	42m	
60m	36m	5m

D(Case of river)

Large size River (L≧300)	10m
Middle size River (40≦L＜300)	5m
Small size River (L＜40)	2m

Figure 9.4-3 Drawing of Standard Structure Type for Bridge, Continuous Bridge of PC Box Girder (Cantilever Method).

3) Structure Type and Span Arrangement of Each River

Table 9.4-3 shows structure type and span arrangement of each river.

Table 9.4-3 Structure Type and Span Arrangement of Each River

No.	Name	Chainage (km)	Bridge Length (m)	Main Structure Type	Span Arrangement (m)
1	Ulhas River (N)	28.50	560	PC – Box Girder	560 (30+10@50+30)
2	Branch of Ulhas River	38.35	200	PC – Box Girder	200 (4@50)
3	Vaitarna River (S), (N)	71.45	2,150	PC – Box Girder	2,150 (43@50)
4	Daman Ganga	166.60	400	PC – Box Girder	400 (8@50)
5	Kolak River	174.85	200	PC – Box Girder	200 (4@50)
6	Par River	190.35	350	PC – Box Girder	350 (7@50)
7	Aurange River	198.20	450	PC – Box Girder	450 (9@50)
8	Kaveri River (S)	212.80	200	PC – Box Girder	200 (4@50)
9	Kaveri River (N)	214.70	200	PC – Box Girder	200 (4@50)
10	Ambica River	228.80	250	PC – Box Girder	250 (5@50)
11	Purna River	240.10	450	PC – Box Girder	450 (9@50)
12	Mindhola River	250.60	120	PC – Box Girder	120 (3@40)
13	Tapi River	276.30	800	PC – Box Girder	800 (16@50)
14	Kim River	293.30	120	PC – Box Girder	110 (3@40)
15	Narmada River	320.20	1,400	PC – Box Girder	1400 (28@50)
16	Dhadhar River	372.90	50	PC – Box Girder	1@50
17	Mahi River	416.65	650	PC – Box Girder	650(13@50)
18	Mohar River	462.95	160	PC – Box Girder	160 (4@40)
19	Vatrak River	473.00	260	PC – Box Girder	260 (30+4@50+30)
20	Meshwa River	476.55	200	PC – Box Girder	200 (4@50)
21	Sabarmati River	503.90	460	PC – Box Girder	460 (30+8@50+30)

(2) Bridge for River, Canals, RUB(Road Under Bridge), RFO(Railway Fly Over)

1) Bridge Type

Structure type of Bridge for river, Canal, RUB and RFO shall be determined based on the applicable span length of each structure. Table 9.4-4 shows the structure type and its applicable span length.

Table 9.4-4 Structure Type and its Applicable Span Length for Bridge.

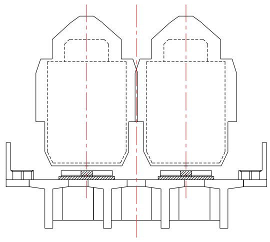
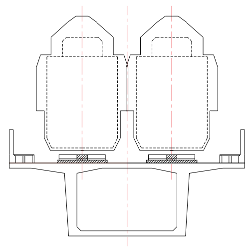
Structure Type	PC T-shaped Girder (Simple Span)	PC Box-Type Girder (Simple Span)	PC Box-Type Girder (Continuous Girder)
Typical Section			
Applicable Span Length	20 – 35(m)	35 – 50(m)	50 – 100(m)
Applicable Construction Method	Cast - in – place Pre – cast	Cast - in – place Pre – cast	Cantilever method (Cast – in –place)

Figure 9.4-4 Bridge for Canal (PC Box Girder for River using Supporting)
Source: http://www.pcken.or.jp

Figure 9.4-5 RUB (Continuous Bridge of PC – Box Girder using Cantilever Method)
Source: http://www.pcken.or.jp

RUB (PC I Shaped Girder)

RFO (PC I Shaped Girder)

Figure 9.4-6 RUB and RFO (PC I shaped Girder)

Source: Study Team

2) Method for Choosing Bridge Type

i) Crossing Point in Embankment Section

In place where the HSR crosses road, small river, or canal, box-culvert is adopted for crossing structure. Box culvert is the simplest and most economical structure, and generally used for railway structures in India and Japan.

ii) River, Canal

・Bridge (Simple-girder, 1-span)

This type can be adopted for the place that has no construction limits. Shape of column is oval (inside river) and rectangle (outside river). The type (I-shaped or Box) and length (30m – 50m) of girder will be set depending on the river width and crossing angle.

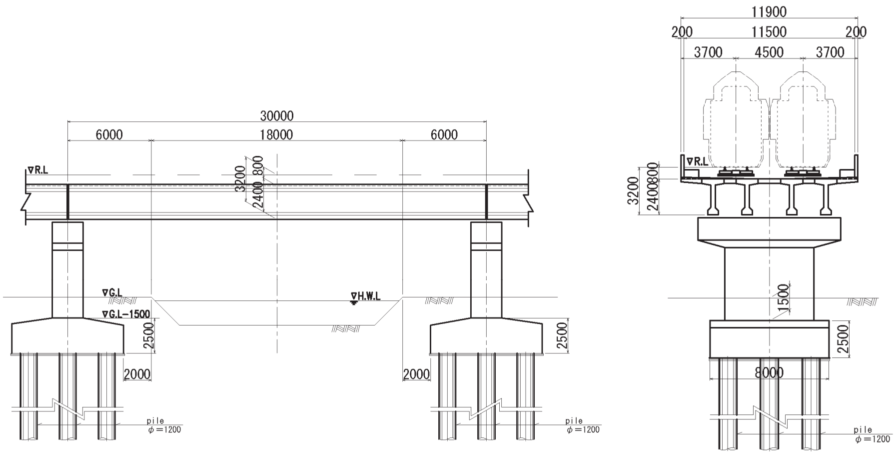


Figure 9.4-7 Bridge (PC I-shaped Girder) (L=30m)

Source: Study Team

・Bridge (Simple-girder, Multi-span)

In places where 1-span bridges are not able to cross the river, multi-span bridge will be adopted. This type can be adopted for the place that has no construction limits. The number of spans and girder length are set depending on the river width, crossing angle, position of piers of bridges around the area (refer to Figure 9.4-1).

・Bridge (PC-girder (Cantilever erection method))

This type is adopted to the place that the simple-girder is not able to be cross due to the construction limits. The number of spans and girder length are set depending on the river width, crossing angle, position of piers of bridges around the area (refer to Figure 9.4-3).

iii) RUB, RFO, ROB

・Bridge (Simple-girder, 1-span)

This type can be adopted for the place that has no construction limits. Shape of column is rectangle. The type (I-shaped or Box) and length (30m – 50m) of girder will be set depending on the road width and crossing angle (refer to Figure 9.3-4).

・Bridge (Simple-girder, Multi-span)

In places where 1-span bridge is not able to cross the road, multi-span bridge will be adopted. This type can be adopted for the place that has no construction limits and piers are allowed to be set in central islands of road in order to shorten the span.

・Bridge (PC-girder (Cantilever erection method))

This type is adopted to the place that the simple-girder is not able to cross the road or railway due to the construction limits, like that railway or road is existing under girders. If allowed, piers will be set in central islands of road in order to shorten the span.

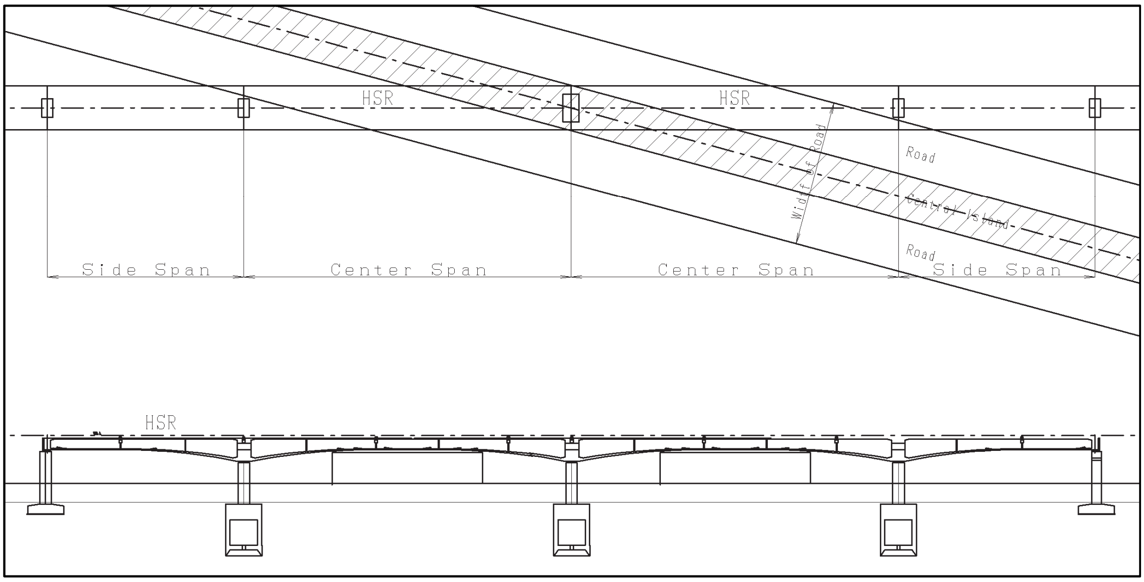


Figure 9.4-8 Bridge (PC-girder (Cantilever erection method))

Source: Study Team

・Bridge (Gantry Type Pier)

In places where HSR alignment is planned parallel with railway or road, the crossing angle is very small and span of girder increase to the length that the normal bridges can't be adopted. In those cases, gantry type pier will be adopted. This type bridge is generally used for railway structure in India and Japan.

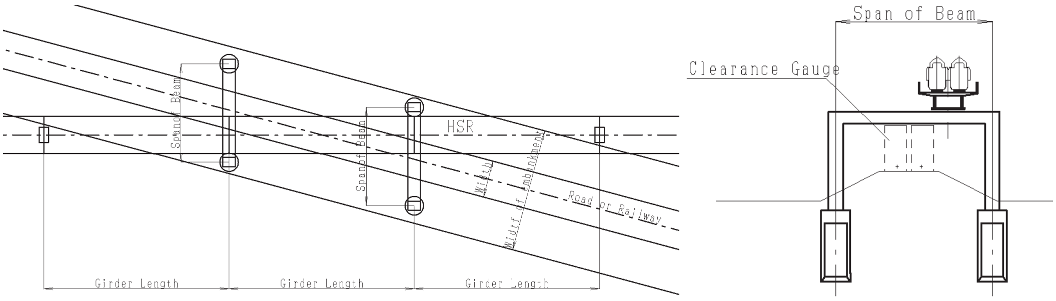


Figure 9.4-9 Bridge (Gantry Type Pier)

Source: Study Team

(3) GAD for Standard Structure

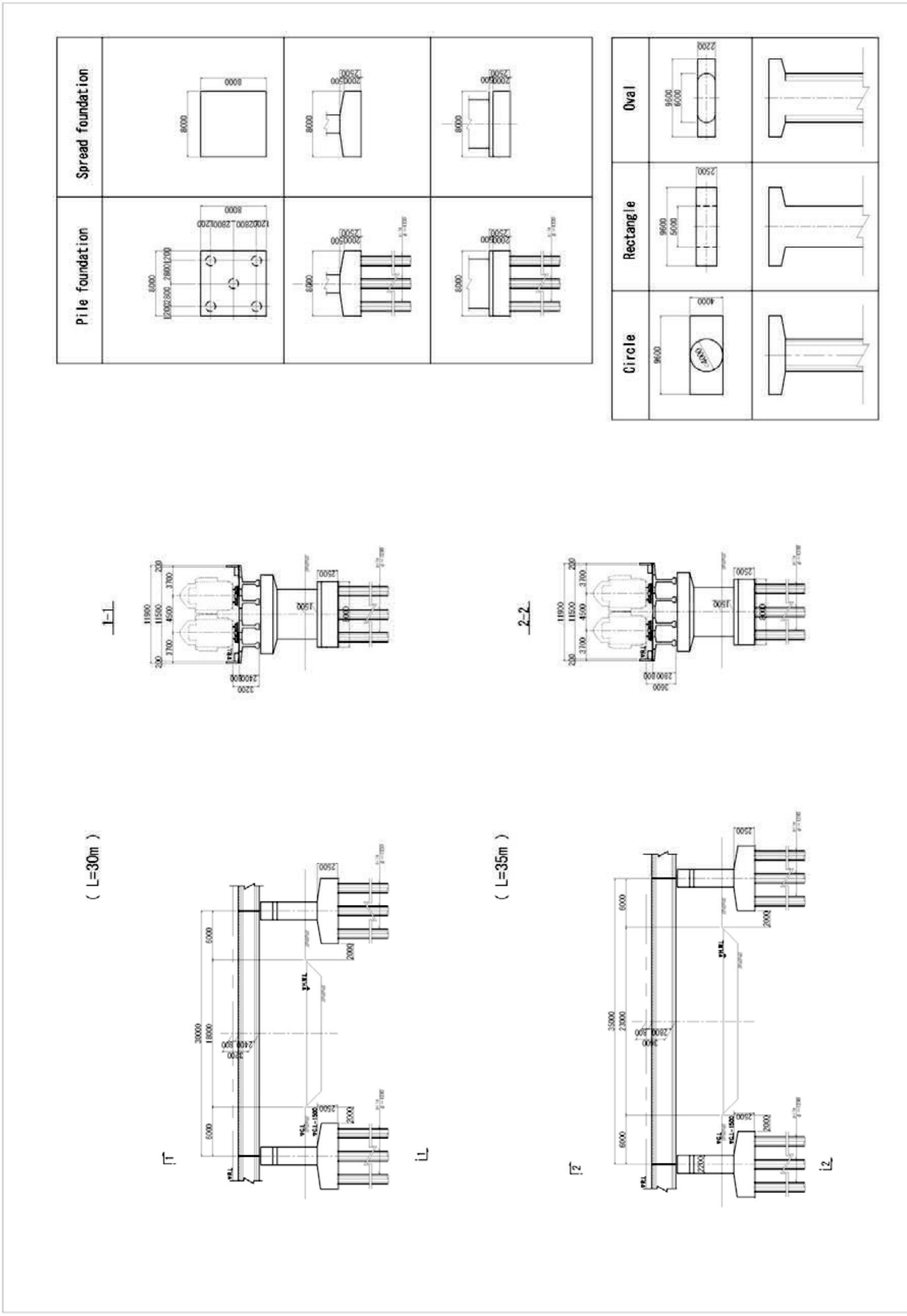


Figure 9.4-10 Drawing of Standard Structure Type for Bridge, Simple-girder, 1-span(1)

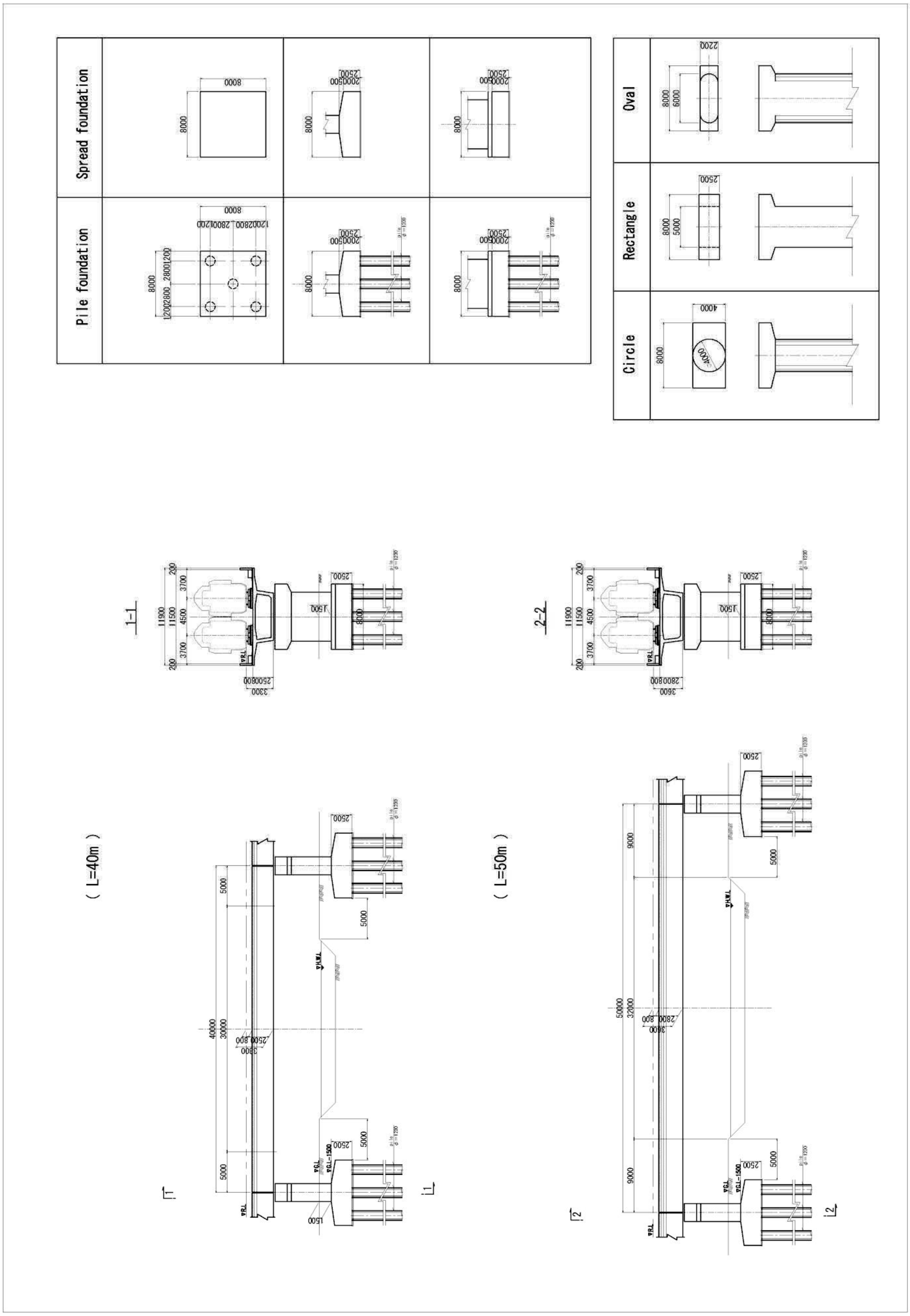


Figure 9.4-11 Drawing of Standard Structure Type for Bridge, Simple-girder, 1-span(2)

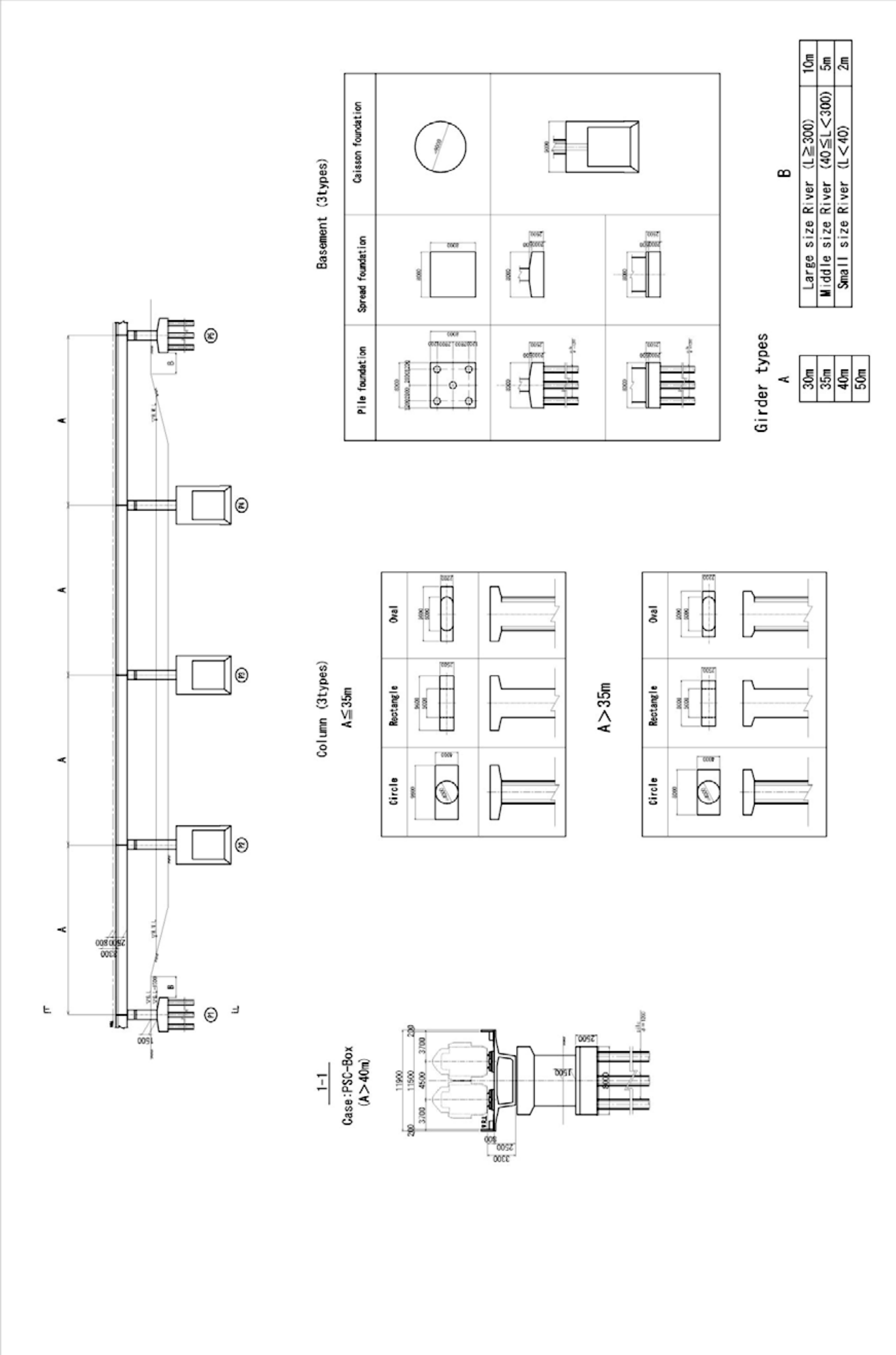


Figure 9.4-12 Drawing of Standard Structure Type for Bridge, Simple-girder, Multi-span

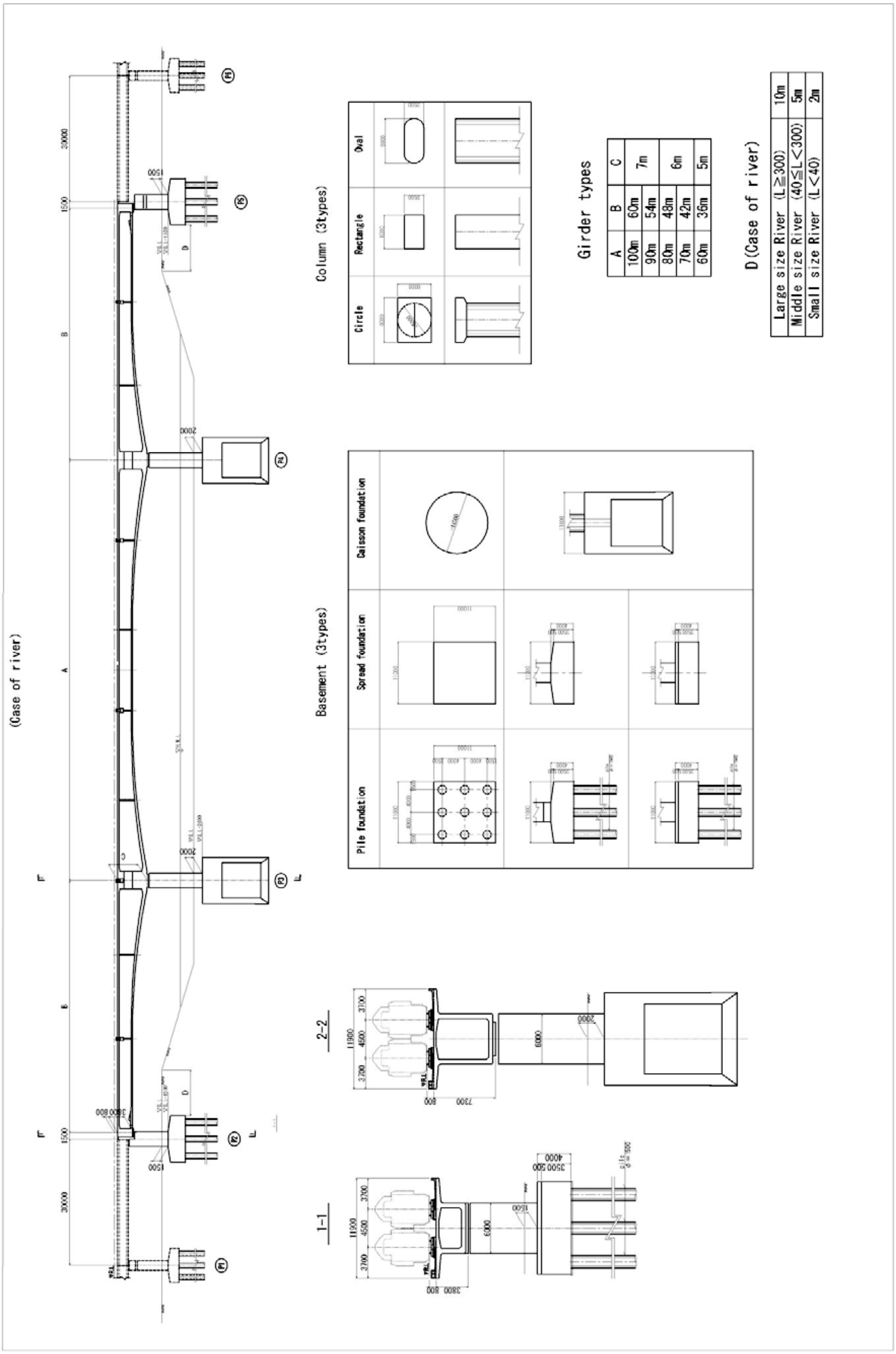


Figure 9.4-13 Drawing of Standard Structure Type for Bridge, Cantilever erection method

9.5 Tunnel

9.5.1 Planning of Location for Tunnels

Tunnels will be used to go through part of the mountainous areas and seabed in the approximately 169 km from Mumbai to Vapi. Currently, TBM or NATM is the leading candidates for the tunnel to cross the Thane Creek under sea tunnel. However, depending on the results of geological surveys and other detailed surveys which will be carried out this study. The other methods as the shield method, the sunken tube method, viaducts and bridges shall be considered as alternatives in this report.

Table 9.5-1 shows the location of the tunnels projected along the route in this plan. Depending on the point where they are constructed, tunnels are normally classified into two. One is the mountain tunnels and the other urban tunnels. In this project planned are 20.5 km-long urban and undersea tunnels (Nos. 1, 2 and 3) that run from the Mumbai city center to Navi Mumbai through the Thane Creek undersea tunnel and 11 mountain tunnels (maximum length 1.5 km) that pass the mountainous area north of Thane. To discuss the tunnel construction plan, we classified them into urban/undersea tunnels and mountain tunnels.

The table below shows a list of proposed tunnels.

Table 9.5-1 Location of the Tunnel List

No.	Chainge from (km)	Chainge to (km)	Length (km)	Type of Tunnel	Remarks
1	0.6	5.77	5.17	Urban and Undersea tunnel	Mumbai area and Thane Creek
2	5.77	13.62	7.85		East side of Thane Creek
3	13.62	21.10	7.48		Navi Mumbai area
4	52.50	53.30	0.80	Mountain tunnel	Mori (Between Thane and Virar)
5	54.60	54.90	0.30		Bapane (Between Thane and Virar)
6	65.65	66.85	1.20		North side of Virar Station
7	67.10	68.00	0.90		North side of Virar Station
8	76.45	77.95	1.50		Saravali (Between Virar and Boisar)
9	125.45	125.90	0.45		Gaurwadi (Between Boisar and Vapi)
10	127.70	128.25	0.55		Jamshed (Between Boisar and Vapi)
11	130.90	131.50	0.60		Ambesari (Between Boisar and Vapi)
12	132.35	132.60	0.25		Ambesari (Between Boisar and Vapi)
13	148.15	148.35	0.20		Ambesari (Between Boisar and Vapi)
14	156.75	157.00	0.25		Ambesari (Between Boisar and Vapi)

Source: Study team

Figure 9.5-1 Location of Undersea Tunnel for Thane Creek

Figure 9.5-2 Tunnel Location around Virar Station

Figure 9.5-3 Tunnel Location between Thane and Virar

(1) Mountain Tunnel

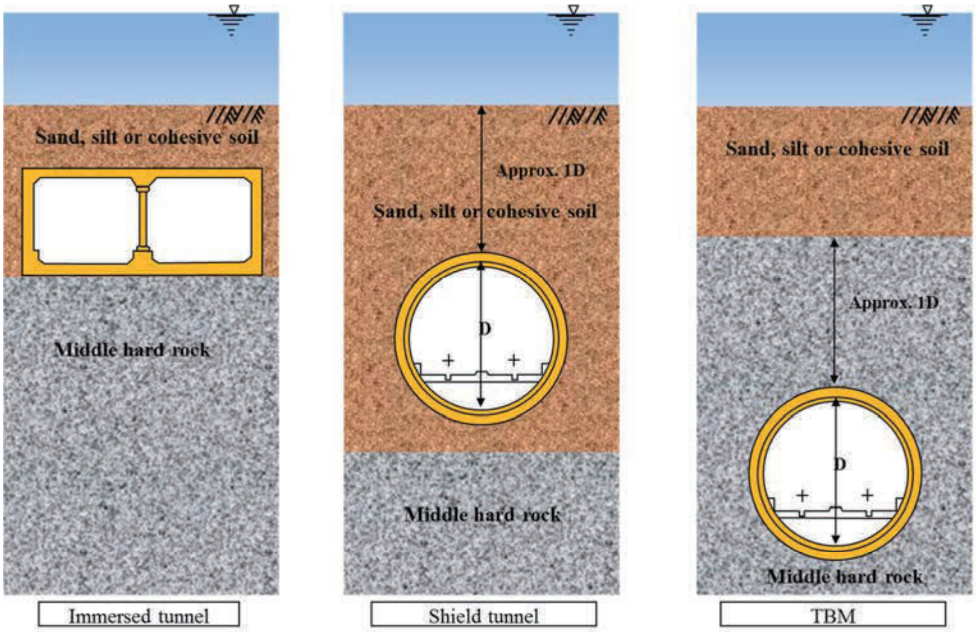
A mountain tunnel is a tunnel which is excavated penetrating mountains. Making the glade of the tunnel in a reversed V shape, that is, making the middle part of the tunnel higher and making the both ends lower, enables natural drainage. Although mountain tunnels often employ one way grade due to geographical conditions, etc., they also can gain natural drainage. Within the section from Thane station to Virar, Boisar and Vapi stations of the proposed route, there are 11 mountain tunnels totaling 7.00 km in length. As the cross-section of tunnels within the section, horseshoe-shaped which is commonly used in NATM is proposed, and single bored tunnel for double tracks is assumed because the tunnel lengths do not exceed 5 km tunnel which was commonly used in single bore tunnel in the world.

(2) Urban Tunnel

Urban tunnel is a tunnel which runs within structures or underground in urban area. In Japan, most tunnels of Metropolitan Expressway and underground railways are urban tunnels. Within the proposed route, the tunnel for the section between Mumbai Station and Thane Creek with a length of about 5.17 km is an urban tunnel. In terms of proposed cross-section of the tunnel for this section, parallel single-track tunnel (twin bored tunnels) or double-track cross-section tunnel (single bored tunnel) with a circular cross-section excavated with TBM is assumed because the ground is assumed to be middle hard rock and includes groundwater, considering the tunnel cases of Mumbai Metro. NATM is superior to TBM to save the construction cost, while TBM is superior to NATM from the viewpoint of construction work period. In this project, study team discussed the cross-sectional profile and method of construction with in terms of economy and construction work.

(3) Underwater Tunnel

Underwater tunnel is a tunnel which is excavated below riverbed or seabed. This type of tunnel requires mechanical drainage because its midsection should be structurally lower than other section. Within the proposed route, the tunnel for the section crossing Thane Creek with a length of about 7.85km is an underwater tunnel. For this section, a tunnel with TBM, shield or immersed tube can be applicable. Geological surveys of this section are to be conducted and a tunnel type is to be selected considering topography of Thane Creek's seabed as shown in Figure 9.5-4 in this study. Construction methods of tunnels as well as longitudinal alignments vary depending on three types of geological conditions as shown below. These matters are studied in this stage. As the construction work of the urban tunnel and the Thane creek undersea tunnel (total length 20.5km) in the Mumbai area makes a critical pass in the whole construction period of this project, Study team discussed a most appropriate method of construction for these tunnels from the viewpoint of safety, economy and construction period.



Source: Study team

Figure 9.5-4 Relationship between Tunnel Types and Topography at Seabed

Immersed tunnels should have double-track cross-section. Whether the other two types should be parallel single-track tunnel or double-track cross-section tunnel directly and indirectly depends on countermeasures against fires, maintenance system, ventilation design, etc. which should be investigated in this stage. Geological conditions, construction method, period and cost of construction and effects on mangrove forest also should be considered, and then, the most appropriate tunnel type at seabed should be selected.

9.5.2 Geological Aspects

(1) Mumbai-Thane

1) Collected study materials

Study team collected the following materials in planning tunnel construction in the Mumbai–Thane section:

- A topographical map with planned Alignment (scale 1/50,000).
- General Drawing for Vashi Bridge: A general (side) view from the planned route to a point approx. 4.5 km south thereof.
- Geological condition for Vashi Bridge: (Pier No. BH40, BH40A, BH41, BH42, BH43).
- A hydrographic chart for ThaneCreeck.
- Geological survey materials for existing railway plans.
- Results of geological survey for this project.

2) Topography, geology condition and surrounding environments

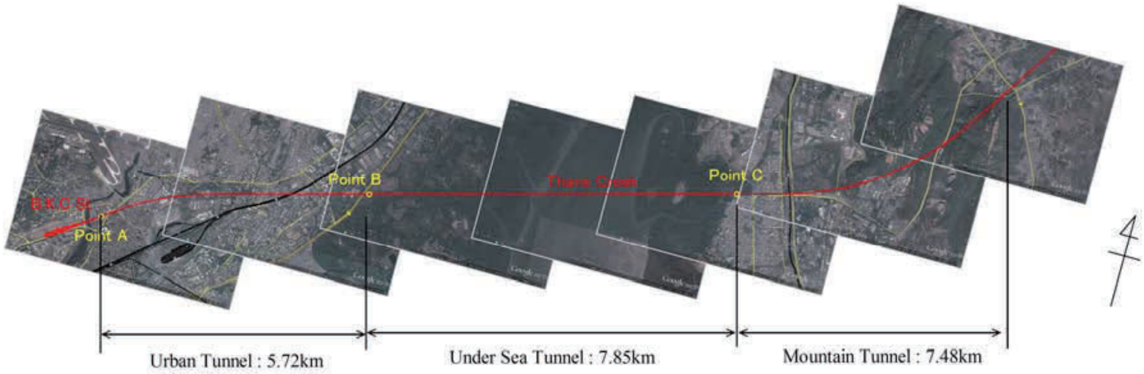
Study team analyzed the collected geological survey materials to obtain the following information:

- Outline of topography.

Figures 9.5-5 and 9.5-6 show the collected topographical map (scale 50,000) and a satellite image, respectively. From the Mumbai underground station 0 km to approx. 5.0 km, an approx. 5.0 km-long tunnel passes under a Mumbai urban residential house swarming area and an existing railway. In this section, there is a gentle hilly area (elevation 25m) to guarantee a sufficient covering thickness. In the approx. 8 km-long section between 5.0 km to approx. 14 km points, the railway passes under the protected forest of mangrove and the Thane creek at an underwater depth of approx. 2m. This point is the topographically lowest point. Due consideration is required, therefore, to secure a sufficient covering thickness. In the approx. 7 km-long section from the 13.6 km to approx. 21 km points, the railway runs through a tunnel in the Navi Mumbai mountainous zone, which we discuss as a normal mountain tunnel.

Source: Study team

Figure 9.5-5 Plane and Profile Drawing



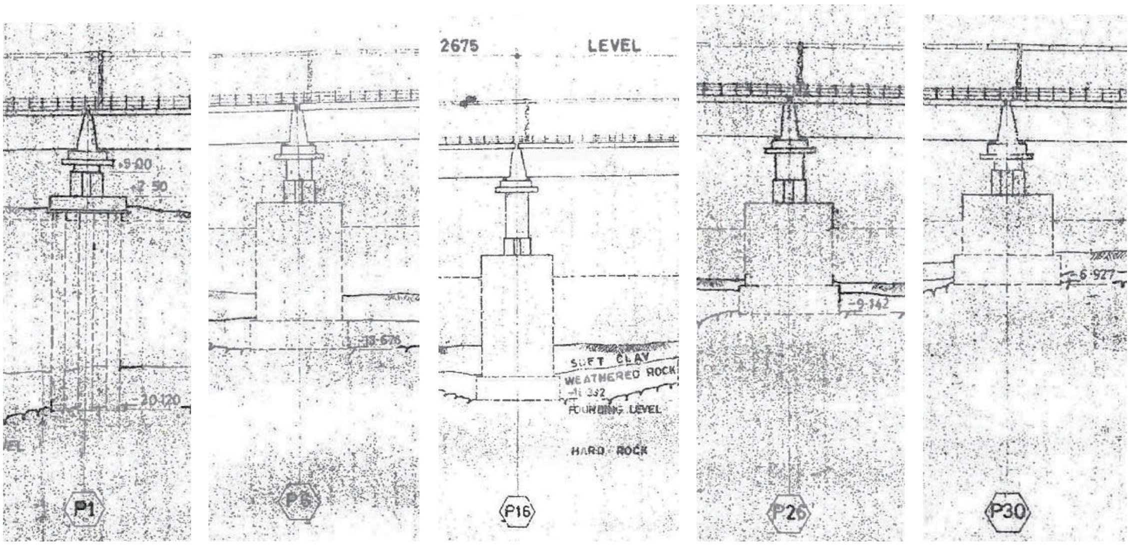
Source: Study team

Figure 9.5-6 Satellite Image Picture

- Outline of geology
  To discuss the ground conditions of the Thane creek, we assumed the bed rock of the planned route based on the general (side) view of the Vashi Bridge existing approx. 4.5 km south of the planned route and Vashi Bridge geological materials (BH40, BH40A, BH41, BH42, BH43). See Figure 9.5-7 for the geometrical relation between the planned route and the geological survey points and Figure 9.5-8 for the general (side) view of Vashi Bridge.

Source: Google earth

Figure 9.5-7 Geometrical Relation
between the Planned Route and the Geological Survey Points



Source: Central Railway

Figure 9.5-8 General (Side) View of Vashi Bridge

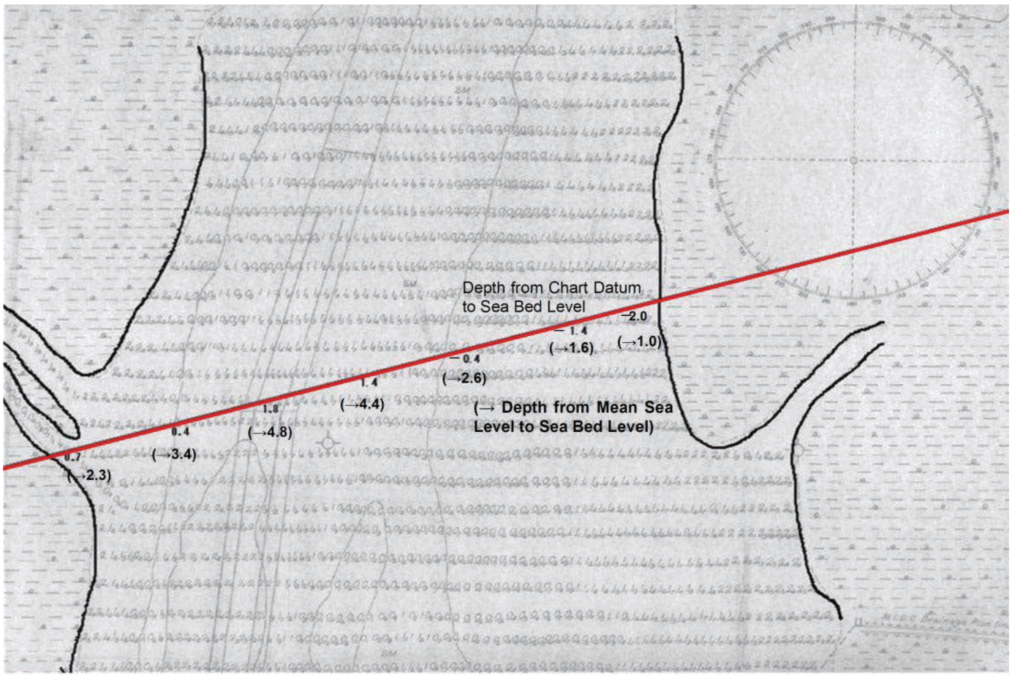
From the general view of Vashi Bridge, the top of the weathered rock layer around A1 is GL 17 to18 m. In the geological survey material (for a point approx. 90 m south thereof) a completely weathered basalt rock appears from GL-17.6 m point. Judging from the depths of these points from the ground surface, the two descriptions are in good agreement. See Table 9.5-2 for the results of the analysis of materials.

Table 9.5-2 General View of Geological Date

	Elevation of Rock Layer(m)	Thickness of weathered basalt rock layer(m)	Thickness of clay layer(m)	Water depth(m)
P1	-19.5	4.0	17.0	-
P6	-13.5	3.0	3.0	7.5
P16	-16.0	3.5	3.5	9.0
P26	-9.0	2.0	1.5	6.5
P30	-6.5	1.0	2.0	3.5

Source: Study team

- Outline of water depth
  The nautical chart of Thane Creek from Vashi bridge to Ghansoli was obtained. The chart was surveyed by Shri A. S. Kadam, D.H.S. under the Direction of CAPT. J. B. Rohilla, FIS, MCA (INDIA), Hydrographer Maharashtra Maritime Board on 9th Feb to 8th Mar and 16th Mar to 20th Mar 2007. The depth from Mean Sea Level to Sea Bed Level at deepest point along the route should be 1.8+2.942≒5m in approximate. (Refer to chapter 6.4)



Source: Thane Creek Vashi Bridge to Ghansoli (Added info. by Study Team)

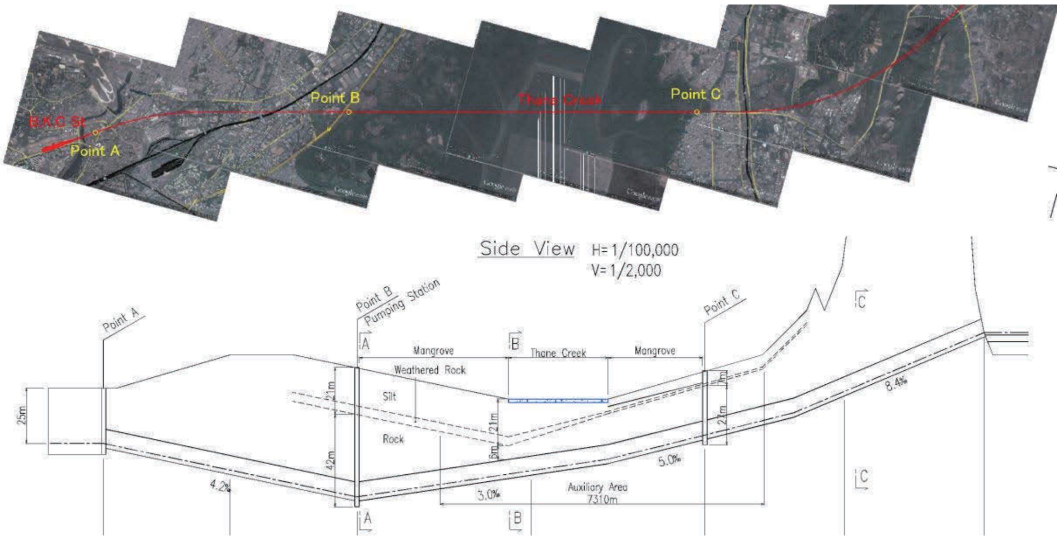
Figure 9.5-9 Nautical Chart around Planning Project Route

3) Setting of topography, geology and water depth for the planned route

- Water depth
  Study team sets the water depth at 0.4 to 1.8 m based on the hydrographic chart and adopts 1.5 m (the average) as a central value.
- Rock layer (Thane creek water area)
  By referring to the Vashi Bridge geological survey materials, study team set the following. The geological survey materials cite RQD as an index of rock. Study team set the following according to the road tunnel ground classification that uses RQD as an index:

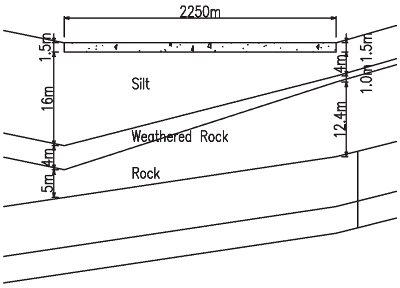
  Cohesive soil layer: N = 8 (according to the average value)
  Weathered rock layer: RQD = 0 to 31 → Ground class DII
  Bed rock layer: RQD = 41 to 48 → Ground class CI

See Figure 9.5-10 for the results of topography, geology and water depth setting for Thane Creek undersea tunnel. Detail for undersea area shown Figure 9.5-11



Source: Study team

Figure 9.5-10 Topography, Geology and Water Depth Setting for Thane Creek Undersea Tunnel



Ground Assumptions	
Silt	N=8
Weathered Rock	DⅡ
Rock	CⅠ

Source: Study team

Figure 9.5-11 Detail for Undersea Area

(2) Thane-Virar

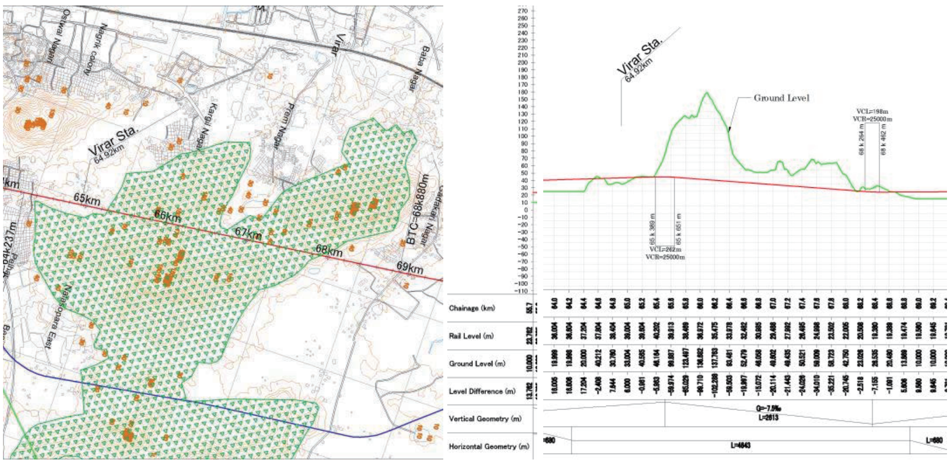
1) Collected materials

- The regional geology map issued by the Indian Geology Survey Institute. (Figure 9.5-13)
- A topographical map with planned alignment (scale 1/50,000).

2) Topography, geology and surrounding environments

- Outline of topography

  Figures 9.5-12 shows the collected topographical map (scale 50,000). From 65.65km to approx. 66.85 km, an approx. 1.2 km-long tunnel passes through mountain area near Virar station. In this section, there is a gentle mountain area (elevation 150m). But some point of section is not enough to guarantee a sufficient covering thickness. Minimum thickness of covering is 16m. The alignment passes under the protected forest area.

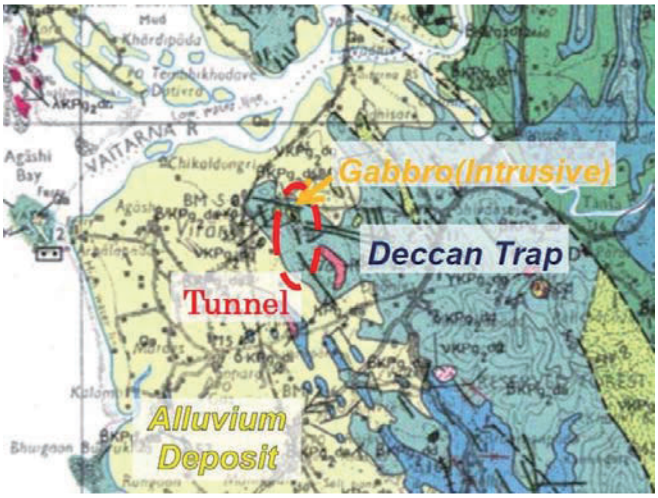


Source: Study team

Figure 9.5-12 Outline of Topography (Thane-Virar)

- Outline of geology

  The geology of the tunnel area is composed of basalt (Deccan strap). Hard exposure of the basalt was observed at all survey points in Maharashtra state. According to the regional geology map (Figure 9.5-13) issued by the Indian Geology Survey Institute, there are penetrations of gabbro and a number of joints around the tunnel. As the ground is hard, therefore, the NATM construction method for normal tunnels is applicable at this site. In applying this construction method, however, due attention shall be paid to crushed zones. It is also required to discuss the possibility of sudden spring water outbreaks as there is a dam in a nearby area.



Source India Geological Survey Institute

Figure 9.5-13 Geological Map of Virar Area

(3) Boisal-Vapi

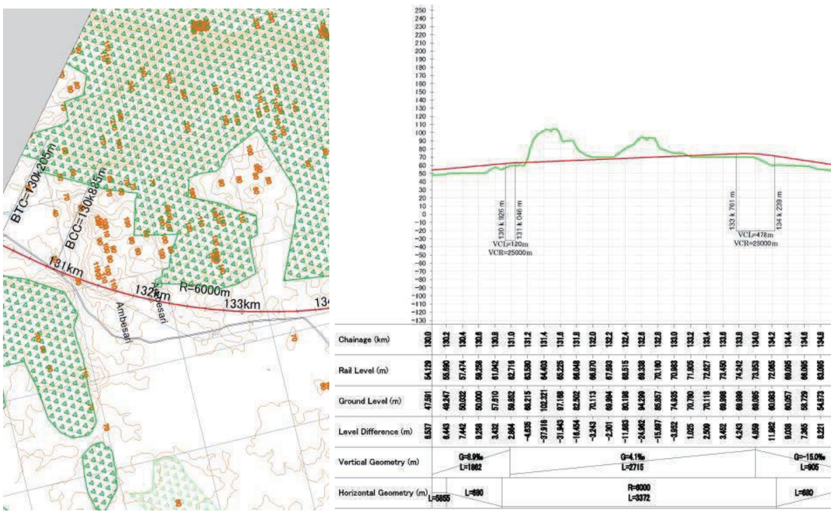
1) Collected materials

- A topographical map with planned alignment (scale 1/50,000).

2) Check of the conformability between collected materials

- Outline of topography

  Figures 9.5-14 shows the collected topographical map (scale 50,000). From 130.90km to approx. 131.50 km, an approx. 0.6 km-long tunnel, from 132.35km to approx. 132.60 km, an approx. 0.25 km-long tunnel, from 148.15km to approx. 148.35 km, an approx. 0.2 km-long tunnel, from 156.75km to approx. 157.00 km, an approx. 0.25 km-long tunnel passes through mountain area of Ambesari. In this section, there is a gentle mountain area (elevation 100m). But some point of section is not enough to guarantee a sufficient covering thickness. Minimum thickness of covering is 20m.



Source: Study team

Figure 9.5-14 Outline of Topography (Boisal-Vapi)

- Outline of geology
  In this section, highly cohesive soil distributes in the surface layer. Soft ground layers having the N-value of less than 4 weren't been found in the past surveys. Furthermore, mountain tunnels pass hilly areas, where the bed rock consists of basalt (Deccan strap). As the exposures observed in the Maharashtra state are all hard, the basalt of the tunnel may also be hard. However, weathering may have progressed at the middle of tunnel section where earth covering is not thick.

9.5.3 Tunnel Configuration and Cross Section.

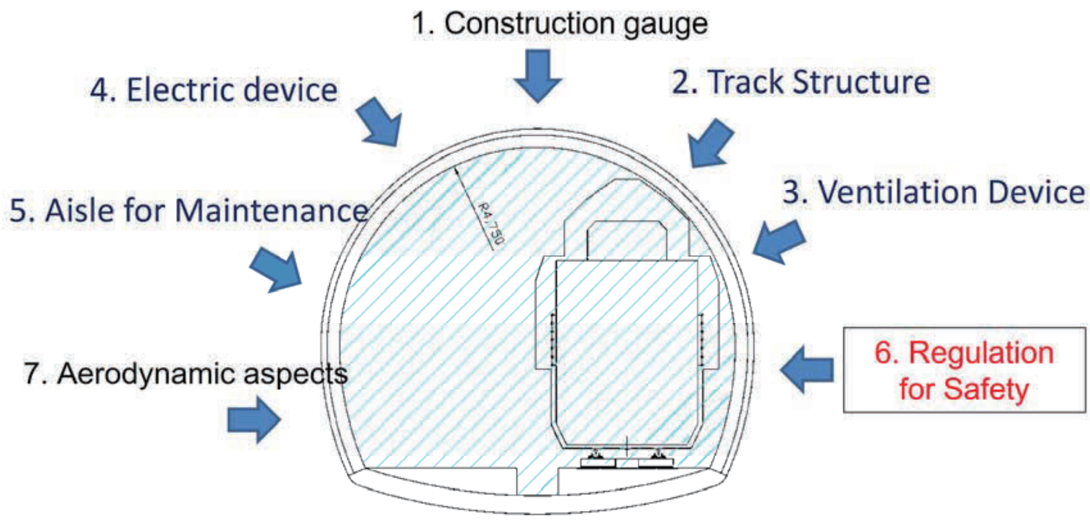
The tunnel profiles are broadly divided into the following two:

- Twin bore tunnel for single tracks
- Single bore tunnel for double tracks

Study team discuss below the tunnels having the above profiles.

(1) Tunnel bore cross section

The tunnel bore cross section shall be determined in consideration of not only safety, easiness of construction and control of maintenance but also economy. As it is extremely difficult to change dimensions after inauguration, the tunnel bore cross section shall be determined by taking into account the items shown in Figure 9.5-15 and foreseeing the long-term conditions of tunnel usage into the future.



Source: Study team

Figure 9.5-15 Determination of Elements for Tunnel Cross Section

(1) Safety aspects

Basic measures against tunnel fires
It is necessary to consider a comprehensive countermeasure against tunnel fires based on the following basic measures:

1) Use of non-combustible material

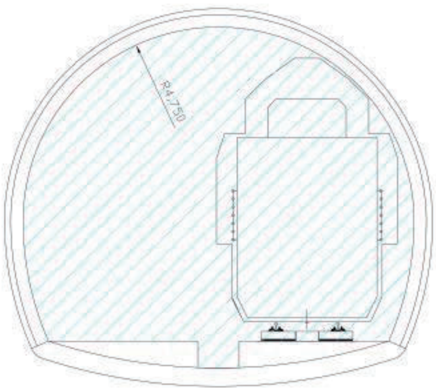
Among basic measures against tunnel fires, the most important thing is to use as much non-combustible material as possible in structures of stations and tunnels as well as train cars. "Standards and Commentaries for Countermeasures Against Fires in Underground Railway Stations, etc." in Japan prescribes measures to decrease the risk of fire and limit the scale of fire when it occurs by eliminating combustible material as much as possible. This is also the most basic idea of measures against tunnel fires in Europe and the USA. NFPA 130 of the U.S.A. also prescribes the use of non- combustible material and the test procedure for approval of non-combustible material.

2) Principles of train service in fire emergency

In fire accident of Hokuriku Tunnel occurred in Japan in 1972, stopping of the train which suffered fire in the tunnel caused increase of damage. Therefore, in present Japan, a basic principle in fire emergency within a tunnel is that the train should run through the tunnel or run to the next station. It also is a basic principle that other trains including oncoming trains should stop at other stations and should keep away from the station where the train which suffered fire has stopped.
On the other hand, there is a difference in standards regarding long length tunnels between Japan and Europe. In Japan, a basic principle in fire emergency within a tunnel is that the train should run through the tunnel or run to the next stopping area which is safety zone for evacuation. In Europe, however, a basic principle in fire emergency within a tunnel is that the train should be stopped any place in the tunnel and passengers should start evacuation within the tunnel.

3) Single-bore double track tunnel and twin-bore single track tunnel

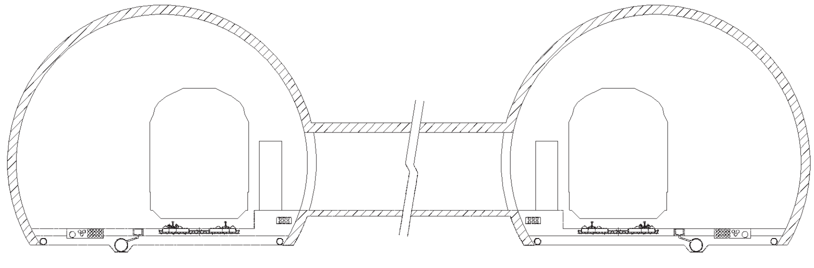
A difference in the tunnel profile stemmed from the difference in the concept of the measurers against fire of long tunnels in Japanese and European standards is in the difference between the single-bore tunnels for double track tunnels (hereinafter referred to as "double track tunnels") and the twin-bore tunnel for single track tunnels (hereinafter referred to as "in-parallel single track tunnels"). See Figure 9.5-16 for the cross-section of the double track tunnels according to the Japanese standards and that of in parallel single track tunnels to the European standards.



A=64m²

Source: Study team

Figure 9.5-16 Tunnel Cross Section of Single Bore for Double Tracks in Japan



55 ㎡＋55 ㎡+connectin tunnel α ＝110＋ α ㎡

Source: Pre-F/S Report

Figure 9.5-17 Tunnel Cross Section of Twin Bore for Double Tracks at Pre-F/S

In Europe, in-parallel single track tunnels are used in principle for tunnels with a length of 5 km or over where train running speed is 200 km/h or over for the purpose of security at recovery from rolling stock derailment or fire accidents and to perform track maintenance, upkeep and control services during the daytime. Whereas it is prescribed in Japan that trains shall not stop in the tunnel but run out in case fire has broken out in a tunnel, trains shall stop in the tunnel in most cases in Europe to make passengers evacuate to the adjacent tunnel through communication passage placed at certain intervals. In Europe, tunnels with a length of 5 km or over are in principle in-parallel single track tunnels having a larger cross-sectional area of 55 m^2.

4) Basic concept for safety

As mentioned above, there are two kind of existing standards such as NFPA 130 and Japanese standard for train fire in long tunnel in the world, this tunnel plan has developed based on the latter. Fire measurement for the viaduct can be reduced compare with it for the tunnel, but from the point of view of mangrove protection, this plan was developed in the case of tunnel. And the plan is as follows.

In Japan, Shinkansen tunnels having a length of 5 km or over are defined as “long tunnels,” with the same definition simultaneously applying to two or more tunnels located continually at intervals of 400 m (equal to the length of a 16-car Shinkansen train-set) or less up to a length of 5 km or over in total. Such long tunnels are now protected with various disaster preventive measures. As Shinkansen cars are extremely incombustible and airtight, it is a basic policy for trains to run out of the tunnel to a pre-determined safe point or up to a nearest station, in case a fire has broken out in tunnel. This policy is practical, as Shinkansen trains composed of passenger-seat cars alone and running on dedicated lines enable detecting and extinguishing a fire at an early stage. Furthermore, Shinkansen trains can pass through even the 25.81 km-long Iwate-Ichinohe Tunnel, one of the above-classified long tunnels, in approximately six minutes. This means that it is possible for Indian High-Speed Railway trains to pass through the 20.5 km-long Thane Creek Tunnel in approximately 7 minutes. Moreover, in case a train on fire cannot help but stop in a tunnel for some reason, passengers can flee outside for safety through an evacuation route. This fire protection measurement was authorized by government as a ministerial ordinance, and each railway company should make the performance criteria following this.

- Measures against train fires in long tunnels

<u>Ground facilities</u>

Table 9.5-3 summarizes ground facilities required against train fires in tunnel.

Table 9.5-3 Ground Facilities Required against Train Fires in Tunnel

Communication facilities	• Installation of leakage coaxial cables • Installation of wayside telephones at equipment/materials pits at intervals of 500 m (with location indicating lamps normally on)
Fire extinguishing facilities	• Installation of 10 to 20 fire extinguishers at each equipment/materials pit
Illumination facilities	• Installation of illuminators on both sides at intervals of 15 to 20 m
Distance displays	• Installation of information panels to indicate the distance to tunnel exits on tunnel walls at intervals of 100 m
Power supply facilities	• Introduction of heat resisting trolley and messenger wires into the overhead power supply system • Additional installation of section disconnecting switches to minimize power-lost areas at accident and prevent the state of train operation inability as far as possible • Installation of protection equipment to immediately stop power feeding when an overhead contact wire has broken to contact EMUs
Train protection equipment	• Installation of train protection switches on the maintenance pass side walls at intervals of 250 m to prevent entry of other trains at abnormality.

Rolling stock facilities

Table 9.5-4 summarizes rolling stock facilities required against train fires in tunnel.

Table 9.5-4 Summarizes Rolling Stock Facilities Required against Train Fires in Tunnel

Rolling stock structure	Cars are extremely fire-resistant as incombustible or fire-resistant materials and those applied with equivalent treatment are used for outside plates, linings, seats and curtains.
Fire extinguishing equipment	Passenger cabins are all installed with two to four reinforcement liquid type fire extinguishers and each driving cab with a fire extinguisher of the reinforced powder type.
Evacuation facilities	In case passengers are required to evacuate from passenger cabins, cars are installed with emergency footplates and ladders, through which passengers can move to the trains on adjacent tracks or climb down to the ground.

- Action at fire outbreak

Shinkansen trains, which are composed of passenger-seat cars alone, feature extremely high fire-resistance and airtightness, thereby enabling train crew to detect/extinguish a fire at an early stage. Furthermore, they can run through the Thane Tunnel in seven minutes. In view of these characteristics of high-speed railway trains, India shall launch the following first-stage safety measures against train fires in principle.

1 Trains shall pass through the tunnel and stop at the safe point outside the tunnel specified in advance. In case the train has once stopped in the tunnel for inevitable reasons, restart, run up to a safe point outside the tunnel and stop. In the present plan, trains bound for Mumbai shall run through the tunnel where a train fire has broken out and stop at a station.

As a second stage safety measure, in case a train fire has broken out simultaneously with an overhead contact wire breakage or a rolling stock accident, due to which the train is forced to stay at the fire occurring point for long hours, train crew shall make passengers flee to a car as far from the fire source as possible and launch initial-stage fire-fighting operation (fire spreading is far from conceivable at this point for reasons of rolling stock structure). Then, train crew shall take the following measures to guide passengers for evacuation while making right judgement on the circumstances in consideration of fire strength, train position (distance from the tunnel exit), whether power supply has stopped or not on overhead contact wires (for up- and/or down-tracks), wind direction in the tunnel, wind strength and other factors.

2 Make passengers move through footplates to a train on the adjacent track.

Shinkansen trains are installed with an information transmitting system for free communications through a train radio system all the time to/from the ground side, which (1) enables the Central Control Center to call any train driver individually or all train drivers simultaneously and (2) allows train drivers to call train dispatchers. Train crews are supposed to take above-mentioned safety measures at fire while communicating with the Central Control Center.

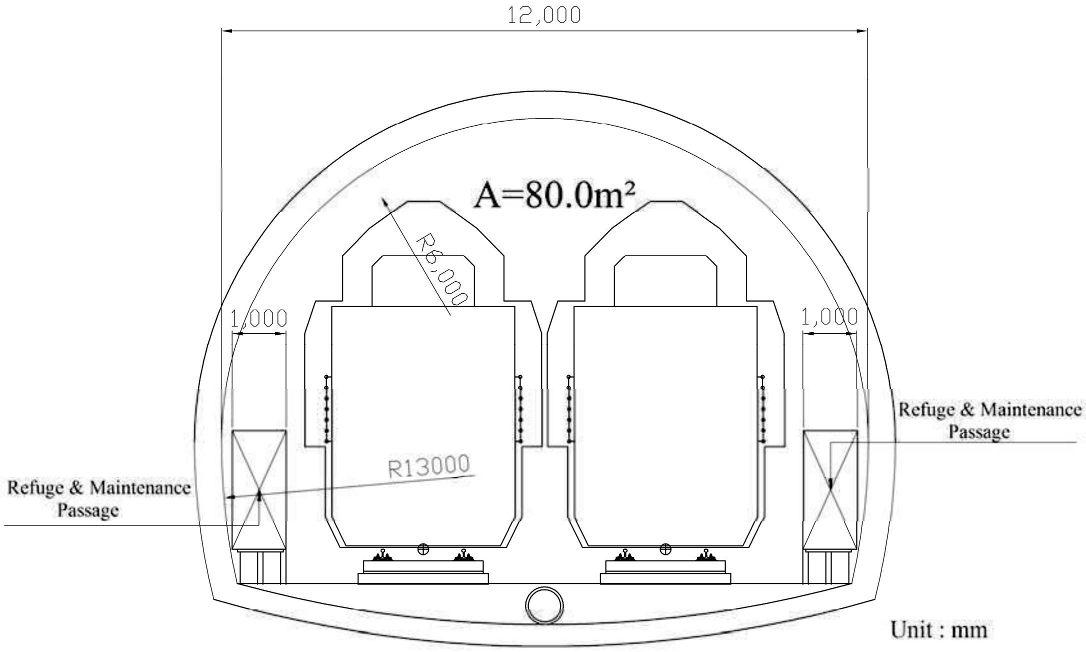
- Summary of measures against train fires in tunnels

For 50 years since their inauguration, measures against train fires have been reinforced for Shinkansen tunnels having a double-track section profile in Japan based on the past experience in the country, through verification in field fire tests and learnt from precedent cases in other countries.

(2) Examination of tunnel cross-section

Study team examines the following four types of cross-section with two type of construction method (TMB and NATM).

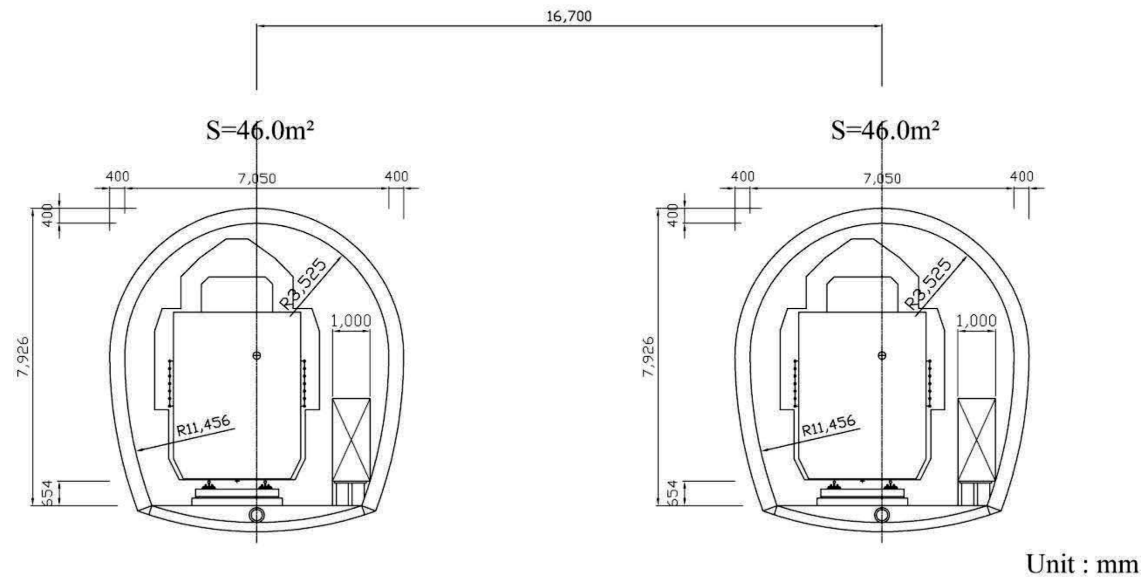
- NATM cross-section for double tracks
  Distance between track centers 4.5 m, maintenance/evacuation passage 1.0 m on both sides, bore cross-sectional area 80 m^2, (homogeneous sound rock ground: concrete bed, other part invert)



Source: Study team

Figure 9.5-18 NATM Cross-Section for Double Tracks (A=80 m^2)

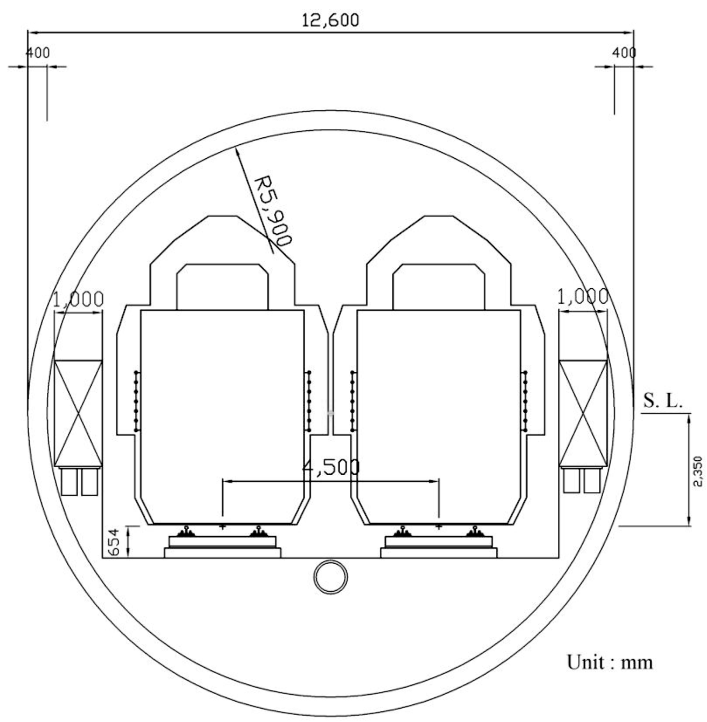
- NATM cross-section for single track in parallel
  Maintenance/evacuation passage 1.0 m on one side, bore cross-sectional area 46m^2, (homogeneous sound rock ground: concrete bed, other part invert)



Source: Study team

Figure 9.5-19 NATM Cross-Section for Single Track in Parallel (A=46+46 m^2)

- TBM for double tracks
  Distance between track centers 4.5 m, maintenance/evacuation passage 1.0 m on both sides, bore cross-sectional area 109m^2, (homogeneous sound rock ground: concrete bed, other part invert)

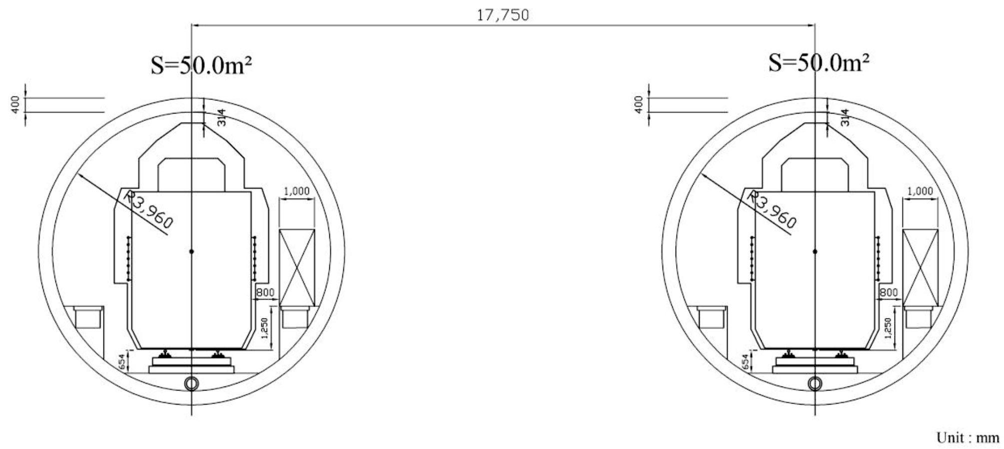


Source: Study team

Figure 9.5-20 TBM for Double Tracks (D=11.8m)

- TBM for single track in parallel
  Distance between track centers 4.5 m, maintenance/evacuation passage 1.0 m on one side, bore

cross-sectional area 50m^2, (homogeneous sound rock ground: concrete bed, other part invert)



Source: Study team

Figure 9.5-21 TBM for Single Track in Parallel (A=50+50m^2)

9.5.4 Civil Work Aspects

Tunnels are broadly divided into Mountain tunnels and urban tunnels depending on their location. Mountain tunnels are normally constructed by the New Austrian Tunneling Method (NATM) developed in Austria as suggested by its name to use sprayed concrete and rock bolts as supports to effectively utilize the hollow space holding capacity, thereby ensuring the safety of tunnel. When compared with conventional tunnel constructing method, it reduces the number of supports to hold the tunnel bore space, thereby substantially cutting the construction cost.
In contrast, urban tunnels are normally constructed, the cut and cover method, shield method (TBM) and urban NATM.
The cut and cover tunneling method is often used to construct large-scale underground stations. The shield tunneling method is mostly used to construct tunnels between stations. It is also being used to construct underground stations in recent years. The urban NATM, an improved version of the standard NATM originally for mountain tunnel construction, is used to excavate urban tunnels while eliminating adverse effect on the ground level buildings.
The following four tunnel construction methods were examined for this project:

(1) NATM

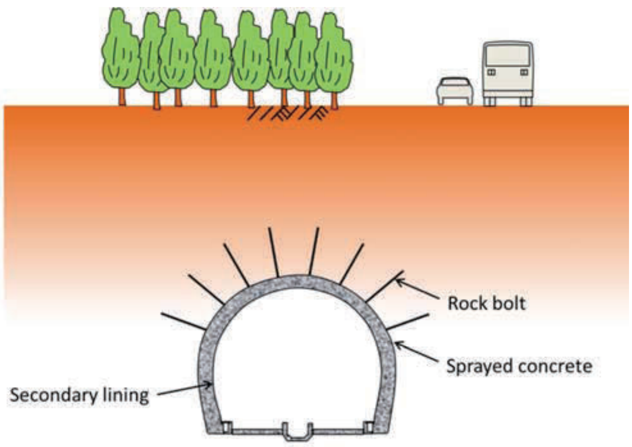
NATM (New Austrian Tunneling Method) is a tunneling method that sprays concrete or uses rock bolts to control deformation during excavation of the ground. Measurement is taken while drilling and a thin lining of concrete is applied after stability of the ground has been confirmed.
The following are the advantages/disadvantages of the tunneling methods:

Advantages

- Studded with a number of mechanized elements to reduce construction workers.
- Features widely-ranged applications to cope with grounds under various geological conditions, when combined with auxiliary constructing methods.
- Applicable to tunnels having large sectional areas.

Disadvantages

- Requires special tools/machines and an operating system thereof to spray concrete and strike rock bolts, thereby potentially making the scale of equipment/facilities larger.
- Inferior to conventional methods for the ground from which sprayed concrete tends to separate.



Source: Study team

Figure 9.5-21 Conceptual Drawing for NATM

(2) TBM (Shield Method)

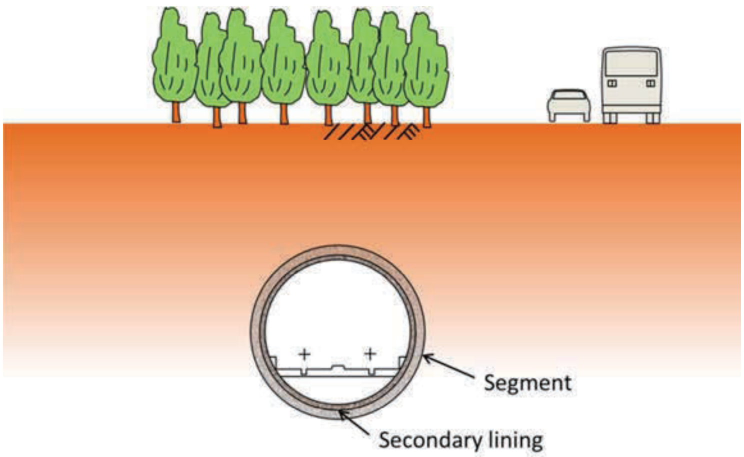
TBM （Tunnel Boring Machine) is a machine used to drill the rock. It has the function to cut using a rotary crushing device called cutter head and the function to remove the muck (debris) after drilling. It is suitable for drilling homogeneous hard rock. Whereas the shield tunneling method is suitable for sand, clay, and rock, the TBM method is a tunneling method suitable for hard ground, such as rock. Because the TBM method uses equipment, such as the TBM, the tunnel can be constructed faster and the construction period can be shorter compared to the NATM method. Unlike the NATM method, which uses blasting, TBM can be used in residential areas as well as in the suburbs.
A shield (outer shell) is a cylindrical steel structure being driven into the ground during drilling. A block known as a segment is connected to the end of the shield to assemble shields into a tunneling structure.
The following are the advantages/disadvantages of the tunneling methods:

Advantages

- High-speed and continuous excavation is possible to cut the construction period.
- Features high-level safety. Excavation of circular spaces eliminates useless excavation space and ensured tunnel stability from the dynamical viewpoint
- Workers needn't stand close to the cutting face.
- The loosened (damaged) zone around the tunnel is smaller than in the case of blasting method to allow decreasing the number of supports.

Disadvantages

- Tends to cause trouble at fault crushed zones and in soft grounds.
- Difficult to use for short tunnels as the costs to fabricate and transport the TBM base machine are high.
- Cross-sectional profiles are limited.



Source: Study team

Figure 9.5-22 Conceptual Drawing for TBM

(3) Open and cut method

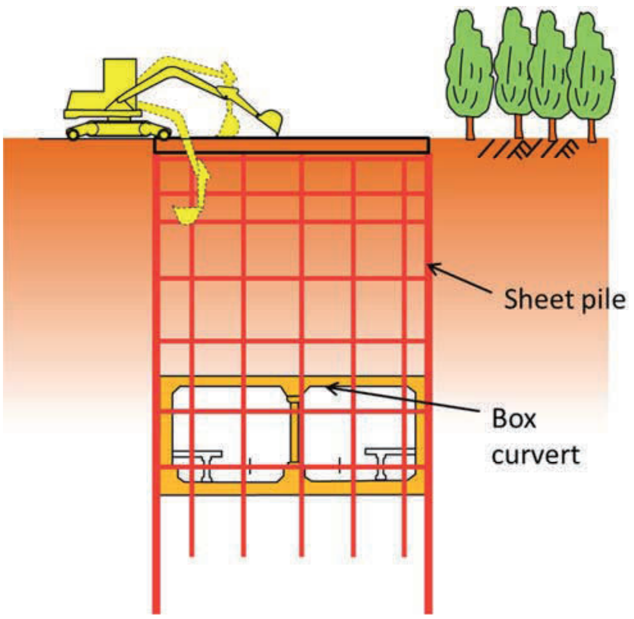
This is a method to excavate the ground from the surface to construct structures in the tunnel and refill afterword, which is used to excavate the portion near the ground surface or to construct stations and other large-scale facilities. The following are the advantages and disadvantages of this construction method:

Advantages

- The construction work is reliable as excavation can be progressed while confirming the changes in the underground water level.
- Construction period is comparatively short.
- Generally economical.
- Features a great number of execution records.

Disadvantages

- Execution in densely populated urban areas tends to cause construction pollution such as disturbance of road traffic, noise/vibration at excavation/earth retaining work and effect on the buildings in the surrounding areas.
- At urban roads where swarming underground assets are buried, relocation and protection of these assets require an enormous amount of costs.
- The total cost is larger than that by other methods in case assets are buried deep underground or surrounding structures are standing cheek by jowl.



Source: Study team

Figure 9.5-23 Conceptual Drawing for Open and Cut

(4) Sunken tube method

Sunken tube method refers to tubes made of concrete or steel plates submerged in the seabed to form a tunnel. In Japan, the first full-scale sunken tube tunnel was the Tama River sunken tube tunnel on the JNR Keiyo Line completed in 1970. It is consisted of six 80-m long tubes sunken onto the seabed and connected underwater. This is a common tunneling method used for crossing rivers, canals, and waterways.
Except in the case where the immersed tunneling method is disadvantageous, tunnels can normally be constructed by this method at lower cost than by TBM and shield methods. The following are the advantages and disadvantages of this construction method:

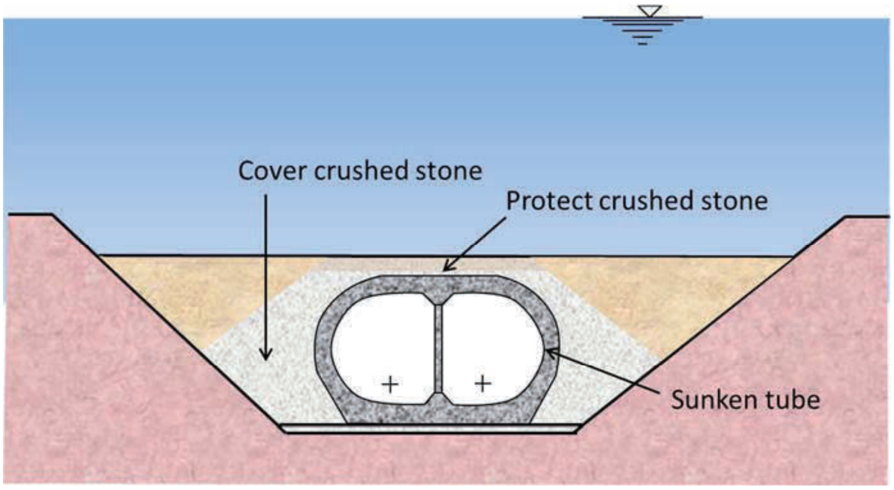
Advantages

- Boxes are manufactured at dry docks or ship building docks by the prefabricating method as a high-quality watertight structure.
- The tunnel covering can be designed smaller to cut the tunnel length.
- As the specific gravity is small, the bearing capacity of the ground needn't be large.

- The prefabricating method cuts the immerging/installing time at site. A number of mechanized elements allow execution by a small number of workers.

Disadvantages

- As the boxes are towed from the dry dock to the submersing point, an appropriate water depth is necessary. However, too large a depth makes submersing impossible.
- Excavation of sea bed potentially causes water quality pollution and other environmental problems.



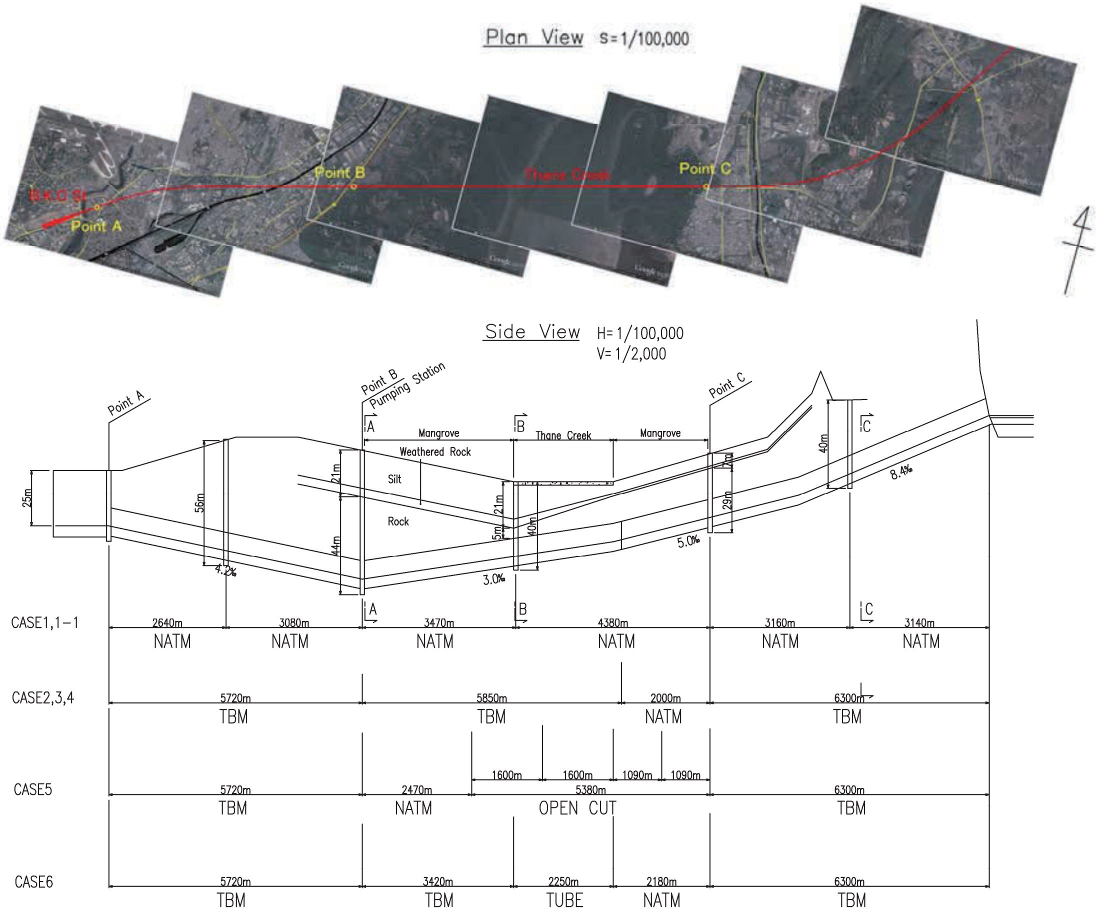
Source: Study team

Figure 9.5-24 Conceptual Drawing for Sunken Tube Method

(5) Examination for the Mumbai undersea tunnel construction method

Study team examined the possibility of various construction methods described in chapter 9.5.4 together with the construction schedule.

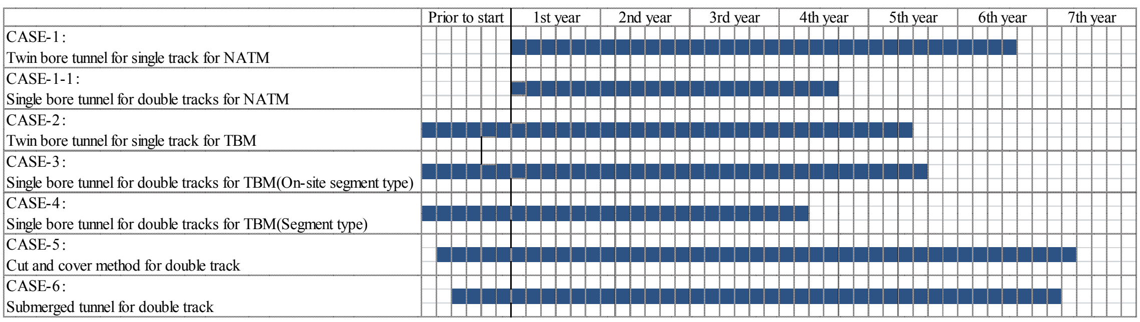
CASE-1 : Twin bore tunnel for single track for NATM
CASE-1-1 : Single bore tunnel for double tracks for NATM
CASE-2 : Twin bore tunnel for single track for TBM
CASE-3 : Single bore tunnel for double tracks for TBM(On-site segment type)
CASE-4 : Single bore tunnel for double tracks for TBM(Segment type)
CASE-5 : Cut and cover method for double track
CASE-6 : Sunken tube tunnel for double track



Source: Study team

Figure 9.5-25 Classification of the Construction Method for Each Case

See Figure 9.5-26 for the result of the examination for the construction period. These figures prove the applicability of the double track cross-section NATM along the whole route. Increasing the number of vertical shafts will realize the planned schedule of three years and substantially cut the construction cost.



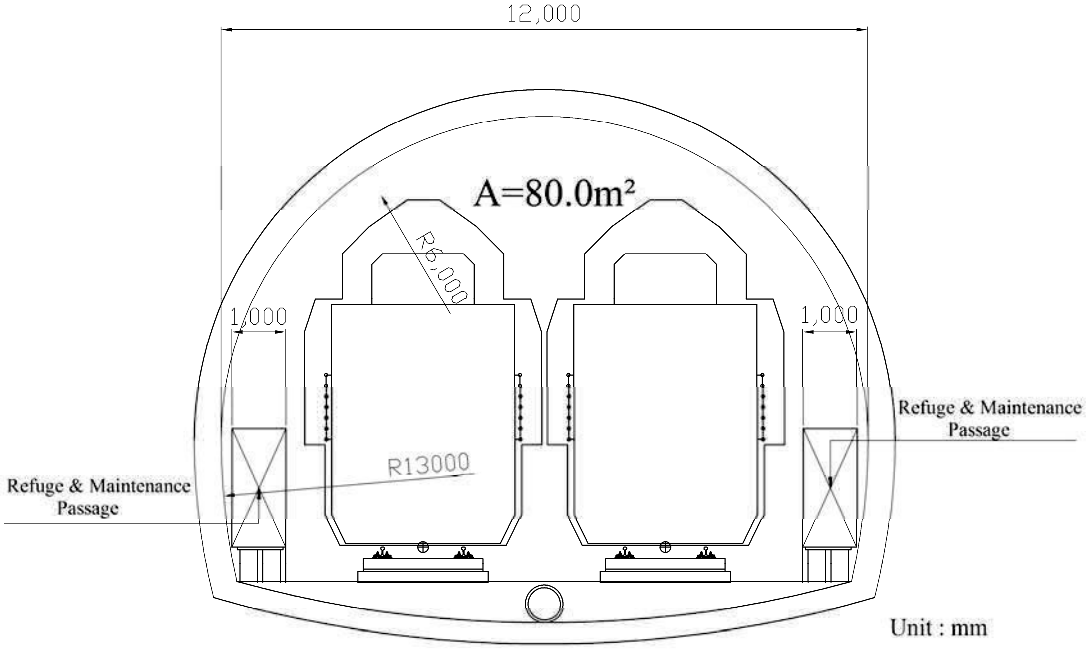
Source: Study team

Figure 9.5-26 Comparison of Construction Period for Each Case

9.5.5 Recommendations

(1) Urban and Undersea tunnel

Based on the results of discussion from the viewpoint of cost, construction period and safety, study team recommend an approx. 21 km-long double track cross-section tunnel to be constructed by the NATM method as the urban and undersea tunnel in the Mumbai area. See Figure 9.5- 27 for a drawing of the recommended cross-section.



Source: Study team

Figure 9.5-27 Basic Cross Section Drawing for NATM

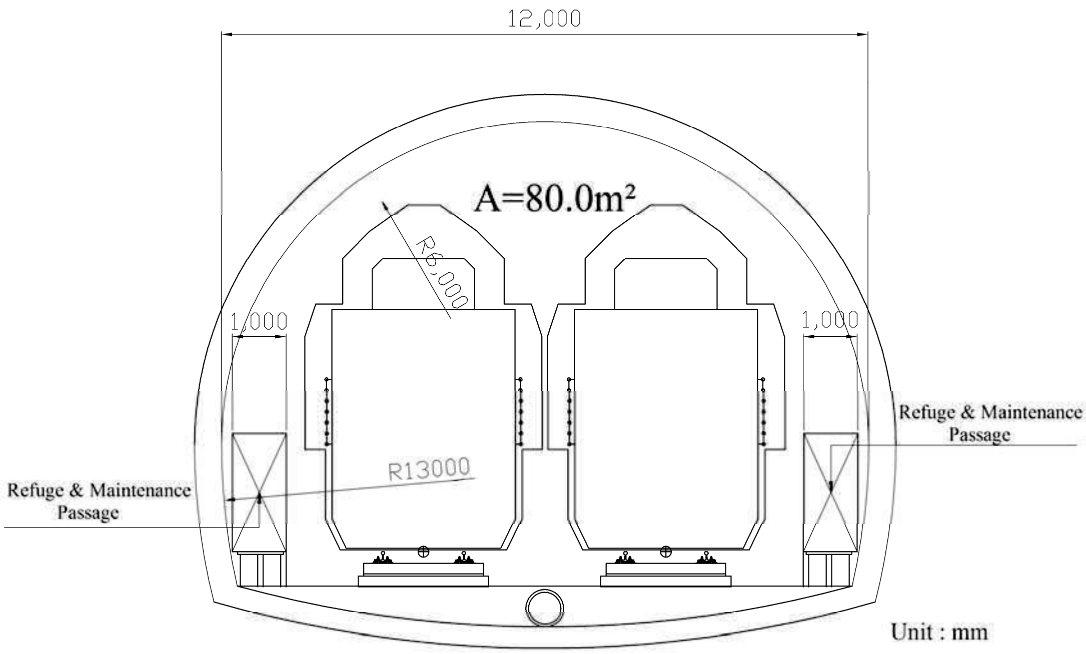
Table 9.5-5 Location of the Tunnel List

No.	Chainge from (km)	Chainge to (km)	Length (km)	Type of Tunnel	Remarks
1	0.6	5.77	5.17	Urban and Undersea tunnel	Mumbai area and Thane Creek
2	5.77	13.62	7.85		East side of Thane Creek
3	13.62	21.10	7.48		Navi Mumbai area

Source: Study team

(2) Mountain tunnel

Based on the results of discussion from the viewpoint of cost, construction period and safety, study team recommend a double track cross-section tunnel to be constructed by the NATM method as the mountain tunnel. See Figure 9.5-28 for a drawing of the recommended cross-section.



Source: Study team

Figure 9.5-28 Basic Cross Section Drawing for NATM

Table 9.5-6 Location of the Tunnel List

No.	Chainge from (km)	Chainge to (km)	Length (km)	Type of Tunnel	Remarks
4	52.50	53.30	0.80	Mountain tunnel	Mori (Between Thane and Virar)
5	54.60	54.90	0.30		Bapane (Between Thane and Virar)
6	65.65	66.85	1.20		North side of Virar Station
7	67.10	68.00	0.90		North side of Virar Station
8	76.45	77.95	1.50		Saravali (Between Virar and Boisar)
9	125.45	125.90	0.45		Gaurwadi (Between Boisar and Vapi)
10	127.70	128.25	0.55		Jamshed (Between Boisar and Vapi)
11	130.90	131.50	0.60		Ambesari (Between Boisar and Vapi)
12	132.35	132.60	0.25		Ambesari (Between Boisar and Vapi)
13	148.15	148.35	0.20		Ambesari (Between Boisar and Vapi)
14	156.75	157.00	0.25		Ambesari (Between Boisar and Vapi)

Source: Study team

(3) GAD for Standard Structure

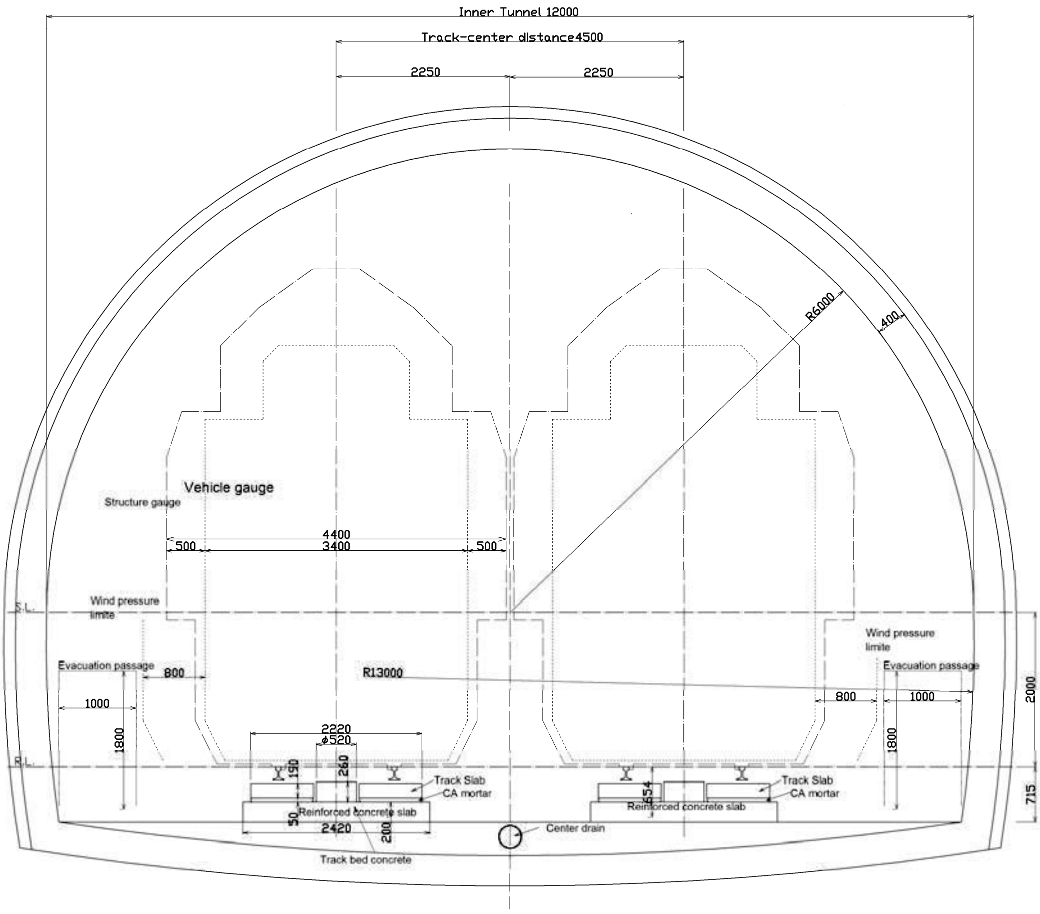


Figure 9.5-29 GAD for NATM Cross Section

9.6 Station

9.6.1 Station Facilities

(1) Station Facilities

HSR stations will become the gateway of the region. The principals of station planning are described in this Chapter 9.6.

A station for the region from an extensive point of view has to be connected to the regional transport mode such as Metro, BRT, taxi, buses, and private vehicles, and also to the existing railway station in several points to supply a connection for wide spread HSR users. Roads, parking areas, and Station facilities for passengers will be designed to handle large number of passengers, with safety and with convenience.

Each station has a difference in location, surrounding environment, number of passengers, frequency of HSR train operation, which gives a difference on each station's planning.

The Stations should generally provide the following facilities:

① Main station building: Station offices, Ticket windows, Ticket gates, Lavatories, etc.

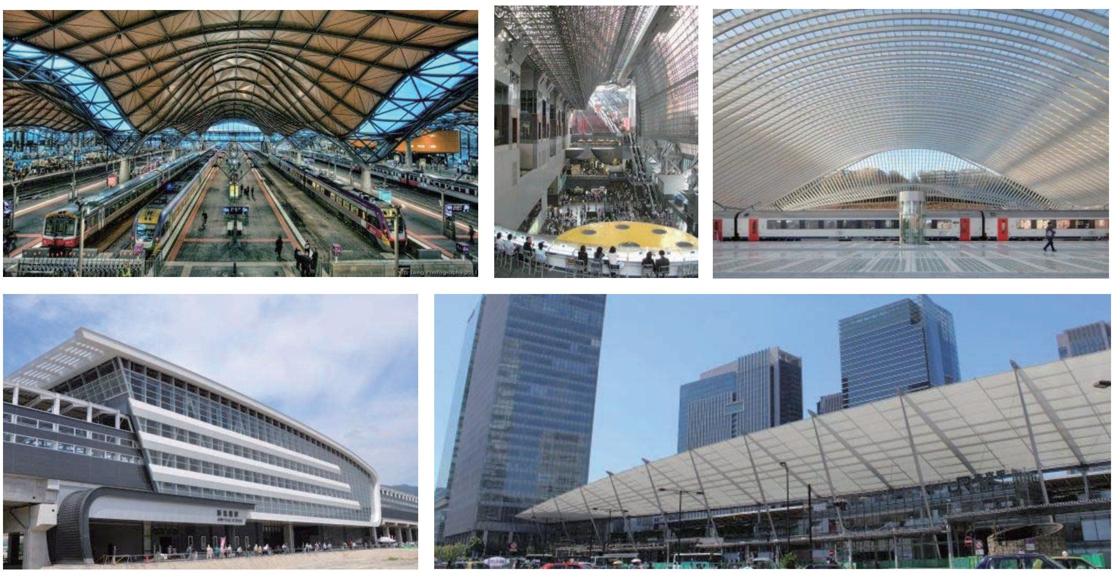
② Platform: Platforms, Windbreak screen, Train sheds, etc.

③ Passenger way: Over-bridges or Underpasses, Concourses, etc.

④ Structures: Signal cabins, Stations, etc.

⑤ Electric facilities: Lighting, Signaling, Communication equipment, etc.

⑥ Others: Security gates, Elevators, Fire prevention equipment, Drainage facilities



Source: JICA Study Team

Figure 9.6-1 Image of a Station Buildings

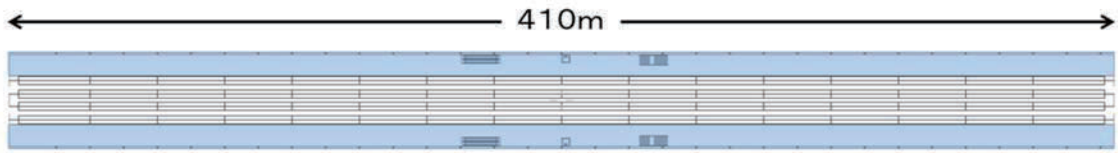
The facilities listed above will be designed under the engagement of universal design which is nowadays the international standards for India HSR operation. The universal design basic policies for the HSR stations are presented below.

- Simple traffic flow (visible access through the station.)
- Simple facility layout (Ex: exits and security gates along the traffic flow)
- Safety and passenger's convenience
- Functional station (efficient facility layout)
- Environmental comfort (air conditioning, lighting, acoustics, design quality, etc.)
- Station for every one (for different religion, language, race and origin)

(2) Areas for the Station

Not only the Station building but the station square, parking areas, and connected surrounding commercial and business facilities will compose the overall station area. The size, especially the length of the HSR Station is related to the platform length. The size of HSR car is 25.0 m long and 3.4 m wide. (The estimated number of cars per train is 10 at the beginning, increasing to 16 trains in the future.)The platform is designed to handle the future 16 car HSR train so the platform length will be designed to be 410m long due to the calculation bellow.

5m extra + 25m×16trains + 5m extra=410m



Source: JICA Study Team

Figure 9.6-2 Length of the station will be 410m due to the Platform Length

Source: JICA Study Team

Figure 9.6-3 Façade Image of the HSR Station

9.6.2 Station Concept

The philosophy of the HSR Station designing:
The following matters will be highly considered when designing the HSR Station.
1) Place the essential station facilities for HSR operation in an appropriate position
2) Accommodate with the development plans around the station
3) Design with comfort and convenience for passengers.

(1) Placing the essential station facilities for HSR operation in an appropriate position

The essential station facility for India HSR is comprised of the elements which are peculiar for HSR stations, and the elements peculiar to the Indian traditions.

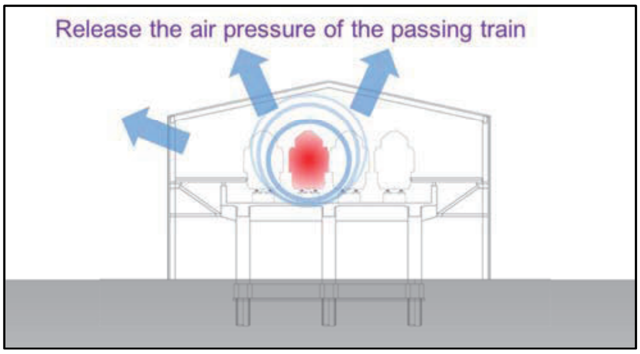
① Elements peculiar to HSR Stations

a) Windbreak screen

Windbreak screen will be constructed on the side of the platform to avoid the air pressure and the sound of the passing trains. System developed in Japanese HSR, releasing the feat and wind pressure of the passing train will be attached on the platform level to increase the passenger's safety

Source: JICA Study Team

Figure 9.6-4 Image of a Windscreen



Source: JICA Study Team

Figure 9.6-5 Ideas to Release the Air Pressure of the HSR Train

b) Train Sheds

A large roof Train Sheds without pillars on the platform level is preferable. This will create a visible platform view and a comfortable architectural space for passengers and also help the safe train operations.

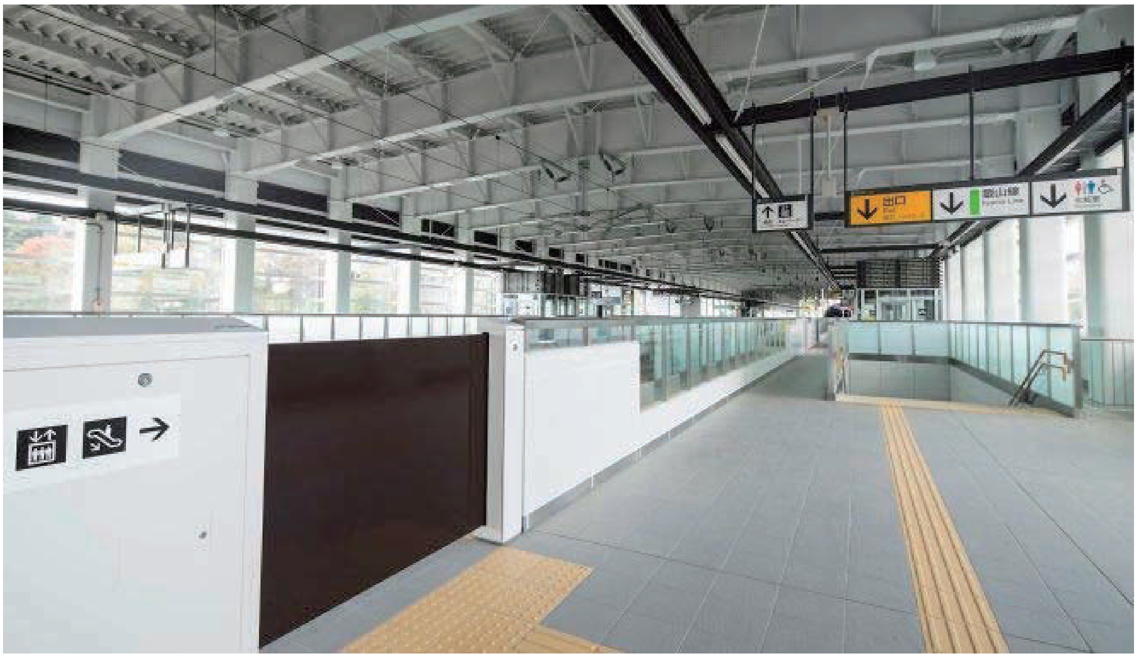
The large roof Train Shads will also prevent the passenger's inconvenience from wind and rain on the platform level. The high roof gives an impressive architectural experiment to the HSR train passengers

Source: JICA Study Team

Figure 9.6-6 Image of a Train Sheds

c) Platform doors

Passengers on the platform should be kept safe from HSR trains passing through the station. The study team has placed the passing tracks at most of the non-stop stations, so that the passengers will not directly face the passing train. Moreover, the study team has designed the size of the platform in advance with enough space for the future construction of the platform doors to achieve a higher safety level. The study team thinks that it is not necessary to provide a platform door system from the begging of the HSR operation, since the prospected number of passenger isnot so large which will not cause a congestion of the platform during these terms. The technological innovation of such external equipment is very fast and even the position of doors might change according to the train coach renewal in the future. It is preferable to install the platform door system at an appropriate period adapting the future situation.

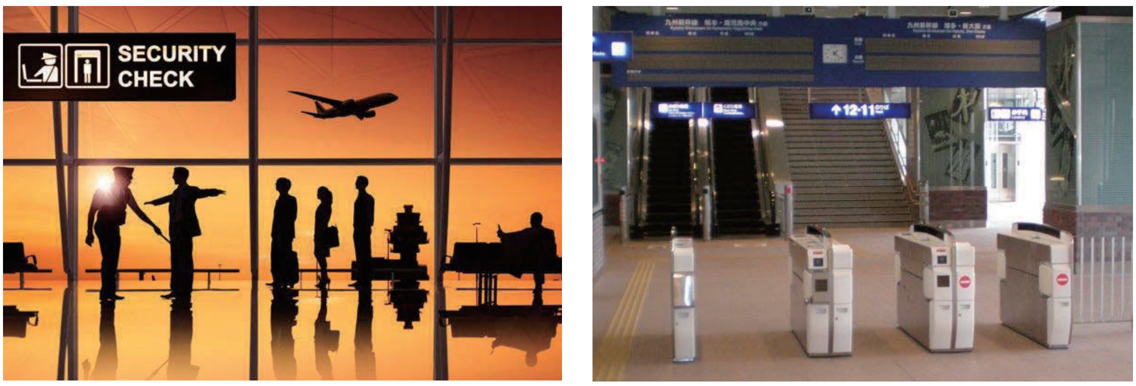


Source: JICA Study Team

Figure 9.6-7 Image of a Platform Doors for the Future Construction

d) Security Check

For safety reasons, same as hotels, airports and some subway stations, security gates are placed at the entrance of the HSR paid concourse. Ticket inspection is also done at this gate which will probably be replaced to AFC in the future.



Source: JICA Study Team

Figure 9.6-8 Image of Security Check Gates and the Future AFC

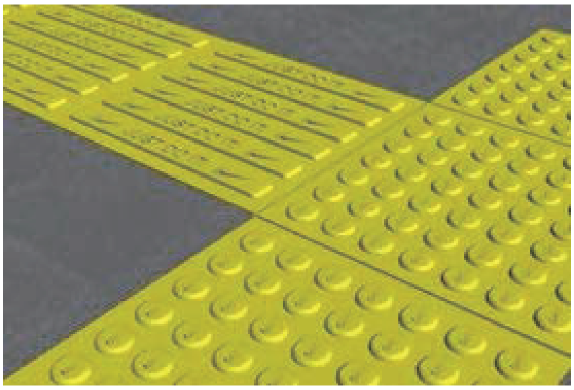
e) Universal Design / Lifts and Escalator

Multi-function lavatory: Multi-function lavatory has an adequate space for wheelchair users which contains handrail, wheelchair accessible wash basin, and baby chair in the cabin. At least one Multi-function lavatory will be preferable to be placed in each lavatory area.

Source: TOTO

Figure 9.6-9 Image of Multi-function Lavatory

Leading blocks: The leading blocks are placed on the floor leading handicapped passengers from the concourse to the platform.



Source: JICA Study Team

Figure 9.6-10 Image of Leading Blocks

Lifts and Escalators: At least one elevator is installed from the concourse to each platform. At least one pair of escalators is installed from the concourse to each platform. It has been designed for every station, that passenger who prefers can approach to the platform from the station square with elevators without using the stairs.

f) Other architectural regulations,

All the dimensions and volume calculations for the architectural facilities placed in the station would be designed based on the Japanese Regulation of HSR, since the size of the train, systems and policy of the operation will be approximately the same. This will enables to construct the station of India HSR without any failure thanks to our long time experiment and knowledge.

② Elements peculiar to the Indian traditions

a) Waiting room

Waiting rooms will be placed on the concourse level which is classified by HSR seat class. Due to the Indian traditions, the waiting room for both men and women will be prepared. Baby room is provided for passengers traveling with infants.

b) Prayer room

Though it has become ordinary to make a prayer room in public areas such as Airports and hotels, due to the Indian traditions, the prayer room is not planed in the India HSR. The policy is to keep the equality with every religion's passengers who will use the station.

Source: JICA Study Team

Figure 9.6-11 Prayer Room will not be Planned in the HSR Station.

c) Signage

Pictograms will be used to simplify the understandings for all station users. Multi language will be used in signage panels likeHindi, English, and Marathi will be described in Stations at Maharashtra. Hindi, English, and Gujarati will be described at Stations in Gujarat. A new regulation for the signage for India HSR might be necessary to be created.

Source: JICA Study Team

Figure 9.6-12 Image of Signage

d) Vegetarian/ Non-Vegetarian

Due to the Indian traditions, all the services in the HSR station are prepared for both Vegetarian and Non-Vegetarian.

e) Facility and service for every station users

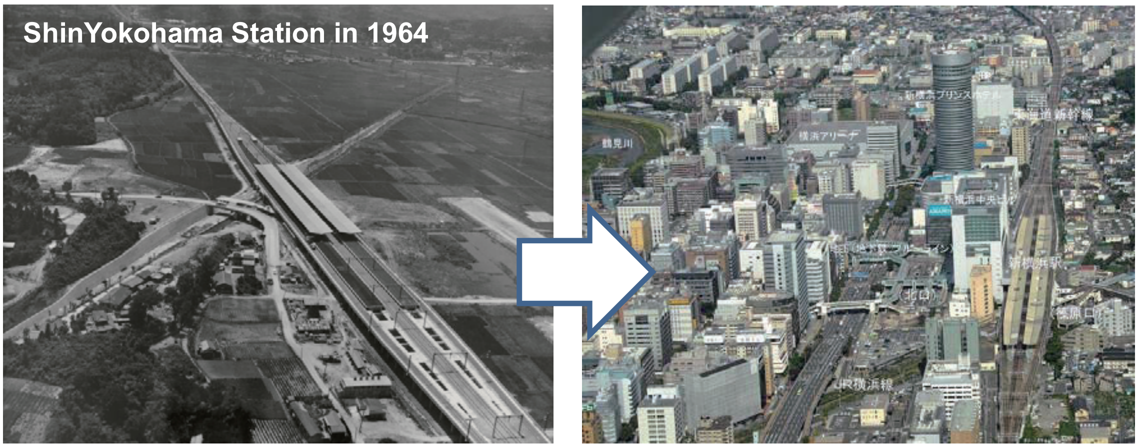
Station facilities (flow, toilet, lightning, security system, backyards etc.) will be designed with safe and comfort to every station users which includes all genders, old and young, and disabled persons. All the services in the HSR station should be in international standard levels, not only for Indian people but also for Passengers from all over the world,. The station facility and services should be friendly to all people with different religion, language, race and origin. This is not only for passengers but also for all Station workers and train Cabin attendants.

(2) Accommodating with the development plans around the station

① Transport: It is important to connect the new station with the mass transport system such as existing railways, Metro and the future planed BRT systems. The station square should be well connected to the main road for the convenient vehicular access.

② Urban planning: Many cities along the HSR line have already made their own master plans of the future urban planning. The study team is ready to cooperate with the local government to create an innovative urban plan concerning the influence of the HSR impact.

③ Proposal for the development plan around the new station: The areas around the stations have high economic potential. The study team is ready to propose a preferable development plans. Suspected relevant volume for business and commercial facilities for each station could be proposed based on the experiment of the study team.



Source: JICA Study Team

Figure 9.6-13 Development around Shin-Yokohama Station during these 50 years.

(3) Designing with comfort and convenience for passengers.

① The regional factors will be reflected in each station design. Local traditions and cultural matters should be highly respected to supply a convenience travel for all passengers with different religion, language, race and origin.

② The platform area will be designed to be visible. This will cause a safe HSR operation as well as helping the passengers to understand their destination easily. Concourse area will also be designed in the same method.

③ High quality designed station will become the new landmark of the city, with an elegant architectural atmosphere and showing the dynamism of the country's development. The station square will also be preferable to be designed together with the new station. The entrance of the station will be designed with a convenience access to and from the station square.

Station Layout concept

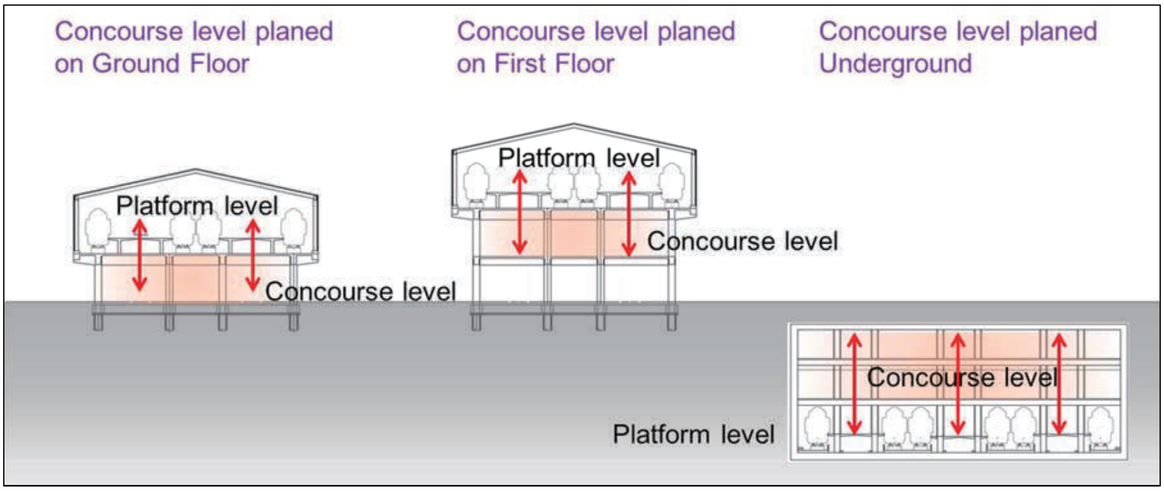
Reflecting the philosophical Station concept written above, the station layout will be designed as follows,

Platform level : the platform level will be placed on the top of the station except Mumbai Station which will be constructed underground.

Concourse level : the concourse level will be placed under the platform level except Mumbai Station which will be constructed underground. Due to the height of the platform level, the concourse level will be placed rather on Ground floor or at First floor.

Concourse level planed on Ground Floor	Virar, Boisar, Vapi, Bilimora, Surart, Bharuch, Anand/Nadia
Concourse level planed on first floor	Thane, Vadodara, Ahmedabad, Sabarmati
Concourse level planed under ground	Mumbai

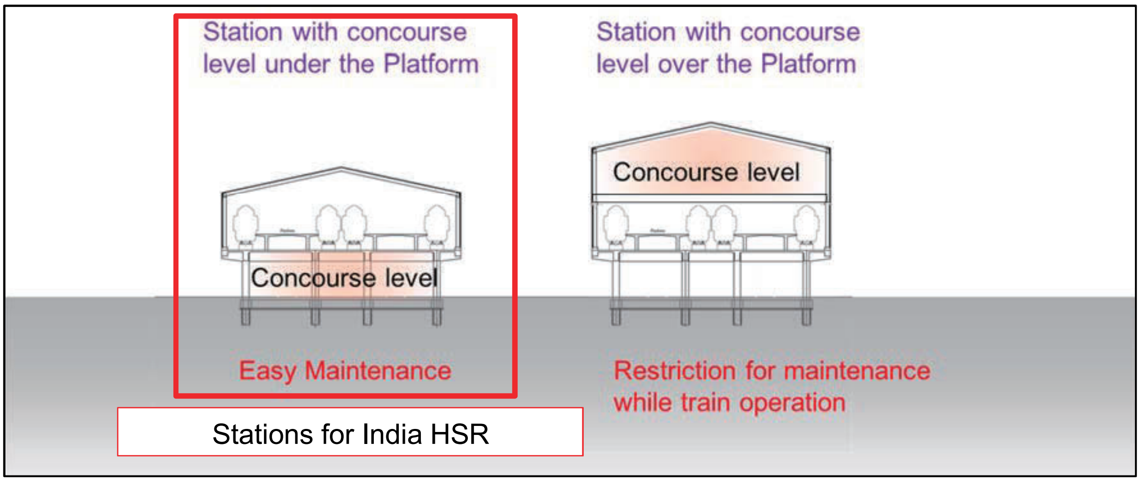
The Concourse level on the first floor will be connected to the ground floor with stairs, Escalators and Elevators, to approach to the station squares. In all stations, the concourse level is connected to the platform level from the paid concourse with stairs and Escalators as well as Elevators.



Source: JICA Study Team

Figure 9.6-14 Difference of Concourse Level

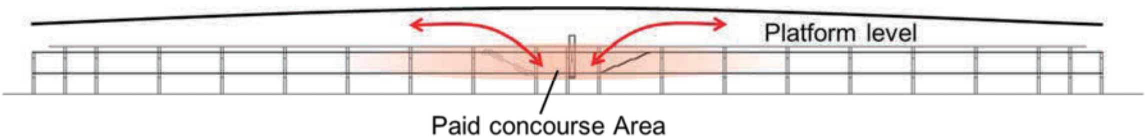
The Concourse level except Mumbai Station is located under the platform level. This will increase the maintenance availability during the train operation.



Source: JICA Study Team

Figure 9.6-15 Easy Concourse Maintenance

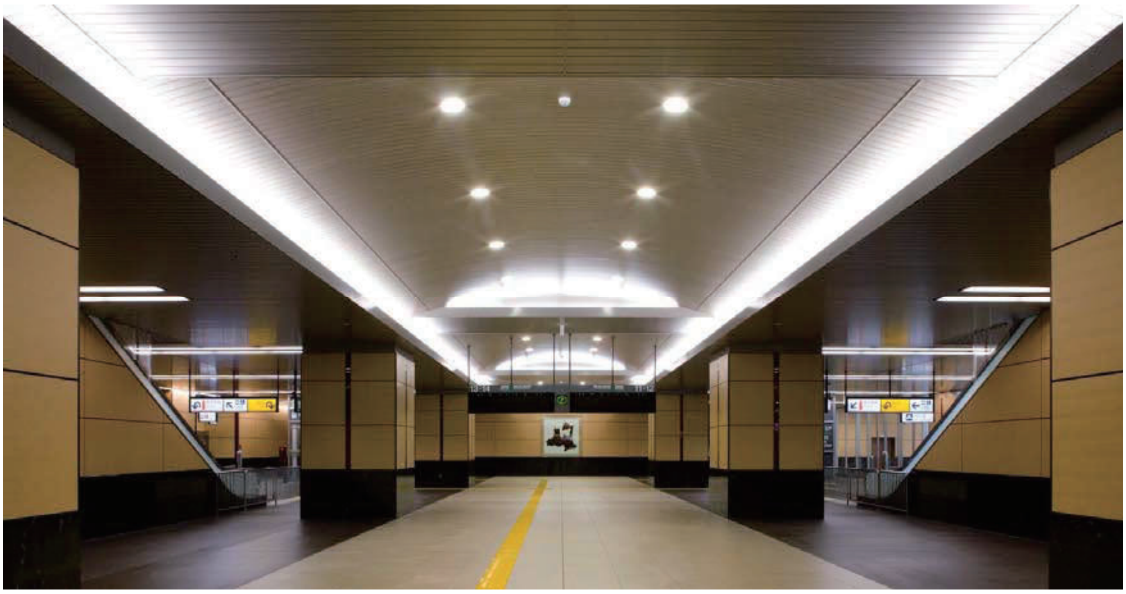
Free concourse and paid concourse: The Concourse area will be divided in to free concourse area and paid concourse area by the security gates. To integrate the ticket inspection at the security gates and simplify the passenger's flow, the paid concourse will be located below the center part of the platform where the stairs and escalator to the platform is situated.



Source: JICA Study Team

Figure 9.6-16 Paid Concourse will be Located in the Center Part of the Station.

Evacuation from the platform: At least one staircase is provided in each platform to be used for evacuation in case of emergency. The number is doubled in underground station. Escalators are not counted as an evacuation route following the Japanese HSR standards while the usage is accepted in Indian railway standards , following the Manual for standards and specification for railways (June 2009 MOR). Though, the Indian manual defines the minimum travel distance to the nearest stair case on the platform (which is not indispensable following the Japanese HSR standard),we have to decide to comply with either standards or create a new standards for India HSR during the next phase. If more the evacuation route is required resembles to the Indian standards, additional staircases will be provided and the layout of the concourse floor will be modified to supply these vertical flows.



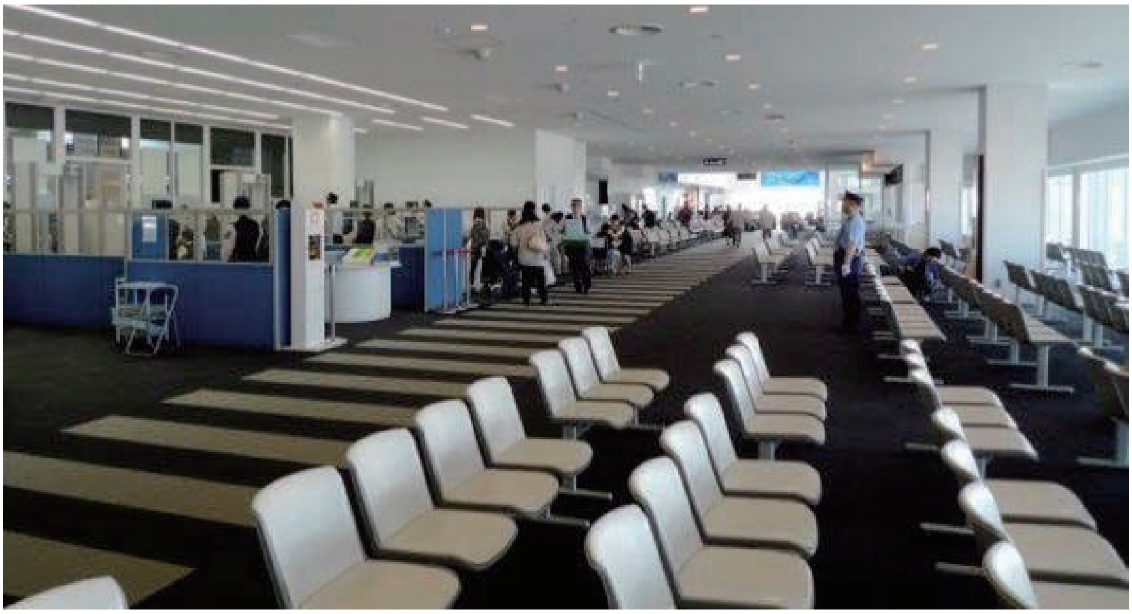
Source: JICA Study Team

Figure 9.6-17 Image of the Paid Concourse

Waiting areas: Security check and ticket inspection sometimes disturbs the passenger's convenient boarding to the train if passengers wait the train at the free concourse area. To avoid this inconvenience, the main waiting room will be placed in the paid concourse area while in some large stations, an additional waiting room will be constructed also in the free concourse area. The waiting room will be separated with passenger's seat class and also divided for each men and women, cause to the Indian tradition.

Source: JICA Study Team

Figure 9.6-18 Image of Waiting Room for Business Class Passengers



Source: JICA Study Team

Figure 9.6-19 Image of Waiting Room for Second Class Passengers

Lavatories: The main lavatory area is placed in the paid Concourse area, which is close to the waiting room for departing passengers and close from the train for arriving passengers. A small lavatory area will also be constructed in the free concourse area. The lavatories will be designed with beauty and should be kept clean with a frequent cleaning all through the day, since the clean lavatories directly effects the passengers satisfaction of using the HSR trains. The clean lavatories will help to represent the high quality services of India HSR.

Source: JICA Study Team

Figure 9.6-20 Image of Lavatories for HSR

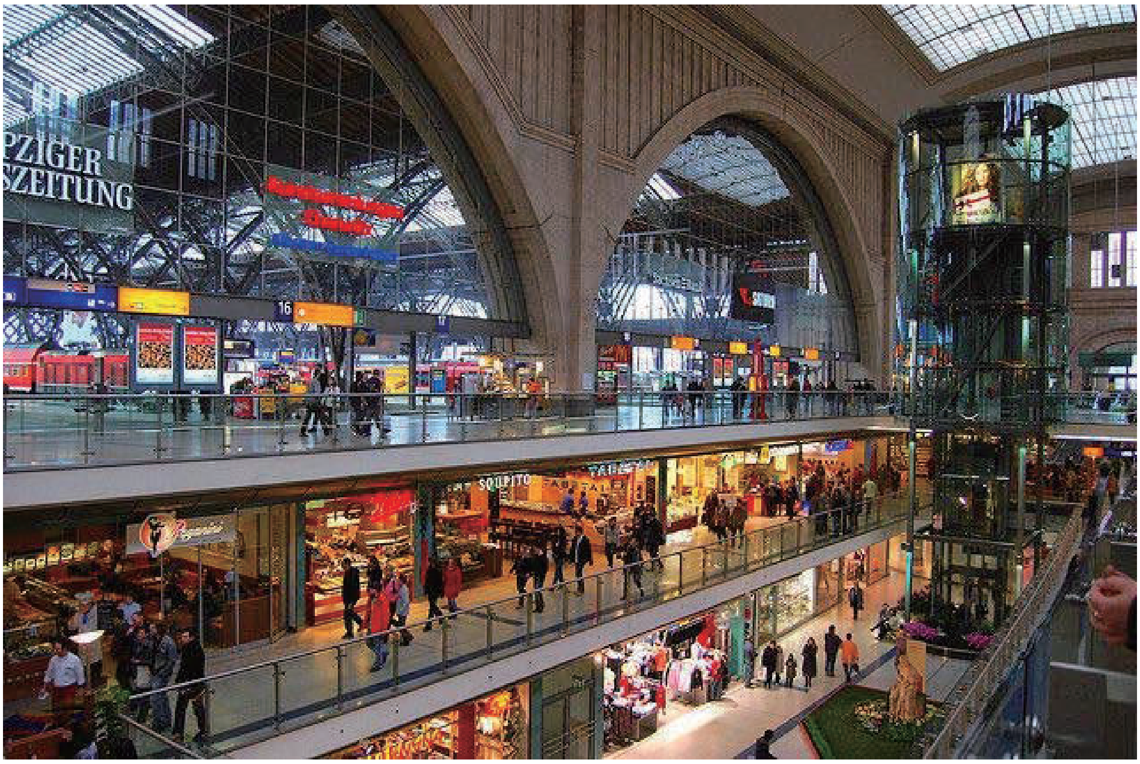
Shops and Restaurants: Shops selling beverages, snacks, light meal and souvenirs will be made in the paid concourse area. Travel agencies, banks, tourist information, taxi and hotel reservation stands will be made in the free concourse area. Our experience shows that restaurants will be better located in free concourse so that passengers can enjoy their meal with non-train users.

Source: JICA Study Team

Figure 9.6-21 Image of Shops in the Paid Concourse Area

Source: JICA Study Team

Figure 9.6-22 Image of Shops and Tourist Information in the Free Concourse Area



Source: JICA Study Team

Figure 9.6-23 Image of Commercial Zone in the Free Concourse Area

Box lunches stands: The sales of box lunch could make a great success in India HSR. Due to our experiment the box lunches would not only satisfy the passenger's appetite but also helps to characterize the region's identity. In Japanese HSR, each station competes to create their original box lunch to fascinate the passenger's heart. The box lunch business for HSR might also succeed in the Indian HSR market.

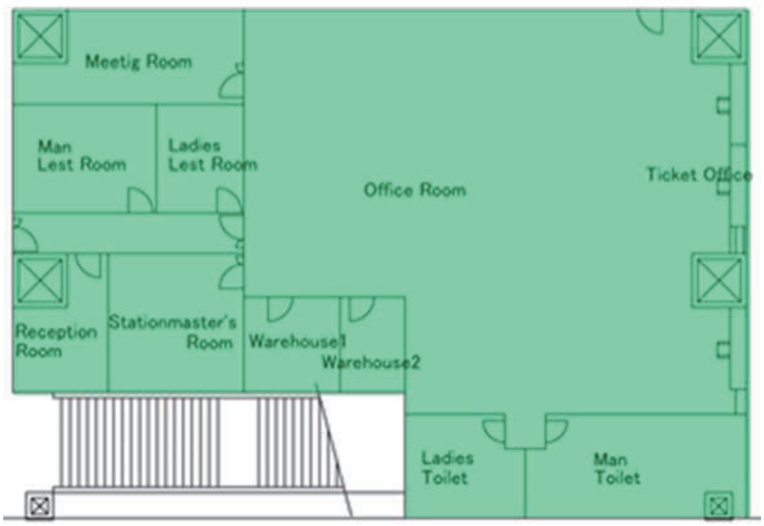
Source: JICA Study Team

Figure 9.6-24 Image of Box Lunch
One of the Most Famous Box Lunch in Japan Soled in Nagano HSR Station

Source: JICA Study Team

Figure 9.6-25 Image of Lunch Box Stand

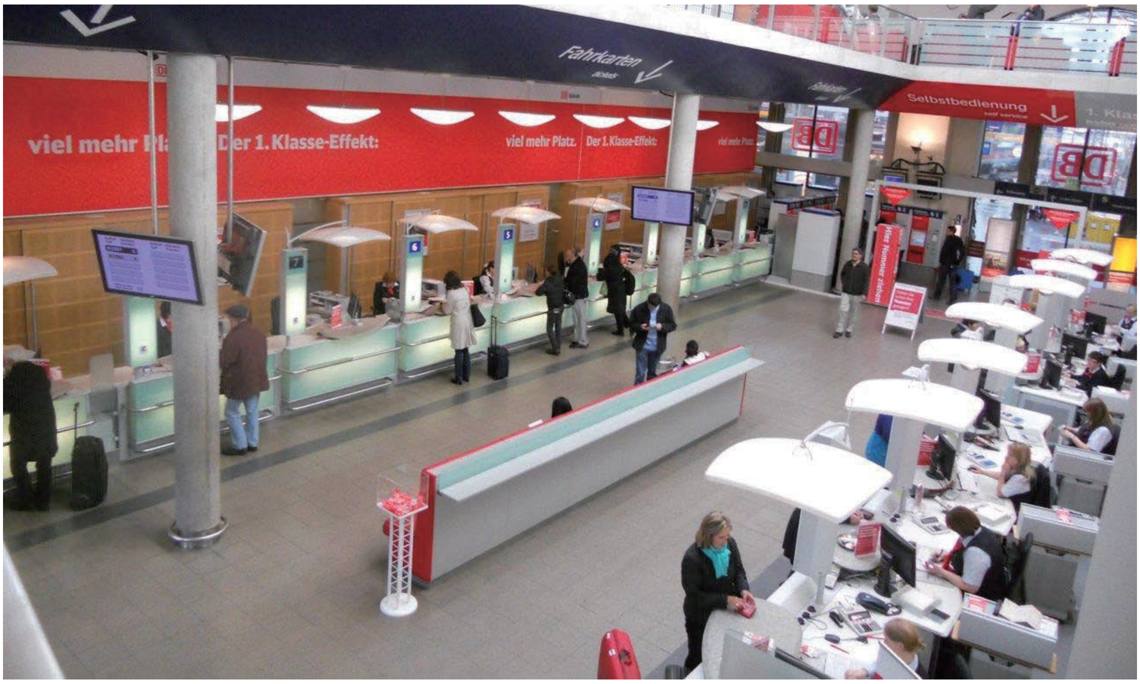
Station Office: Station office will be located close to the security gates and to the ticket office. The volume of the office is calculated based on the study team's experiences, though we will cooperate to determine the exact volume needed for each station.



Source: JICA Study Team

Figure 9.6-26 Image of Station Office for Small HSR Station

Ticket Counters: Although the tickets could be purchased by internets and in travel agencies, ticket counters would be placed in the free concourse area of the station. Preferably they would be located close to the station office since the cashing system is better to be combined.



Source: JICA Study Team

Figure 9.6-27 Image of Ticket Counters

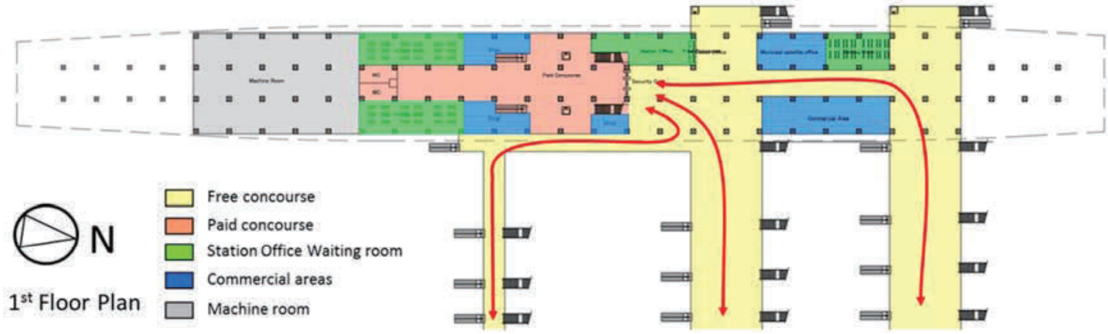
Municipal satellite office: Municipal satellite office could be situated in the station area in request bases.

Source: JICA Study Team

Figure 9.6-28 Image of Municipal Satellite Office

Machine room: Machine rooms are needed in all stations to place the machineries for electricity, sanitary and air conditioning and also place for a transformer substation in each station will be needed.

Connection with the existing station: As written in detail in chapter 4, Ahmedabad and Vadodara station locates close to the existing railway station. HSR Station will be connected with the existing station rather with a renovated existing bridge or by building a new passenger bridge. The bridge will be connected to the free concourse of the HSR station where passengers can buy their tickets.



Source: JICA Study Team

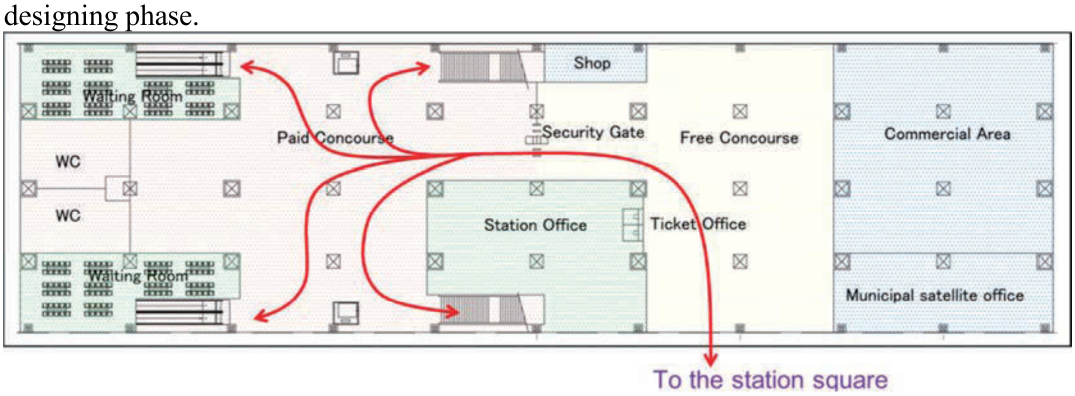
Figure 9.6-29 Connection to the Existing Railway Station (Vadodara Station)

Connection to the city: The HSR station will be connected to the city by both public and private transportation. The connection to other transport mode will be held mainly at the station squares located on the ground floor. The details are described in Chapter 9.6.5 and 9.6.6. An easy access flow is made to lead passengers to the station concourse and offers a convenient boarding to the HSR

Source: JICA Study Team

Figure 9.6-30 Connection with Other Transport Mode to Connect the City

Based on the station Layout concept written above, the typical concourse plan is designed as follows. The dimension and capacity of each facility will be decided more in detail during the designing phase.



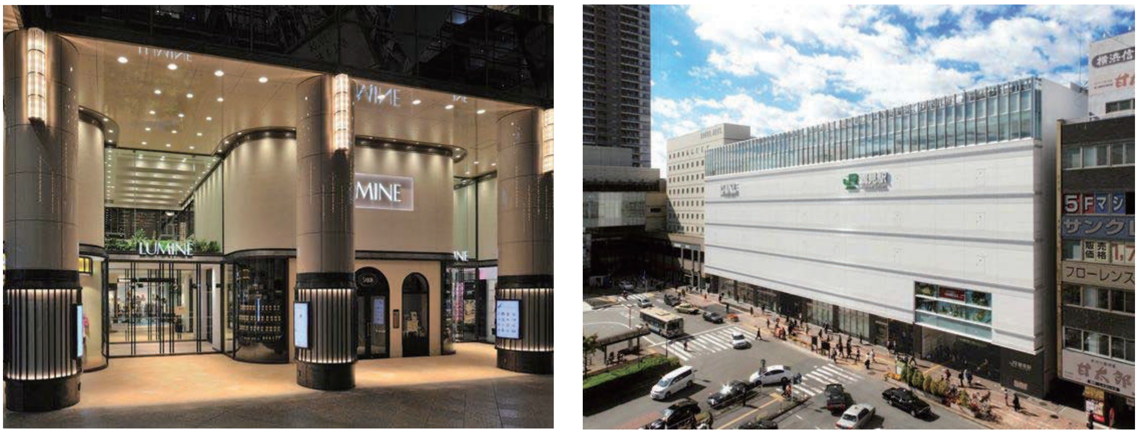
Source: JICA Study Team

Figure 9.6-31 Typical Concourse Floor Plan

Other related business: The effective use of land will help to increase the profit of HSR business. Office towers could be built around the station since real estate business is one of the main services for railway companies nowadays. Department stores, hotels also have a good congeniality with HSR business. Space bellow the RC rigid frame structure of the HSR train track could also be used as parking spaces for cars and buses.

Source: JICA Study Team

Figure 9.6-32 Image of Real Estate Business around the Station



Source: JICA Study Team

Figure 9.6-33 Image of Department Stores

Source: JICA Study Team

Figure 9.6-34 Image of Hotels

Source: JICA Study Team

Figure 9.6-35 Image of Parking bellow the Train Track

Respect the local identity: Since the new HSR station will become a landmark of the region, the architectural design will be modern to show the development of the country. But at the same time it should be designed with full understanding of the Indian culture and traditions. As like the example of the new Mumbai Airport terminal, architects will work to elaborate new modern Indian style architecture.

Figure 9.6-36 Elaborate a New Modern Indian Style Architecture for the HSR Stations
(Image of Mumbai Airport)

Station Overall design: The planes of each station shown below gives the basic ideas for the HSR station in each location. These are planed somehow with the minimum requests and budget which is necessary for the HSR operation. With further studies and cooperation with the local governments and railway companies, the study team is ready to design a station to better fits the demand and to create a marvelous land mark for the region. The additional budget from the local governments to improve the function and to design a beautiful architectural station is highly welcome and is occasional in HSR development in Japan

Source: JICA Study Team

Figure 9.6-37 Examples of Beautiful Stations around the World

9.6.3 Station Structure

(1) Standard Structure Type for Elevated Stations

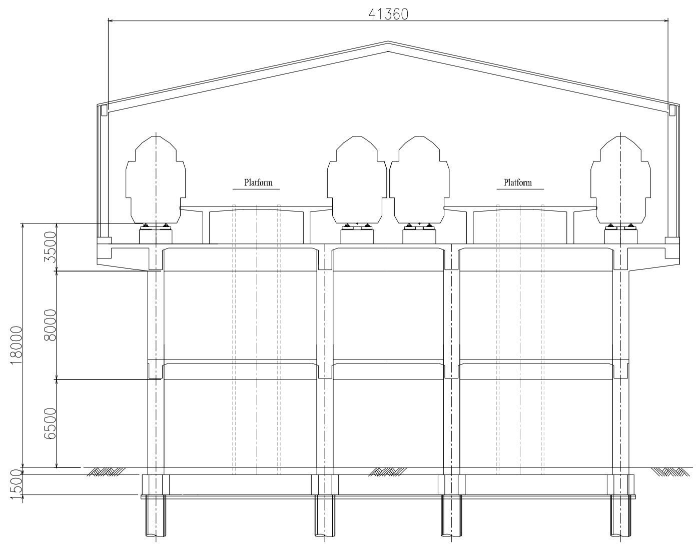
Structure types for elevated stations are categorized into two types based on the platform type of each station which could be reconsidered after following stage survey. Table 9.6-1 below shows the structure types of elevated station.

Table 9.6-1 Structure Types of Elevated Station

Platform Type	Structure Type	Stations
● Island platform with 2-platforms and 4-lines ● Island / Separate platform with 2-platforms and 5-lines	RC Rigid Frame / Integrated type of civil and architect structure	Thane, Boisar, Surat, Bharuch, Vadodara, Ahmedabad, Sabarmati
● Separate platform, 2-platforms with 4-lines	RC Rigid Frame / Hybrid type of civil and architect structure	Virar, Vapi, Bilomora, Anand/Nadiad

1) RC Rigid Frame / Integrated Type of Civil and Architectural Structure

Integrated type is used for the stations which are the "Island platform with 2-platforms and 4-lines", and "Island / Separate platform with 2-platforms and 5-lines". The civil structure is made of RC rigid frames that consist of the RC-slab which is supported by upper beams (main beams and lateral beams aboveground) and also main & lateral beams underground and piles. The architectural elements such as platform roof, windbreak screen, are composed by steel frame structures. The roof is decided not to leave pillars on the platform level to create a visible platform view. Figure 9.6-38 shows the typical cross section of the station structure.

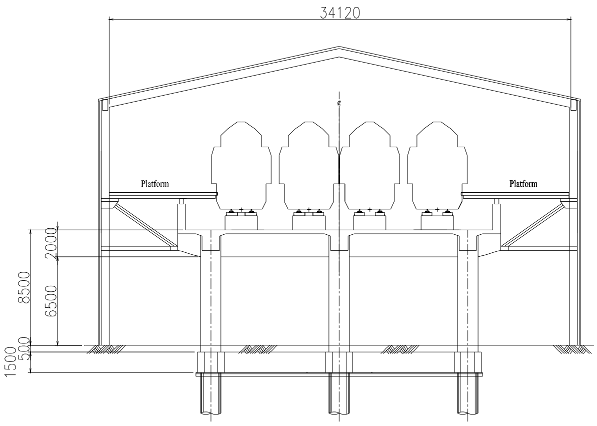


Source: JICA Study Team

Figure 9.6-38 Typical Section of Station Structure (Integrated Type)

2) RC Rigid Frame / Hybrid type of civil and architectural structure

Hybrid type, which consists of the civil structure (supporting the tracks) and the architectural structure (roof and exterior coverage) will be used for the stations with the platform type "Separate platform, 2-platforms with 4-lines". Similar to the integrated type, the civil structure is made of RC rigid frames that consist of RC-slab which is supported by upper beams (main beams and lateral beams aboveground) and also main & lateral beams underground and piles. The architectural elements such as platform roof, windbreak screen, are composed by steel frame structures. The roof is decided not to leave pillars on the platform level to create a visible platform view. Figure 9.6-39 shows the typical cross section of the station structure.

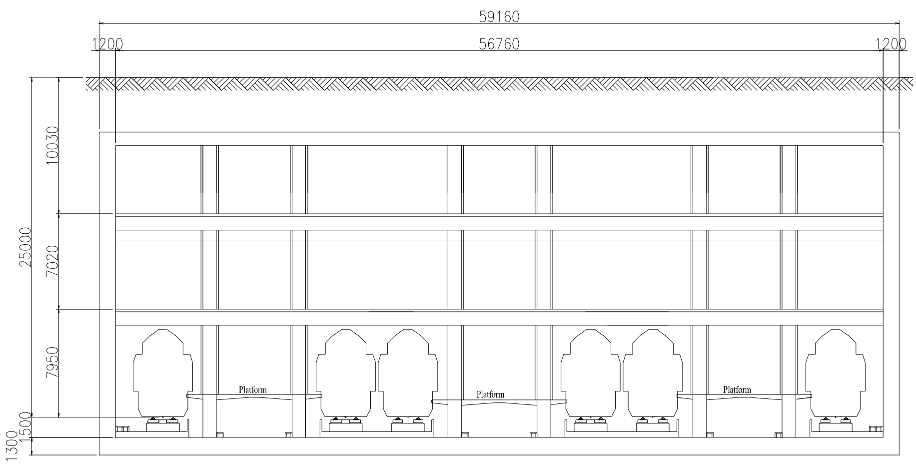


Source: JICA Study Team

Figure 9.6-39 Typical Section of Station Structure (Hybrid Type)

3) Station Structure Type for Underground Station (Mumbai Station)

RC rigid frame with three underground layers is used for the underground station structure. Figure 9.6-40 shows the typical cross section of the station structure



Source: JICA Study Team

Figure 9.6-40 Typical Section of Station Structure (Underground Station)

9.6.4 Station Square

(1) Calculation of Area for Station Square

The following table shows the calculation for the demanded area of the station square. It is calculated by a Japanese standard formula, which is widely used in Japan, which we recommend to adopted for India HSR stations. In some stations the result shows quite small a number related to the estimated number of passengers, the study team has decided to have 5000m^2 as a minimum demanded area for the HSR stations in India.

Table 9.6-2 Formula of Area Calculation of Station Square

Upper limit	A = 0.271 x B +11.22 √B (B ≦ 30,000) A = 58.90 x √B (B ≧ 30,000)
Normal	A = 0.238 x B + 9.85 √B (B ≦ 30,000) A = 51.65 x √B (B ≧ 30,000)
Lower limit	A = 0.217 x B + 8.99 √B (B ≦ 30,000) A = 47.16 x √B (B ≧ 30,000)

- A: Area of station square, B:No. of station users (passengers and visitors) per day

Table 9.6-3 Result of Area Calculation of Station Square

Station	No. of station users per day (in Year 2053)	Area of station square (m^2)
Mumbai	157,000	- - -
Thane	15,598	6,000
Virar	10,708	5,000
Boisar	3,922	5,000
Vapi	10,064	5,000
Bilimora	5,074	5,000
Surat	23,844	9,000
Bharuch	4,620	5,000
Vadodara	31,094	11,000
Anand/Nadiad	18,444	7,000
Ahmedabad	109,762	(20,000)
Sabarmati	13,676	(6,000)

- Area of Station Square is rounded up to the nearest 1,000 m^2.
- All estimated station square area is calculated with a Japanese standard formula.
- The minimum area of station square is decided as 5,000 based on experience in Shinkansen.
- The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

Source: JICA Study Team

Figure 9.6-41 Image of Station Square

9.6.5 Parking Space at the Stations

Park & Ride is a system to connect private vehicles to the public transportations. This system is recommended especially at the station located at the suburban area, to make convenient access to the railways and accelerates the use of HSR train. In some stations this system will help to increase the passenger's accessibility to the station.

(1) Area of Parking Space at Each Station

Based on the Japanese calculation formula, the area of parking space is calculated as bellow:

A x 1/2 x B x C = D

A: No. of boarding & alighting at each station (in Chapter 5)
B: Share of private cars at each station
C: Average No. of passengers on each car (1.3 persons/car: based on the manual for design and implementation of station square in Japan)
D: No. of cars expected to use parking space

D x 30 m^2/car* = E

*: Required parking space per a car (based on the manual for design and implementation of station square in Japan)
E: Required parking area (m^2)

The share of private cars at each station is defined as below to estimate the volume of the parking area required.

(2) Share of Private Cars at Each Station

The share of private cars of each station is estimated compared to the similar station in Japan.

For Mumbai, Vadodara and Ahmedabad stations, which are located at the central part of the mega city, the share at Tokyo station is applied (0.2%*). Tokyo station is located at the central part of Tokyo city. Tokaido, Tohoku, Joetsu and Hokuriku Shinkansen and many conventional lines are available at the station.

For Thane, Surat and Sabarmati stations, which are located at suburban area of the mega city, the share at Shin-Yokohama station is applied (1.0%). Shin-Yokohama station is located at the suburban area of Yokohama city. The station was built in middle of a field when Tokaido Shinkansen wasinaugurated. The station was connected to the central part of Yokohama city and the area around the station has developed gradually.

For Virar, Boisar, Vapi, Bilimora, Bharuch and Anand/Naidad, which are located at suburban area of the middle sized city, the share of Shin-Kobe station (17.78) is applied. Shin-Kobe station is located at suburban area of Kobe city which is one of the major cities in western part of Japan. Shinkansen is not connected to conventional line at the station but the terminal of conventional line is located close to the station.

(3) Area of Parking at Each Station

The parking area is estimated below based on the calculation in (1).

Station	Number of Private Cars	Area of Parking (m^2)
Mumbai	(121)	(3,700)
Thane	60	1,800
Virar	732	22,000
Boisar	268	8,100
Vapi	688	20,700

Bilimora	347	10,500
Surat	92	2,800
Bharuch	316	9,500
Vadodara	(24)	(800)
Anand/Nadiad	1261	37,900
Ahmedabad	84	2,600
Sabarmati	53	1,600
Total	-	122,000

Source: Study Team

The particular consideration is required at Mumbai and Ahmedabad station since the space around both stations is limited.

On the other hand, drastic park & ride scheme can be proposed at suburban station such as Surat station where the space for parking can be secured since around the proposed station is green field area and huge passenger demand can be expected. As the case of park & ride for HSR, Aix en provence station of TGV is shown, where the parking area for park & ride is facilitated around the station. Passengers can come to the station by highway and transfer to TGV.

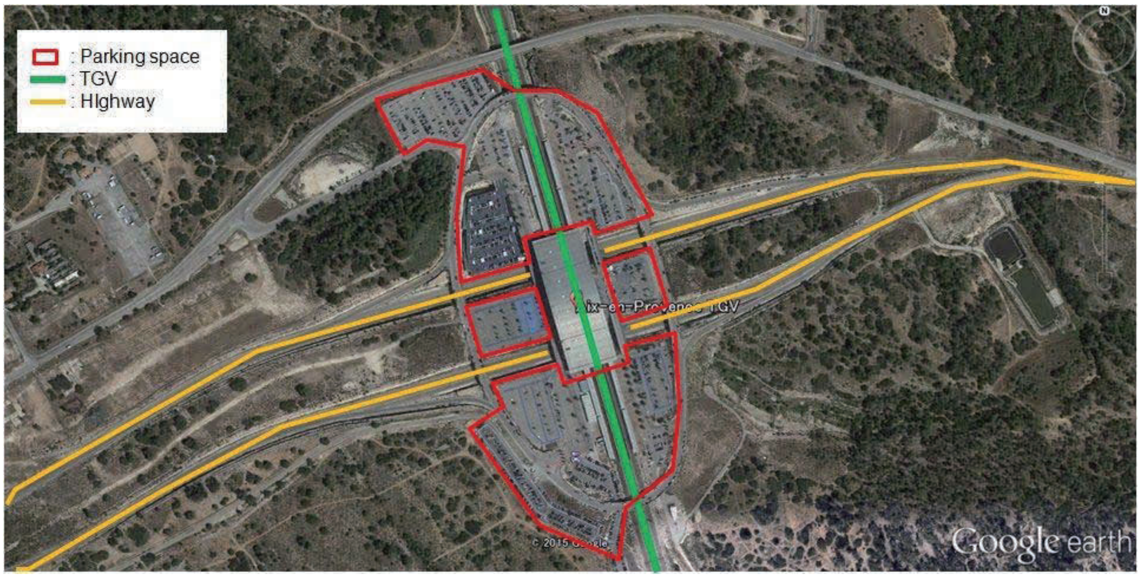


Figure 9.6-42 The Case of Aix en Provence Station of TGV, France

Since proposed Surat station is located in green field area, some space around the station can be shared for parking area as shown in Figure 9.6-43. But the area in front of the station has huge potential for land use such as commercial, business and residential, the balance of each land use should be considered and planned.

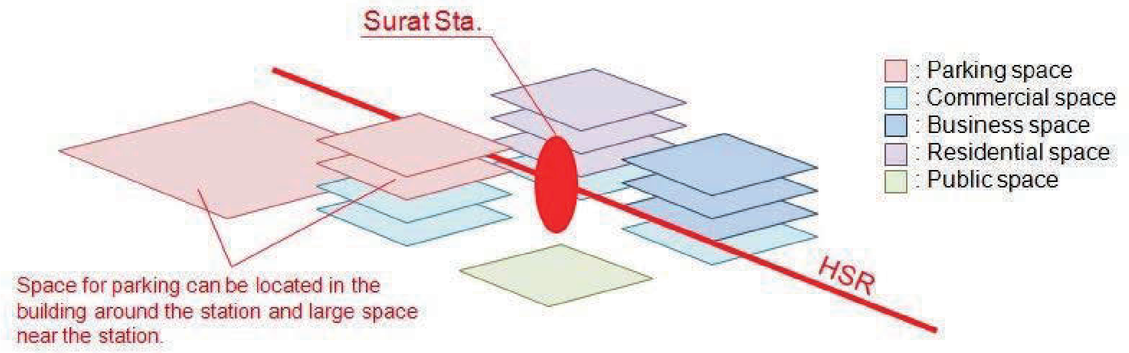


Figure 9.6-43 Image of Parking Space Distribution at Surat Station

At Vadodara and Sabarmati station, the railway land around the station can be used for parking space.

At Vadodara

There is huge railway land parcel at Sabarmati station. The area of the space is 220,000m2 which is equal to parking area for 7,300 cars. Though the area should be utilized by applying other land use such as commercial, business and residential, the area can be used for encouraging park & ride scheme.

Figure 9.6-44 Railway Land Parcel around Sabarmati Station

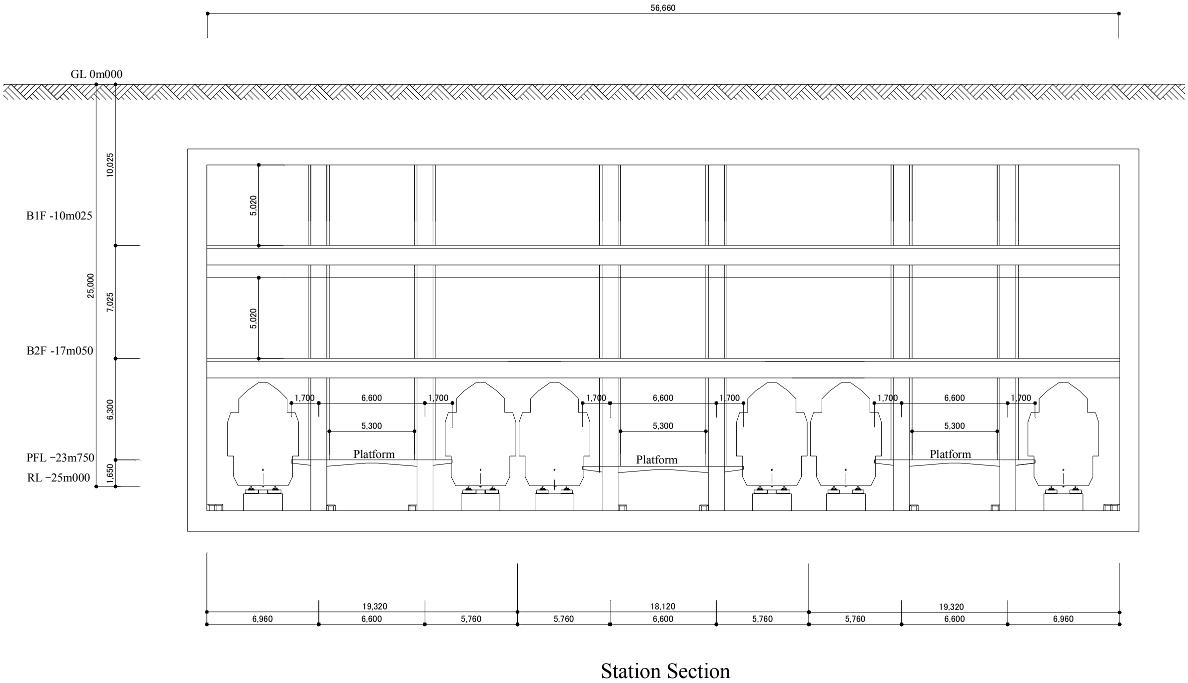
9.6.6 Station and Station Square Plan

Plans, Sections of each station and the minimum size of the required station square are shown in this chapter. As written in Chapter 9.6.2, Plans and design shown below gives only the basic ideas for the HSR station in each location. These are planed somehow with the minimum requests and budget which is necessary for the HSR operation. The study team will discuss with the local governments and railway companies to create the real plans in the next phase of the consulting work. The dimension and capacity of each station facility (including commercial facilities) should be decided more in detail during the next phase. The usage of the ground floor of the 3leveled station (Thane, Vadodara, Ahmedabad and Sabarmati) is kept undecided, since more coordination with the related agencies are needed to finalize the usage of this space including the coordination with the existing railway facilities.

(1) Mumbai

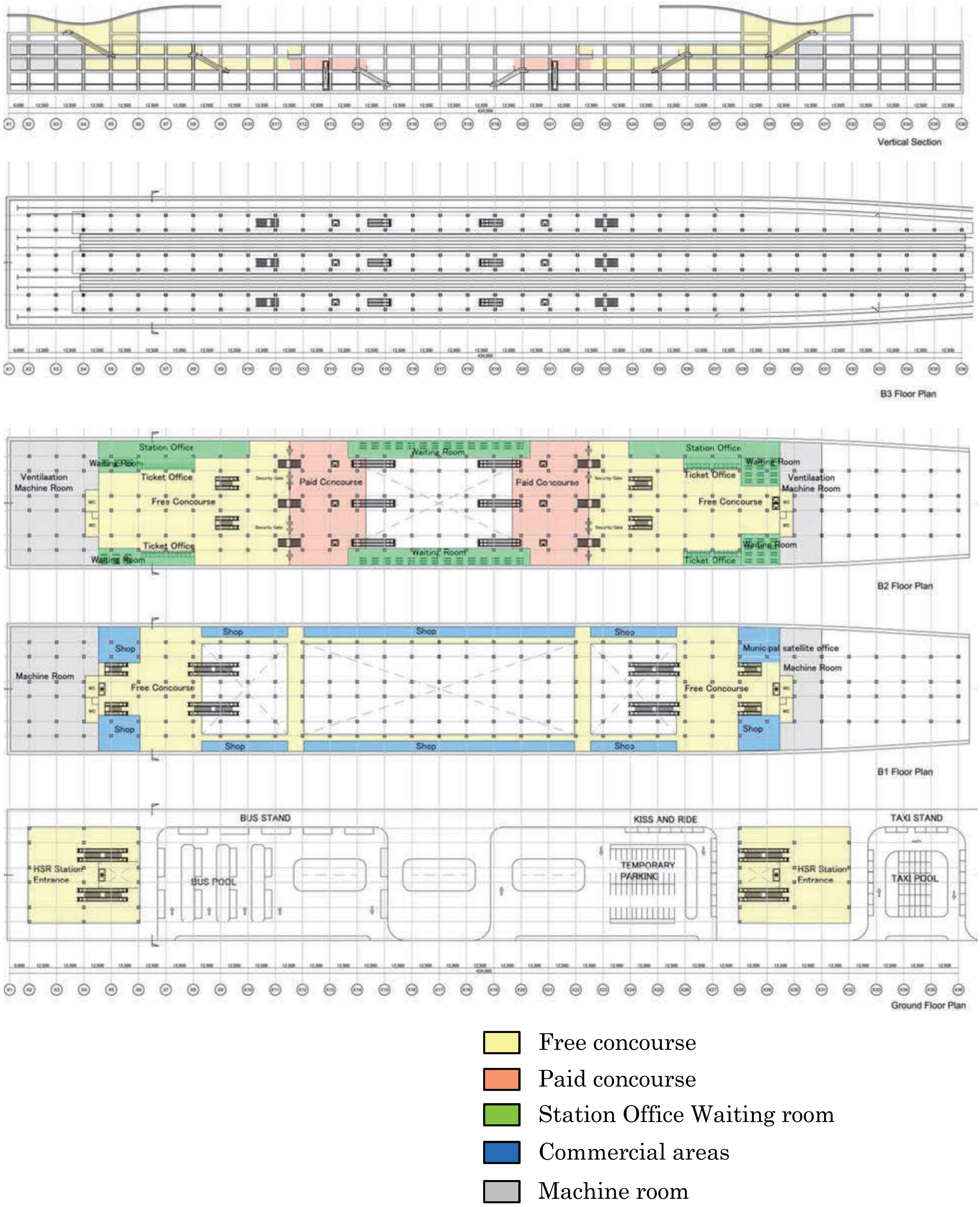
1) Station Building

Mumbai Station is planned as an underground station. Three (3) island platforms with six (6) lines will be in the basement third floor and a concourse on the basement second floor. Interchanges to the Metro rail will be provided on the basement first floor. The ground floor will be used for bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

Figure 9.6-45 Cross-sectional View of Mumbai Station



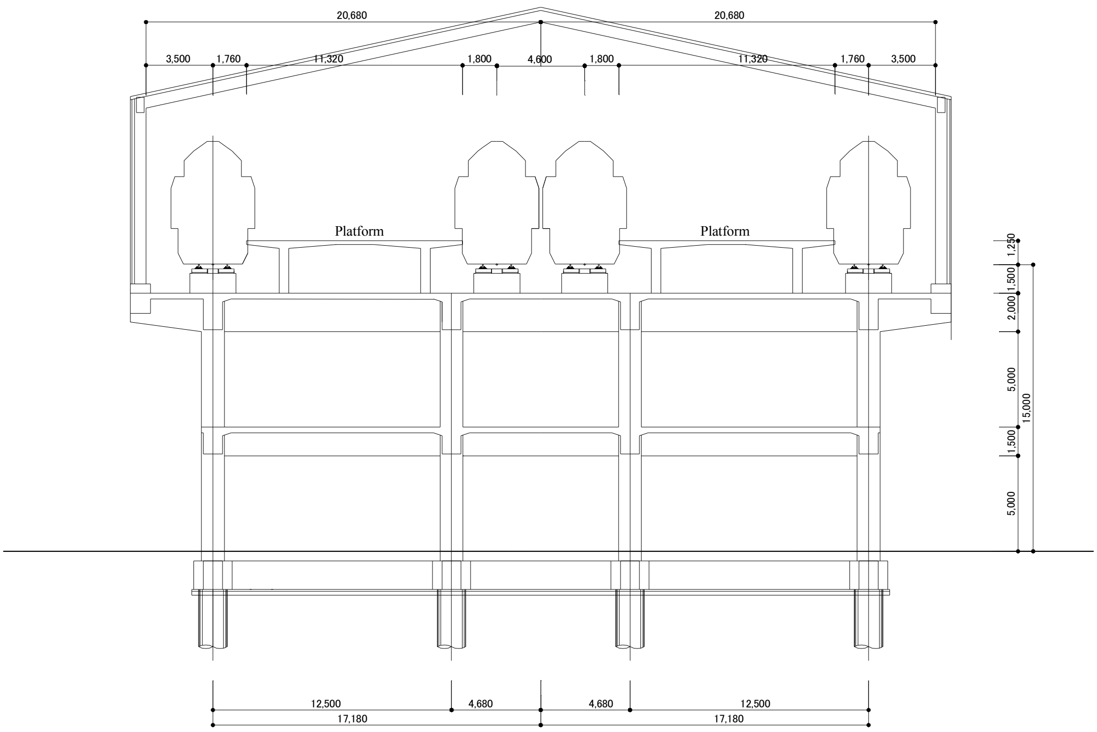
Source: JICA Study Team

Figure 9.6-46 Top View of Mumbai Station Plan

(2) Thane

1) Station Building

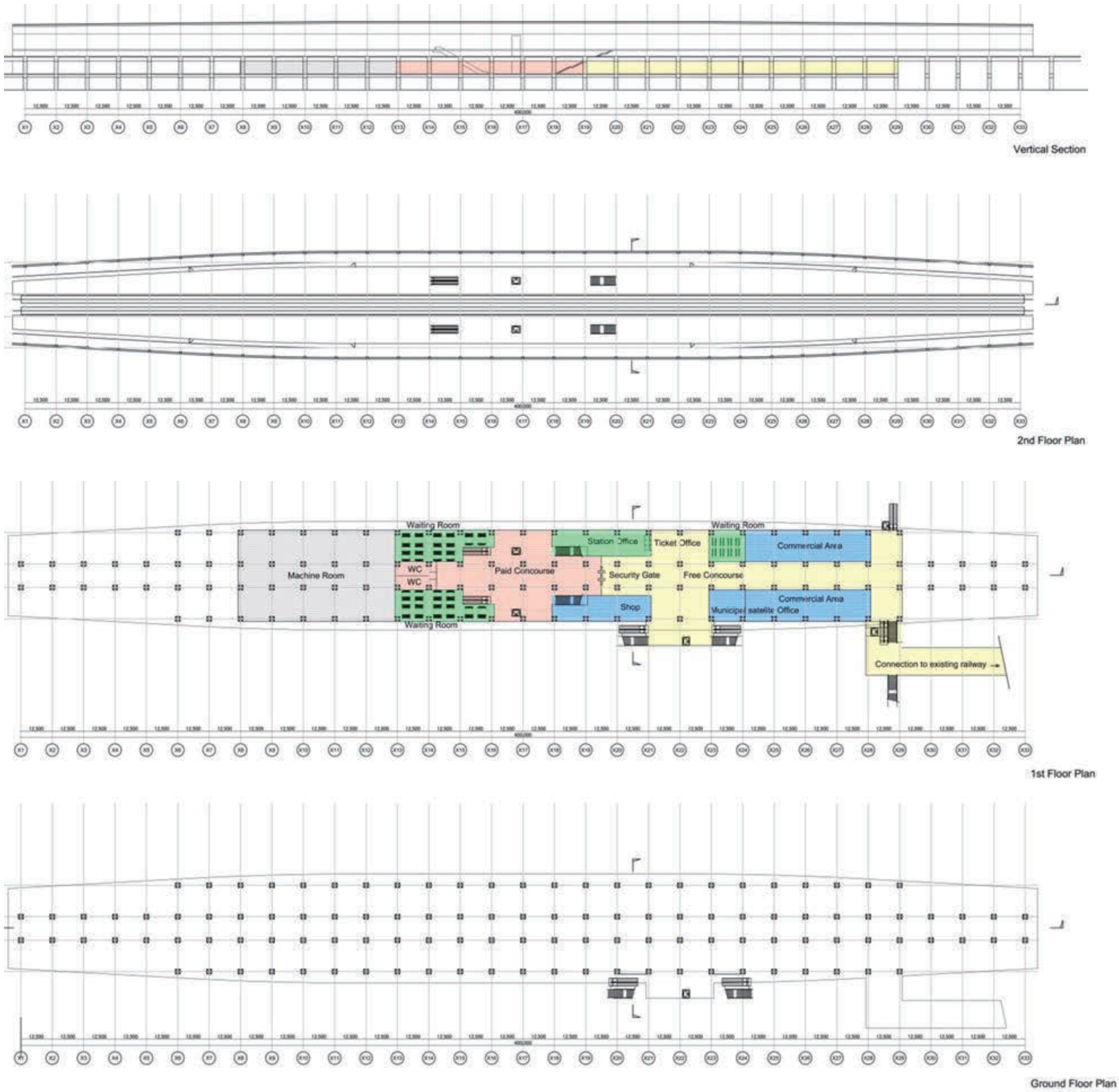
Thane Station is planned to comprise of three elevated stories. Two (2) island platforms with four (4) lines will be on the second floor and a concourse on the first floor. Interchanges to the Conventional rail will be provided on the first floor. The ground floor will be used for bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

Figure 9.6-47 Cross-sectional View of Thane Station

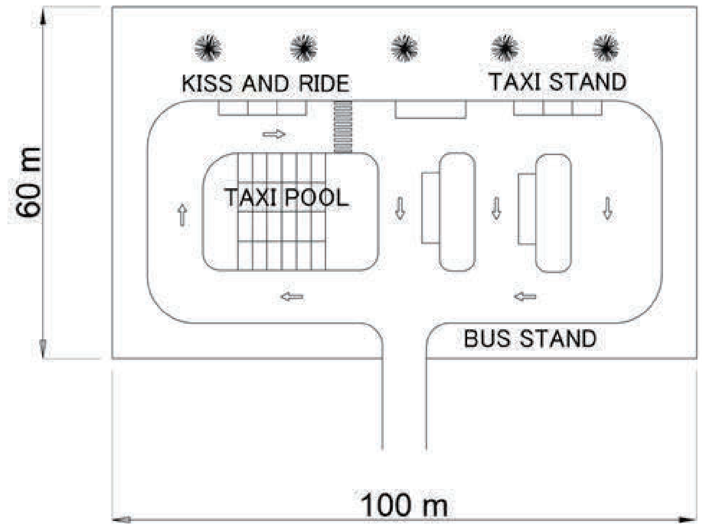


Source: JICA Study Team

Figure 9.6-48 Top View of Thane Station Plan

2) Station Square

The plan for Thane station square is shown below. It is necessary to consider separately the new station square of conventional Station.



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

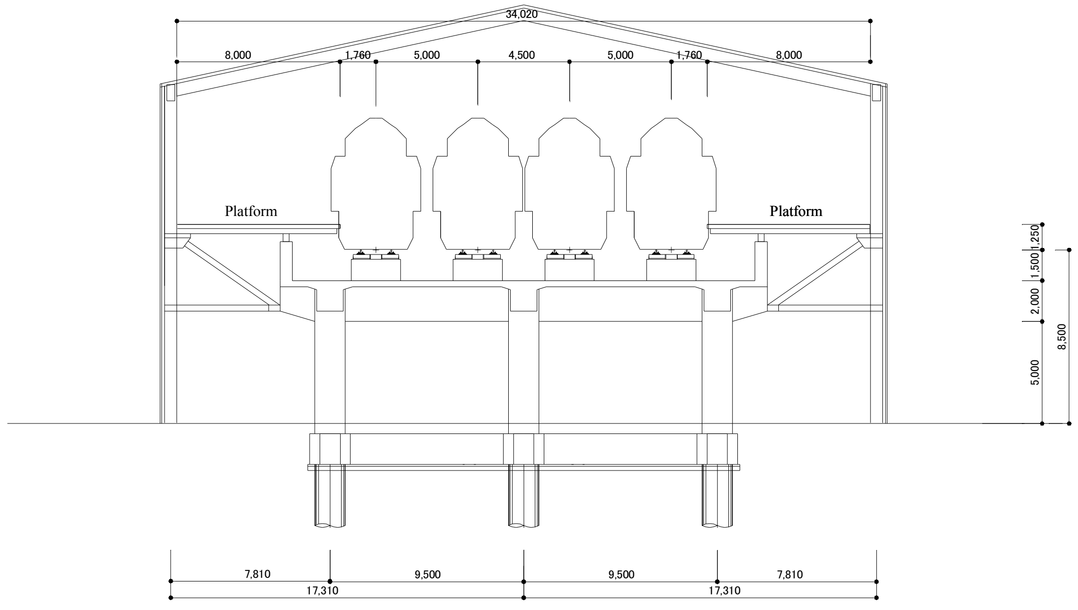
Source: JICA Study Team

Figure 9.6-49 Top View of Thane Station Square

(3) Virar

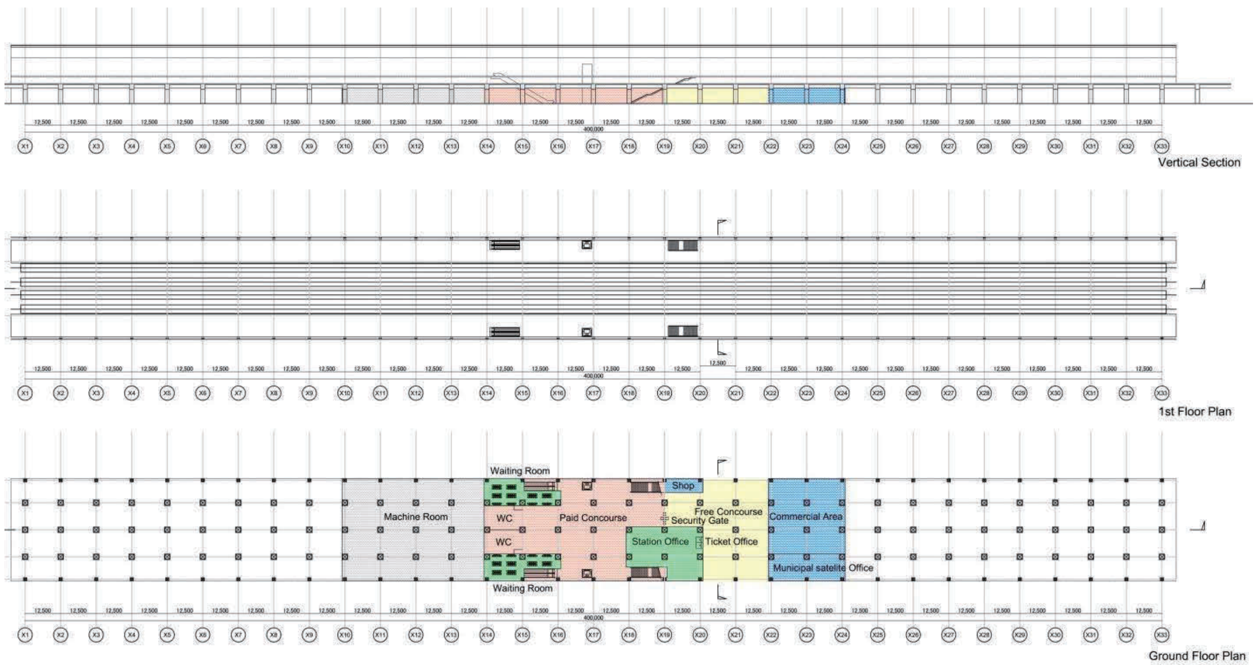
1) Station Building

Virar Station is planned to comprise of two elevated stories. Two (2) side platforms with four (4) lines will be on the first floor and a concourse on the ground floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

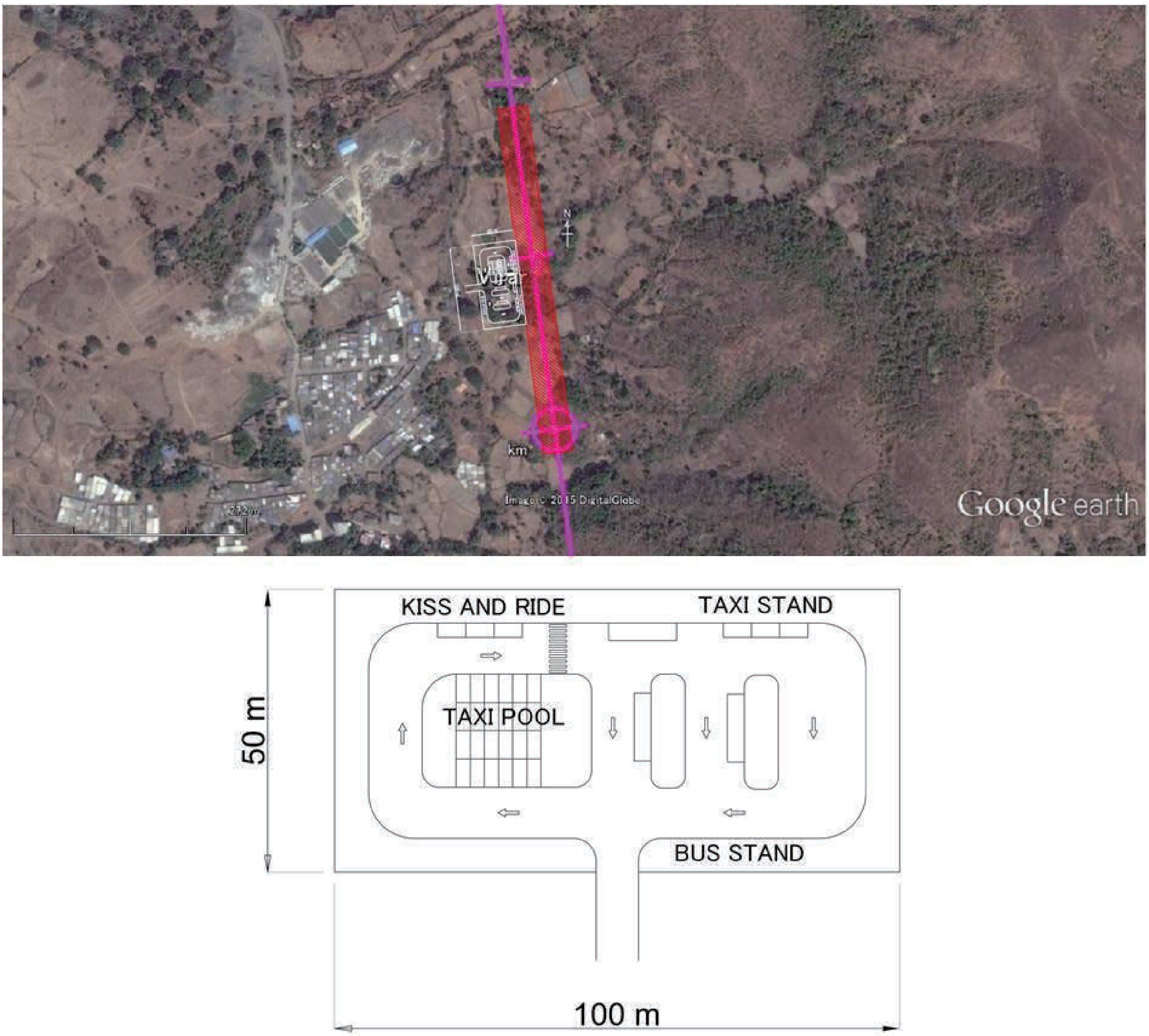
Figure 9.6-50 Cross-sectional View of Virar Station



Source: JICA Study Team

Figure 9.6-51 Top View of Virar Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

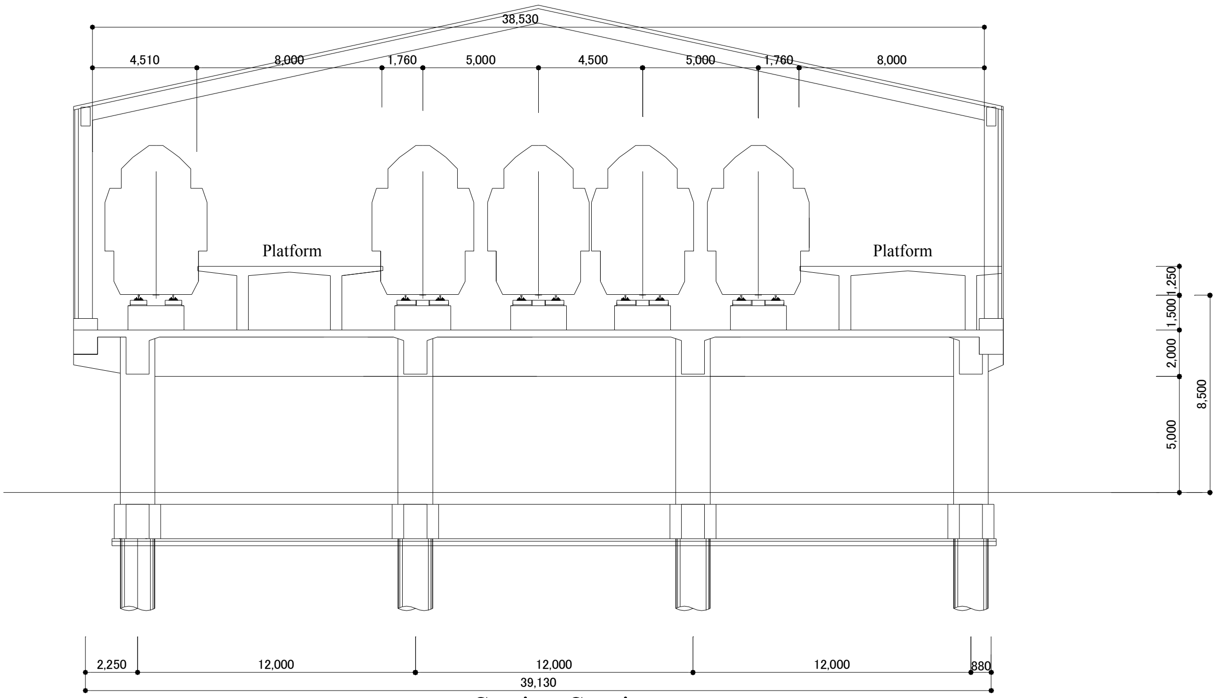
Source: JICA Study Team

Figure 9.6-52 Top View of Virar Station Square

(4) Boisar

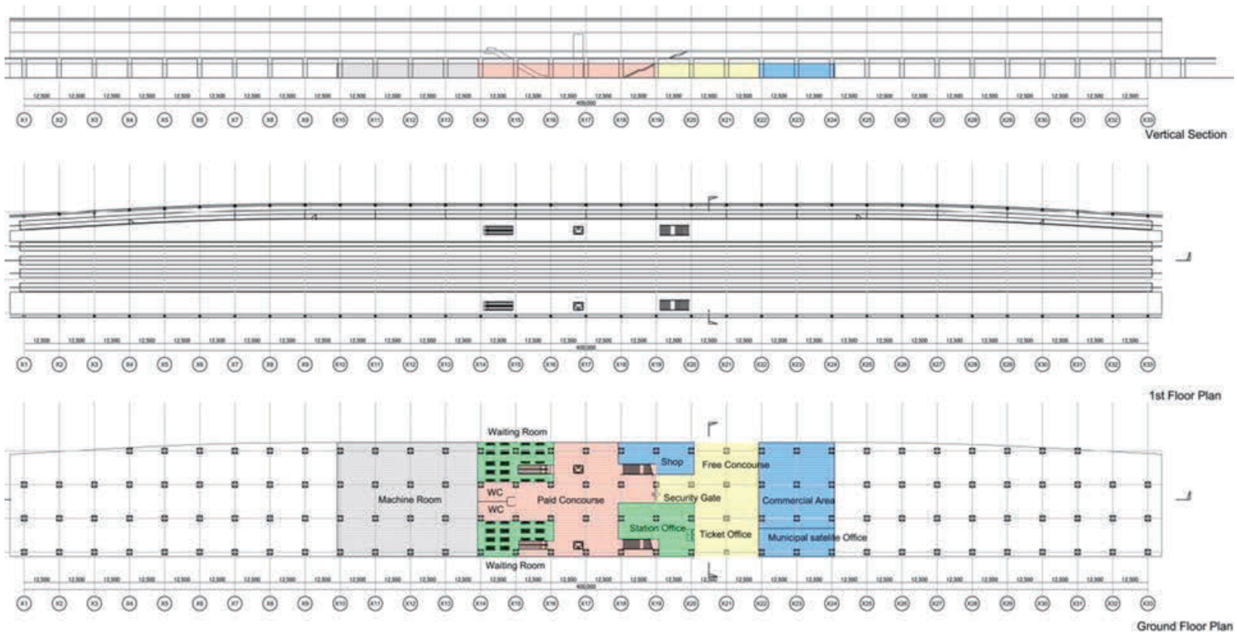
1) Station Building

Boisar Station is planned to comprise of two elevated stories. One (1) side platform and one (1) island shaped platforms (which in functionally is a side platform) with five (5) lines will be on the first floor and a concourse on the ground floor. This island shaped platform is used as a side platform, since the train track on the edge is designed as a refuge truck for test running train. So the dimension of the platform is designed following the side platform standards, however in case the usage of both side of the platform is supposed, the platform should be designed with the island platform standards. The ground floor will be used for bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

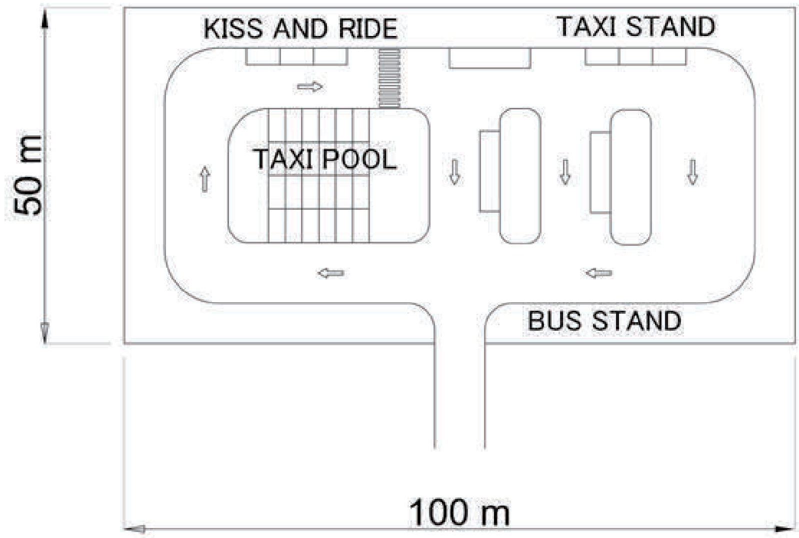
Figure 9.6-53 Cross-sectional View of Boisar Station



Source: JICA Study Team

Figure 9.6-54 Top View of Boisar Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

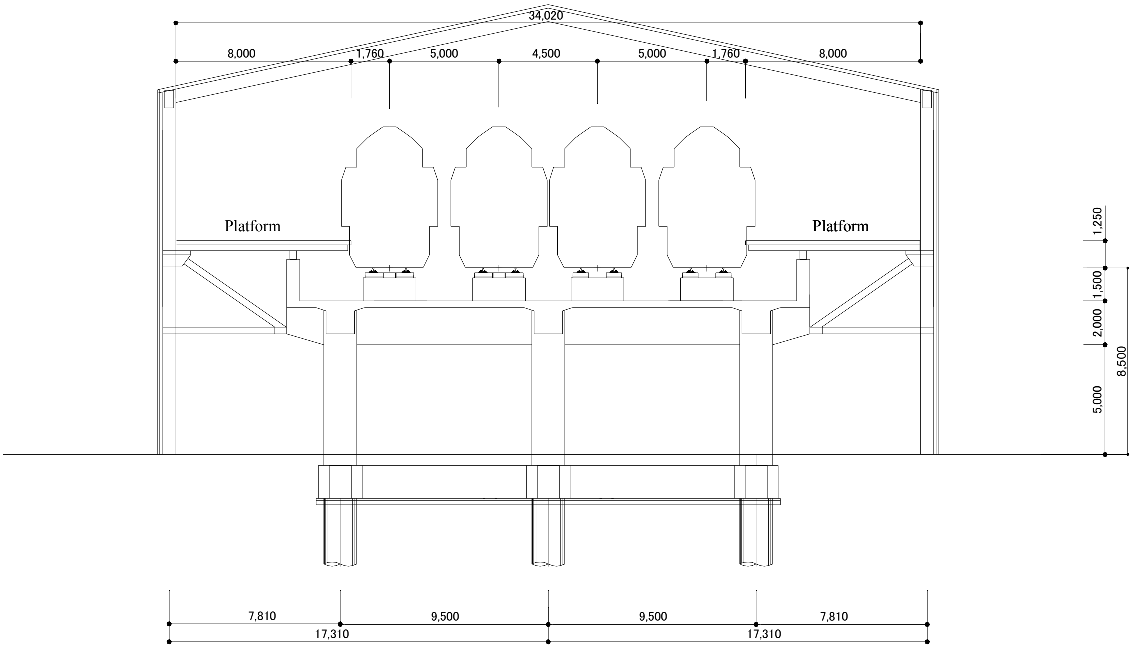
Source: JICA Study Team

Figure 9.6-55 Top View of Boisar Station Square

(5) Vapi

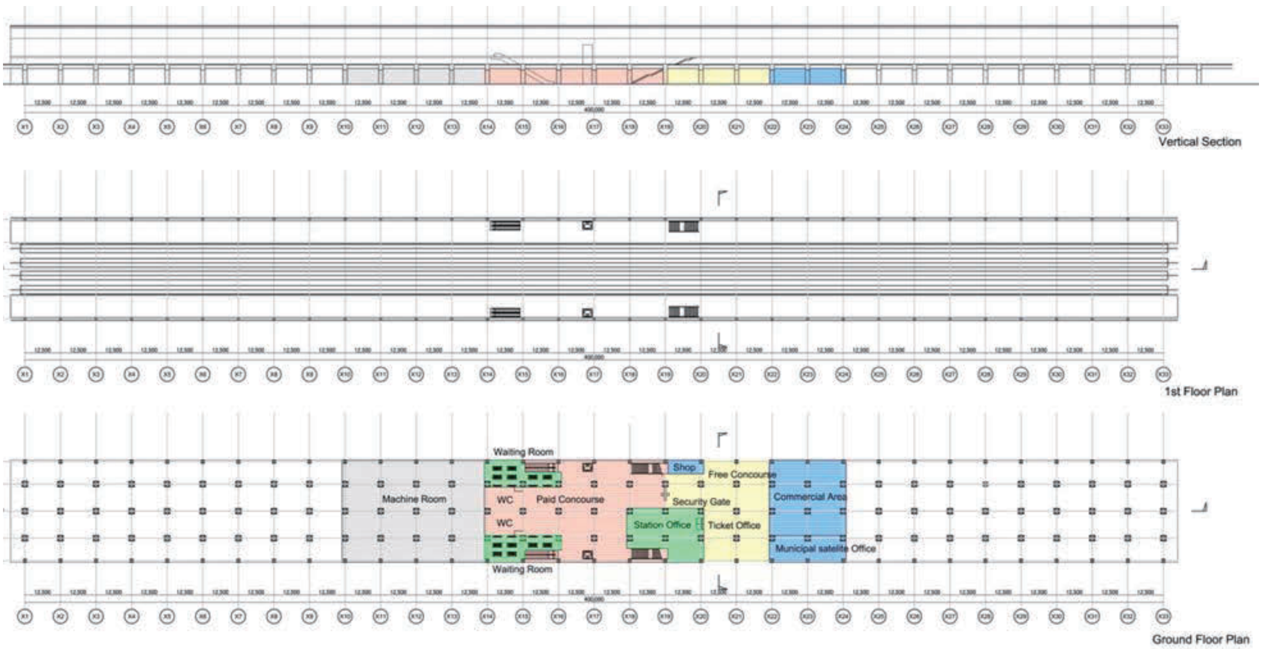
1) Station Building

Vapi Station is planned to comprise of two elevated stories. Two (2) side platforms with four (4) lines will be on the first floor and a concourse on the ground floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

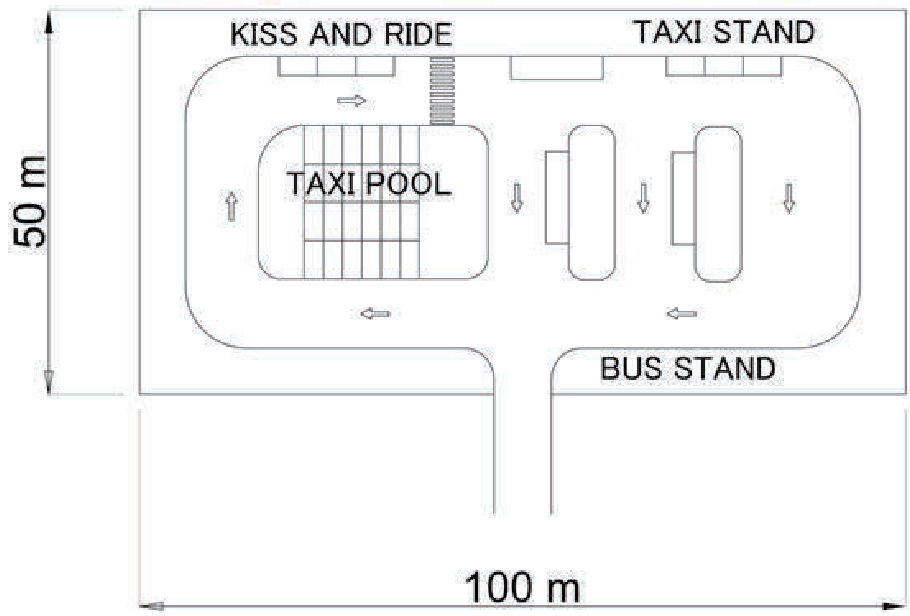
Figure 9.6-56 Cross-sectional View of Vapi Station



Source: JICA Study Team

Figure 9.6-57 Top View of Vapi Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

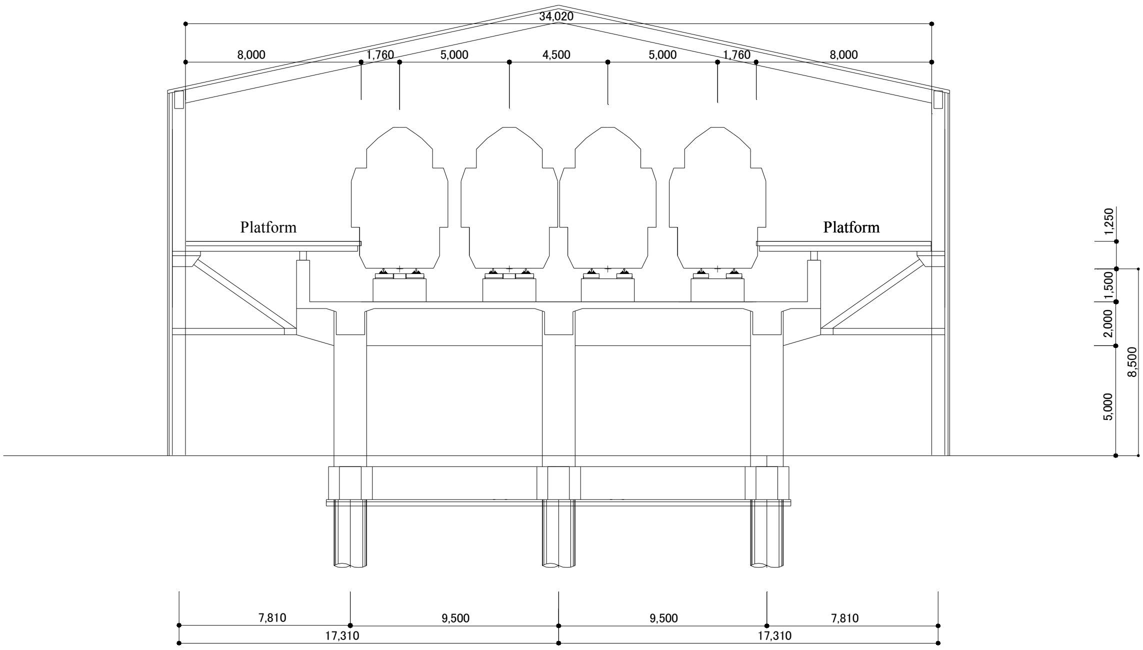
Source: JICA Study Team

Figure 9.6-58 Top View of Vapi Station Square

(6) Bilimora

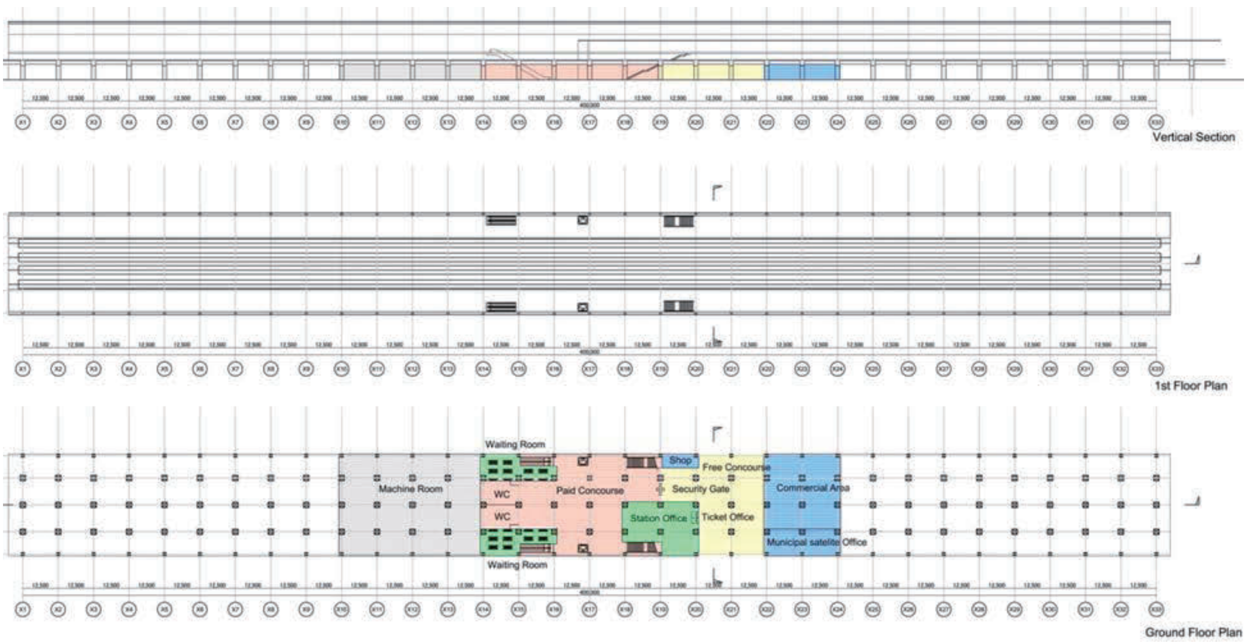
1) Station Building

Bilimora Station is planned to comprise of two elevated stories. Two (2) side platforms with four (4) lines will be on the first floor and a concourse on the ground floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

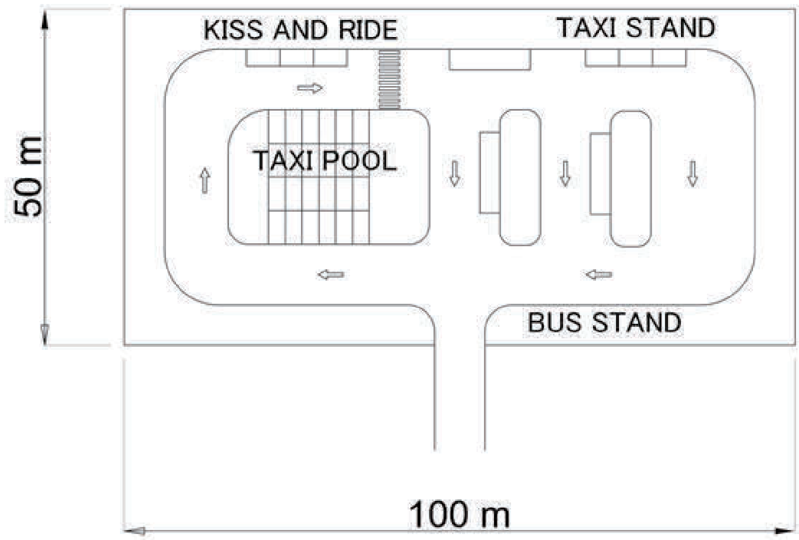
Figure 9.6-59 Cross-sectional View of Bilimora Station



Source: JICA Study Team

Figure 9.6-60 Top View of Bilimora Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

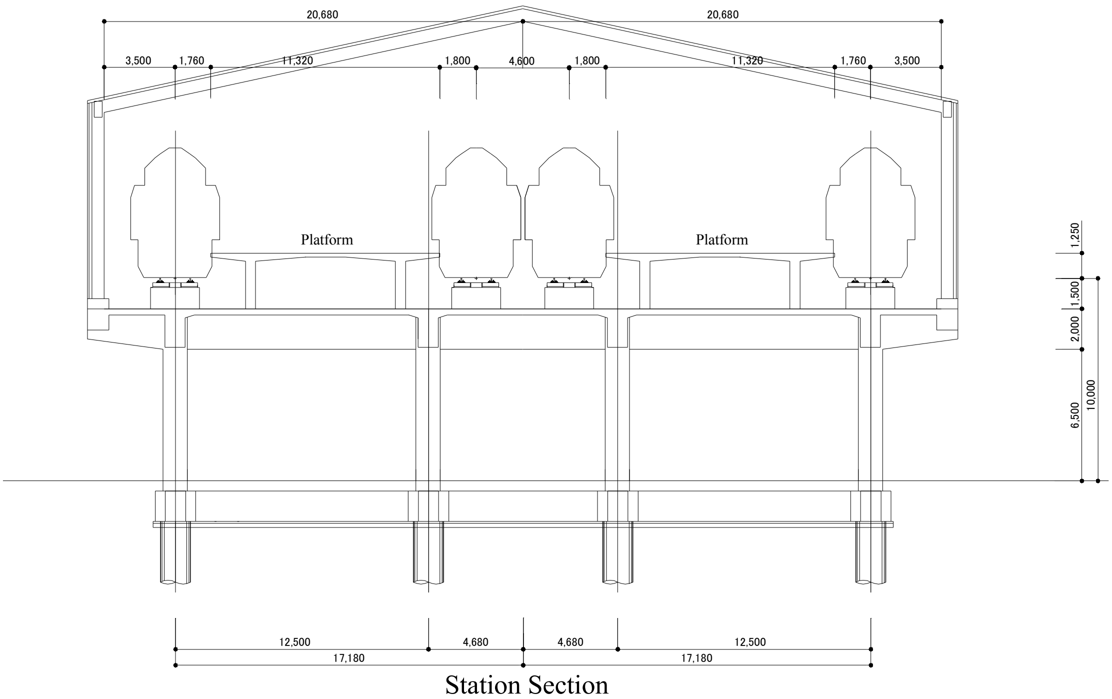
Source: JICA Study Team

Figure 9.6-61 Top View of Bilimora Station Square

(7) Surat

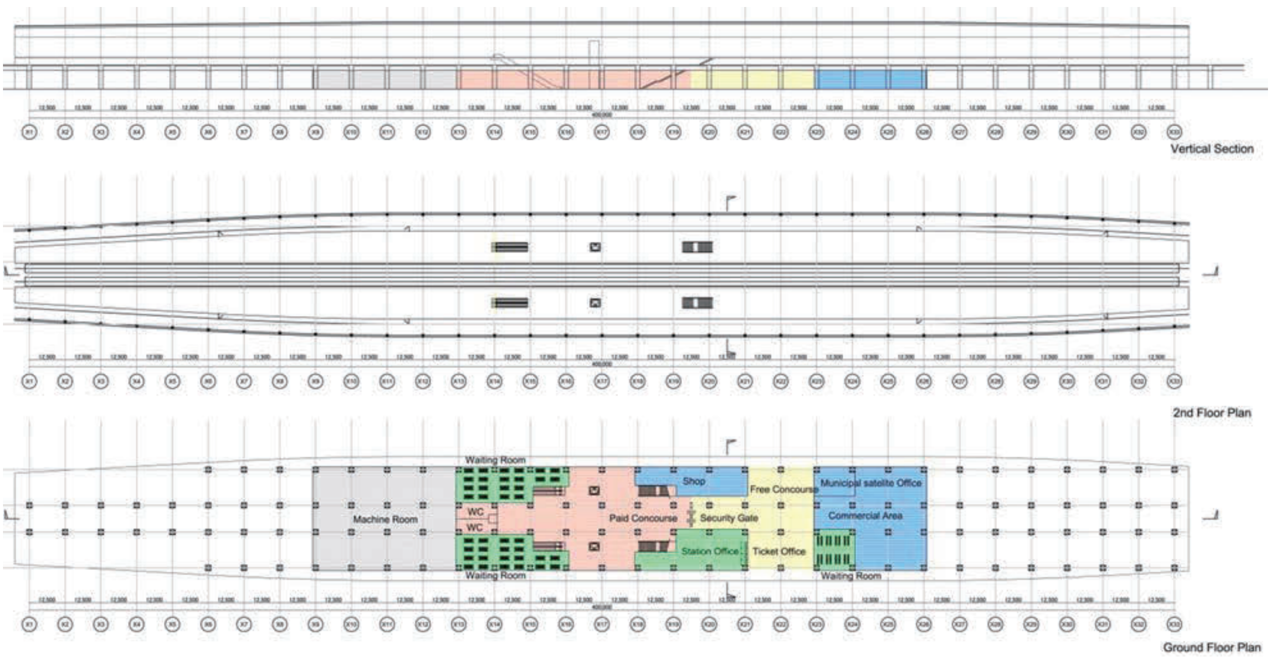
1) Station Building

Surat Station is planned to comprise of two elevated stories. Two (2) island platforms with four (4) lines will be on the first floor and a concourse on the ground floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Source: JICA Study Team

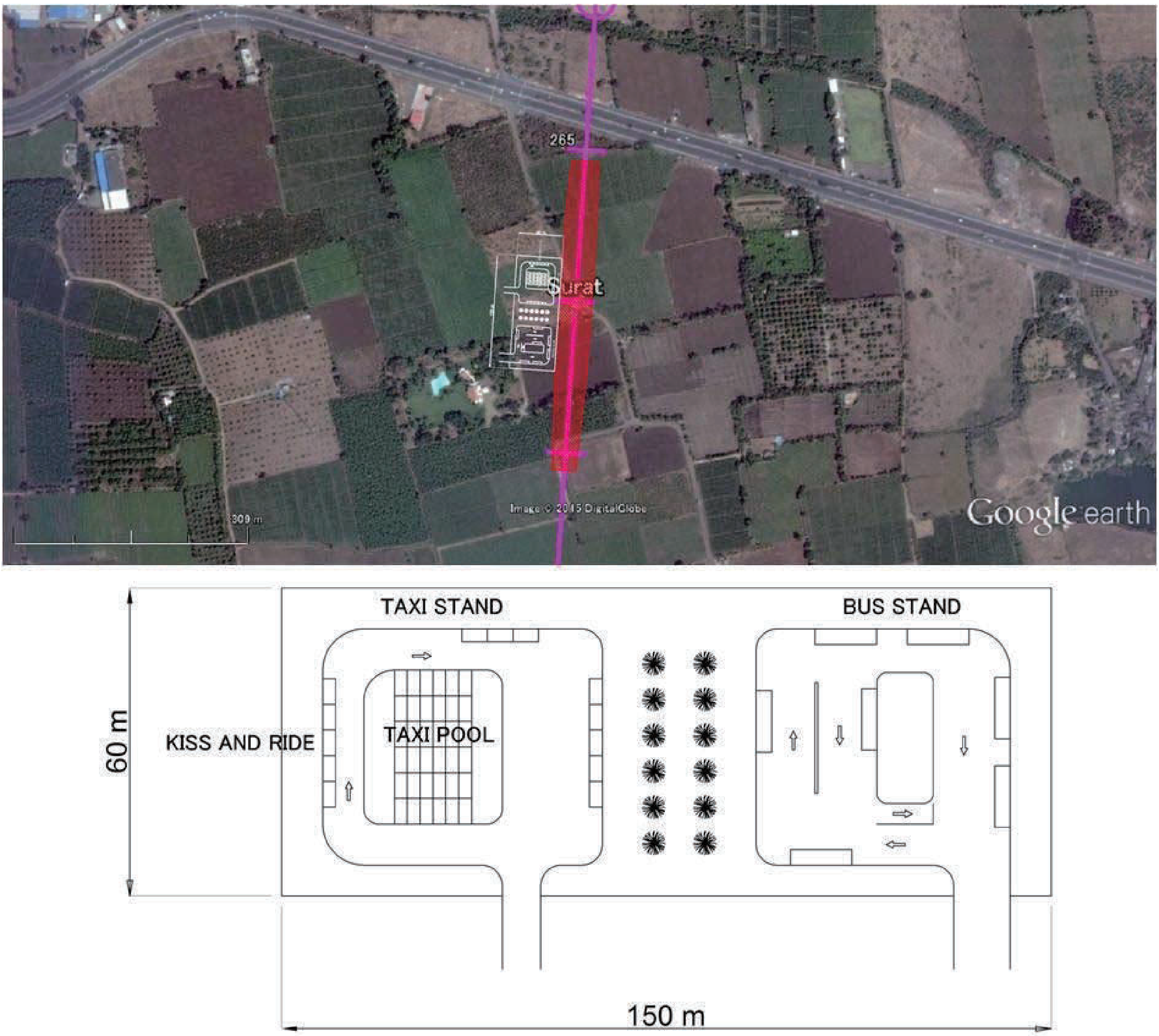
Figure 9.6-62 Cross-sectional View of Surat Station



Source: JICA Study Team

Figure 9.6-63 Top View of Surat Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

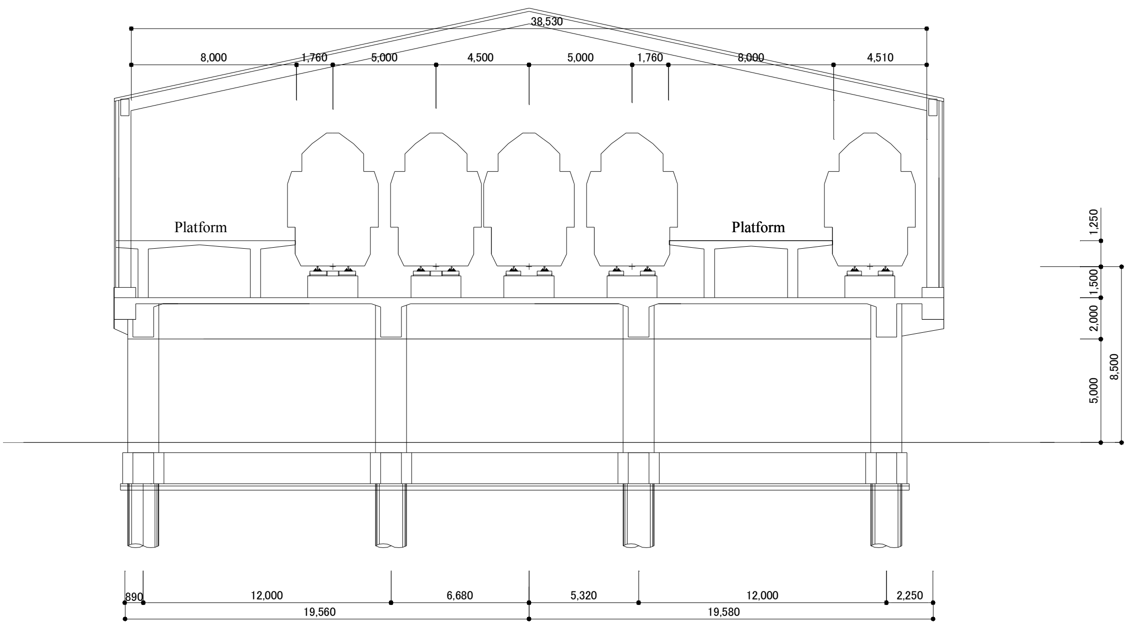
Source: JICA Study Team

Figure 9.6-64 Top View of Surat Station Square

(8) Bharuch

1) Station Building

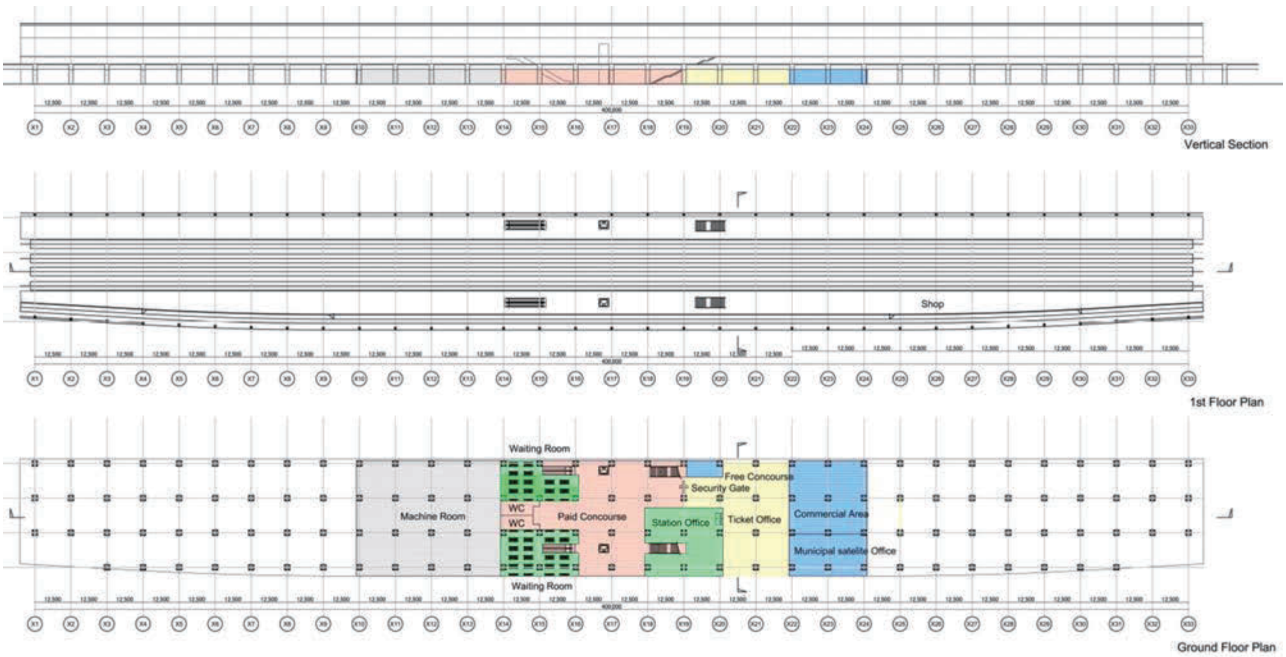
Bharuch Station is planned to comprise of two elevated stories. One (1) side platform and one (1) island shaped platforms (which in functionally is a side platform) with five (5) lines will be on the first floor and a concourse on the ground floor. This island shaped platform is used as a side platform, since the train track on the edge is designed as a refuge truck for test running train. So the dimension of the platform is designed following the side platform standards, however in case the usage of both side of the platform is supposed, the platform should be designed with the island platform standards. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

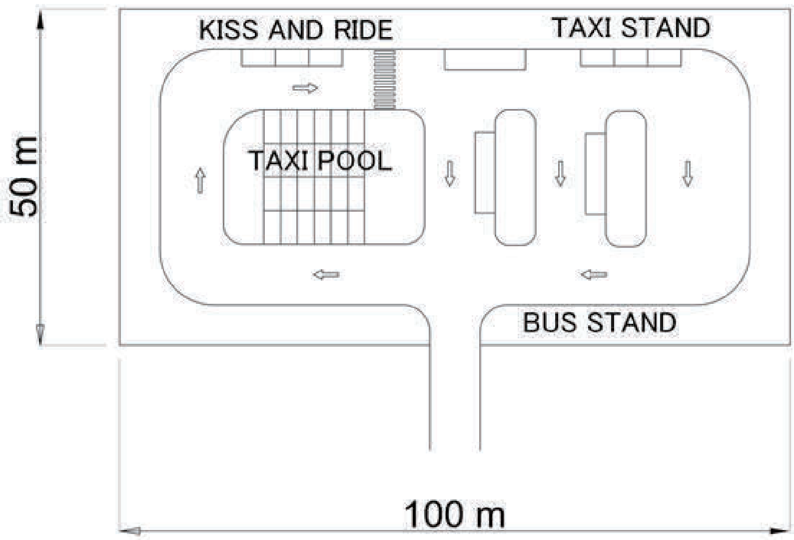
Figure 9.6-65 Cross-sectional View of Bharuch Station



Source: JICA Study Team

Figure 9.6-66 Top View of Bharuch Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

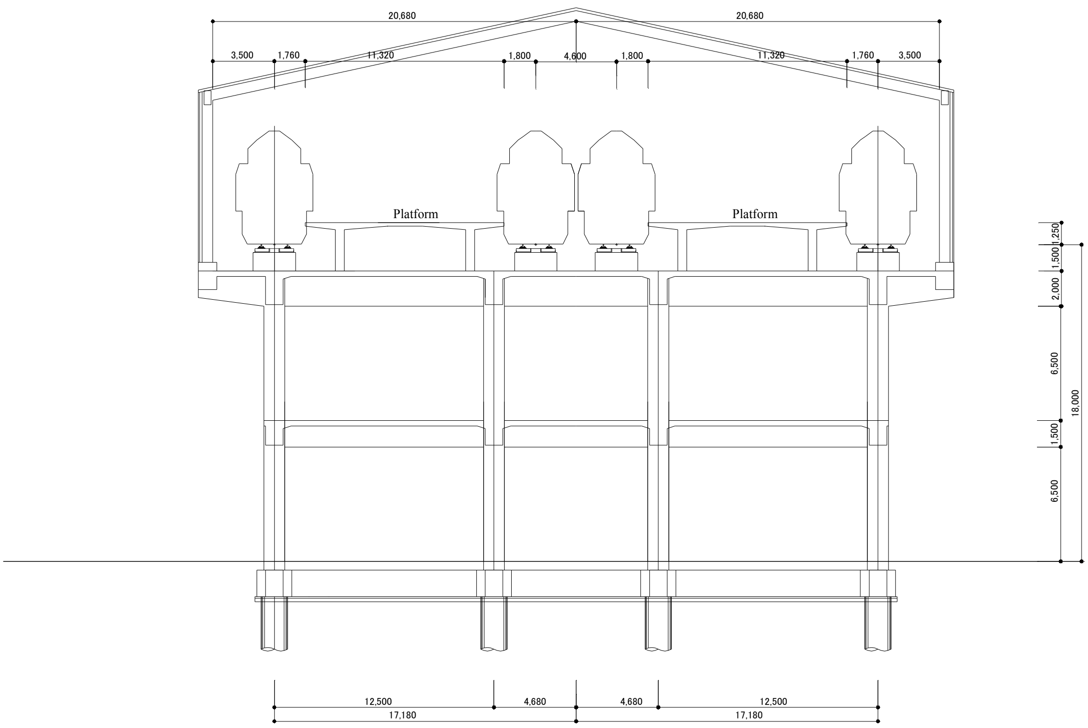
Source: JICA Study Team

Figure 9.6-67 Top View of Bharuch Station Square

(9) Vadodara

1) Station Building

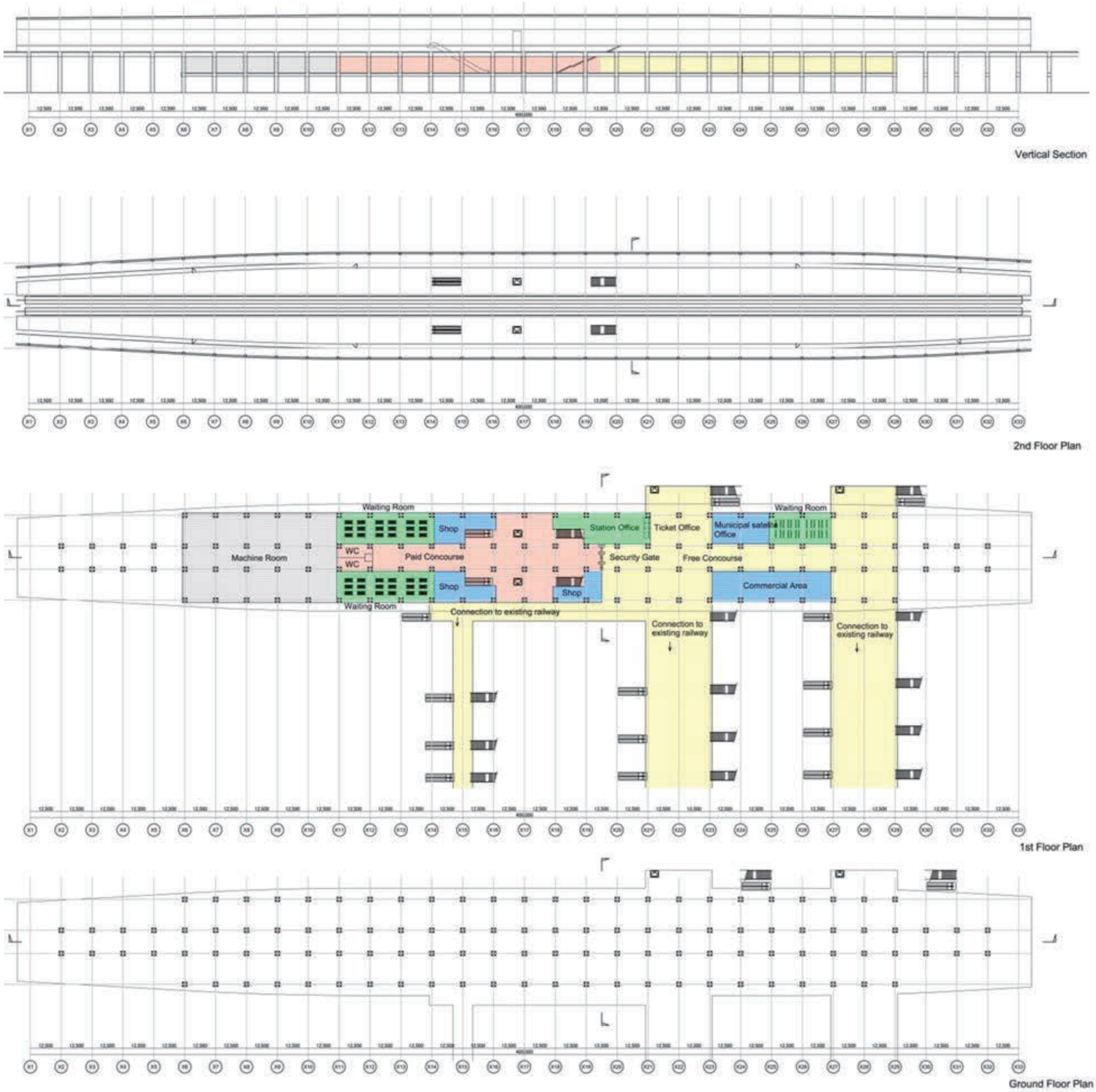
Vadodara Station is planned to comprise of three elevated stories. Two (2) island platforms with four (4) lines will be on the second floor and a concourse on the first floor. Interchanges to the Conventional rail will be provided on the first floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

Figure 9.6-68 Cross-sectional View of Vadodara Station

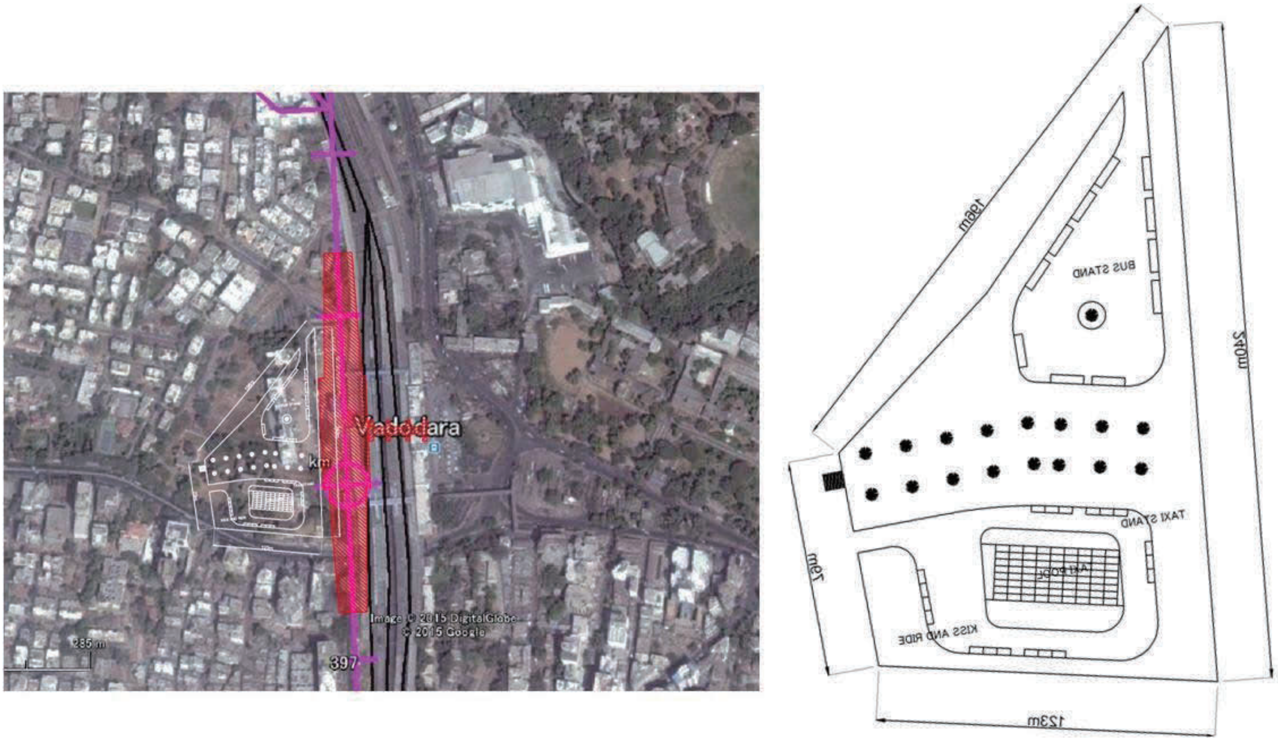


Source: JICA Study Team

Figure 9.6-69 Top View of Vadodara Station Plan

2) Station Square

New station square should be proposed to be planned in the west side of the station since the station square for existing rail located in the east side of the station is crowded.



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

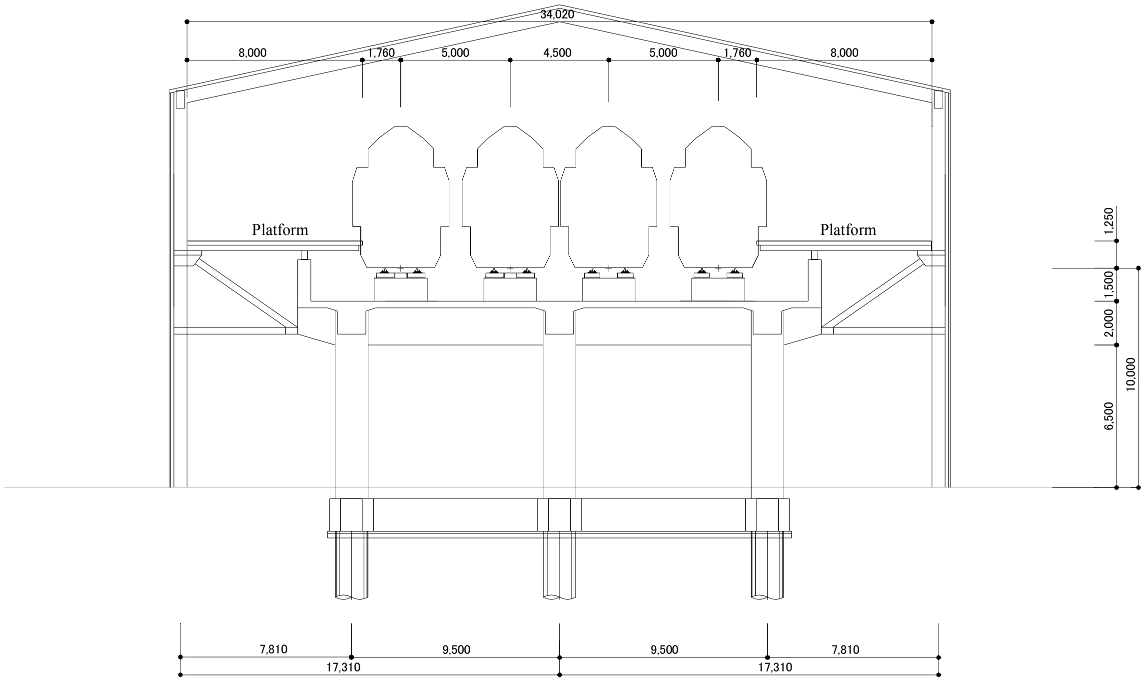
Source: JICA Study Team

Figure 9.6-70 Top View of Vadodara Station Square

(10) Anand/Nadiad

1) Station Building

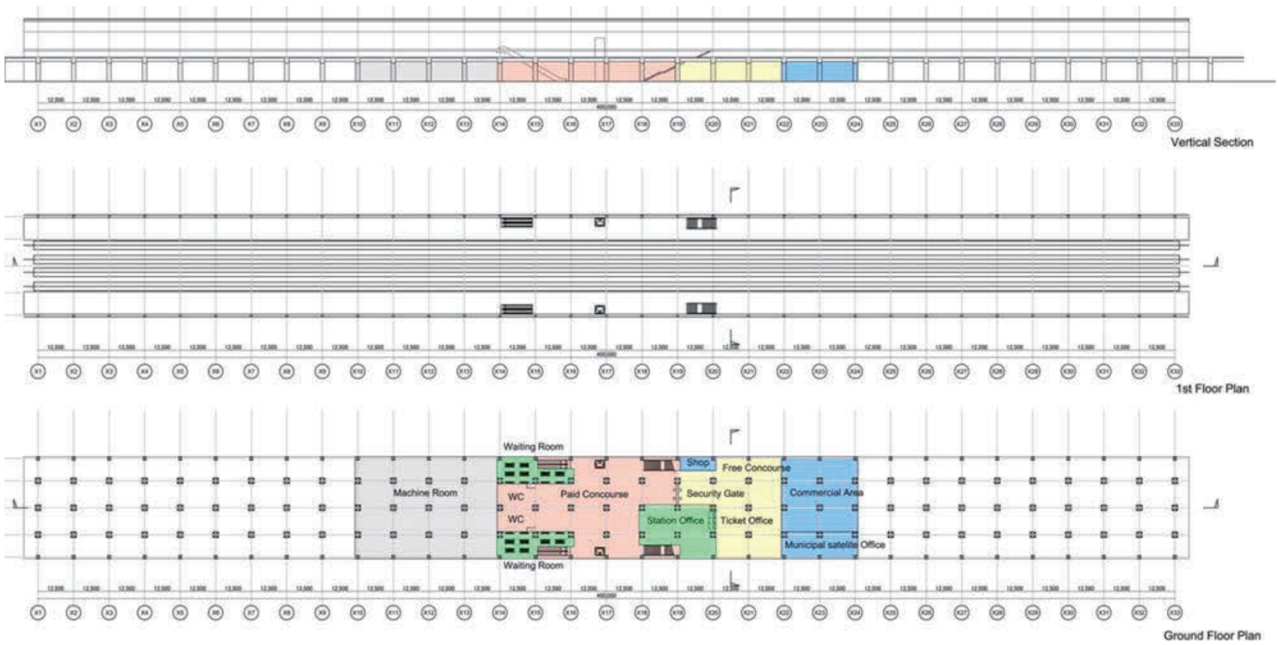
Anand/Nadiad Station is planned to comprise of two elevated stories. Two (2) side platforms with four (4) lines will be on the first floor and a concourse on the ground floor. The ground floor will be used as bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

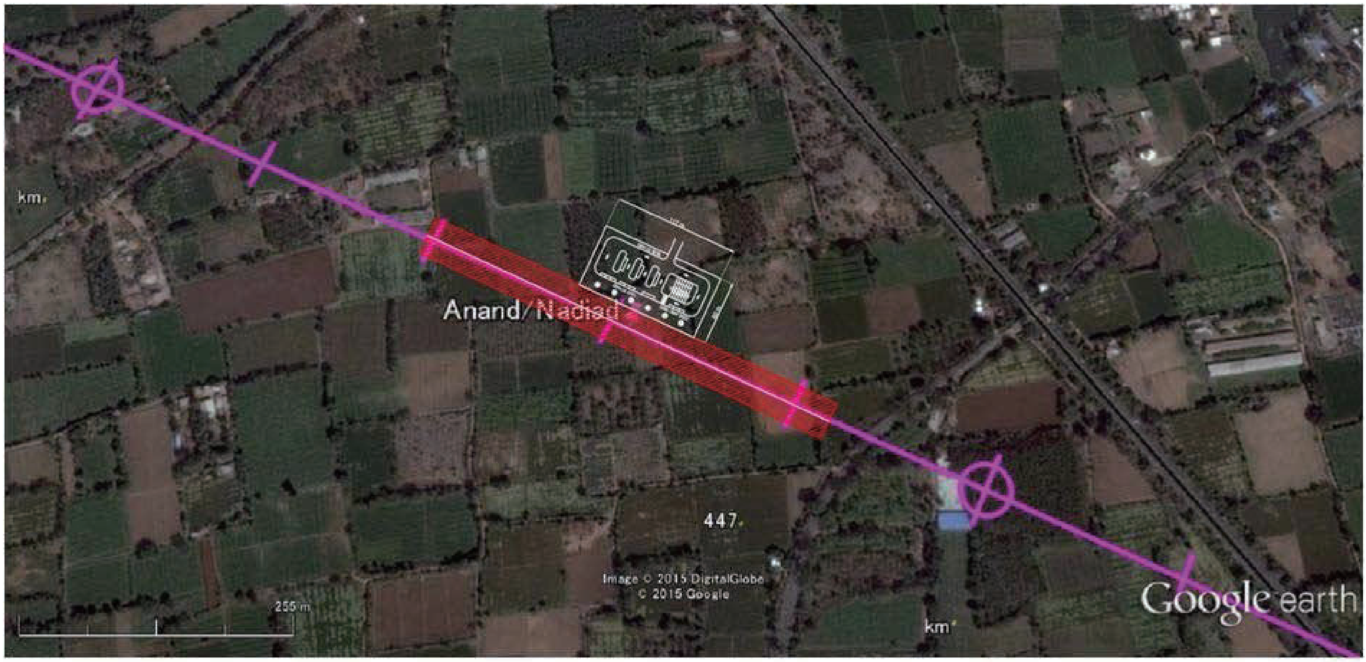
Figure 9.6-71 Cross-sectional View of Anand/Nadiad Station

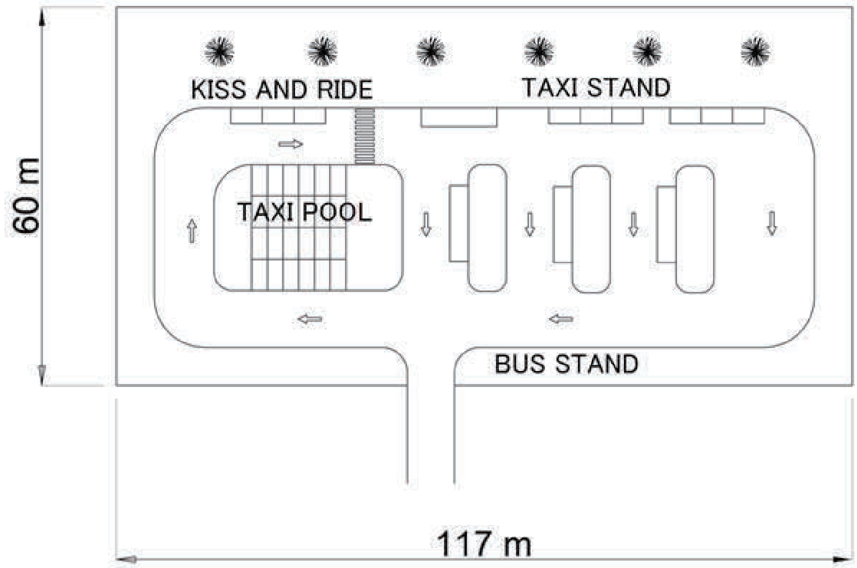


Source: JICA Study Team

Figure 9.6-72 Top View of Anand/Nadiad Station Plan

2) Station Square





* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

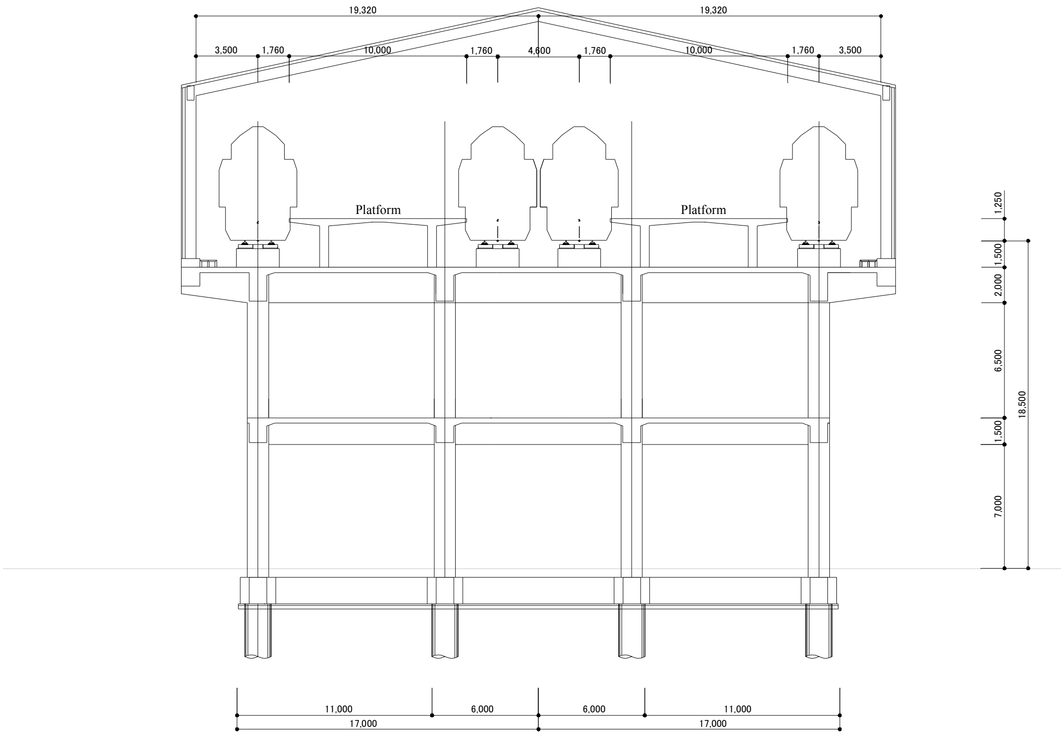
Source: JICA Study Team

Figure 9.6-73 Top View of Anand/Nadiad Station Square

(11) Ahmedabad

1) Station Building

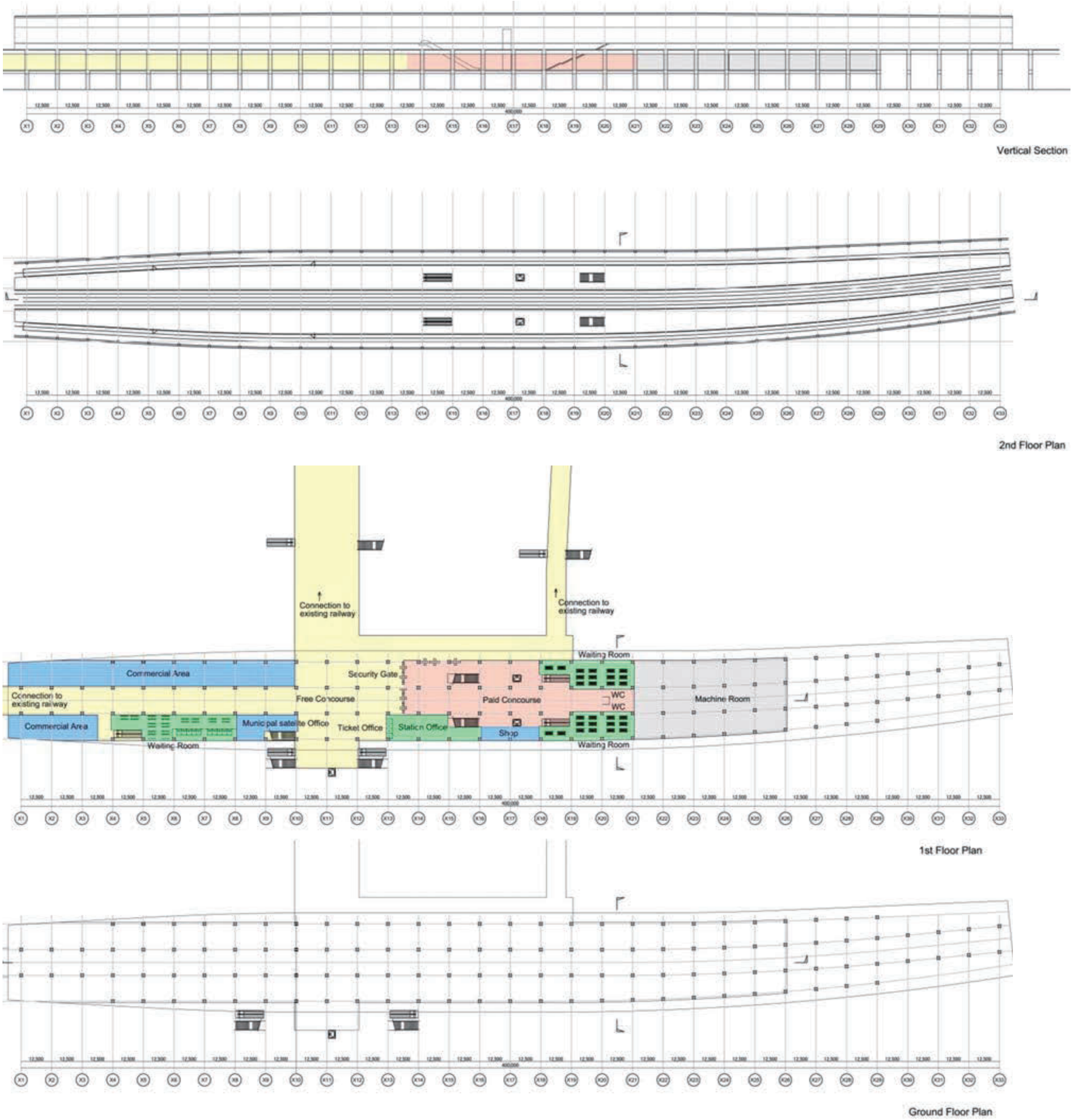
Ahmedabad Station is planned to comprise of three elevated stories. Two (2) island platforms with four (4) lines will be on the second floor and a concourse on the first floor. Interchanges to the Conventional rail will be provided on the first floor. The ground floor will be used for Conventional rail, bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

Figure 9.6-74 Cross-sectional View of Ahmedabad Station

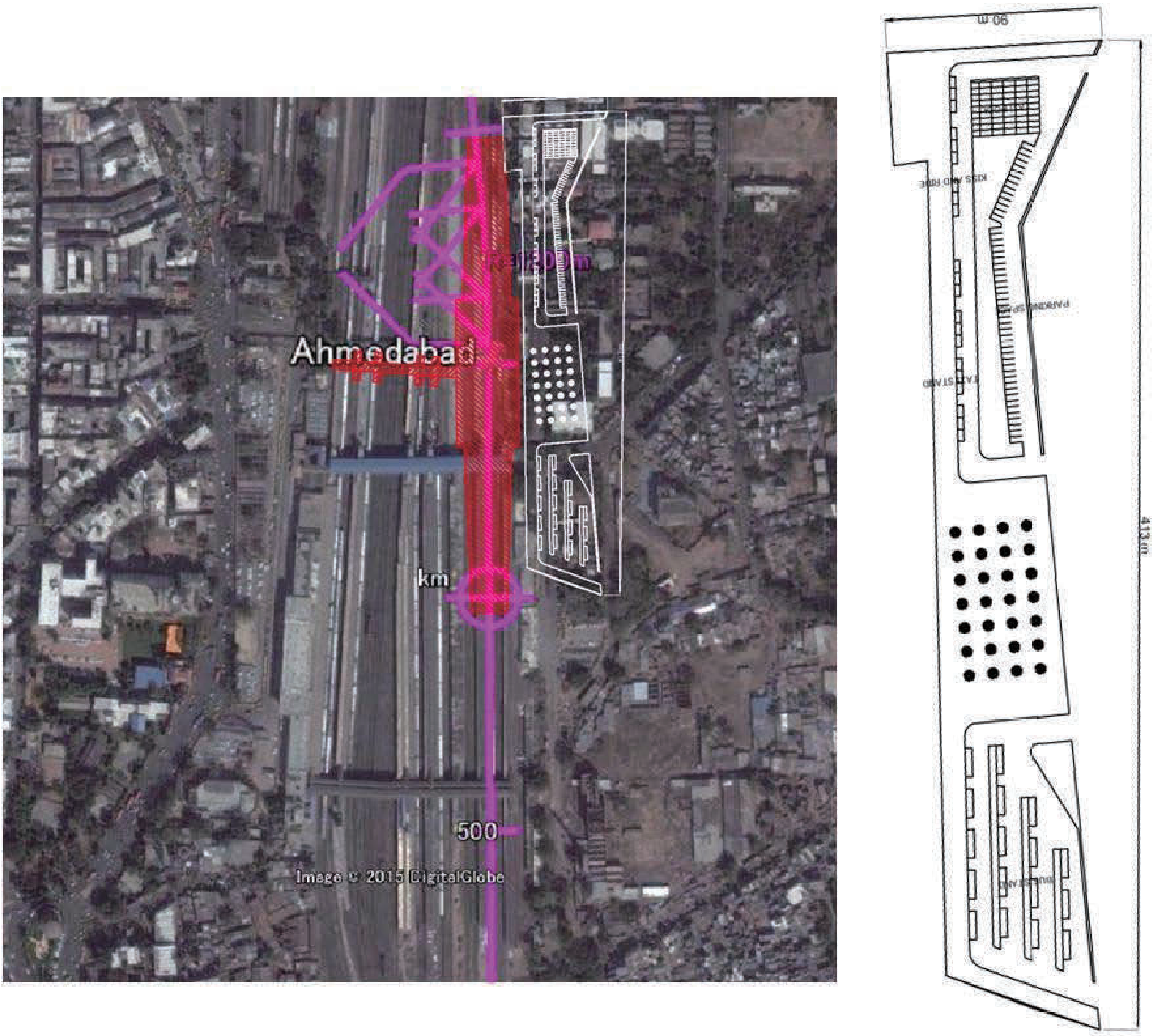


Source: JICA Study Team

Figure 9.6-75 Top View of Ahmedabad Station Plan

2) Station Square

Since existing station square in the west side of the station is crowded, new station square is proposed in the east side of the station which is mainly for HSR passengers. Connectivity between the new station square and the exit of metro rail station should be considered and planned.



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

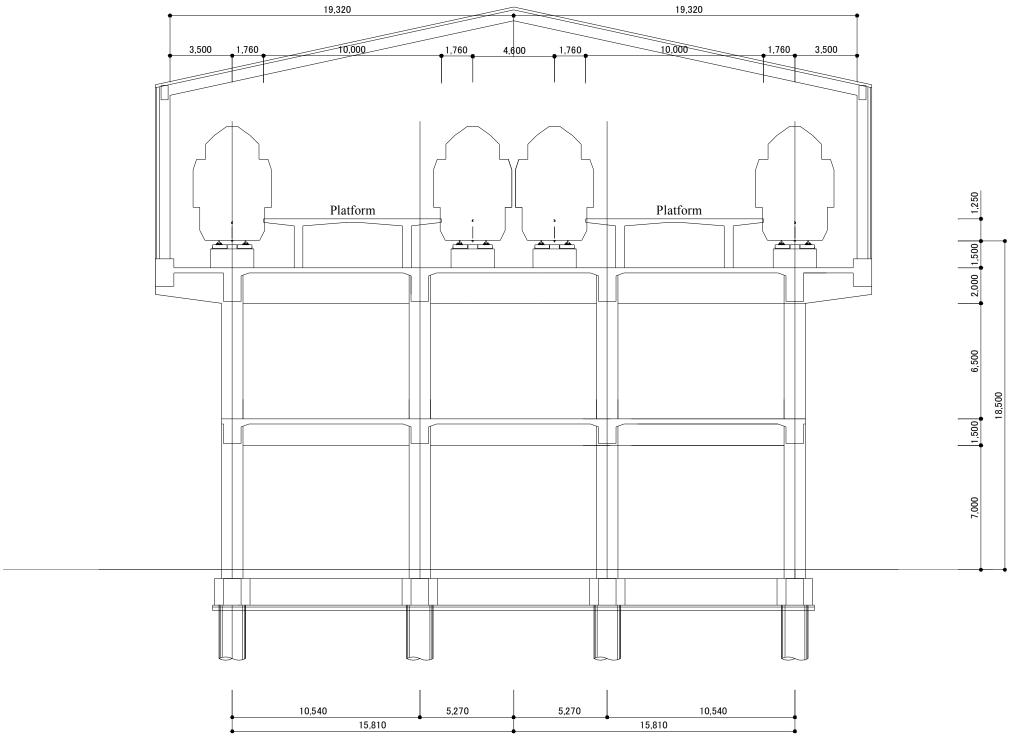
Source: JICA Study Team

Figure 9.6-76 Top View of Ahmedabad Station Square

(12) Sabarmati

1) Station Building

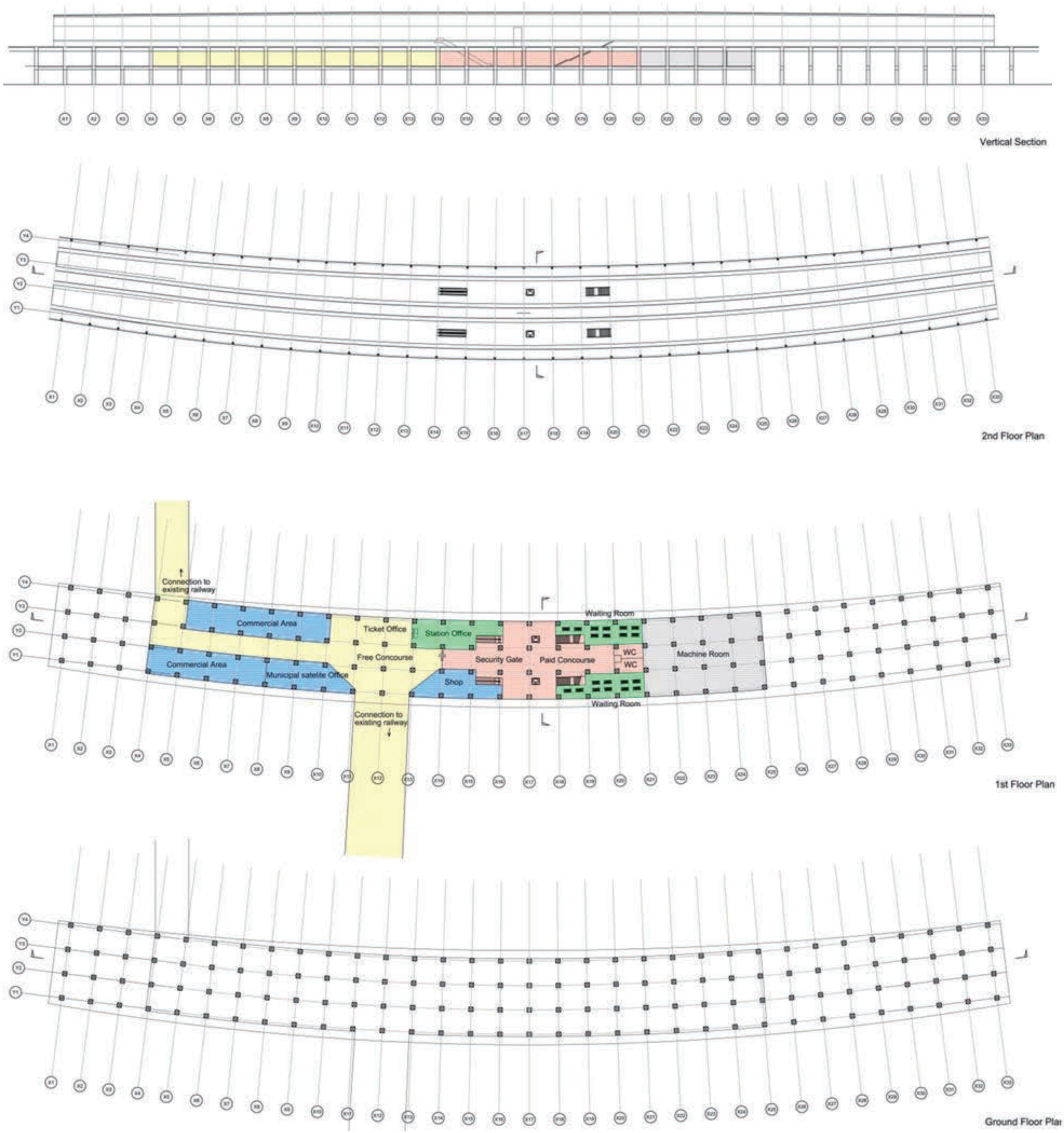
Sabarmati Station is planned to comprise three elevated stories. Two (2) island platforms with four (4) lines will be on the second floor and a concourse on the first floor. Interchanges to the Conventional rail will be provided on the first floor. The ground floor will be used as Conventional rail, bus and taxi berths with open space for pedestrians.



Station Section

Source: JICA Study Team

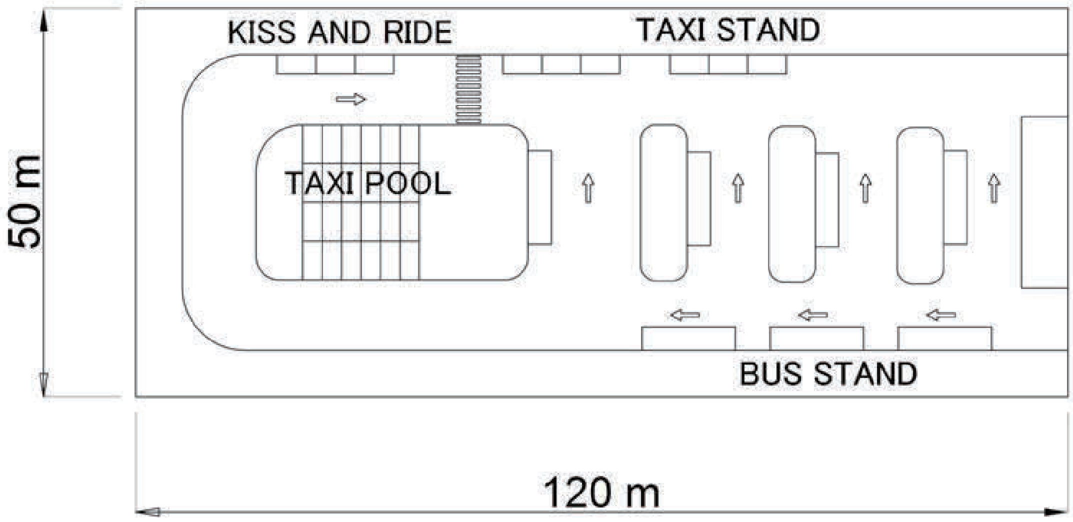
Figure 9.6-77 Cross-sectional View of Sabarmati Station



Source: JICA Study Team

Figure 9.6-78 Top View of Sabarmati Station Plan

2) Station Square



* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

Source: JICA Study Team

Figure 9.6-79 Top View of Sabarmati Station Square

9.6.7 Transport Connectivity of HSR and Other Modes in Station Area

Proposed 12 stations are shown below: One of the key issues on station area development is to enhance good connectivity of HSR and other transport modes. Especially, passenger transfers from HSR to other transport modes outside of the station in Mumbai, Ahmedabad and Sabarmati station and thus good connectivity by improvement of the facilities is required. Mumbai, Vadodara, Ahmedabad and Sabarmati station are located in the central part of the city. Here, extraction of problems related to the connectivity of transport modes and walking space for pedestrians and solution for them are discussed.

Table 9.6-4 Proposed 12 Stations

No.	Station	Location	Connection with Other Public Modes
1	Mumbai	New Urban Station	Metro rail, Bus
2	Thane	New Suburban Station Juxtaposed to Existing Station	Conventional rail, Bus
3	Virar	New Suburban Station	Bus
4	Boisar	New Suburban Station	Bus
5	Vapi	New Suburban Station	Bus
6	Bilimora	New Suburban Station	Bus
7	Surat	New Suburban Station	Bus
8	Bharuch	New Suburban Station	Bus
9	Vadodara	Juxtaposed to Existing Station	Conventional rail, Bus
10	Anand/Nadiad	Juxtaposed to Existing Station	Bus
11	Ahmedabad	Juxtaposed to Existing Station	Conventional rail, BRTS*, Metro rail, Bus
12	Sabarmati	Juxtaposed to Existing Station	Conventional rail, Metro rail, BRTS*, Bus

*BRTS: Bus Rapid Transit Service

(1) Mumbai

Mumbai is the largest city in India and the center of its economic. Proposed HSR station locates in the center of BKC area which is one of CBDs in Mumbai and lots of major companies operatesaround the station and the stations of planned Mumbai metro also are located near HSR station.

Key points for the station area are to secure good connectivity with Metro and BKC area.

Mumbai Metro Line 2 and 3 are on the stage of planning and for which station locations were mostly decided. It is required to study connectivity of HSR with these Metros.

Connectivity with Metro Line 2 (Blue line in Figure 9.6-80): Bharat station on Line 2 is the nearest station to HSR station and both are underground. The proposal is to construct a walkway between these underground stations directly underground.

Connectivity with Metro Line 3(Yellow line in Figure 9.6-80): HSR station can be connected to Metro Line 3-Bandra station by underground passage and passenger can get off HSR and transfer to Line 2 at Bharat Nagar station, then get off at Income Tax Office station and transfer to Line 3 at Bandra station. For this way, it is important to ease transferring between Income Tax Office station and Bandra station by installation of escalator and elevator, etc.

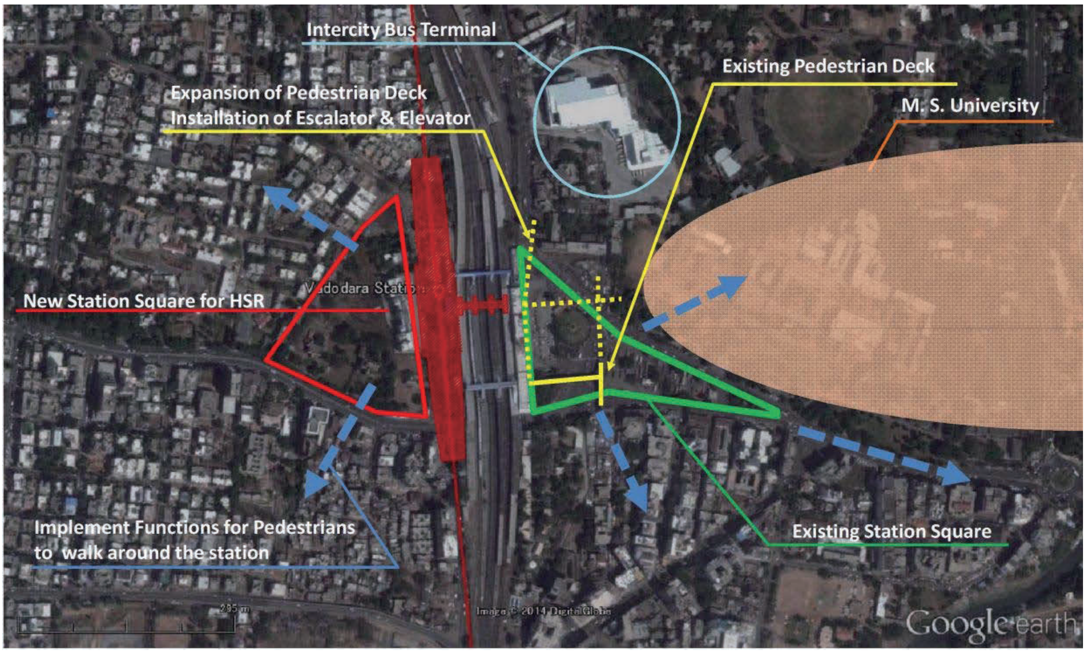
Source: Compiled with Google Earth by Study Team

Figure 9.6-80 Connection with Mumbai Metro Station

(2) Vadodara

Proposed HSR station in Vadodara, which is one of the major cities on the HSR corridor, locates adjacent to conventional railway station. Key points of station area development are (i) to secure the space for new station square for HSR passengers and (ii) function for railway passengers to walk around HSR station.

1) Improvement of Station Area



Source: Compiled with Google Earth by Study Team

Figure 9.6-81 Connection of HSR with
Other Transport Modes and around Station Area

The new station square is proposed to be planned in the west side of the station since existing station square is crowded. The bus stops and taxi stands are to be implemented in the new station square.

Also, there are major spots such as city central where huge market exists, palace, university and residential area locates around 1-3 km from the station. Good connectivity between the station and the area around the station should be created by for instance, expanding and improving existing walkway.

Source: Study Team

Figure 9.6-82 Existing Station Front of Vadodara Station

(3) Ahmedabad

Metro and BRT are being planned and constructed in Ahmedabad. Construction of some parts of BRT line started around proposed Ahmedabad HSR station. BRT is basically elevated and MRT is underground. Connection between HSR station and BRT and Metro needs to be considered.

Since BRT is basically elevated around the station, it is recommended to construct elevated walkway to connect HSR station and BRT stop. The walkway is to be expanded widely around the station to connect the east and west side of the railway station. (See Figure 9.6-83)

Since the Metro is planned underground, the underground walkway from the planned station square at the east side of the station to Metro station is recommended. The walkway goes to west side from east side to connect the west area of the station and Metro station easily. (See Figure 9.6-83)

Source: Compiled with Google Earth by Study Team

Figure 9.6-83 Connection of HSR with Other Transport Modes at Ahmedabad Station

(4) Sabarmati

It is needed to consider the connection from HSR station to BRT and Metro station around Sabarmati station.

The BRT station is planned at the southeast side of the HSR station and both stations are elevated. It is suggested to connect the station by the elevated walkway. (See Figure 9.6-84)

The Metro station is planned at the south west side of HSR station. The elevated walkway to connect the Metro station and HSR station is recommended since both stations are elevated.

Combined with both walkway constructions, redevelopment of station square is recommended to improve the convenience of station area. The existing station square does not fully consider the mode of transfer between HSR and bus, taxi and other modes. Since the passengers seem to increase by the inauguration of HSR, the station square is to be rebuilt to secure the area of bus, taxi and other transport modes.

Source: Compiled with Google Earth by Study Team

Figure 9.6-84 Connection of HSR with Other Transport Modes at Sabarmati Station

9.6.8 Summary of Station Elements

A summary of HSR station elements is shown below.

Table 9.6-5 HSR Station Elements

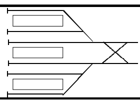
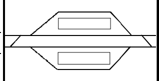
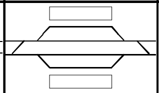
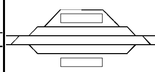
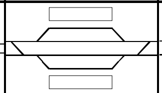
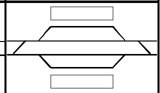
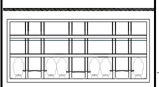
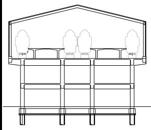
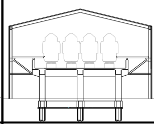
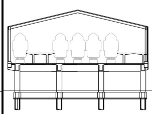
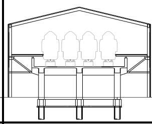
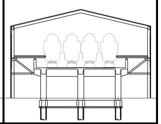
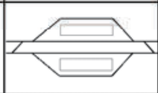
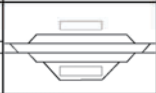
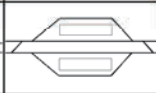
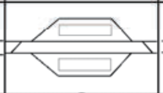
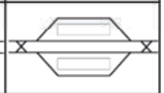
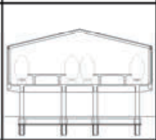
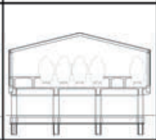
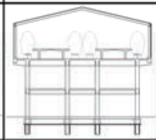
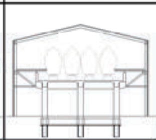
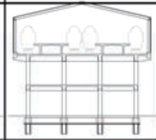
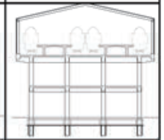
Station Name	Mumbai(BKC)	Thane	Virar	Boisar	Vapi	Bilimora
Location	0K000m	27K950m	65K170m	104K260m	167K940m	216K580m
Track Layout						
Station Section						
Station Type	Underground	Elevated	Elevated	Elevated	Elevated	Elevated
Platform Type	Island Platform	Island Platform	Side Platform	Side Platform	Side Platform	Side Platform
Rail Level from Ground(m)	-25	15	8.5	8.5	8.5	8.5
Platform Length(m)	410	410	410	410	410	410
Platform Width(m)	10.0+10.0+10.0	11.32+11.32	8.0+8.0	8.0+8.0	8.0+8.0	8.0+8.0
Station Area (m2)	36,500	23,900	20,900	32,600	23,800	23,900
Platform Floor Area(m2)	23,300	17,000	14,000	16,200	14,000	14,000
Concourse Floor Area(m2)	31,250	9,500	4,500	5,065	4,500	4,500
No of Gates	2	1	1	1	1	1
No of Elevators (Paid Area/ Public Area)	6/4	2/2	2/0	2/0	2/0	2/0
No of Escalators (Paid Area/ Public Area)	12/16	4/4	4/0	4/0	4/0	4/0
No of Staircases (Paid Area/ Public Area)	6/8	2/2	2/0	2/0	2/0	2/0
No of Toilets (M/F/Disable)	2 / 2 / 2	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1
Transit to Local Railway	To be Connected	To be Connected	None	None	None	None

Table 9.6-5 HSR Station Elements

Station Name	Surat	Bharuch	Vadodara	Anand/Nadiad	Ahmedabad	Sabarmati
Location	264K580m	323K110m	397K060m	447K380m	500K190m	505K750m
Track Layout						
Station Section						
Station Type	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated
Platform Type	Island Platform	Side Platform	Island Platform	Side Platform	Island Platform	Island Platform
Rail Level from Ground(m)	10	8.5	18	10	18.5	18.5
Platform Length(m)	410	410	410	410	410	410
Platform Width(m)	11.32+11.32	8.0+8.0	11.32+11.32	8.0+8.0	10+10	10+10
Station Area (m2)	24,200	32,600	24,200	23,500	23,500	26,600
Platform Floor Area(m2)	17,000	16,200	17,000	14,000	15,900	15,900
Concourse Floor Area(m2)	5,500	5,065	8,615	4,500	9,380	8,505
No of Gates	1	1	1	1	1	1
No of Elevators (Paid Area/ Public Area)	2/0	2/0	2/2	2/0	2/2	2/2
No of Escalators (Paid Area/ Public Area)	4/0	4/0	4/4	4/0	4/4	4/4
No of Staircases (Paid Area/ Public Area)	2/0	2/0	2/2	2/0	2/2	2/2
No of Toilets (M/F/Disable)	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1	1 / 1 / 1
Transit to Local Railway	None	None	To be Connected	None	To be Connected	To be Connected

9.7 Track

9.7.1 Detailed Track Structure

(1) Track structure recommended for Indian HSR

For the discussion in this report, Study team adopts the "frame-type slab track" laid for Shinkansen railways in warm areas in Japan.

1) Structure of track components

Figures 9.7-1, 9.7-2 and 9.7-3 illustrate the standard cross-section of frame-type slab tracks in viaduct/bridge, earth structure and tunnel sections, respectively. In these sections, although the structures of reinforced concrete track bed are different, the track slab thereon is basically common to all sections.

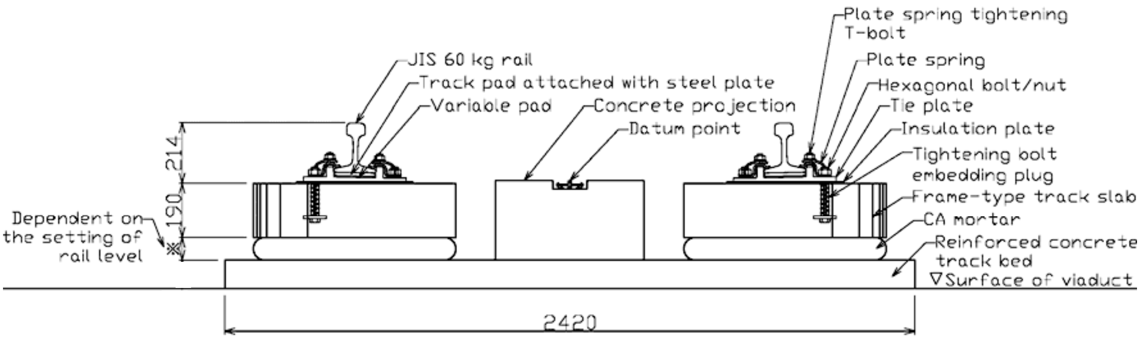


Figure 9.7-1 Standard Cross-section of the Tracks in Viaduct/Bridge Sections

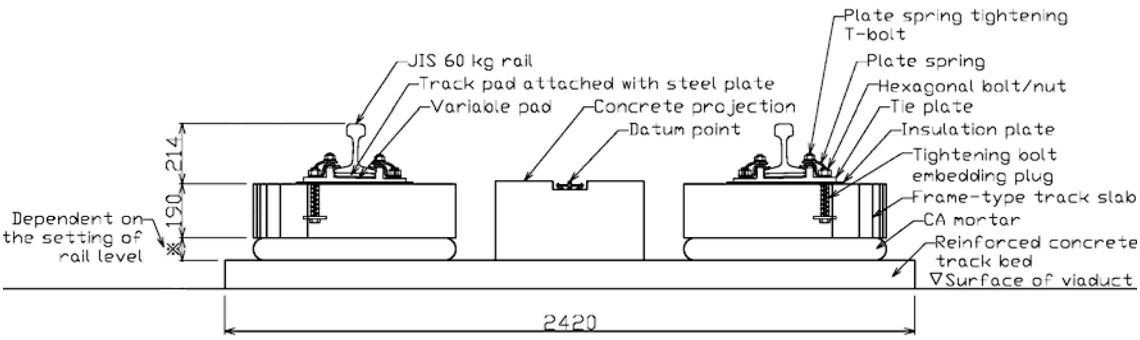


Figure 9.7-2 Standard Cross-Section of the Tracks in Embankment Section

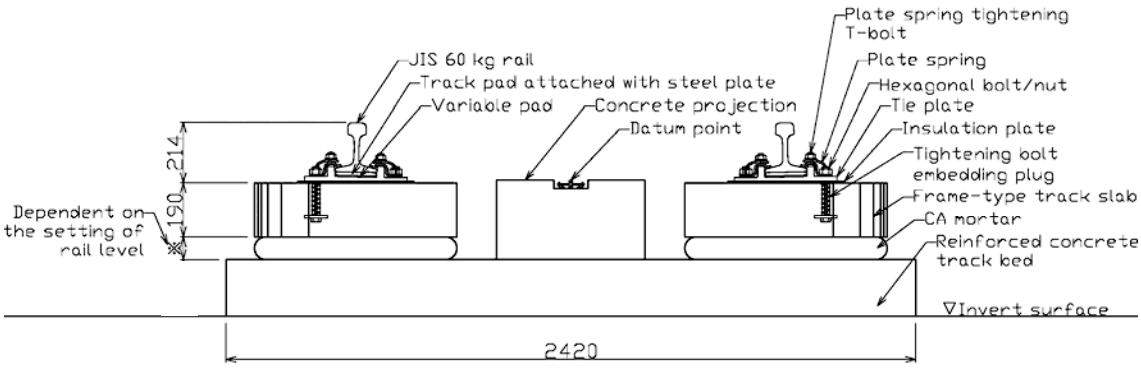


Figure 9.7-3 Standard Cross-Section of the Tracks in Tunnel Sections

2) Reinforced concrete track bed

In stab track sections, a reinforced concrete track bed is installed in place of the track bed ballast of the ballast track, of which the structure and thickness are different on different civil engineering structures.

The reinforced concrete track bed (i) is to guarantee a flat surface to lay track slabs thereon in viaduct/bridge sections or (ii) has a structure to cope with the subsidence and deformation of civil engineering structures over years in tunnels and earth structure sections. In earth track bed sections in particular, the reinforced concrete track bed supports the track skeleton as a girder on the elastic earth structures. At the initial stage of development of the slab track, the ballast track was used in earth structure sections, as it was not possible to use the slab track. However, after the reinforced concrete track bed for earth structures was developed and verified for validity through verification tests, it became possible to use the slab track on earth structure sections.

Figures 9.7-4, 9.7-5 and 9.7-6 illustrate the reinforced concrete track beds in viaduct/bridge, earth structure and tunnel sections, respectively, and Figure 9.7-7 a scene of the work to construct a reinforced track bed.

The reinforced concrete track bed in earth structure sections is larger in terms of thickness and width than those in viaduct/bridge and tunnel sections.

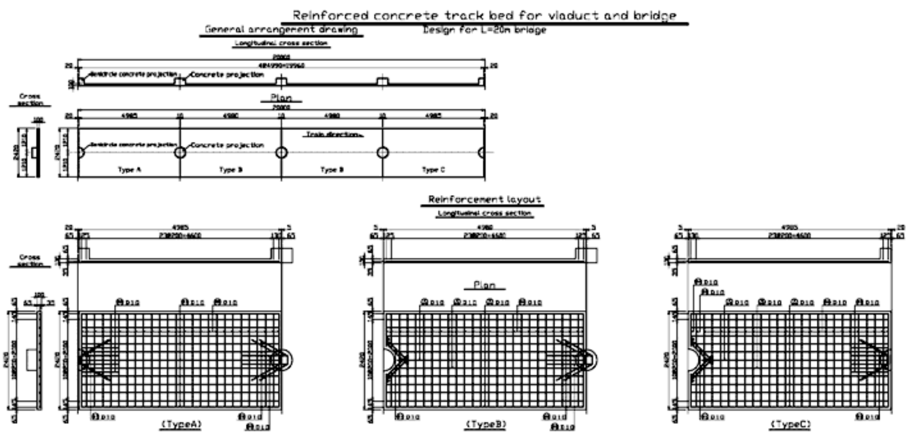


Figure 9.7-4 Reinforced Concrete Track Bed (Viaduct/Bridge Sections)

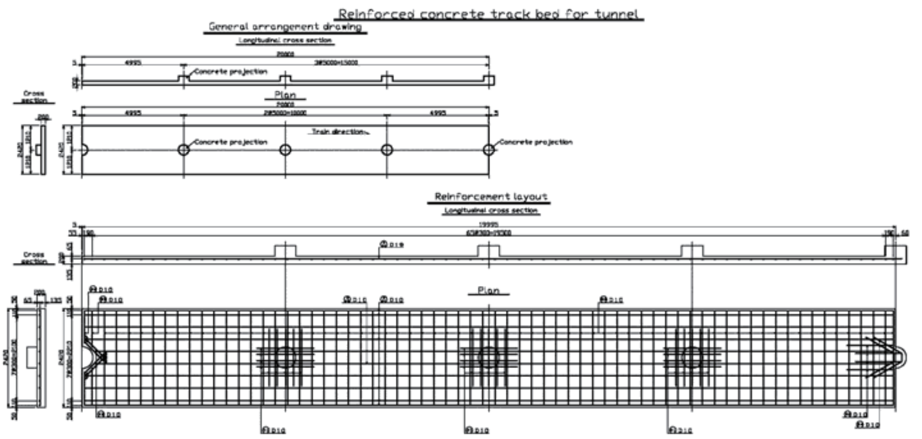


Figure 9.7-5 Reinforced Concrete Track bed (Tunnel Section)

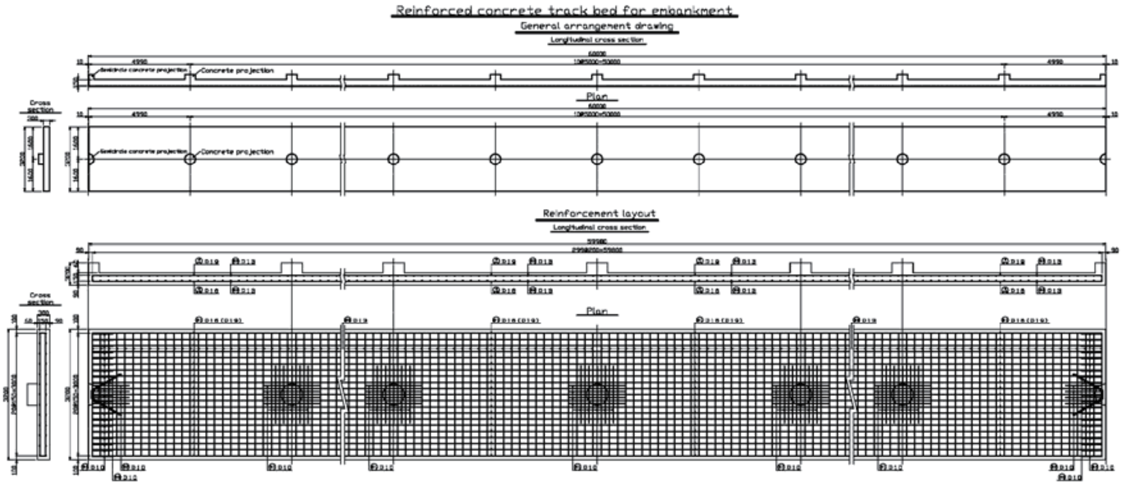


Figure 9.7-6 Reinforced Concrete Track Bed (Embankment Section)

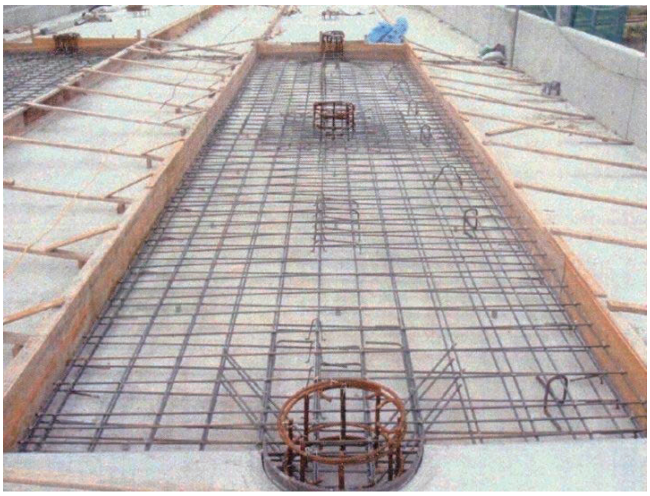


Figure 9.7-7 A scene of the Work to Construct a Reinforced Concrete Track Bed

3) Concrete projection

To support the reaction force against the loads in the longitudinal and lateral directions caused by running trains or in brake application and longitudinal loads due to temperature changes, Study team sets circular or semi-circular "concrete projections" on the reinforced concrete track bed.

A "datum point" is set in the concave at the top of the concrete projection to make a datum point for alignment survey and track slab installation.

Figures 9.7-8 drawings of concrete projection, and Figures 9.7-9 and 9.7-10 show concrete projections being molded and completed reinforced concrete track bed, respectively.

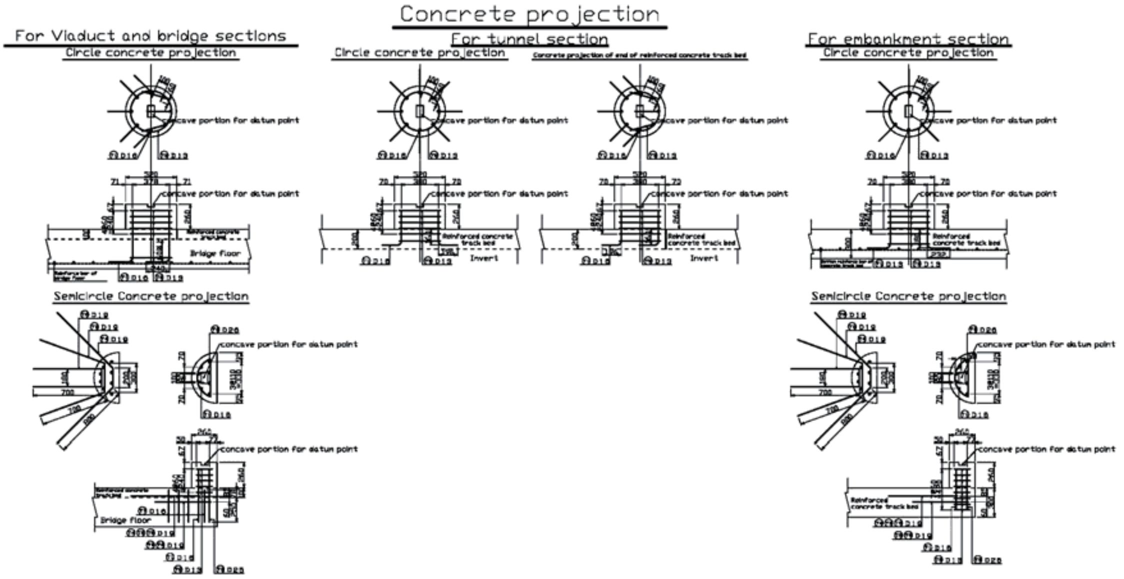


Figure 9.7-8 Drawings of Concrete Projection

Figure 9.7-9 Concrete Projections being Molded

Figure 9.7-10 Completed Reinforced Concrete Track Bed

4) Track slab

The slab track uses "track slabs" or reinforced concrete plates in place of the sleepers used for ballast tracks. In this report, Study team adopts the frame-type track slab of a RC structure used in warm areas in Japan, which can be manufactured, to replace the conventional plate-type track slabs, by hollowing the center of a track slab to improve economy and minimize its warp due to temperature changes.

There are two versions of track slab having different lengths: one is a 5 m-long standard track slab and the other a 4 m-long auxiliary. Combinations of these two versions can cover all girders (structures) having a length of 8 m or over, except those having a length of just 11 m.

In the manufacturing process, track slabs are molded with plugs, one to embed a tie plate and the other two, one each on each side to fix metals used to lift and transport the track slab. On each end, a semicircular notch is also cut to mate with a concrete projection.

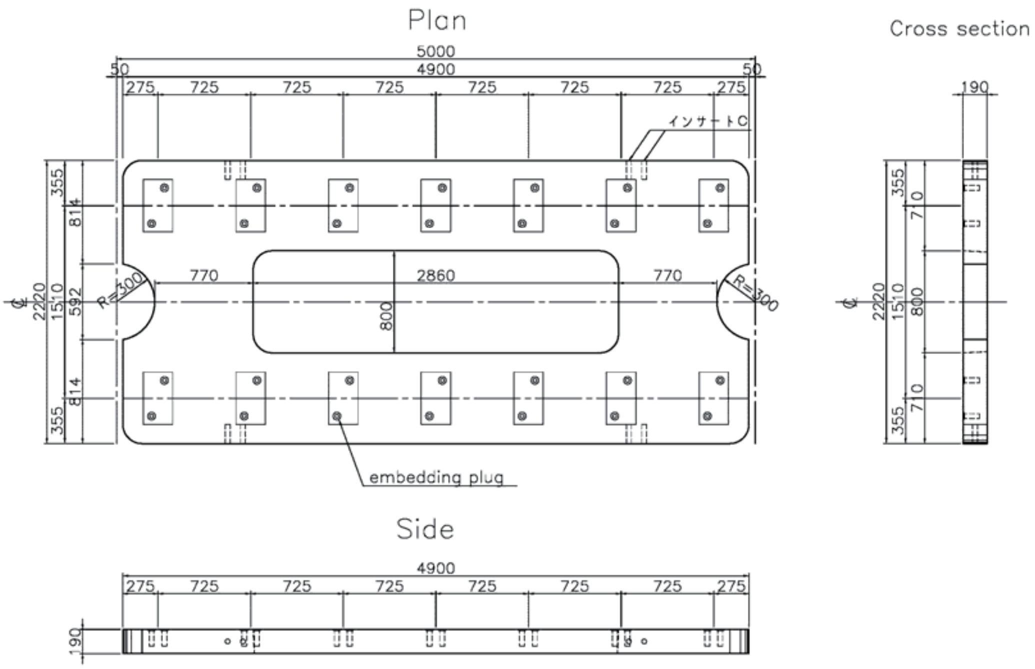


Figure 9.7-11 Drawing of the Frame-type Track Slab

5) CA mortar

CA mortar is grouted between track slabs and reinforced concrete track bed. Whereas the surface of the reinforced concrete track bed has unevenness to some extent, as concrete is cast and manually smoothed at the site, the track slabs manufactured at a factory to high-level precision shall be installed correctly aligned with the track center line and the rail level. Therefore, the gap between the track slab and the reinforced concrete track bed shall faultlessly be filled with a highly fluid material.

Furthermore, CA mortar is moderately elastic so that it elastically transmits the train load to the reinforced concrete track bed, in the same way as the track bed ballast used for ballast tracks does.

CA mortar is a material made by kneading to mix “asphalt emulsion,” “cement,” “sands,” “water” and “an admixture.”

6) Material to grout around the concrete projection

In the gap between the concrete projection and the semicircular notch of the track slab, urethane resin is injected in open sections and CA mortal in tunnel sections. Like the reinforced concrete track bed, the concrete projection tends to rest slightly out of position due to installation errors. Therefore, the gap with the track slab correctly in position shall completely be filled with a highly fluid material.

7) Fastener

Study team use “direct fixing type 8 fasteners” at intervals of 725 mm or at a rate of seven pieces per 5 m-long track slab.

Rails are fastened in the following manner. The tie plate is fixed to the slab track sandwiching an insulation plate in between. The resinous tie-plate “embedding” plug buried in the track slab in advance insulates between the left and right rails combined with the insulation plate.

Rails are placed on tie plates. A T-bolt is inserted into the notch cut in the tie plate to fix the rail with a plate spring. A “variable pad” and a “track pad” are inserted between the rail bottom and the tie plate. The variable pad is a plastic bag containing resin to finely adjust the rail height by changing the volume of resin. The track pad is used to provide elasticity against the vertical load to make a “dual elastic fixing structure” in the vertical direction combined with the plate spring. The track slab used in open sections is a rubber-bonded steel plate.

Viaduct and bridge structures elongate/contract due to temperature changes, with rails following suit to some extent in the track longitudinal direction at temperature changes or under train loads. In the case of ballast tracks, however, the relative displacement between rail and sleeper composing a monolithic structure or a “track skeleton” is absorbed in the displacement between sleeper and track bed ballast and, therefore, doesn’t present a visible form.

In the case of slab tracks on the other hand, as the track slabs are fixed to the reinforced concrete track bed, they behave synchronized with the engineering structure thereunder at temperature changes. Therefore, relative displacement between rail and base structure emerges between the rail base and track pads.

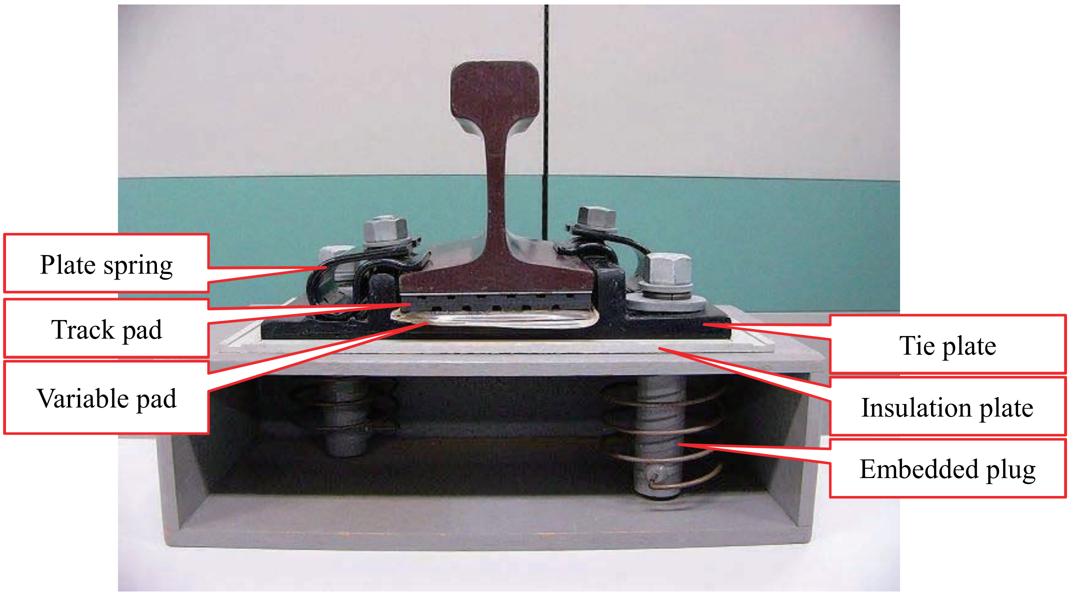
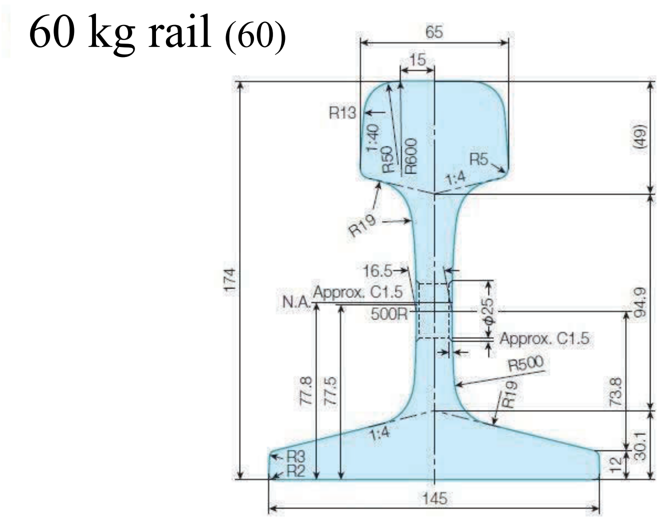


Figure 9.7-12 Direct Fixing Type 8 Fastener

Therefore, rail fasteners shall be designed to rigidly fix rails in the lateral direction to resist the lateral force caused by train loads while allowing rails to move in the longitudinal direction at the same time. For this purpose, plate springs have a contour to linearly contact the rail flange to allow rails to move in the longitudinal direction, while rigidly fixing rails in the lateral direction. Furthermore, a steel plate is bonded on the top surface of the track pad in contact with the rail base to allow rails to slide in the longitudinal direction.

8) Rail

Study team recommends to use the JIS 60 kg rail based on the proven stability for high-speed operation. If India uses the UIC rail instead, its affinity with wheel tread shall duly be verified to guarantee stable high-speed operation.



(Source: Nippon Steel & Sumitomo Metal Corporation)

Figure 9.7-13 Cross-section of 60kg Rail

(2) Track structure at turnout

If Study team uses a slab track in turnout sections of main track, complicated and uneconomical "track slabs for turnouts" shall be manufactured. If Study team uses "synthetic sleepers" featuring high durability and processability like that of wooden sleepers, Study team will be able to adopt a "synthetic sleeper ballast-less track" to ensure stable high-speed operation and manpower saving in maintenance.

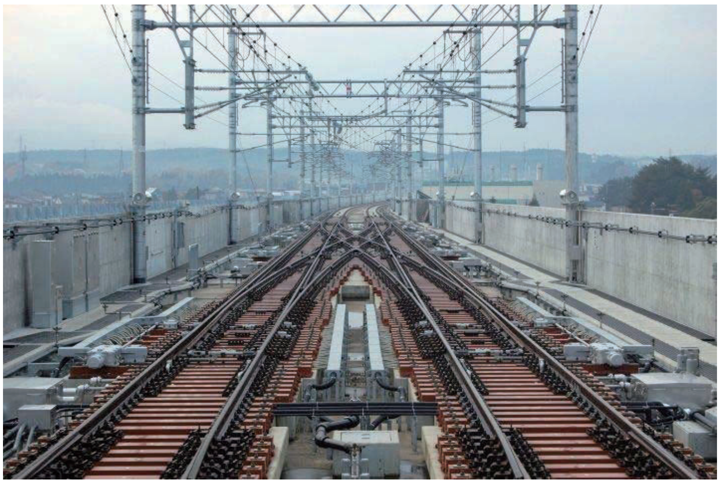


Figure 9.7-14 Synthetic Sleeper Ballast-less Track

1) Track structure in different sections.

Figures 9.7-15 and 9.7-16 show the cross-section in viaduct/bridge and embankment sections, respectively. For reference, there are no mountain tunnels in which turnouts shall be installed.

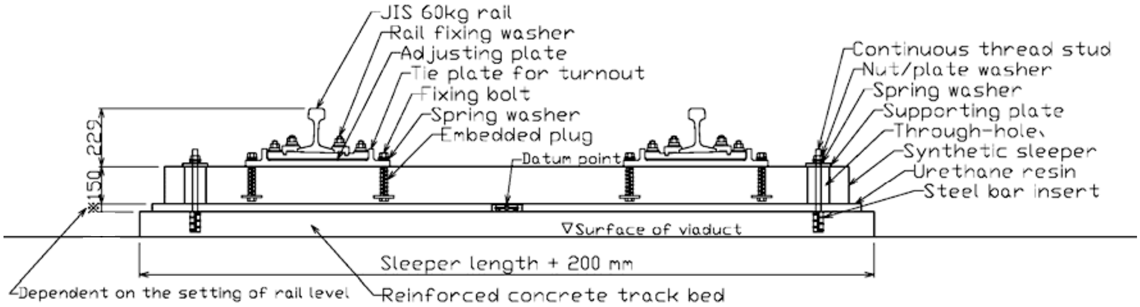


Figure 9.7-15 Standard Cross-section of the Track Structures at Turnouts in Viaduct/Bridge sections.

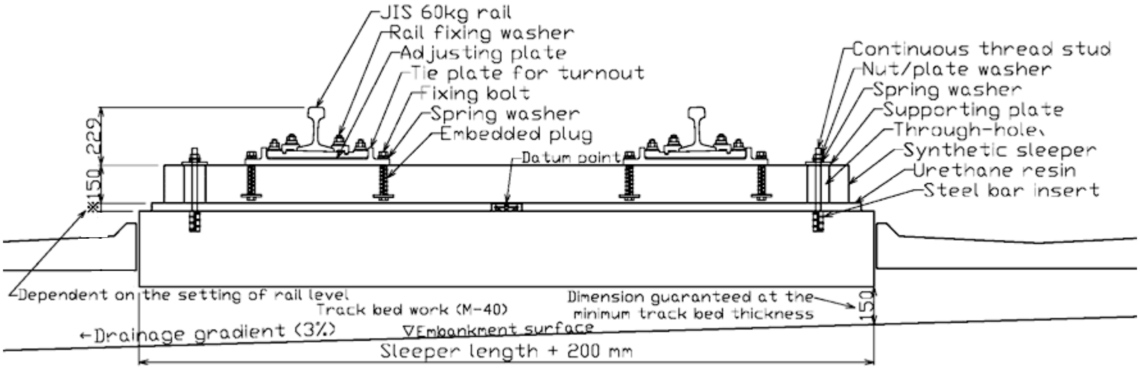


Figure 9.7-16 Standard Cross-section of the Track Structure at Turnouts in Embankment Sections.

Like for slab tracks, the reinforced concrete track bed in earth structure sections is larger in terms of thickness and width than those in viaduct/bridge sections. However, turnouts are common to viaduct/bridge and earth structure sections.

2) Reinforced concrete track bed

The reinforced concrete track bed is basically an RC structure like the slab track, having a width of “sleeper length” + “100 mm on each side (200 mm in total).”

Synthetic sleepers don’t need concrete projections, as they are fixed to the reinforced concrete track bed with anchor bolts.

A level shall be placed on the top of the reinforced concrete track bed between sleepers.

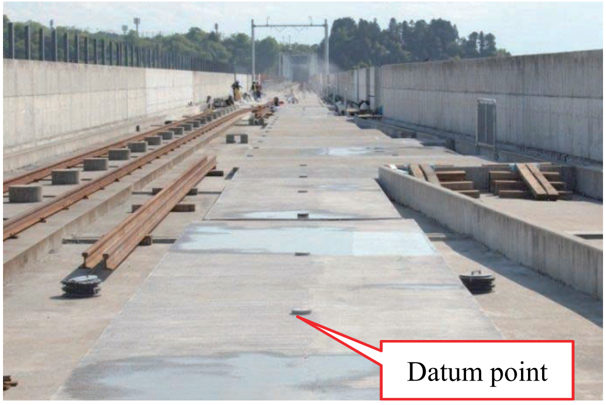


Figure 9.7-17 Reinforced Concrete Track Bed at Turnout

3) Synthetic sleeper

Synthetic sleepers are glass fibers solidified with resin, featuring high durability and the strength/processability equivalent to those of wood.

Urethane resin, having moderate elasticity, is injected between synthetic sleepers and reinforced concrete track bed. The synthetic sleeper fixing mechanism is as follows. Synthetic sleepers have two through-holes, each drilled at one end. A steel pipe insert is buried in the reinforced concrete track bed. To fix the synthetic sleeper, a continuous thread stud passed through each through-hole thereof is inserted into the steel pipe insert in the reinforced concrete track bed and tightened.

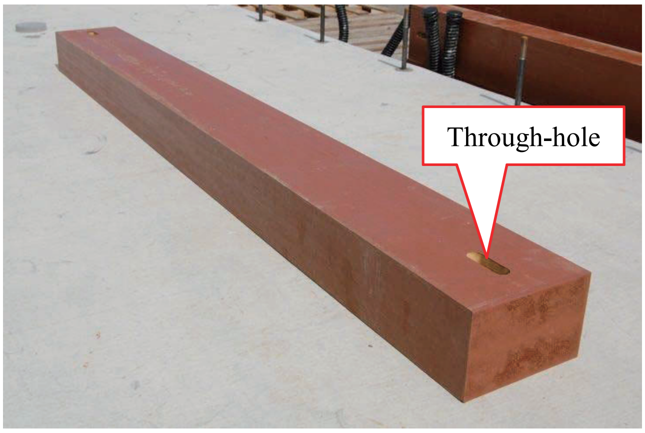


Figure 9.7-18 Synthetic Sleeper

4) Fastener

As the fastener for turnouts, Study team recommends the “dual floor plate type fastener” which is composed of a “bottom floor plate” to connect the turnout floor plate to synthetic sleepers and a “top floor plate” to fasten rails, with an adjusting iron plate inserted in between.

In fabricating a turnout at installation, a 5 mm-thick “adjusting iron plate” is inserted between the top and bottom floor plates, the thickness of which can be changed to adjust the rail level in case the base structure has sunk slightly after inauguration.

(3) Track structures at rolling stock depot and maintenance depot

As train speed is low in rolling stock depot and maintenance depot, high-level precision is not required for tracks. Therefore, Study team adopts ballast tracks featuring low construction cost for these bases.

Figure 9.7-19 Ballast Tracks at Rolling Stock Bases

1) Track structure

Figures 9.7-20 and 9.7-21 show the standard track cross-section at rolling stock depot and maintenance depot, respectively.

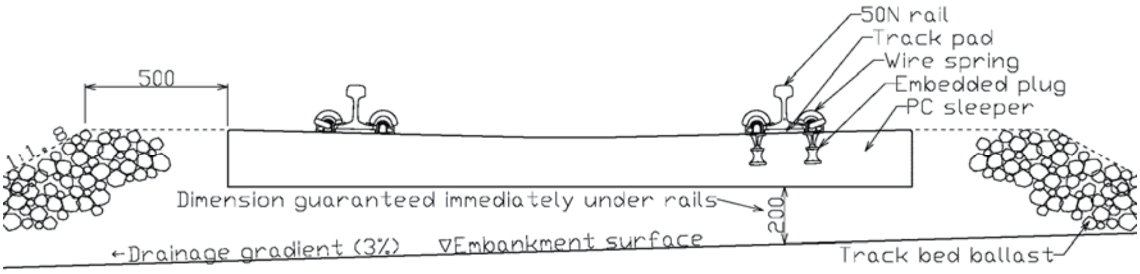


Figure 9.7-20 Standard Track Cross-section at Rolling Stock Depot.

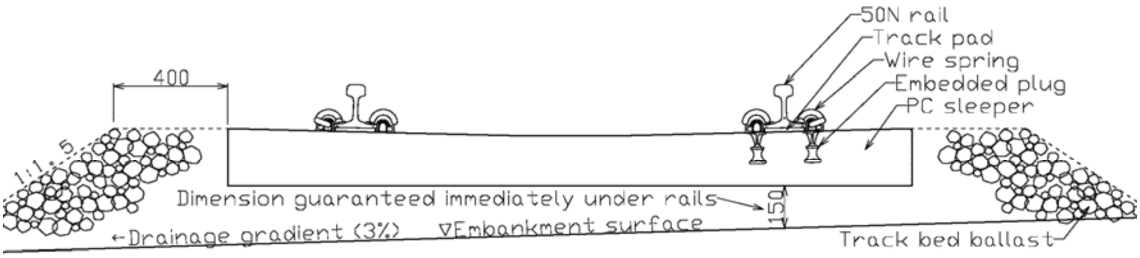


Figure 9.7-21 Standard Track Cross-section at Maintenance Depot.

2) Track bed ballast

Table 9.7-1 shows the configuration of track bed ballast.

Table 9.7-1 Configuration of Track Bed Ballast

Division	Ballast thickness*	Ballast shoulder width	Ballast slope gradient
Rolling stock depot	200 mm	500 mm	1:1.8
Maintenance depot	150 mm	400 mm	1:1.5

* As the embankment surface is inclined for drainage, the ballast thickness referrers to the minimum value immediately under rails.

3) PC sleeper

Study team adopts the "P3T sleepers" proven at the rolling stock base of Shinkansen, Japan. To save the construction cost, it may also be possible to use the standard sleepers in India after modifying the applicable track gauge from 1,676 to 1,435 mm.

4) Fastener

Track pads shall be inserted between the rail base and sleepers to guarantee the required spring constant. Rails shall be fixed with wire springs (Pandrol clips).

5) Rail

As train speed is low in rolling stock/maintenance bases, Study team uses 50 kg/m rails, which have a name "50N rail" with a symbol "N" is added to the name "50 rail" of the conventional 50 kg/m rail to indicate that it is a version of 50kg/m rail with the profile improved.

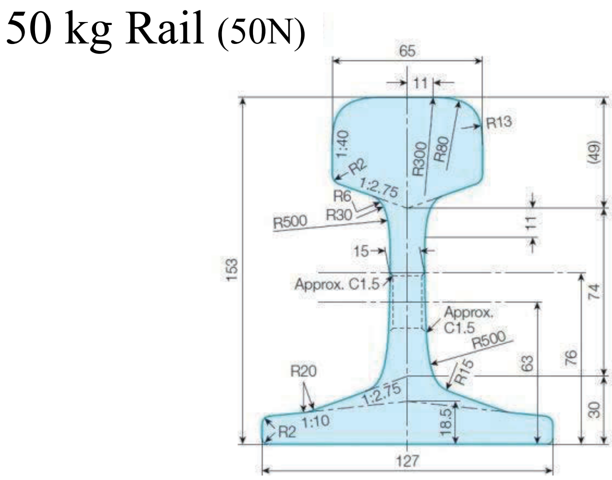


Figure 9.7-22 Cross-section of 50N Rail
(Source: Nippon Steel & Sumitomo Metal Corporation)

(4) Mainline turnout

Study team uses the "simple turnout T-No. 18" (turnout angle 3°11') in principle at branching points from mainline to sub-mainline in station yards and for crossover tracks between up- and down-tracks. Dimensions related to the simple turnout T-No. 18 are: radius of lead curve 1,106 m, train passing speed on the turnout side 80 km/h and radius of turnout curve of sub-mainline 1,200 m.
At terminal stations, Mumbai and Sabarmati are equipped with cross over tracks (scissors crossings). If the turnout CO-No. 18 is used for crossover tracks, the rail lacking portions of the left and right rails on the turnout side will overlap. Therefore, Study team uses the turnout SC-No. 16 (turnout angle 3°34'30") for scissors crossing tracks. At maintenance/rolling stock bases, as the train speed on the turnout side needn't be high, Study team uses the turnout T-No. 12 (turnout angle 4°46').
Study team uses the "movable nose crossing" at stations where non-stop trains pass at a speed of 110 km/h over (stations other than the Mumbai, Surat, Ahmedabad and Sabarmati stations). As the nose of this turnout moves, the rail lacking portions at crossing can be eliminated to guarantee the safety of high-speed operation.
At terminals and stations where train passing speed is at 110 km/h or less restricted by sharp curves ahead or behind (Mumbai, Surat, Ahmedabad and Sabarmati stations), Study team uses the normal "fixed nose turnout" from the viewpoint of economy.

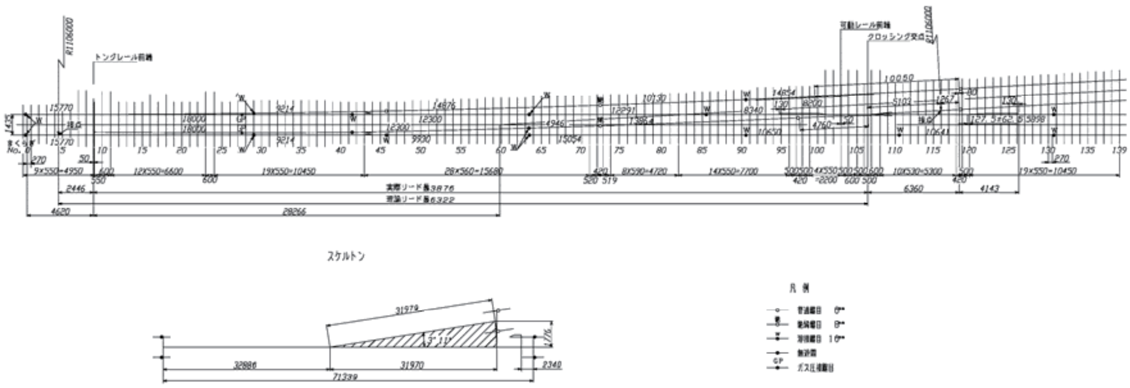


Figure 9.7-23 Drawing of Simple Turnout T-No.18

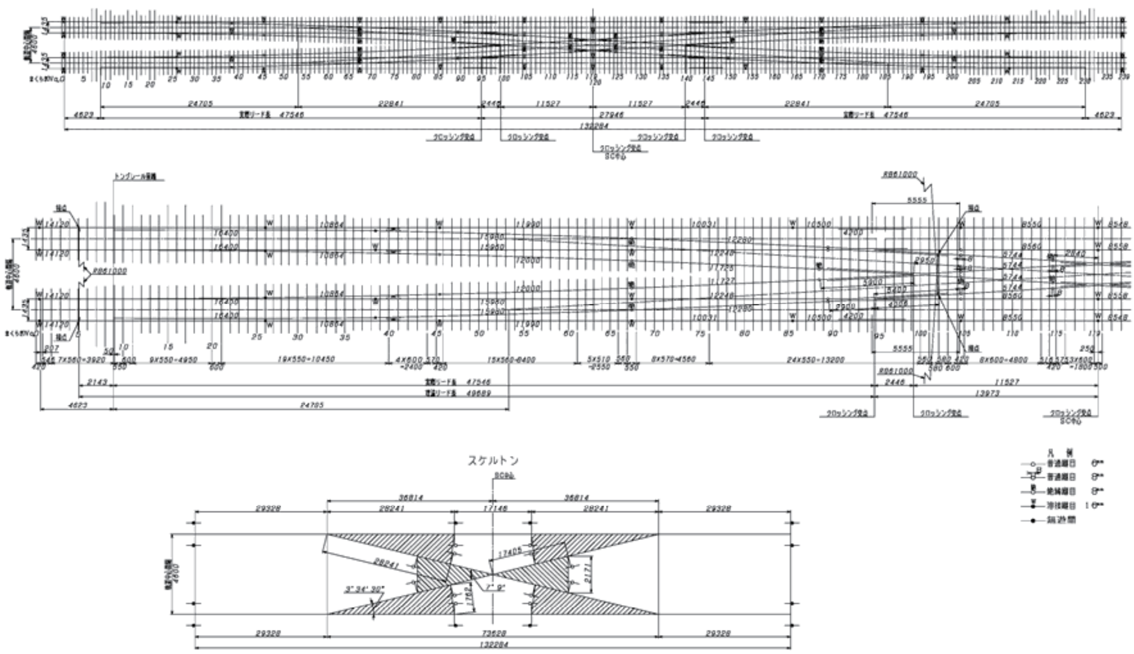


Figure 9.7-24　Drawing of Scissors Crossing Turnout SC-No.16.

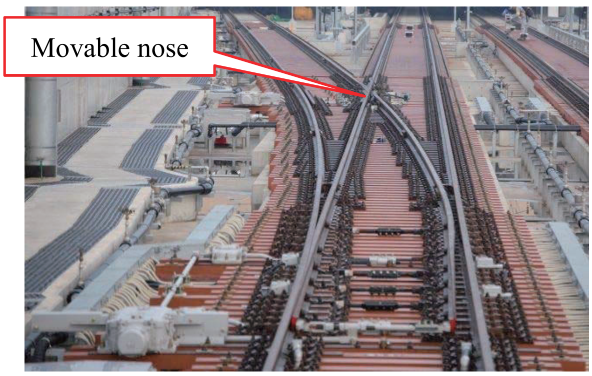


Figure 9.7-25 Turnout No.18

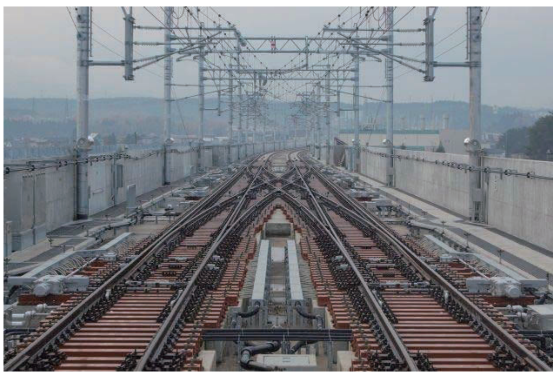


Figure 9.7-26 Turnout No.16

Table 9.7-2 List of the Quantities of Mainline Turnouts

Station	T#12		T#16	SC#16	T#18		CO#18	
Nose	Fixed	Movable	Fixed	Fixed	Fixed	Movable	Fixed	Movable
Mumbai			4	1				
Thane	1	2				4		2
Virar						4		2
Boisar	1					6		2
Vapi	1					4		2
Bilimore	1					4		2
Surat	1					4		2
Bharuch	1					6		2
Vadodara	1				4		2	
Anand/Nadiad	1					4		2
Ahmedabad					4		2	
Sabarmati			4	2				
Sub total	8	2	8	3	8	36	4	16
Total	85							

(5) Turnouts at rolling stock and maintenance bases

Study team uses the "turnout T-No. 9 (turnout angle 6°22')" at ballast track branching points and the "turnout SC-No. 12 (turnout angle 4°46')" for crossover tracks at rolling stock and maintenance bases.

For long-rail receiving/sending broad-gauge tracks, Study team uses Indian Railways standard turnout No. 8.5.

Figure 9.7-27 Turnout T-No.9

Figure 9.7-28 Scissors Crossing SC-12

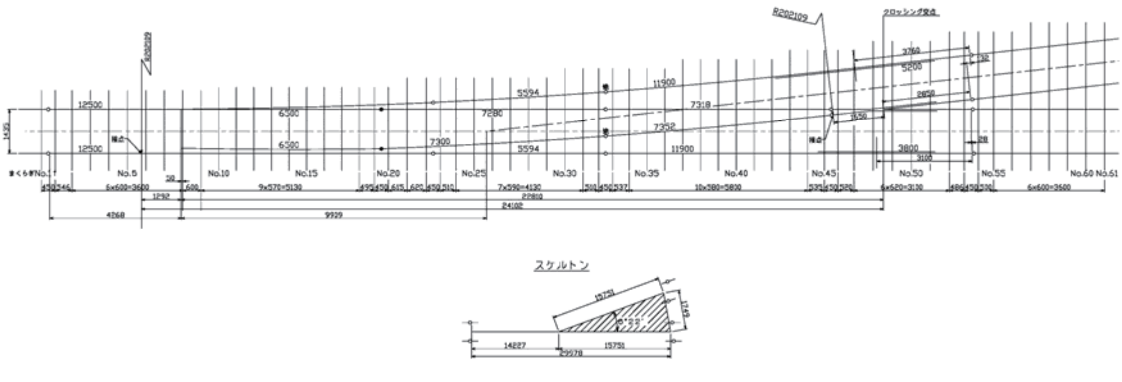


Figure 9.7-29 Drawing of simple turnout T-No.9

Table 9.7-3 List of the Quantities of Turnouts at Rolling Stock and Maintenance Depot

Station	T#9	SC#12	T#8.5
Thane M. depot	11		2
Thane depot	71	3	
Boisar M. depot	11		
Vapi M. depot	11		
Bilimore Con. Car base	2		
Surat M. depot	9		2
Bharuch M. depot	11		
Vadodara M. depot	11		2
Anand/Nadiad M. depot	11		2
Sabarmati M.depot	14		2
Sabarmati base, work shop	46	4	
Sub total	208	7	10
Total			225

(6) Expansion joint

Expansion joints are set before and after the turnouts installed at stations to isolate them from the axial force working in the continuously welded rails (long-rails) used for mainlines.
In the case of long bridges and other structures subject to large elongation and contraction due to temperature changes, their expansion and contraction are transmitted to rails. Rails jut out when the axial force in the direction into which rails elongate has increased to exceed the limit fastening force of fasteners. On the other hand, in case a rail has broken to some extent to cause a force to make the rail to shrink, the rail causes a desperate gape at the breakage point to compromise the safety of train operation. As detailed calculation is out of the scope of this report, Study team simply assumes that expansion joints be set before and after long bridges without relying on calculation.
Study team recommends the “Shinkansen type expansion joint” having two rail expansion and contraction absorbing points for mainline sections subject to high speed operation and the “simplified Shinkansen type expansion joint” having one rail expansion and contraction absorbing point at terminals and for sub-mainline sections subject to low-speed operation.
See Figure 9.7-30, a schematic presentation of the locations of expansion joints.

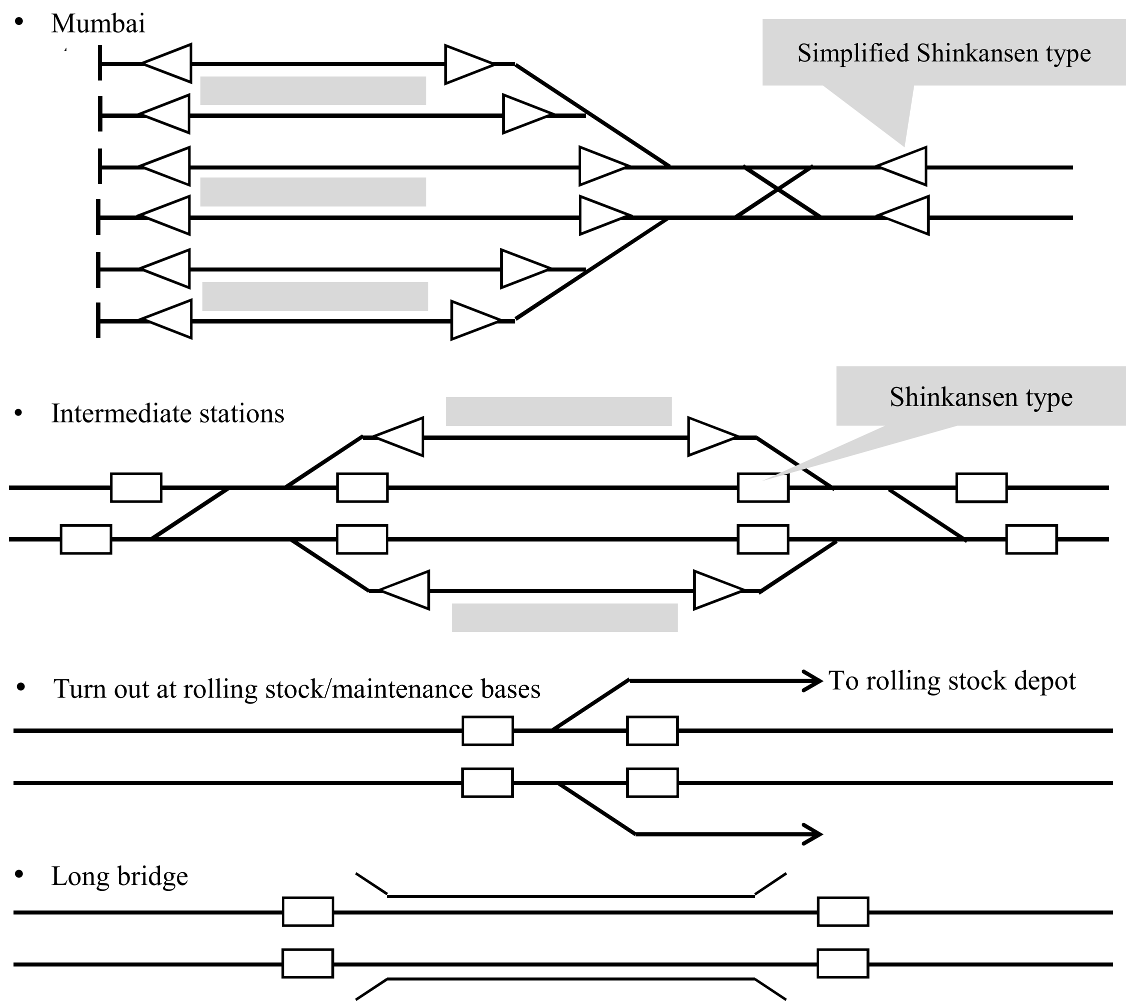


Figure 9.7-30 A Schematic Presentation of the Locations of Expansion Joints

Table 9.7-4 List of the Quantities of Expansion Joints

Kilometer	Place	Shinkansen type	Simplified type
0 k 000 m	Mumbai sta.		14
27 k 920 m	Thane sta.	12	4
29 k 000 m	Ulhas river	4	
29 k 510 m	Thane base	4	
38 k 500 m	Branch of Ulhas river	4	
64 k 920 m	Virar sta.	8	4
71 k 500 m	Vaitarna river (south)	4	
73 k 000 m	Vaitarna river (north)	2	
104 k 350 m	Boisar sta	8	6
167 k 500 m	Daman ganga	4	
168 k 900 m	Vapi sta.	8	4
177 k 000 m	Kolak river	4	
196 k 500 m	Par river	4	
199 k 000 m	Aurange river	4	
213 k 500 m	Kaneri river (south)	4	
216 k 000 m	Kaneri river (nouth)	2	
217 k 300 m	Bilimora sta.	8	4
230 k 000 m	Ambica river	4	
241 k 500 m	Purna river	4	
265 k 430 m	Surat sta.	8	4
322 k 000 m	Narmada river	4	
322 k 950 m	Bharuch sta.	8	6
396 k 750 m	Vadodara sta.	8	4
398 k 180 m	Vadodara M. base	2	
418 k 000 m	Mahi river	4	
446 k 980 m	Anand/Nadiad sta.	8	4
474 k 500 m	Vatrak river	4	
478 k 000 m	Meshwa river	4	
499 k 590 m	Ahmedabad sta.		12
505 k 100 m	Sabarmati river		2
505 k 200 m	Sabarmati sta.		12
505 k 400 m	Sabarmati base		2
	Sub total	142	82
	Total		224

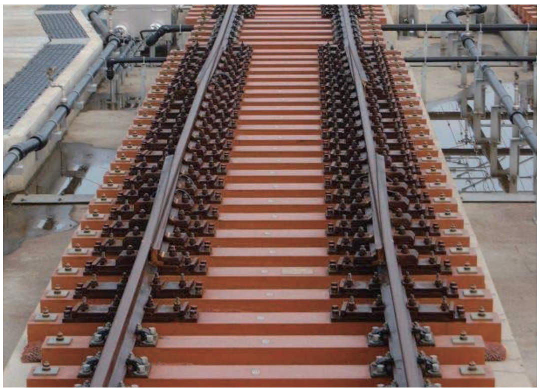


Figure 9.7-31 Shinkansen Type Expansion Joint

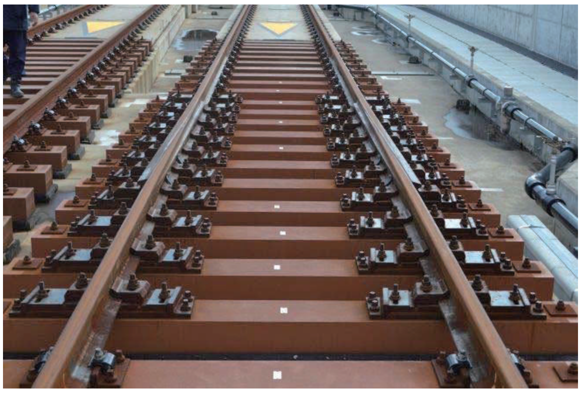


Figure 9.7-32 Simplified Shinkansen Type Expansion Joint

(7) Maintenance depot

1) Concept of the location of maintenance base

To follow the convention of Shinkansen in Japan, the daytime primarily to operate trains is defined as the "train operation time zone" and the rest at the nighttime as the "maintenance time zone" to distinctly differentiate the two in this report.
The working time zone is composed of the following.

>Changeover time for the operation control system from the operation time zone to the working time zone
>Maintenance work time
>Pilot car operation time
>Changeover time for the operation control system from the working time zone to the operation time zone

The changeover time between the two time zones is approximately 15 minutes.

1) Operation of the pilot car

The pilot car is a car to be operated in the time zone from the completion of overnight maintenance work to the operation of the first revenue service train of the day to confirm that there are no obstacles on the route (inside the rolling stock gauge). The pilot car is equipped with a headlight and a camera to monitor the status of the route ahead. To assist the visual inspection, the pilot car is also equipped with a "bottom clearance disorder detector (sensor) to issue an alarm in case the sensor contacts an obstacle remaining inside the rolling stock gauge when the car driver has failed in visually locating one.

The pilot car runs at 110 km/h to allow the driver to drive the car while watching the route ahead. Before operating the pilot car, the "system for maintenance" is run to switch turnouts at stations and establish the route for the car. The pilot car checks the route with the section between adjacent two stations as a unit. Therefore, Study team decided to locate sheds for the pilot car at stations. To complete the inspection along the whole route in approximately one hour, thereby guaranteeing a sufficiently long maintenance time, Study team planned the number of pilot cars and the location of the pilot car sheds.

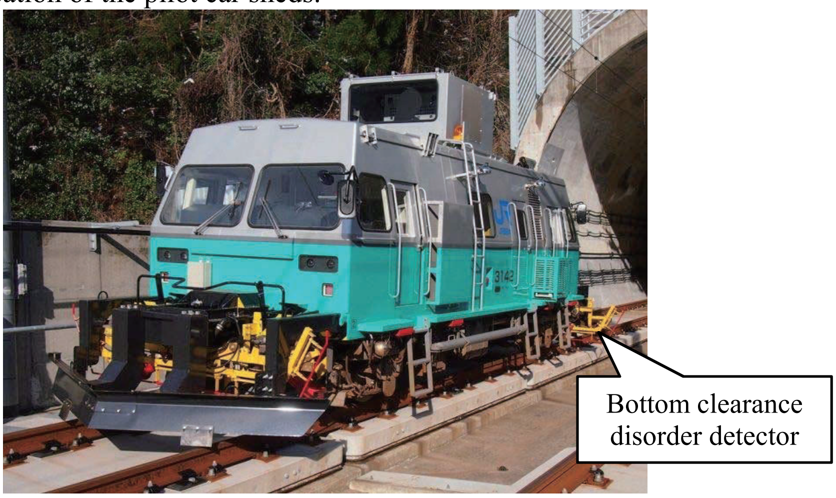


Figure 9.7-33 Pilot Car

2) Location of maintenance bases

The time for maintenance work is the working time zone from which the system changeover time and the pilot car operation time are deducted. Let's keep an eye on the working time at the remotest point on the route under assignment while assuming a maintenance car running speed of 40 km/h. The working time is different with different maintenance bases depending on their location. Under the distribution map of track maintenance bases in Table 9.4-5, working time of

2.5 hours will be guaranteed at the midpoint of the longest Vapi–Surat section.
As slab tracks don't require maintenance work on a regular basis (tamping, ballast renewal, etc.), what is required as the maintenance work is primarily control of tightening torque and long-rail creeps. Therefore, it is thought that the maintenance work on a regular basis is possible within the working time referred to above.
Below summarized are the location and equipment/facilities of different bases and maintenance car operation diagrams.

Table 9.7-5 List of Maintenance Depot

Kilometer	Place	Con. Car base	Men. Car base	L. rail delivery
29 k 510 m	Thane	○	○	○
104 k 350 m	Boisar	○	○	
168 k 900 m	Vapi	○	○	
217 k 300 m	Bilimora	○		
265 k 480 m	Surat	○	○	○
322 k 950 m	Bharuch	○	○	
398 k 180 m	Vadodara	○	○	○
446 k 980 m	Anand/Nadiad	○	○	○
506 k 000 m	Sabarmati	○	○	○

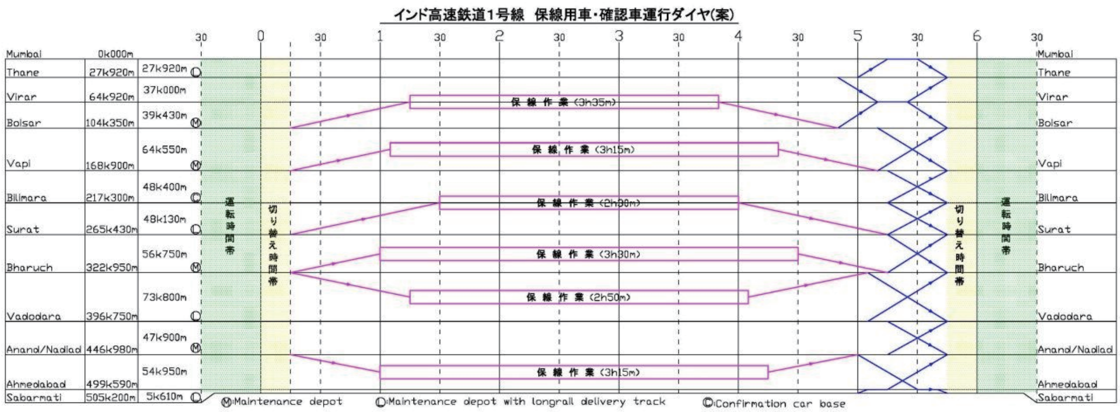


Figure 9.7-34 Maintenance Work and Pilot Car Operation Diagram

9.7.2 Track Work Schedule

(1) Outline of track work schedule

As an overall track construction work schedule, Study team assumed two to three years for construction and approximately one year for inspection, running tests and training runs. Study team makes arrangements to execute construction work during the daytime in principle to minimize the scope and number of "construction work machines" that shall newly be manufactured for the construction work.
Track laying work will follow the completion of related civil engineering work step by step, with that of some sections scheduled to delay approximately one year from that in other sections as the construction work of relevant civil engineering structures is apprehended to take a long period of time due to difficulty or they are implemented in urban areas or close to existing railways. These impedimental construction projects include the construction of the Mumbai underground station, submarine tunnel between Mumbai and Thane and viaducts in the Vadodara station area and those between Ahmedabad and Sabarmati.
Table 4.9-6 summarizes the work schedule determined in consideration of the records in Japan, night and day execution and the working environment in India (larger track construction bases, fewer private houses in wayside areas and less noise-related restrictions on the working time).

Table 9.7-6 List of Maintenance Depot

Item	Work contents	Process	Monthly speed
Construction of temporary track	Long-rail sliding-out	10 150 m-rail sending-out (for 750 m-track length) per day x day/night execution x 25 days/month	35 km
Laying of track slabs	Track slab transport, laying, adjustment, CA mortar grouting	40 track slabs (for track length 200 m) per day x day/night execution x 25 days/month	10 km
Secondary welding	Long-rail welding	6 lot rail-welding (for track length 450 m) x day/night execution x 25 days/month	20 km
Rail top aligning		Same speed as that of track slab laying	10 km
Rail axial force resetting	Rail axial force resetting, tertiary welding	A 1 km-section per day x day/night execution x 25 days/month	50 km

Study team define an approximately 50 km-long section as a construction work unit section by taking into consideration the above execution periods and speeds. Study team uses maintenance bases in principle as the base for track construction work.
For the purpose of long-rail carrying-in operation, however, the points of long-rail receiving from existing railways are insufficient in number with maintenance bases alone and locations of maintenance bases having long-rail receiving equipment/facilities are biased toward the end of the route. Therefore Study team install long-rail receiving/forwarding bases equipped with portal-frame telphers and connected to the existing railway close to the intersections with an existing railway at 80 km-, 224 km- and 330 km-points and a temporary crossover track between the track construction work base and the mainline for track slab carrying-in operation at the 45 km-point.

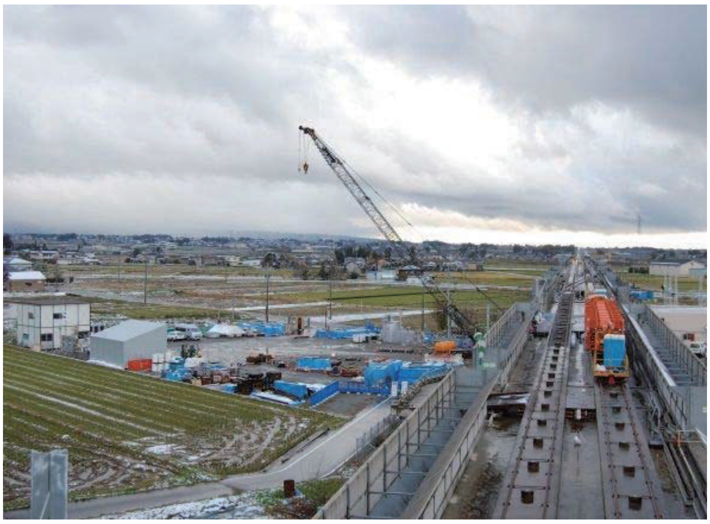


Figure 9.7-35 Track Construction Work Base

Table 9.7-7 List of the Construction Work Bases and Construction Work Unit Sections

Construction work unit section	Start point	End point	Length	Long-rail base	Track slab base
A	0 k 000 m	27 k 920 m	27 k 920 m	Thane M. base	Thane M. base
B	27 k 920 m	80 k 000 m	52 k 080 m	Thane M. base	Const. base No.1
C	80 k 000 m	137 k 000 m	57 k 000 m	Const. base No.2	Boisar M. base
D	134 k 000 m	195 k 000 m	58 k 000 m	Const. base No.3	Vapi M. base
E	195 k 000 m	250 k 000 m	55 k 000 m	Const. base No.3 Surat M. base	Const. base No.3
F	250 k 000 m	305 k 000 m	55 k 000 m	Surat M. base	Surat M.base
G	305 k 000 m	360 k 000 m	55 k 000 m	Const. base No.4	Const. base No.4
H	360 k 000 m	415 k 000 m	55 k 000 m	Vadodara M. base	Vadodara M. base
I	415 k 000 m	470 k 000 m	55 k 000 m	Anand/Nadiad M. base	Anand/Nadiad M. base
K	470 k 000 m	507 k 800 m	37 k 800 m	Sabarmati M. base	Sabarmati M. base

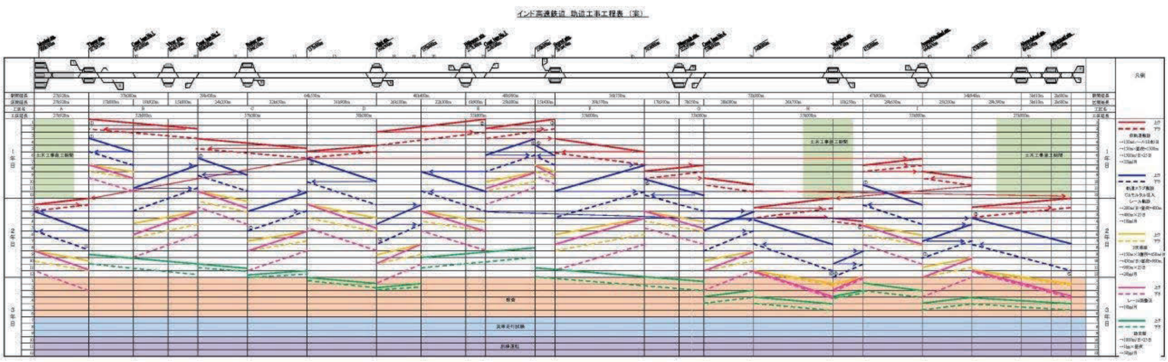


Figure 9.7-36 Track Construction Work Schedule

(2) Procurement of rail

1) Rail

High-speed railway track construction work requires high-level finishing precision, based on the high-level straightness of the rails in use. To guarantee the stability of high-speed operation, rigorous control of rail cross-section profile is also important together with the fitting for the rolling stock wheel tread profile. In this report, therefore, Study team adopts Japan-made proven rails having a JIS standard cross-section which have been used for Shinkansen for long years.

2) Required quantity

As the total track length including mainlines and sub-mainlines is 1,034.5 km, the required lengths (the total of those on the left-hand and right-hand sides) is 1,034.5 x 2 = 2,069 km, which is 2.069,000 m x 60 kg/m = 124, 140 t in weight when 60 kg/m rails are appropriated or 137,000 t including a 10% margin.

3) Method of procurement

For the slab track construction work in Japan, rails manufactured at ion mills are cut into 25 m rails, transported to slab track construction bases by trailers or other transport means and welded to 150 to 200 m long-rails, as transport of long rails in Japan to track construction bases by rail or sea is difficult and therefore, constructors cannot help but rely on road transport. Given the working environment in India in contrast, however, it is thought that long rails manufactured at iron mills can be carried into track construction bases intact, thereby contributing to cutting the schedule and cost for construction work.

In concrete terms, iron mills in Japan will roll steel ingots into rails having an approximately 160 m length, cut their ends subject to warp in the manufacturing process to produce 150 m rails, ship them on dedicated steel material transporting ships at their quays and transport to India intact.

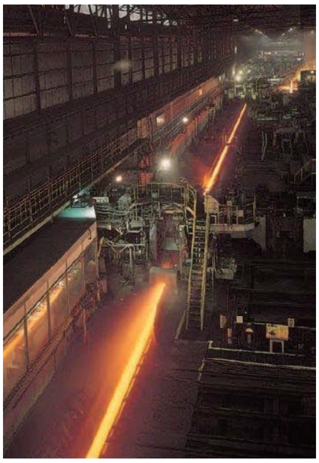


Figure 9.7-37 Manufacture of Rails
(Source: Nippon Steel & Sumitomo Metal Corporation)

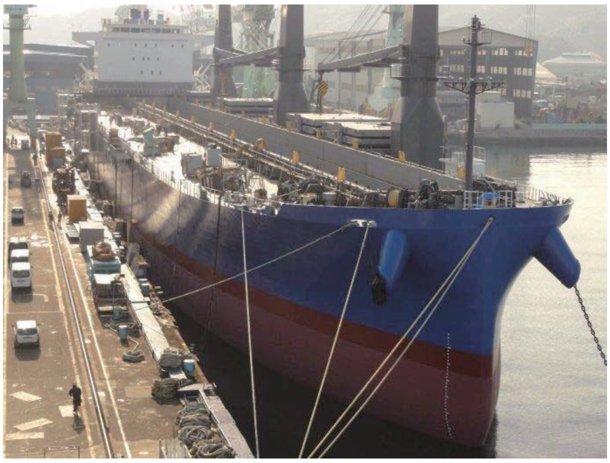


Figure 9.7-38 Long-Rail transporting Ship
(Source: Sumitomo Corporation)

To unload the rails from the ship arrived in India, Study team select a port having a water depth and a quay to accommodate a steel material transporting ship with an existing railway line is, or can be, connected thereto. At present, Study team has an idea to select the Mumbai Port, which is subject to a detailed survey in the future, however. The rails will be transshipped to long-rail transporting freight cars at the port with a crane mounted on the ship.

The rails on the long-rail transporting cars are sent via existing railways to rail receiving/forwarding tracks at the maintenance bases and track construction work bases attached to the high-speed railway.

(3) Manufacture of track slabs

1) Outline

Track slabs required for the slab track construction work will be manufactured at a track slab manufacturing plant constructed close to the mainline. As high-level precision is required for steel frames used to manufacture track slabs, they shall be manufactured by experienced manufacturers in Japan. However, reinforcing bars, ready mixed-concrete and accessary components required for manufacturing track slabs will be procured in India.

Figure 9.7-39 Track Slab Manufacturing Plant (External View)

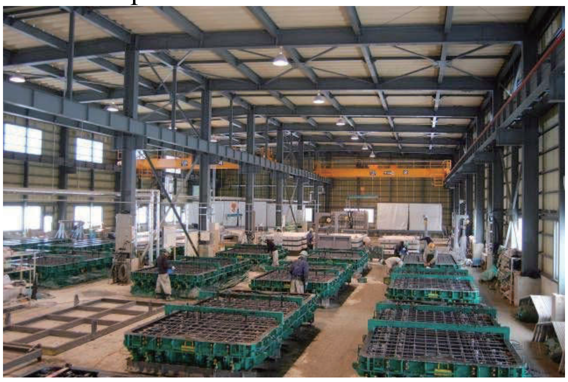


Figure 9.7-40 Track Slab Manufacturing Plant (Internal View)

2) Required quantity

As the total track length of mainlines and sub-mainlines is 1,034.5 km, the required quantity is 206,900 pieces (1,034.5 m/5 m = 206,900).

3) Manufacturing plant

Manufacture of track slabs starts two years before the kickoff of track construction work to last for four years in parallel with laying work.
A track slab can be manufactured with a frame per day or 1,200 pieces per year (one piece/day x 25 days/month x 12 months/year x 4 year = 1,200). This requires 172 frames (206,900 pieces/1,200 pierces/frame = 172).
As manufacture of approximately 10 frames per line is a standard according to the record in Japan, 18 lines are required in total. Therefore, Study team assumes installation of five plants (four lines per plant) in this report.

4) Manufacturing processes

Figure 9.7-41 illustrates a flow of track slab manufacture.

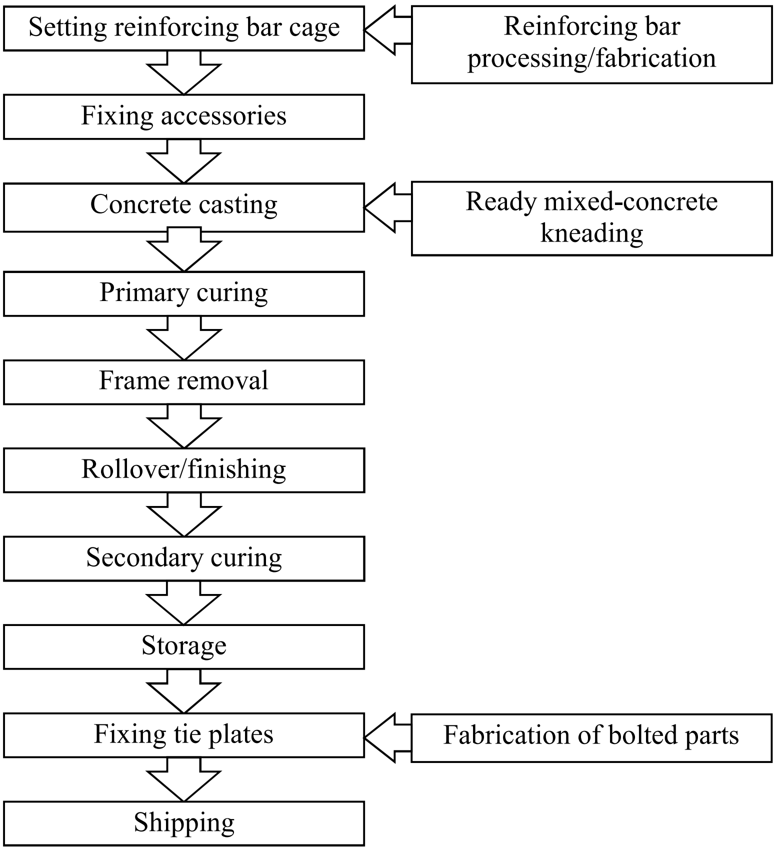


Figure 9.7-41 Flow of Track Slab Manufacture

i) Reinforcing bar processing and fabrication

Reinforcing bars used for track slabs shall be processed to specified dimensions and fabricated on a dedicated rack to manufacture "a reinforcing bar cage" of specified size.

Figure 9.7-42 Fabrication of a Reinforcing Bar Cage

ii) Setting of reinforcing bar cage

Clean and fabricate the steel frame and set the fabricated reinforcing bar cage.

iii) Fixing of accessories

Fix embedded plugs and inserts.


Figure 9.7-43 Setting of Reinforcing Bar Cage Figure 9.7-44 Fixing of Accessories

iv) Concrete casting
Cast the ready mixed-concrete manufactured at a concrete plant in the frame using a hopper.

v) Primary curing
Cover the cast concrete with a sheet and humidify with steam to cure at night until the next day.


Figure 9.7-45 Concrete Casting Figure 9.7-46 Primary Curing

vi) Frame removal
Check the compressive strength of the test piece manufactured simultaneously with the track slab at the test site. After confirming that the concrete has the specified strength, disjoint and remove the steel frame.

vii) Rollover to finish
As the track slab is manufactured upside down, reverse the track slab from which the frame has been removed and finish the surface.


Figure 9.7-47 Frame Removal Figure 9.7-48 Rollover

viii) Secondary curing
Put the track slab in a water tank for wet curing for several days.

ix) Storage
As the speed of track slab laying work on the mainline is higher than that of manufacturing track slabs, start manufacture of track slabs before the kickoff of the laying work and keep a certain quantity in stock at the storage place.


Figure 9.7-49 Wet Curing


Figure 9.7-50 Storage

x) Fixing of tie plates
Fix tie plates to track slabs taken out of the storage place immediately before shipping.

xi) Shipping
Transport track slabs using a trailer or other cars to the track laying work base.


Figure 9.7-51 Fixing of Tie Plates


Figure 9.7-52 Shipping

(4) Laying of slab tracks

1) Flow of the Slab Track laying work

Figure 9.7-53 shows a flow of slab track laying work.

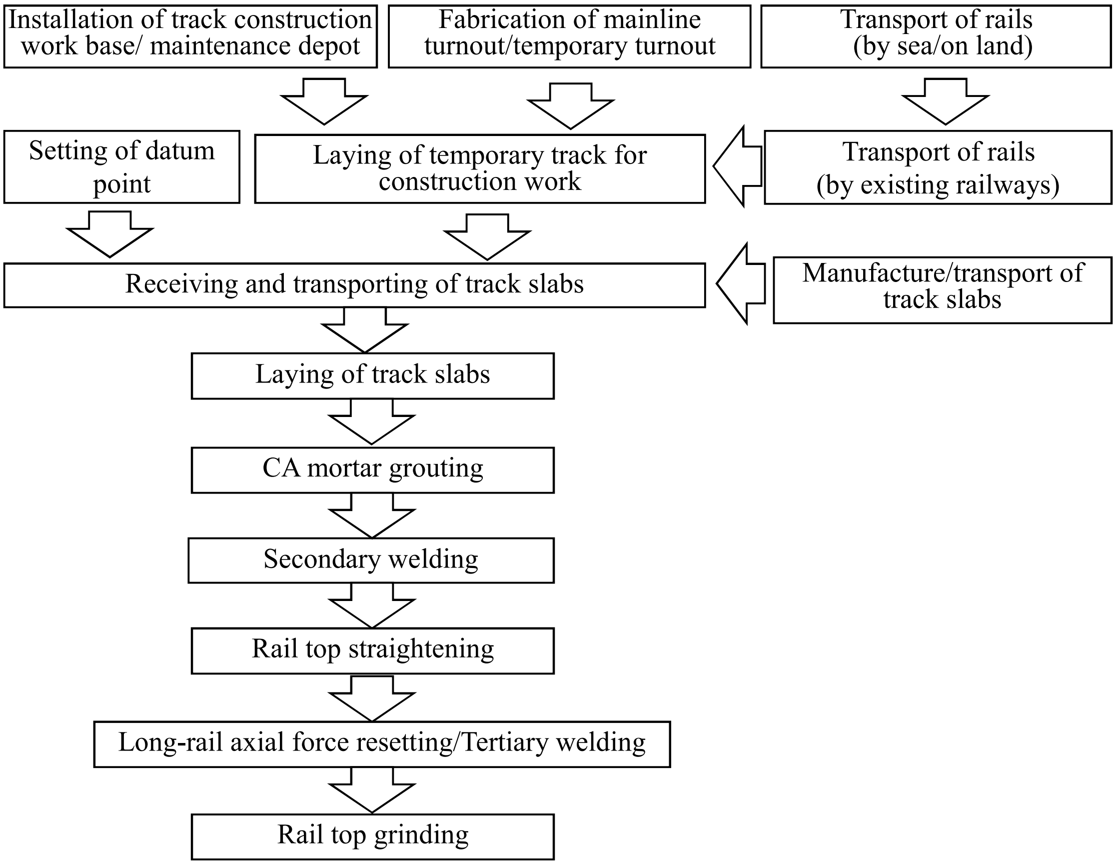


Figure 9.7-53 A flow of Slab Track Construction Work

2) Setting datum point

Set a "datum point" on the concrete projection to make a datum point for track slab laying and rail adjustment.

Process the measurements with a computer to calculate the "modified alignment." Based on the result, set the "datum point pin" of the level at the track center and fix it firmly with mortar.

Figure 9.7-54 Datum Point

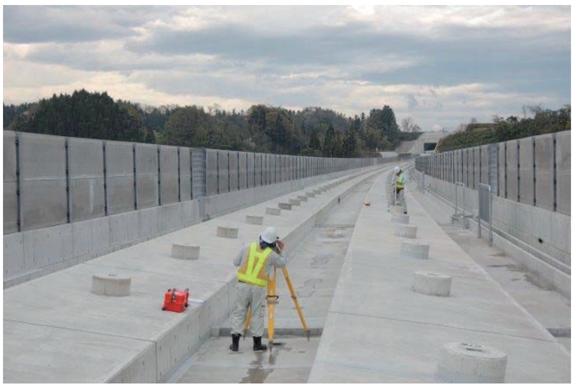


Figure 9.7-55 Survey

3) Laying of temporary tracks for construction work

The "rail sliding-out train" used to lay temporary tracks is composed of a "rail sending-out car," 19 sets of "iron-made truck (loading capacity 10 t)" and a "power car (motor car)."
On the long-rail receiving/forwarding tracks, transship the long rails arrived via existing railway lines to the "rail sliding-out train" for the high-speed railway. The quantity to be transshipped is 10 pieces per operation. The iron-made truck is equipped with "fixing metals" to fix the rails mounted thereon.
Run the rail sliding-out train mounted with rails up to the front end of the temporary track.
When the rail sliding-out train has arrived at the front end of the temporary track, pull the long rails on the iron-made truck with a winch into the "rail sending-out car" at the head of the train and make them protrude forward from the car by using the car-mounted rail forward sending rollers.
After the completion of sliding-out operation, temporarily fix the rails on the reinforced concrete track bed to hold a track-gauge of 1,435 mm.
Run the train 150 m on the temporary track, stop it at the front end and slide out the next rails. Slide out five pieces of rails per day on each side (equivalent to a track length 750 m) to extend the temporary track. After that, return to the track construction work base and load the train with the rails for the next operation.

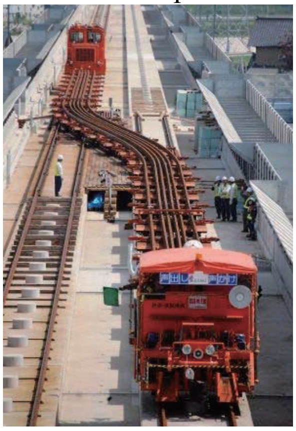


Figure 9.7-56 Rail Sliding-out Train

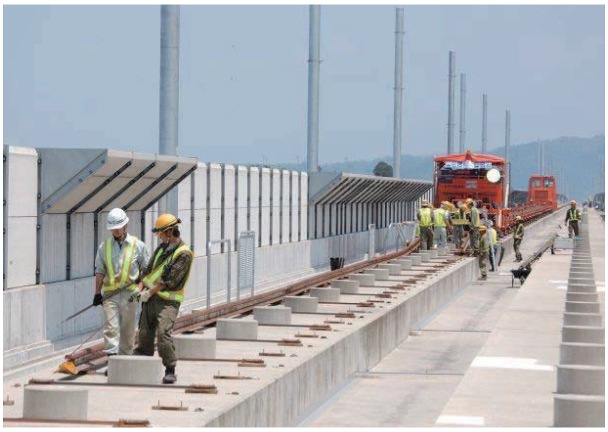


Figure 9.7-57 Rail Sliding-out Operation

4) Track slab receiving/transporting operation

After the completion of the temporary track laying work for each construction unit section, shift to the track slab laying schedule.
Transport the track slabs manufactured at a plant and stored in stock to the track construction work base first and load the "track slab transporting train" on the mainline with them. The train is composed of a "workers car," 10 sets of truck (each loading capacity 10 t) and a power car.

Figure 9.7-58 Loading the Train with Track Slabs

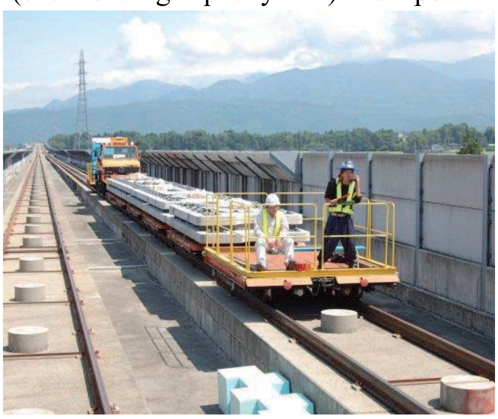


Figure 9.7-59 Transport of Track Slabs

The trucks accommodate two sets of two-stage piled track slabs or 20 pieces per train in total. Move the train mounted with track slabs on the temporary track for construction work up to the point of track slab laying operation.

5) Laying of track slabs
Expand the track-gauge of the long rails from 1,435 mm to 3,000 mm first, at the remotest point from the track construction base among the track construction work unit sections. Relocate the "track slab transporting train" onto the rails in the temporarily expanded track-gauge section.
At the end of the 150 m-section of the expanded track-gauge on the construction work base side, lay approximately. 50 m-long rails to generate a "lap-rail section" where 1,435 mm- and 3,000 mm-gauge rails exist in parallel. Stop the track slab transporting train within the lap-rail section and move the crane installed on the track slab laying car to lift track slabs in a posture striding over the train. Hold the track slabs lifted with the crane, transport them to the track slab laying point and release on the reinforced concrete track bed.

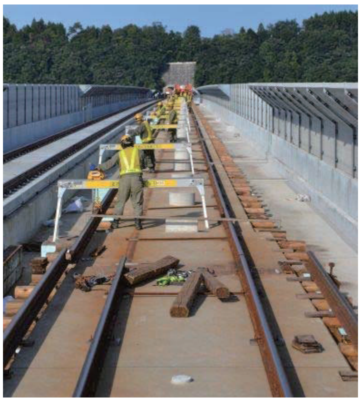


Figure 9.7-60 Expansion of Track-gauge

Figure 9.7-61 Lap-rail Section

Figure 9.7-62 Lifting of Track Slabs

Figure 9.7-63 Laying of Track Slabs

6) Adjusting of track slabs
Adjust the track slabs released from the crane with respect to longitudinal and lateral positions, height and cant by using a dedicated measuring instrument. Place the instrument on the datum point pin and a track slab to confirm that the slab track is correctly in position.

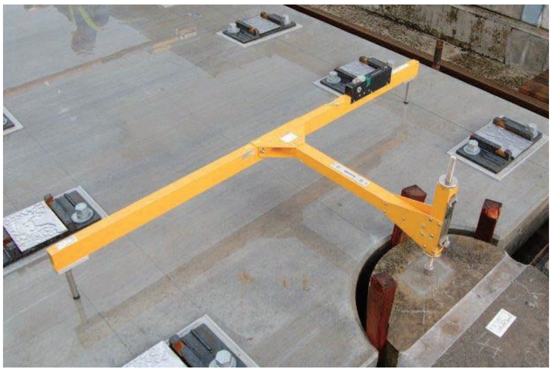


Figure 9.7-64 Adjusting of Track Slabs

Figure 9.7-65 Measuring Instrument

7) Injection of CA mortar

Inject CA (cement asphalt) mortar into the gap between reinforced concrete track bed and track slabs for which adjustment has been completed.

CA mortar is a material of kneaded fine aggregates (sands), asphalt emulsion, cement, water and an admixture. Run a dedicated plant car loaded with necessary materials on the track opposite to one into which CA mortar is to be injected (on the up-track for CA mortar injection into the down-track, for example) and stop it to the side of the object track. The plant car is equipped with a mixer. Supply the mixer with the materials in water/emulsion tanks and sand boxes, knead and discharge them through the cock at the bottom of the mixer and pipes for injection.

8) Injection into the gap around the concrete projection

Inject urethane resin into the gap around the concrete projection.

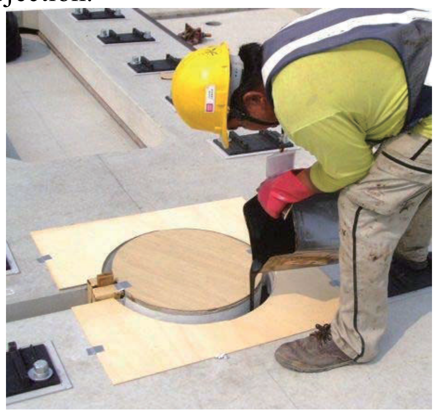


Figure 9.7-66 Injection of CA Mortar

Figure 9.7-67 Injection of Urethane Resin around the Concrete Projection

9) Relocation of rails

After the completion of track slab laying and relocation of rails, connect 150 m-long rails by the gas-pressure welding method to an approximate length of 1 km, with a gas-pressure welding machine mounted on a truck to move along the track.

10) Secondary rail welding

After the completion of track slab laying and relocation of rails, connect 150 m-long rails by the gas-pressure welding method to an approximate length of 1 km, with a gas-pressure welding machine mounted on a truck to move along the track.

Figure 9.7-68 Relocation of Rails

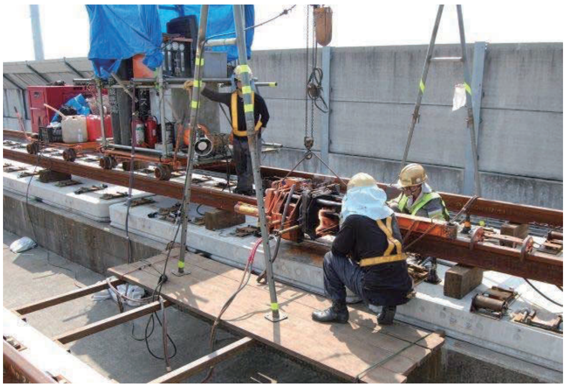


Figure 9.7-69 Secondary Welding

11) Rail top straightening

As track slabs are manufactured at high precision and set in position to satisfy the specified precision level. At the stage of relocation of rails, therefore, the track conditions may be satisfactory. Despite that, however, the rail-related four items (track-gauge, lateral level, alignment and longitudinal level) shall be checked for precision in order to guarantee the safety and stability of high-speed operation at 300 km/h or over.

In concrete terms, measure the above four items and adjust by using a measuring device or leveling string to guarantee the specified precision of rail position, with the lateral direction adjusted by shifting tie plates as a whole in the lateral direction and the vertical position by lifting the rails to adjust the height and inserting variable pads (plastic bags in which resin is injected for gradual solidification) in the gap between tie plates and track pads.

Figure 9.7-70 Adjusting of Rails

Figure 9.7-71 A measuring Jig

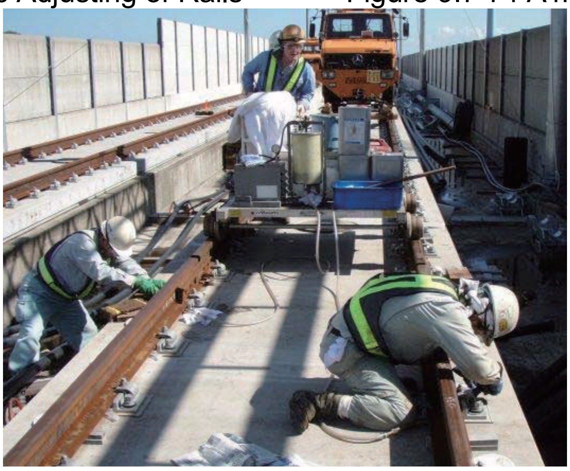


Figure 9.7-72 Insertion of Variable Pads

After adjusting the rail position, run a measuring device (track master) to check track finishing conditions and fasten fasteners with a bolt tightening/untightening power wrench.

Figure 9.7-73 Measurement with a Track Master

Figure 9.7-74 Rail Fastening

12) Rail axial force resetting/tertiary welding

For the purpose of tightening approximately 1 km-long rails with the rail temperature maintained at the specified rail-setting temperature, which is impossible in actuality, follow the steps below.

At a temperature lower than the specified rail-setting temperature, calculate the length for the rail to elongate when the temperature supposedly changes from the current temperature to the specified rail-setting temperature, apply a tension force using tensioners for the rail to extend up to the length obtained from the calculation and fasten the rail with the tensile force kept unchanged.

After that, weld 1km-long rails to produce a long-rail by the enclosed arc welding method.

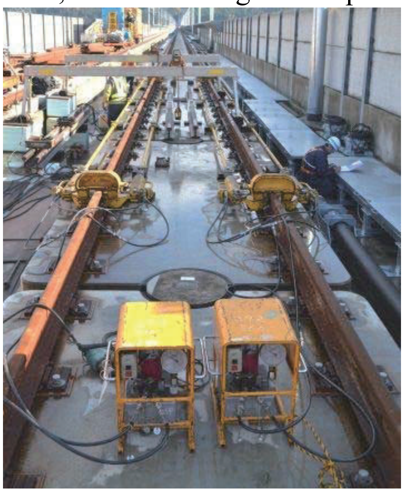


Figure 9.7-75 Tensioners

Figure 9.7-76 Tertiary Welding

(5) Construction work machines

Table 9.7-8 summarizes the quantities of construction work machines required for different construction work unit sections In this Table, however, it is assumed that construction work machines are transferred from the unit sections where work starts earlier to those where work starts later to compress the total quantities required for this construction work. The figure “0” in the Table means a late starter awaiting transfer of the machine coming from a forerunner.

Table 9.7-8 List of the Construction Work Bases and Construction Work Unit Sections

Unit section	Power car	Truck	Rail sending-out car	CA plant car	Slab laying car
A	0	0	0	0	0
B	3	27	1	1	1
C	3	27	1	1	1
D	3	27	0	1	1
E	6	54	1	1	1
F	3	27	0	1	1
G	3	27	0	1	1
H	3	27	0	0	0
I	3	27	0	1	1
J	0	0	0	0	0
K	0	0	0	0	0
Total	27	243	3	7	7

Figure 9.7-77 Rail-road Dual-mode Power Car

Figure 9.7-78 Engine Power Car

Figure 9.7-79Track Slab Transport/Laying Car

Figure 9.7-80Rail Sliding-out Car

Figure 9.7-81 CA Mortal Plant Car

Figure 9.7-82 Truck

(6) Synthetic sleeper ballast-less track

1) Flow of construction work

Figure 9.7-83 illustrates a flow of synthetic sleeper ballast-less track construction work.

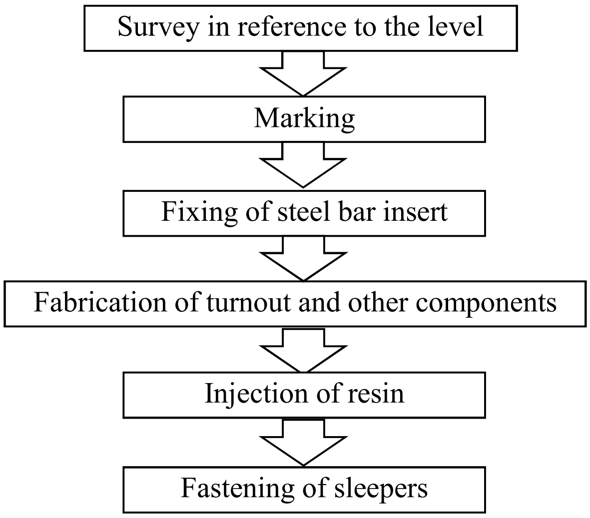


Figure 9.7-83 CA Mortal Plant Car

2) Survey in reference to the level

In the same way as in the slab track construction work, install levels for surveys to set modified alignment.

In the slab track construction work, the level is set on the concrete projection. In the synthetic sleeper ballast-less track construction work, however, the level is set between "sleepers" at intervals of approximately 5 m in addition to such places as the front end, rear end and theoretical intersection of turnout.

3) Marking

On the reinforced concrete track bed, mark the permanent way center lines on the mainline and branch line sides and the sleeper center lines in reference to the set level.

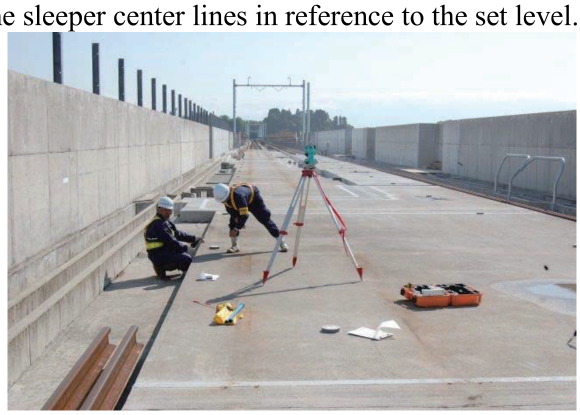


Figure 9.7-84 Marking

4) Steel bar insert

Plant the sleeper pipe insert to be used to fix sleepers at the point of sleeper center line marked on the reinforced concrete track bed.

In concrete terms, cut a hole on the reinforced concrete track bed with a drill, plant the steel bar insert in the hole and inject polyester resin into the gap.


Figure 9.7-85 Drilling


Figure 9.7-86 Planting of Steel Bar Insert

5) Fabrication of turnout
Fabricate the turnout with materials/components carried onto the mainline. Support the turnout with jacks and adjust its height in reference to the level.

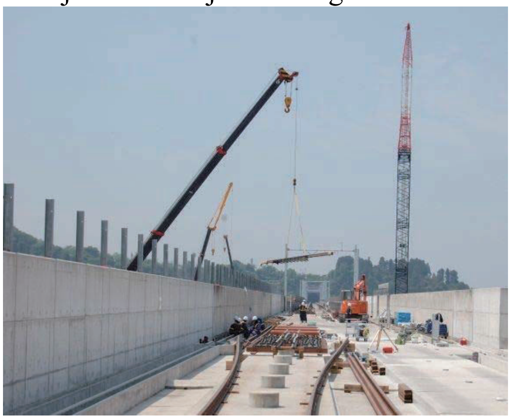


Figure 9.7-87 Carrying-in of Materials


Figure 9.7-88 Fabrication of Turnout

6) Injection of resin
After fabricating the turnout, inject urethane resin in the gap between sleepers and the reinforced concrete track bed.

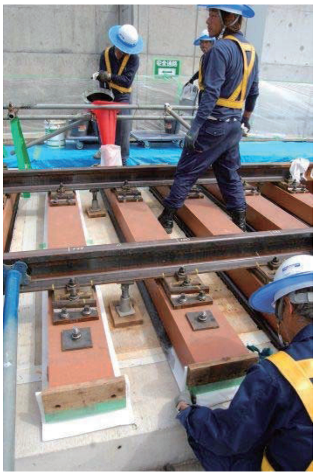


Figure 9.7-89 Injection of Resin

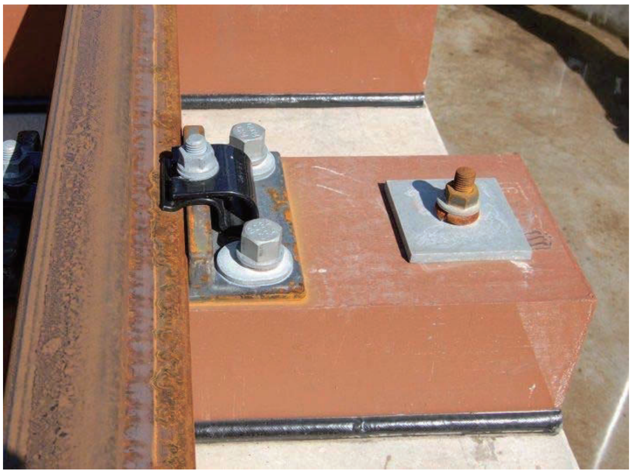


Figure 9.7-90 Fastening of Sleeper

9.8 Rolling Stock

9.8.1 General Concept

As described in Chapter 4, main characteristics of the rolling stock which will be adopted in this project have been decided as bellow.

Table 9.8-1 Main Characteristics of Rolling Stock Proposed.

Item	Dimension	Remarks
Train Type	EMU	
Formation	8 to 16 cars (tentative)	To be revised based on passenger demand forecast
Maximum operation speed	320 km/h	At inauguration
Car body width	3200~3,400mm	Wide body type
Seat arrangement	5-seat arrangement (2-seat/3-seat arrangement)	Standard car
Car body materials	Aluminum alloy	Airtight structure

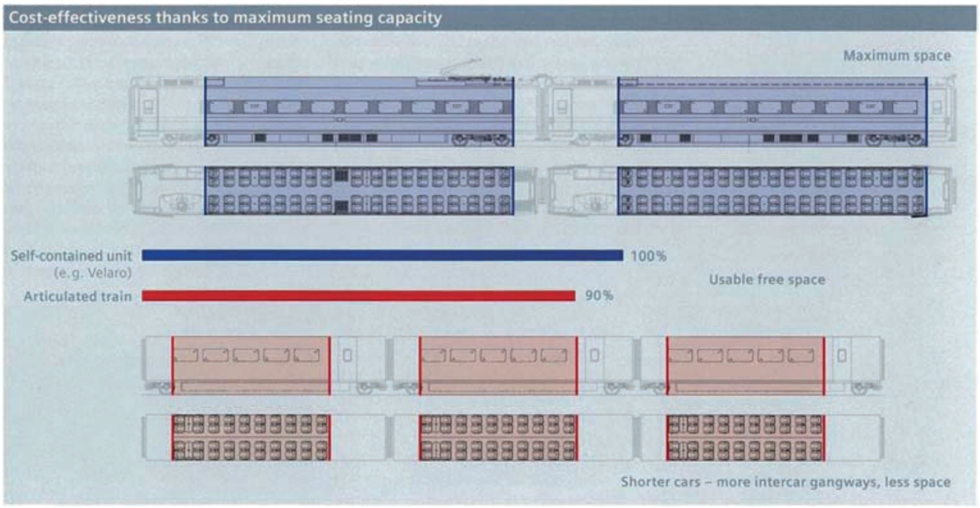
Source: Study team

Based on these, other items are compared and analyzed at the outset and the detailed dimensions and specifications are investigated.

9.8.2 Formation/Dimensions and Basic Performance

(1)Formation: Articulated /Non-articulate

From the viewpoints of manufacturing cost and ride comfort, articulated or non-articulated trains are not significantly different from each other, despite that their technologies have developed to satisfy different requirements. Whereas articulated train sets are advantageous for maintenance to the extent that they incorporate fewer bogies in number, they require cumbersome operation for train set composition/decomposition. This means that either system has merits and demerits simultaneously. One of the most outstanding differences is the size of effective space appropriated for passengers, in that the articulated system has more car-end sections in number to reduce the effective space for passengers. Figure 9.8-1 compares the articulated and non-articulated trains in which the ratio of effective space of articulated bogie system is taken as 90% of that of non-articulated bogie system. Articulated has lower capacity than non-articulated by 20% approximately.
Therefore, it is easier to realize mass-transport with the non-articulated bogie system than with the articulated bogie system.



Source: Study team

Figure 9.8-1 Comparison of Non-articulated and Articulated Bogie System

It is recommended adopting the non-articulated train formation with an ample space effectively usable for passengers to enable mass-transport.

(2) Car body width

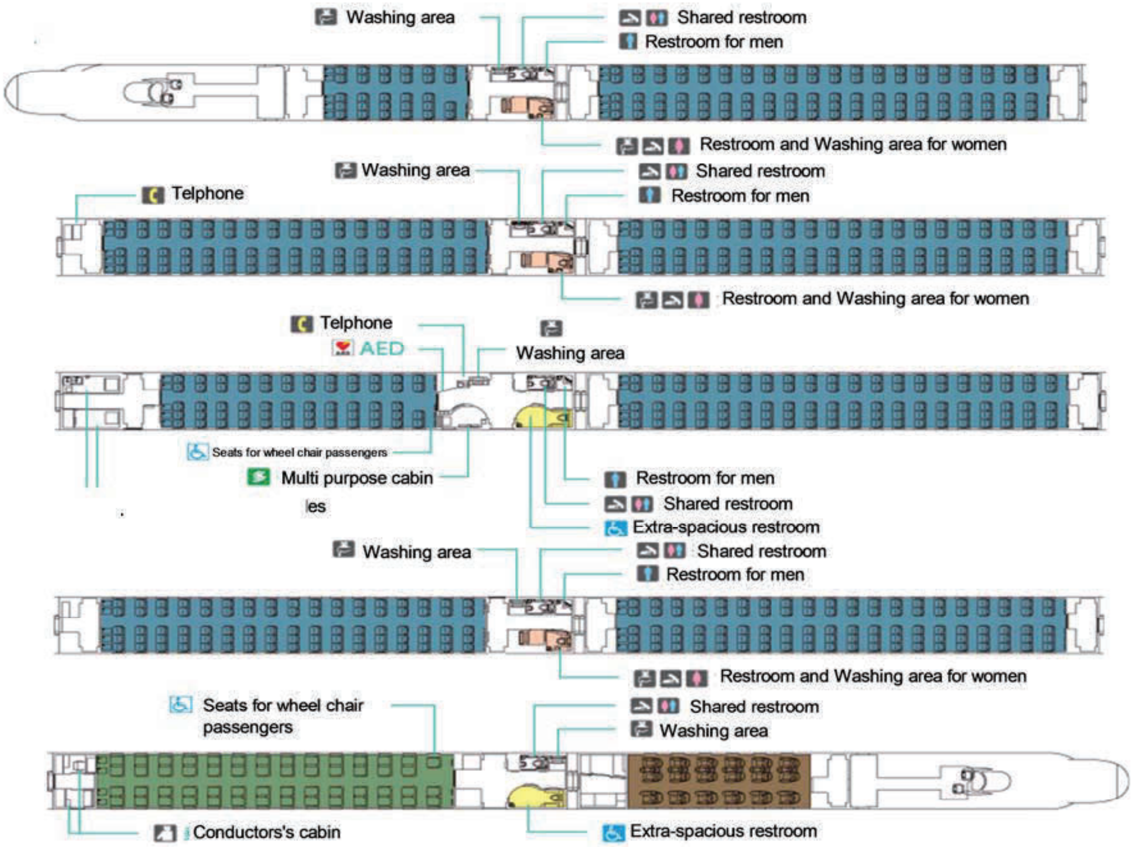
As shown in Table 9.8-1, it have been decided that Wide body type should be adopted and body width is within a range from 3200mm~3400mm. In the JMC held in June 2014, low-fare train is referred for the purpose of respond to demand of low-fare seats and effective utilization of off-peak hours. Therefore Convenience class, which has 3+3 seats arrangement, needs to be considered. Realizing that arrangement which is described in later section 9.8-3, it is advisable that 3380 mm width, which is the widest one in World HSR, should be adopted.

(3) Floor layout plan

The standard passenger room layout is composed of passenger compartments, luggage storage spaces, sanitary areas and vestibules. Table 9.8-2 shows Comparison of floor layout about E5, TGV-R and ICE3.

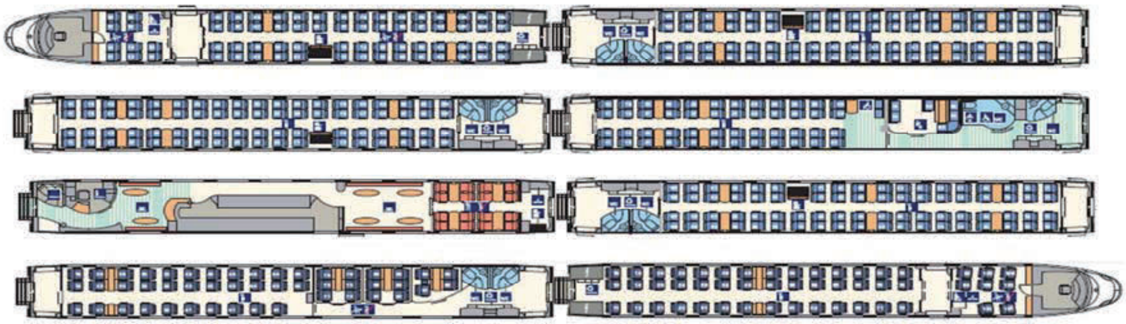
One car is normally equipped with two vestibules on each side (four in total) except for articulated small-length cars of TGV train sets, one toilet at most and a urinal for men additionally with Shinkansen. Standard-class seats are of the reclining and rotating with E5, the fixed reclining type with ICE3 and the fixed type with TGV. The seat pitch is as large as 1,040 mm with E5 to improve comfort and facilitate revolution of three-seat blocks. ICE3 has reduced the seat pitch from 970 to 920 mm to increase passenger capacity. TGV and ICE have catering facilities including spaces for ingestion in the train set composition, while Shinkansen train sets a space for on-the-train selling base. TGV and ICE3 train sets have luggage storage spaces at several places in the train composition, while E5 train sets a space to house luggage, 550 x 450 x 250 mm in size, on the overhead luggage racks, though they don't have luggage storage spaces. As the spaces for sanitation, luggage storage and catering reduce passenger capacity, numbers and places of these spaces shall be determined while considering the environment and time zone of the operation of these trains. Figure 9.8-2 summarizes typical passenger room layouts of Shinkansen and ICE3.

Shinkansen



Source: Http://www.jreast-shinkansen.com

ICE3



Source: http://xn--9ck2a5dua8e5028en3c.jp

Figure 9.8-2 Typical Passenger Room Layouts of Shinkansen and ICE3

Table 9.8-2 Comparison of Floor Layout

Class	Japan Series E5	France TGV-R	German ICE3
Type	EMU	Loco	EMU
Train-set and length	10-cars 250m	11-cars 200m	8-cars 200m
Passenger capacity	731 seats	375 seats	444 seats
Number of end of car sections with doors (standard class)	2 end of car sections/car	1 end of car section/car	2 end of car sections/car
Luggage storage	—	○	○
Number of toilets (sanitary)	8 toilets/train set (shared restroom) 2 toilets/train set (extra-spacious restroom) 4 toilets/train set (for men)	9 toilets/train set (shared restroom)	9 toilets/train set (shared restroom) 1 toilet/train set (extra-spacious restroom)
Catering	Preparation for on-board sales	○	○
Seat type (standard class)	Rotating and reclining seat	Fixed and non reclining seat	Fixed and reclining seat
Seat pitch (standard class)	1040mm	unknown	920mm

Source: Study team

Proposed floor layout plan is shown in Table 9.8-3. Passenger capacity is required 750 seats or over for 10-cars train sets and 1200 seats or over for 16-cars train sets in consideration of operation planned. Swinging type reclining seats should be adopted both for business and standard class accommodations to improve seating comfort by setting a standard-class seat pitch to facilitate swinging of three-seat blocks having a seating comfort ensuring width, thereby guaranteeing the required passenger capacity.

Table9.8-3 Floor Layout Specification

Item	Design Specification	Comment
Passenger capacity	750 seats or more: 10-car train sets 1200 seats or more: 16-car train sets	
Number of end of car sectionswith doors	Standard class: 2 end of car sections/car Business class: 1 end of car section/car	To facilitate smooth boarding/alighting even to/from cars
Luggage storage	Each car Width: 500～1000mm (along the rail)	In consideration of the environment of India
Sanitary	Every 2cars	Shared restroom: 2 toilets Restroom for men: 1 toilet Washing room: 2rooms Extra-spacious restroom: 1 toilet/train set
Catering	3 rooms/train sets	Preparation for on-board sales
Seat arrangement	Standard class: 5-(2+3) Business class: 4-(2+2)	Rotating and reclining seat to improve seating comfort 6-(3+3) is possible
Seat type	Rotating and reclining seat	
Seat pitch	Standard class: 1000～1040mm Business class: 1160mm	Guaranteeing the required passenger capacity and comfort.

Source: Study team

Two doors on each side (four in total per car) should be installed to facilitate smooth boarding/alighting even to/from cars having a passenger capacity of 100 persons. A luggage storage space on each car should be provided in consideration of the manners and customs in India. A sanitary space every 2cars (five in a train composition) equipped with a toilet for men and two shared toilets and washrooms should be installed, and one car for each train sets has a car installed with a large-size barrier-free toilet in place of the shared toilets and the toilet for men.

As a means of catering services, set a space for on-the-train selling preparatory work at three places: the head car, tail car and car at the center.

(4)Axel load

Table 9.8-4 indicates that, among the typical high-speed railway train sets in the world, the maximum axle load of the train sets in Europe and others based thereon is as large as 17 t, while that of Shinkansen is 12 to 13 t. The car weight per person (the car weight divided by passenger capacity) is 500 to 600 kg with Shinkansen in Japan, while that of high-speed train sets in Europe is 900 to 1,000 kg. In terms of the car weight per person, ICE3 based China CRH-3 runs ahead of the high-speed train sets in Europe owing to its 5-seat arrangement and TGV-R-based South Korean KTX-Ⅰ follows suit with its long train set compositions. However, either Chinese or South Korean version falls behind the Shinkansen railways in Japan. The output per person is 10kW to 13kW with Shinkansen and others based there on, while that of high-speed train sets in Europe is 22kW to 23kW. This also holds true with the output per person, in that both CRH-3 and KTX-Ⅰ surpass the European specifications (13 to 23 kW per person), while it falls behind Shinkansen.

Table 9.8-4 Comparison of the Train Sets and Axle Load

Class	Japan		France		German		Italy		Spain		China			Taiwan	South Korea	
	Serise E5	Serise E4	TGV -R	TGV -D	ICE1	ICE3	ETR -500	AGV -Italo	S100	S103	CRH -2C	CRH 380A	CRH -3	700T	KTX - Ⅰ	KTX - Ⅱ
Train configuration	8M2T	4M4T DD	2L8T	2L8T DD	2L12T	4M4T	2L11T	5M7T	2L8T	4M4T	6M2T	6M2T	4M4T	9M3T	2L 2M16T	2L8T
Train length (m)	253	201.4	200.2	200.2	358	200.7	327.6	201	200.2	200	201.4	203	203	304.7	388.1	201.3
Car body width (mm)	3350	3380	2904	2896	3020	2950	2860	3000	2904	2950	3380	3370	3260	3380	2904	2970
Train Capacity (person)	731	817	375	512	703	556	671	450	375	404	610	480	444	999	935	358
Max. Axele Load (t)	13.1	16	17	17	19.5	17	17	17	17	17	14	15	17	11.7	17	17
Weight/Person (kg/person)	622	524	1035	762	1188	1023	951	884	1035	1126	624	869	804	564	749	1212
Output/Person (kW/person)	13.1	8.2	23.3	18.1	13.7	18.0	13.1	14.8	23.3	21.8	11.8	20.0	14.7	10.4	14.5	24.6

Source: Study team

Larger axle loads cause stronger vibration of tracks/track beds and decreases passenger capacity, to subsequently lead to larger energy consumption when trains are running. It is required, therefore, to determine the axle load in consideration of passenger room accommodations and guarantee of the performance of electric components and strength of rolling stock compatible with the circumstance of running sections.

On the other hand, maximum axel load of civil infrastructure design standard has been decided by technical and cost comparison analysis.

All these things considered, large-width car bodies should be adopted and the average axle load at 17t or less, of course the lightweight is preferable, should be set.

(5)Basic Performance

- Maximum operation speed

The maximum operation speed is set at 320 km/h to shorten the traveling time, aiming at 350 km/h in the future stage, admitting the fact that 320 km/h is the highest speed of the world HSR which is currently engaged in revenue service constantly and stably.

- Acceleration and Deceleration

The main aim of HS train is to reduce travelling time between stations, acceleration/deceleration performance is a particularly important factor especially for running short distance and having many stops. The important factors for high-speed railways are not only starting acceleration but also acceleration performance at high speed. These factors are determined by the traction system performance set according to rolling stock weight, ambient temperature and other conditions of specification.

Furthermore, the traction system performance governs energy consumption and capacity/weight of components. It is required, therefore, to set appropriate performance of acceleration/deceleration in consideration of the distance between stations and pattern/frequency of train operation.

To cut the travel time and energy consumption, the initial acceleration at 1.7 to 1.8 km/h/s should be set and the emergency deceleration from 70 km/h at 4.0 km/h/s, in consideration of the average distance between stations of approximately 50 km, operation patterns and frequency of train operation (four trains per hour), the propulsion system operating environment and powering performance to 320 km/h from a medium-speed range.

9.8.3 Recommendation for Rolling Stock Plan

Based on comparison and analysis described above, an example of proposed rolling stock plan is shown in Table 9.8-5.

Table 9.8-5 Dimensions and Specification Recommended

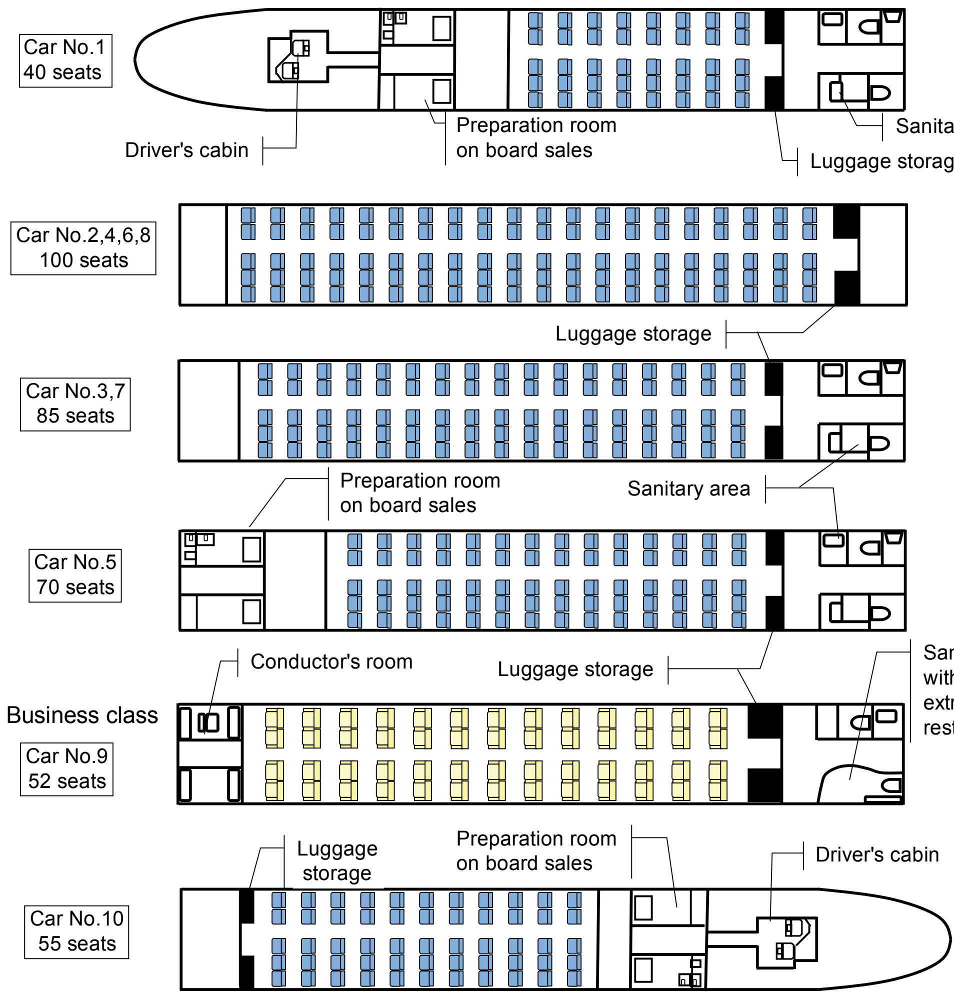
Item	Dimension	Remarks
Train set composition and configuration	10-car train sets: 8M2T 16-car train sets: 14M2T	EMU type Non-articulated
Maximum operation speed	320 km/h	Max. design speed: 350km/h
Acceleration (Approx.)	1.70km/h/s	Initial acceleration
Deceleration	4.0km/h/s	<70km/h Energency braking rate
Maximum axle load	17t or less	The lighter is preferable
Car body width	3,400mm	3+3 seats arrangement is possible
Passenger capacity (Approx.)	750 persons: 10-car train set	2-class system Seat pitch: 1000～1040 mm (standard class) 1,160mm(bisiness class)
	1,200 persons: 16-car train set	
Seat arrangement	5-seat(2+3) arrangement	Standard class 6-seat(3+3) arrangement is possible
	4-seat(2+2) arrangement	Business class
Car body structure	Aluminum double-skin structure	Airtight structure
Type of bogie	Bolster-less type	Air spring suspension system
Track gauge	1,435 mm	Standard gauge
Wheelbase and Wheel diameter	Wheel base: 2,500mm Wheel diamater: 860 mm	Adopt a combination of proven rail tread and wheel profile Hollow axle with induction hardening
Supply power system	AC 25 kV 50 Hz	
Traction circuit and configuration	VVVF inverter control	Using IGBT and asynchronous traction motor
Braking system	Regenerative brake Electric/Pneumatic brake blending	Normal, Emergency and High deceleration against earthquakes

Source: Study team

(1)An example of Floor layout plan

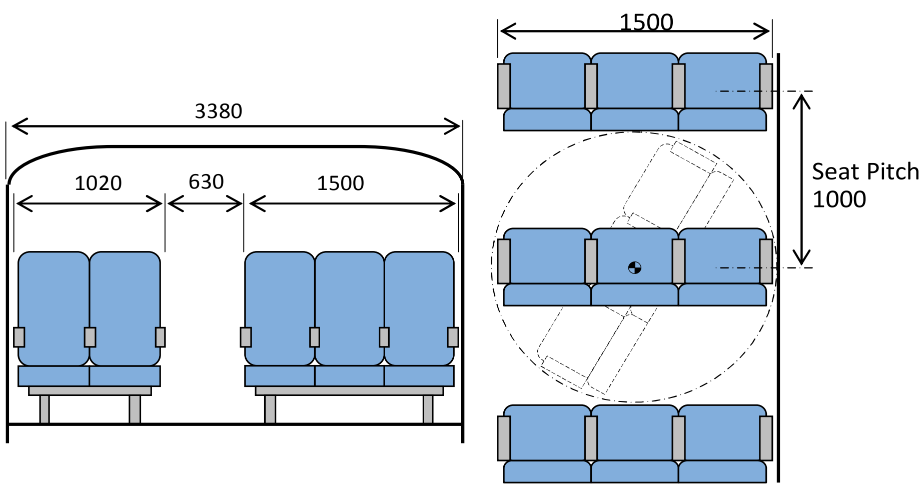
- Standard plan

Figure 9.8-3 is an example floor layout plan realizing the above-mentioned accommodation for both business-and standard-class passenger seats according to the train operating plan. A standard-class seat pitch is 1,000 mm to facilitate rotating of three-seat blocks having a seating comfort ensuring width of 1,500 mm, which is shown in Figure 9.8-4 In this case, passenger capacity is 52seats for business-class and 735seats for standard class.



Source: Study team

Figure 9.8-3: Recommendation for Rolling Stock Dimensions Specifications



Source: Study team

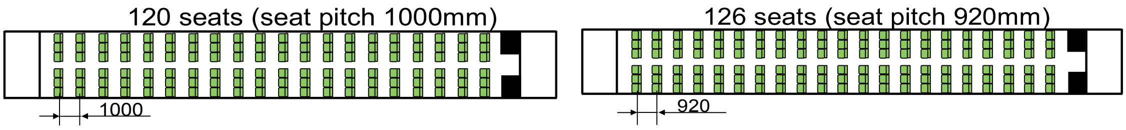
Figure 9.8-4 Seat Width and Pitch

- Increasing passenger capacity for realizing low-fare seats

Table 9.8-6 shows passenger capacity, seats type and pitch. In order to realize low cost transportation, 3+3 seat arrangement is set for low-fare class, and it is possible to increase a seating capacity. When it is considered as the above-mentioned floor layout and five cars of train sets are set to low fare class, a capacity increases 10%. Furthermore, a fixed seat type is installed by seat pitch as 920 mm, as shown in Figure 9.8-5 a capacity will increase 20%. For adopting 3+3 arrangement, securing seat width and passage width, car body width is required 3380 mm or more.

Table 9.8-6 Increasing Passenger Capacity

seat type	Business	2+3(Rotating)	3+3(Rotating)	3+3(Fixed)	Total
seat pitch	1160mm	1000mm	1000mm	920mm	
standard train set	52seats (1car)	735seats (9cars)			787seats
low fare train set		410seats (5cars)	462seats (5cars)		892seats
more low fare train set		410seats (5cars)		528eats (5cars)	938seats



Source: Study team

Figure 9.8-5 An Example Floor Layout for (6-(3+3) Seat Arrangement)

(2)Main structure and equipment

1) Body structure

Among the high-speed railways in the world, some of the car bodies are made of steel like French TGV-R and high speed train based on TGV-R: Spain Renfe 100 and South Korean KTX-I: and an aluminum alloy with others including TGV-D which was required for light weight double-decker. KTX-II, which is the latest series of HSR in South Korea, also adopted aluminum alloy to its body materials.

Aluminum alloy is lighter than steel, also aluminum alloy is highly resistant against corrosion.

For trains to pass tunnels at high speed, the car body shall be airtight to prevent discomfort of passengers (so-called sudden ear pops) due to pressure changes in tunnel. It is essential, therefore, that the rolling stock structure be welded seamlessly. In this respect, however, stainless steel, which is frequently used in recent years for car body structure together with aluminum alloys, does not suit high-speed rolling stock for its difficulty of seamless welding.

So double-skin structure using aluminum alloy materials featuring superb corrosion and resistance that enable construction of airtight and lightweight should be adopted.

2) Propulsion system

- Traction Motor

As a result of the development of power electronics technology, the AC motor driving system controlled by VVVF inverter is now used in wide ranges. In the case of EMU type high-speed rolling stock, AGV trains use AC synchronous motors and others trains AC induction motors as shown in Table 9.8-7. Induction motors are more advantageous in that they feature a simple structure, high reliability and low costs.

Table 9.8-7 Comparison of Propulsion System for EMU

Class	Japan Serise E5	German ICE3	Italy AGV-Italo	China CRH-2C	China CRH-3	Taiwan 700T
Train configuration	8M2T	4M4T	5M7T	6M2T	4M4T	9M3T
Traction Motor	asynchronous	asynchronous	synchronous	asynchronous	asynchronous	asynchronous
Number of TMs per Transformer	8 Motors	8 Motors	Unknown	8 Motors	8 Motors	12 Motors
Traction unit formation	2M x 4units	2M1T x 2units	Unknown	2Mx 3units	2M1T x 2units	3M x 3units
Number of Pantographs	1 pantograph	1 pantograph	1 pantograph	2 pantographs	1 pantograph	2 pantographs

Source: Study team

- Traction unit

A train set of the EMU type high speed railways is composed of plural traction units, each having a transformer, converter-inverters and traction motors. Attention shall duly be paid to the traction unit to ensure environment-compatible propulsion performance, guarantee redundancy against component failure, underfloor component layout with weight distribution and unify spare parts through standardization of components.

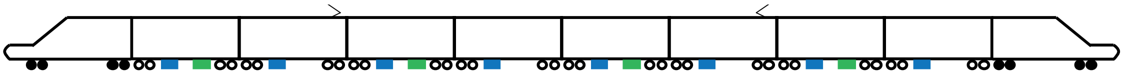
Except for 700T with which three-unit composition is readily possible for 12-car train sets, a traction unit is composed of two converter-inverter sets, each controlling four traction motors, installed in combination under a transformer, thereby driving eight traction motors in total. As shown in Table 9.8-7. A train set of E5 or Shinkansen-based CRH2-2C is composed of redundancy-ensuring three traction units or over, each composed of two cars, one installed with a converter-inverter and the other with a transformer plus a converter-inverter. A train set of ICE3 and ICE3-based high-speed rolling stock (S103 and CRH-3) is composed of two units, each composed of two motor cars and a trailer, the former of which are installed with a converter-inverter per car and the latter installed with a transformer to distribute underfloor components and disperse their weights. In the case of 700T, a unit is composed of three cars, with the first car mounted with a transformer, the second with two sets of converter-inverter and the third with one set of converter-inverter to guarantee redundancy, distribute underfloor components and disperse their weights.

- Pantographs

To guarantee redundancy against failure, each train set of the EMU type high-speed railways is equipped with two sets of pantograph for single power source sections. Despite that, however, train sets except those of CRH2 and 700T are normally running using only one pantograph to guarantee the current collecting performance and avoid the adverse effect on overhead contact wires shown in Table 9.8-7

- Propulsion system Configuration

As traction motors, adopt induction motors featuring low costs and a simple structure and widely proven among high-speed railways. Establish a traction unit formation for propulsion with two cars, with one installed with a transformer plus a converter-inverter and the other with a converter-inverter, to drive eight motors equipped on the two cars, while guaranteeing propulsion performance compatible with the environment in India, providing redundancy against component failure and considering unification of spare parts through standardization of components. Compose 8M2T train sets, each having four units or eight power cars, added with two trailers. Install two pantographs on each train set to ensure redundancy, but use one in running to reduce running noise and adverse effect on contact wires, shown in Figure 9.8-6.



Source: Study team

Figure 9.8-6 Configuration of Propulsion System and Braking System (10-car Train Sets)

3) Braking system

➢ System configuration

One of the most essential components for high-speed railways is a brake system to safely stop trains running at high speed. Brake systems adopted for EMU type high-speed rolling stock across the world perform blending control to combine regenerative, pneumatic and eddy current brakes to cut power consumption by regenerating power and reduce wear of abrasive friction brake parts. Wheel mounted disk brakes are normally used as a pneumatic brake. Table 9.8-8 shows comparison of braking system. As a brake system for trailer cars not equipped with traction motors, axle mounted eddy current disk brakes are used for 700T; eddy current brakes plus axle disk brakes for ICE3 and axle disk brakes for E5 and CRH2. Although eddy current brakes feature superior maintainability as they don't have abrasive parts, they require due consideration for the small effective speed range, increases in the unsprung weight, temperature rises at brake application and effect on the systems on the ground including signals.

Table 9.8-8 Comparison of Braking System for EMU

Series	Japan Serise E5	German ICE3	China CRH-2C	Taiwan 700T
Braking system	Regenerative brake Pneumatic brake	Regenerative brake Pneumatic brake Eddy current brake	Regenerative brake Pneumatic brake	Regenerative brake Pneumatic brake Eddy current brake
Driven axle	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk
Trailing axle	Wheel mounted disk Axle mounted disk	Wheel mounted disk Axle mounted disk	Wheel mounted disk Axle mounted disk	Wheel mounted disk Eddy Cirrent disk
For earthquakes	○	—	—	—

Source: Study team

To cut power consumption, an electric command type electric/pneumatic brake blending control system should be adopted to use regenerative brakes as far as possible, with insufficient braking force compensated for by pneumatic brakes. Three braking categories, service, emergency brakes and a high-deceleration brake as a measure against earthquakes should be installed corresponding to the rate of earthquake occurrence in India As the foundation brake rigging, wheel disks on driving axles and wheel disks plus axle disks on trailer axles should be equipped to compose a proven earthquake brake system shown in Figure 9.8-6.

➢ Countermeasures against earthquakes

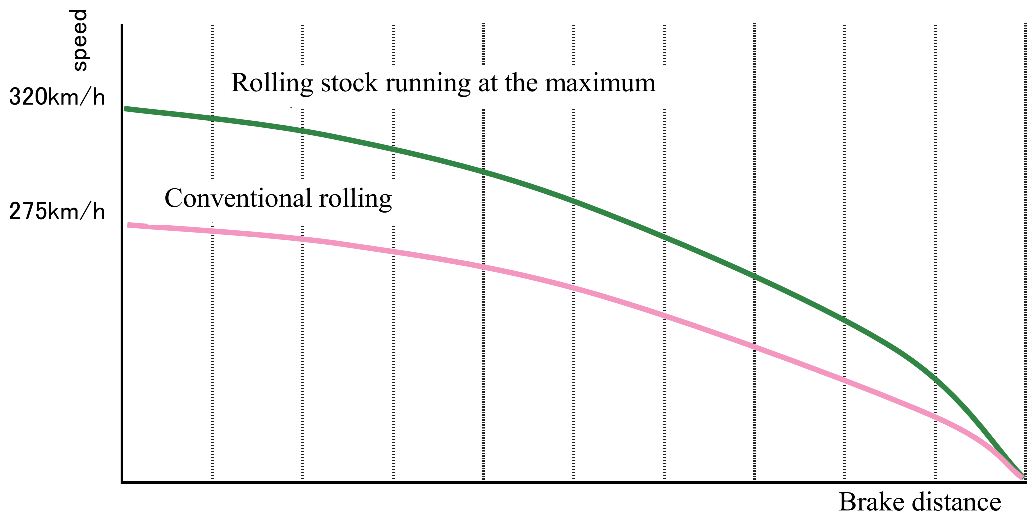
As shown in Table 9.8-9, Japan has frequently been hit by earthquakes, a number of earthquake damage preventive measures have been established, which are broadly divided into two categories: one is "to quickly stop trains" and the other "to prevent the train from aberrance in case a train has derailed." As seen in the case of Great East Japan Earthquake a few years ago, when trains were all safely stopped without claiming human lives or causing injuries at all, the system in Japan is thought to be a sole and one of the most advanced measures against earthquake damage in the world. In this context, it is recommended for India, where earthquakes are anticipated to occur in the future, to adopt the same system in Japan to prevent earthquake damage, the details of which are described below.

Table 9.8-9 Earthquake Damage Preventive Measures in Japan, China and Europe

	Japan	China	EU
Frequency of earthquake occurrence*	29	5	0
Earthquake damage preventive measures on rolling stock	Yes	No	No

* Frequency of earthquake occurrence indicates the number of earthquakes, 6 or over on the Richter scale, in and after 2000.
Source: Study team

As a measure to quickly stop, Shinkansen trains fully activate the brake system used for normal operation, without using any additional equipment.
When the primary quake of an earthquake has been received, substations immediately stop power feeding. When a voltage drop and fluctuations of frequency are detected on the contact wire, trains activate brakes without delay.
The latest trains, having decelerating performance maximum 1 km/h/s higher than that of the normal emergency brake, stop at a braking distance equivalent to that of the trains running at 275 km/h, even when they are running at a speed of 320 km/h. Figure 9.8-7 represents an image of the brake distance at earthquake.



Source: Study team

Figure 9.8-7 Brake Distance at Earthquake

4) Running gear

- Bogie

To ensure safety for high-speed rolling stock, bogies are one of the most important components, for which fundamental requirements are to guarantee high-speed performance free from hunting and strength of parts of bogies. Among the bogies now used by high-speed railways in the world, the current mainstream is the lightweight bolster-less bogie composed of side frames and cross beams to eliminate bolsters.

The wheelbase that governs running stability is 2,500 mm with the EMU type Shinkansen cars, ICE3 cars and their derivatives and 3,000 mm with TGV trains and those stemmed therefrom. Longer wheelbases improve running stability in high-speed operation but make bogie frames larger to increase bogie weight and reduce the space for underfloor components.
The wheel diameter is 920 mm with TGV cars, ICE3 cars and others designed based thereon and 860 mm with Shinkansen cars and those designed according to Shinkansen specifications. Shinkansen cars, ICE cars and their derivatives use hollow axles. Smaller wheel diameters and hollow axles reduce unsprung weight and the effect on tracks and running stability.
Regarding the method to evaluate bogie strengths, proven standards shall be used to verify durability of bogies. European countries use an evaluating method prescribed in EN, while Japan and Taiwan where high-speed railways are based on Shinkansen specifications a version stipulated in JIS. On the other hand, China applies the evaluating method for rolling stock that makes the basis of high-speed railways, shown in Table 9.8-10

Table 9.8-10 Comparison of Bogie Specifications

Class	Japan SeriseE5	France TGV-R	German ICE3	Italy AGV -Italo	Spain S103	China CRH-2C	China CRH-3	Taiwan 700T	South Korea KTX-Ⅱ
Wheelbase (mm)	2500	3000	2500	3000	2500	2500	2500	2500	3000
Wheel diameter (new) (mm)	860	920	920	920	920	860	920	860	920
Axle Type	Hollow	Solid	Hollow	Solid	Hollow	Hollow	Hollow	Hollow	Solid
Strength Evaluation	JIS	EN	EN	EN	EN	JIS	EN	JIS	EN

Source: Study team

Bolster-less bogies featuring a simple and lightweight structure with frames having welded parts to which an allowable stress, proven from the viewpoint of safety, should be applied to guarantee a lightweight and sufficiently strong structure.

- Surface treated of axel

Axles shall ensure safety in high-speed operation. Therefore, sufficient strengths shall be guaranteed not only for wheel/disk brake seats and other fitting parts but also for non-fitting parts such as cylindrical sections at the axle center. Furthermore, it is required to prevent cracks caused by dust, traces of impact during operation and effect of the rust generated by long-staying massive water in the rainy season. Axles of Shinkansen cars have residual compressive stress caused by induction hardening on the surface, which increases the endurance limit and allowable stress for the material and suppresses the development of cracks, if any, on the axle surface due to the impact during operation and rust by the effect of water, shown in Table 9.8-11.

Lightweight hollow axles, having a sufficiently proven strength and applied with induction hardening to suppress cracking caused by rust or dents due to shock during operation, should be adopted in consideration of the circumstaces in India.

- Wheel profile

Wheel profile is required to simultaneously guarantee high-speed running stability and curve-negotiating performance, which makes the equivalent tread gradient against the rail surface an important factor. Most of the high-speed railways in the world use a combination of UIC standard rail and UIC wheel profile, in Japan and Taiwan a combination of JIS standard rail and Shinkansen wheel profile is adopted and China uses a combination of Chinese standard rail and wheel profile. There are no cases where a combination of rail and wheel profile according to different standards is in use. China uses conical wheel profile, while UIC and Shinkansen specifications prescribe arc wheel profile featuring little wear-caused decrease in high-speed running stability. The geometrical profile of the rail tread/wheel profile contact face ensures the highest running stability in high speed operation with Chinese convention, followed by Shinkansen and UIC schemes in the descending order, which is shown in Table 9.8-11

Table 9.8-11 Comparison of Surface Treated of Axle and Wheel Profile

Class	Japan SeriseE5	France TGV-R	German ICE3	Italy AGV -Italo	Spain S103	China CRH-2C	China CRH-3	Taiwan 700T	South Korea KTX-Ⅱ
Surface treated of axle	Induction hardening	None	None	None	None	Induction hardening	None	Induction hardening	None
Wheel Profile	Shinkansen (Arc)	UIC (Arc)	UIC (Arc)	UIC (Arc)	UIC (Arc)	China (Conic)	China (Conic)	Shinkansen (Arc)	UIC (Arc)
Rail Standard	JIS	UIC	UIC	UIC	UIC	China	China	JIS	UIC

Source: Study team

Even when it wears out, it is considered as the arc wheel profile to which high speed stability cannot fall easily. Also, a proven wheel profile should be adopted to guarantee high-speed running stability and curve-negotiating performance simultaneously. It is also impoerant that a combination of rail tread and wheel profile is provem.

(3) Other items for Passenger comfort

- Ride comfort

To guarantee high-degree ride comfort by absorbing vibration of rolling stock in running, the running gear is normally equipped with a secondary suspension system and dampers to effect appropriate damping force. In the case of high-speed rolling stock, however, rolling motion in the lateral direction increases due to aerodynamic force as running speed becomes higher. This phenomenon is conspicuous in particular at the end of train set and in tunnel sections. An active suspension system or semi-active dampers suppress yawing motion, thereby improve the ride comfort at high speed and inside the tunnels. Ride comfort is reduced due to the centrifugal force when cars pass curved sections at high speed. To mitigate this effect, a car body tilting system using air springs is used.
Using proven ride control system shown in Table 9.8-12 should be recommended. In consideration of the planed minimum radius of curve and the track structure of curved sections and the fact that there are only a few tunnels claiming a small total length and large sectional areas, active suspensions, car body tilting systems and other special ride comfort improving mechanisms could be avoided to cut manufacturing costs.

Table 9.8-12 Ride Comfort System

Location	Item	Remark
Between axle box and bogie frame	Coil spring and Vertical damper	Primary suspension
Between bogie frame and car body	Air spring and Lateral damper	Secondary suspension
	Yaw damper	Anti hunting
Between car body	Between car body damper	Anti yawing motion

Source: Study team

➢ Air tightness

For trains to pass tunnels at high speed, the car body shall be airtight to prevent discomfort of passengers (so-called sudden ear pops) due to pressure changes in tunnel. Therefore, car bodies shall be structured airtight to prevent sudden ear pops, with sufficient ventilation guaranteed in passenger rooms by adopting a continuous ventilation system to cope with pressure fluctuations, given the fact that Shinkansen operate passing through tunnels for long distances. On the other hand in Europe where tunnels feature large sectional areas, high-speed railways adopt a system to cut off the ventilation system in tunnel. Pressure fluctuations in tunnel repeat compression and decompression to cause fatigue loads on car bodies and subsequently limit the life of Shinkansen car body to approximately 20 years. An airtight car body structure with a system to cut off the ventilation system in tunnel should be adopted to prevent sudden ear pops, as only a few tunnels are planned.

The effect of repeated airtight loading on the car body fatigue life may be neglected, as the frequency of running in tunnel is not high.

➢ Air conditioning

Air conditioning system has given way to the concentrated or semi-concentrated type versions, most of which are currently installed on the rooftop or underfloor of car body. The rooftop arrangement has higher heat exchange efficiency and decreases the influence of dust than underfloor arrangement. Using the underfloor arrangement, it is possible to make smaller car body, which is advantageous for reducing external noise at high speed, shown in Table 9.8-13

Table 9.8-13 Comparison of Air Conditioners Arrangement

Class	Japan		France		German		Italy	Spain		China		Taiwan	South Korea
	Serise E5	Serise E4	TGV -R	TGV -D	ICE1	ICE3	AGV -Italo	S100	S103	CRH -2C	CRH -3	700T	KTX - Ⅱ
Train configuration	EMU	EMU	Loco.	Loco.	Loco.	EMU	EMU	Loco.	EMU	EMU	EMU	EMU	Loco.
Arrangement On the roof		○				○	○		○		○		
Underfloor	○		○					○		○		○	○
Others				○	○								

Source: Study team

In consideration of the track structure (slab tracks), effect of dust and environmental conditions (air-conditioner inlet temperature 50˚C, maximum humidity 90%), adopt air-conditioners of the rooftop installation type featuring a readily available air conditioning capacity, thereby aiming at a compact and lightweight system.

➢ Attention for climatic conditions

Considering the operating ambient temperature at 0 to 50˚C and humidity at 90% or over is required to reflect the environmental conditions in India and salty atmospheric conditions during hot seasons as well as concentrations of SO_2 and particulate matters suspended in the atmosphere.

9.9 Maintenance Facilities for Rolling stock

Maintenance facility plan depends on the specifications of rolling stock, which of this project has not been decided yet, and should be executed later in a detail design phase. Therefore a plan described in this chapter is just a tentative one, the purpose of which is that it provides a tangible figure, based on which project cost estimation is performed for feasibility study.

9.9.1 Maintenance System and Equipment/Facilities for HS Rolling Stock

Appropriate maintenance of rolling stock, which consists of preventive and breakdown maintenance, is a key to guarantee safe and reliable operation of high-speed railways and an inevitable/essential basis for safe and highly reliable rotation of rolling stock.

It is the most important mission and function of depots and workshops to undertake maintenance of rolling stock, which is realized by the rolling stock maintenance system, equipment/facilities for inspection, high level skills of the workers in charge and the maintenance ability of managers.

In the case of high-speed rolling stock claiming a life as long as 20 years or over and is used for a long period of time, safe, stable and high-frequency operation cannot be attained, unless high-quality, reliability and availability are guaranteed for rolling stock by the maintenance system, machines and equipment/facilities and technologies of engineers at depots and workshops.

In this respect, the Shinkansen railways in Japan have attained remarkable records: “zero passenger death accidents,” “zero collision/derailment or other serious accidents” and “less than one minute average delay time per train” for 50 years since inauguration. This is positive evidence to prove the high quality-level of rolling stock maintenance technologies and the execution of rolling stock maintenance services to the point deploying inspection equipment/facilities appropriate for high-speed rolling stock.

This also proves the fact that systems and mechanisms have been established to guarantee reasonable inspection/repair for running gears such as trucks, wheel-sets, traction motors and Digital ATC and other security systems.

Despite that the equipment/facilities at depots and workshops are an important infrastructure to be used for 50 to 100 years, they shall be able to flexibly cope with changes and developments of rolling stock and railway systems in the world as a result of technological innovation and progresses.

Japan has made efforts to improve and develop rolling stock maintenance technologies for long years, incorporated the achievements and new technologies into inspection systems/methods and innovated/developed mechanisms and inspection equipment/facilities, and eventually compiled the results into an efficient inspection system studded with latest technologies. We will propose for the Indian high-speed railway the Shinkansen maintenance system in Japan and rolling stock depots and workshops that have realized safety and stability unrivaled in the world.

9.9.2 Maintenance System

According to the pre-F/S, the maintenance system is as follows:

Inspection Level Frequency	Frequency
Level 0A	4.000 - 5.000 km
Level 1A	20.000 km
Level 1B	80.000 km
Level 1C	240.000 km
Level 1D	480.000 km
Level 2A	1.200.000 km
Level 2B	2.400.000 km

Source: TGV maintenance synthetic schedule

Each of the inspection level consists in the following main tasks:

1. Every 4.000 – 5.000 km, a Level 0 inspection taking about 1½ hour lead time is undertaken. The waste collection tanks of WC closed toilets are emptied, and fresh water tanks are refilled. Eventual major defects (e.g. malfunctioning doors) are rectified.
   Furthermore, safety tests are conducted. This includes:
   - ✓ checking the pantograph force applied to the overhead line
   - ✓ cleaning and checking for cracks in the pantograph's rooftop insulators
   - ✓ inspecting transformers for leakage
   - ✓ checking the pantograph's current collector for wear
   - ✓ visual inspection of wheelsets and bogies.

2. Every 20.000 kilometers, a Level 1A inspection taking about 2½ hour lead time is carried out.
   During this inspection, the brakes, the on-board signaling systems and the anti-skid equipment are checked as well, in addition to the operations of the previous level.

   After 80.000 kilometers, the train undergoes a Level 1B inspection, lasting eight hours, which includes brakes thorough check, as well as air conditioning and the bar-restaurant equipment check. The batteries are also checked, as well as the seats and the passenger information system.

3. Once the train has reached 240.000 kilometers, the Level 1C inspection requires a check of the electric traction motors, the axle boxes, the wheel sets and the couplers.
   Like Level 1B inspection also Level 1C inspection is usually carried out in two modules taking eight hours each.

4. About once a year (when reaching around 480,000 km) the Level 1D takes place, divided in three modules lasting eight hours each. Additionally to the other check-up phases, it includes checks of the pneumatic systems, the transformer cooling, and maintenance works inside the passenger compartment.

5. The Level 2A Revision is carried out after 1.2 million km. It includes a thorough checkup of all components of the train and is carried out in two five days modules.

6. The seventh and final scheduled maintenance step is the Level 2B, which happens when the trains reaches 2.4 million kilometers. At this step all the train bogies are exchanged for new

ones completely overhauled. All major train components are disassembled and checked. This step also takes two five days periods, considering the time for dismounting and replacing equipment. The time for off-line components overhaul has to be considered apart.

On the other hand, the maintenance system of Shinkansen in Japan simply consists of four stages, as Table 9.9-1 shows, with a rolling stock inspection system and equipment/facilities established, put in use and operated since inauguration to attain high-quality, safety and stability. The study team will propose a maintenance system based on the proven operation control system above that has been operational for 50 years.

Table 9.9-1 Periodic Maintenance

Type		Period	Maintenance Content
Train Preparation		After each leg	· Car cleaning, servicing, water supply, removal og sewage, other work
Light Maintenance	Daily Inspection	48 hours	· Check status of bogie, wheels, pantograph, doors and other items while cars are connected. · Check train functions inspect pantograph contact strips and brake linings. · Replace consumable for brakes, pantographs and other items.
	Regular Inspection	30,000 km or 30 days	· Train function test through the driving-cab monitoring system. · Inspects/checks the mechanical functions of controllers and the brake riggings. · Inspection of controllers for VVVF inverters and thyristor phase control systems. · Inspectors check the wheel treads, wheel systems and axles for flaws, check the driving gears and also check the brake lining for wear and replace.
Heavy Maintenance	Bogie Inspection	600,000 km or 18 months	· Principal bogie components are disassembled. · Inspect the wheel sets, wheels, axles, driving gears, traction motors and riggings. · All of the bogies are exchanged wit spar bogie that have already been inspected. · After the bearings are removed, wheel sets are subject to visual inspection of the bearing portions, ultrasonic flaw detection for axel-wheel fitting portions and wheel cutting for tread re-profiling. · After completion of the bogie inspection, each bogie is subjected is to a car running test as a final check under the same conditions as those of actual train operation.
	General Inspection	1,200,000 km or 36 months	· The general inspections conducted on every part of cars. · Bogies and all major components are disassembled from the carbody Cars, air-conditioners, pantographs and some other components are exchanged with spares that have already been inspected and maintained under a spare component circulating system.
Offer Maitenance	Protective Device Inspection (for ATC)	90 days	· Also perform on board day leg inspector of function related to protective devices.
	Ultrasonic Flaw Inspection	30,000 km or 30 days	· Perform ultrasonic inspection of wheels when monthly inspection is performed to check for any flaws.
	Wheel Reprofiling	100,000 km	· Use wheel profiler to correct wheel shape and maintain ride comfort lever.

Source: Study team based on Japan Shinkansen Maintenance system

9.9.3 Policy of the High-speed Rolling Stock Safety Control System and Features of Maintenance

Study team plans and design the maintenance system for high-speed, high-frequency mass-transport high-speed railway rolling stock based on the following fundamental concept.

(1) A mechanism and equipment/facilities to guarantee high-level safety and reliability and maintenance of high-speed railway rolling stock
- Maintenance based on the preventive maintenance
- Inspection/test equipment/facilities to prevent derailment and collision accidents
- Implementation of maintenance by workers having high-level technologies and knowledge of maintenance services and managers having high-level managing power.

(2) Installation of equipment/facilities for rolling stock depots and workshops to constantly shop out highly safe and reliable rolling stock
- Quality control with high-precision inspection/test apparatus for digital-ATC and other security devices
- Quality control by severe limit control for trucks, wheel-sets and other running gears
- Check of truck performance after fabrication with a high-speed truck running test apparatus.
- Car body airtightness test

(3) Efficiency improvement for inspection/repair services
- Efficiency improvement for bogie inspection … bogie exchanging equipment/facilities and the spare parts/components circulating system
- Efficiency improvement for bogie relocating work with mobile temporary trucks
- Efficiency improvement for parts inspection/repair with conveyor lines under a tact system.
- Automation of inspection/test apparatus
- Railway cars are now equipped with car-borne monitoring devices to memorize and store on-condition data, which is used for analysis of failures and operating conditions of cars when they are under inspection/repair at depots and workshops and can also be sent to depots and workshops before their entry for inspection/repair through telecommunication lines to allow the recipient maintenance organizations to perform in-advance assessment of rolling stock conditions, thereby contributing to efficiency improvement and optimization of inspection/repair services at depots and workshops.

In the maintenance methods at Indian existing depots, there are elements common to the basic concept of Japanese maintenance conventions, which we have incorporated into the present plan. Despite that, rolling stock of high-speed railways is one thing and that of existing railways is another in principle. Therefore, Study team discusses the maintenance of rolling stock by regarding the guarantee of safety as the most important mission currently for India and Japan.

Figure 9.9-1 illustrates the work flow at a workshop in Japan planned based on this fundamental concept.

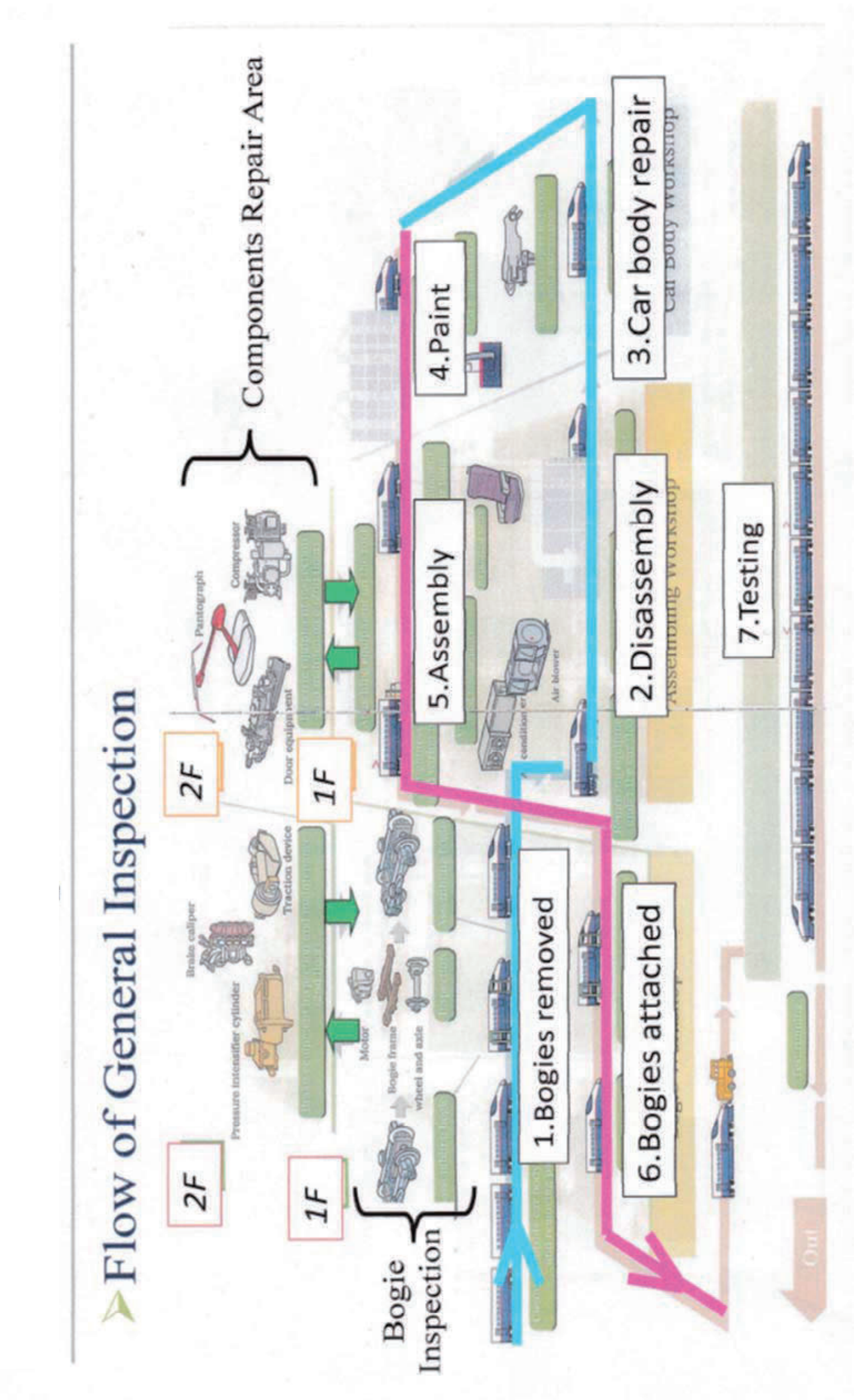


Figure 9.9-1 Example of HSR Rolling Stock Workshop

9.9.4 Introduction of Japanese Maintenance for Shinkansen

(1) Light Maintenance

1) Major facility for light maintenance

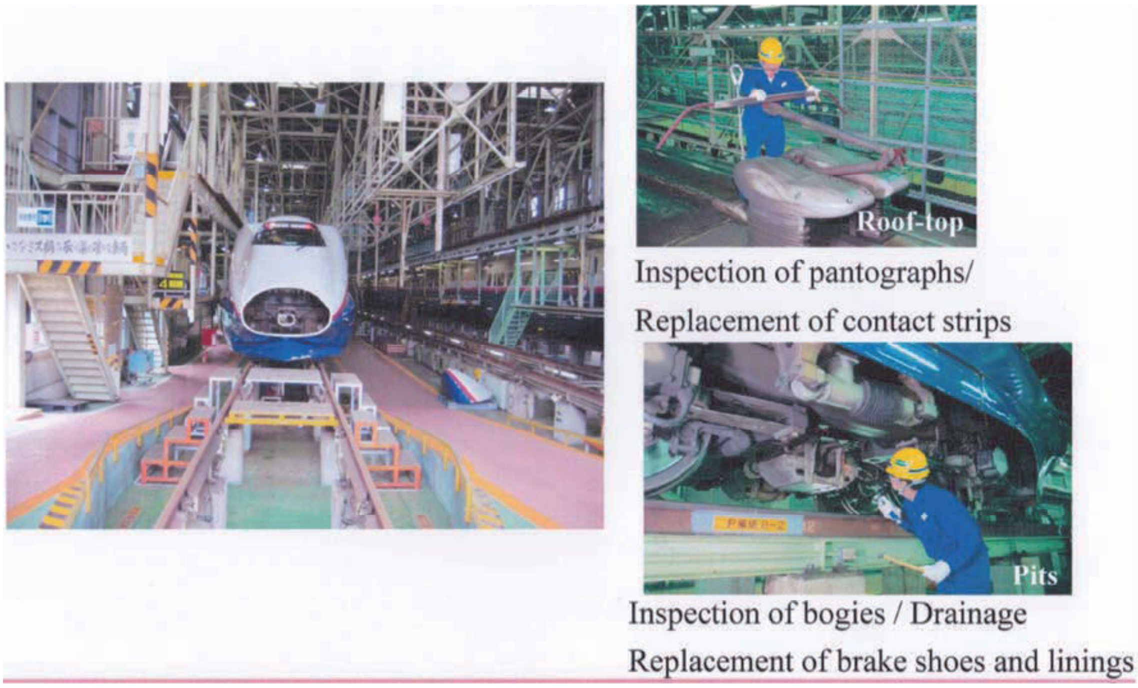


Figure 9.9-2 Inspection Deck

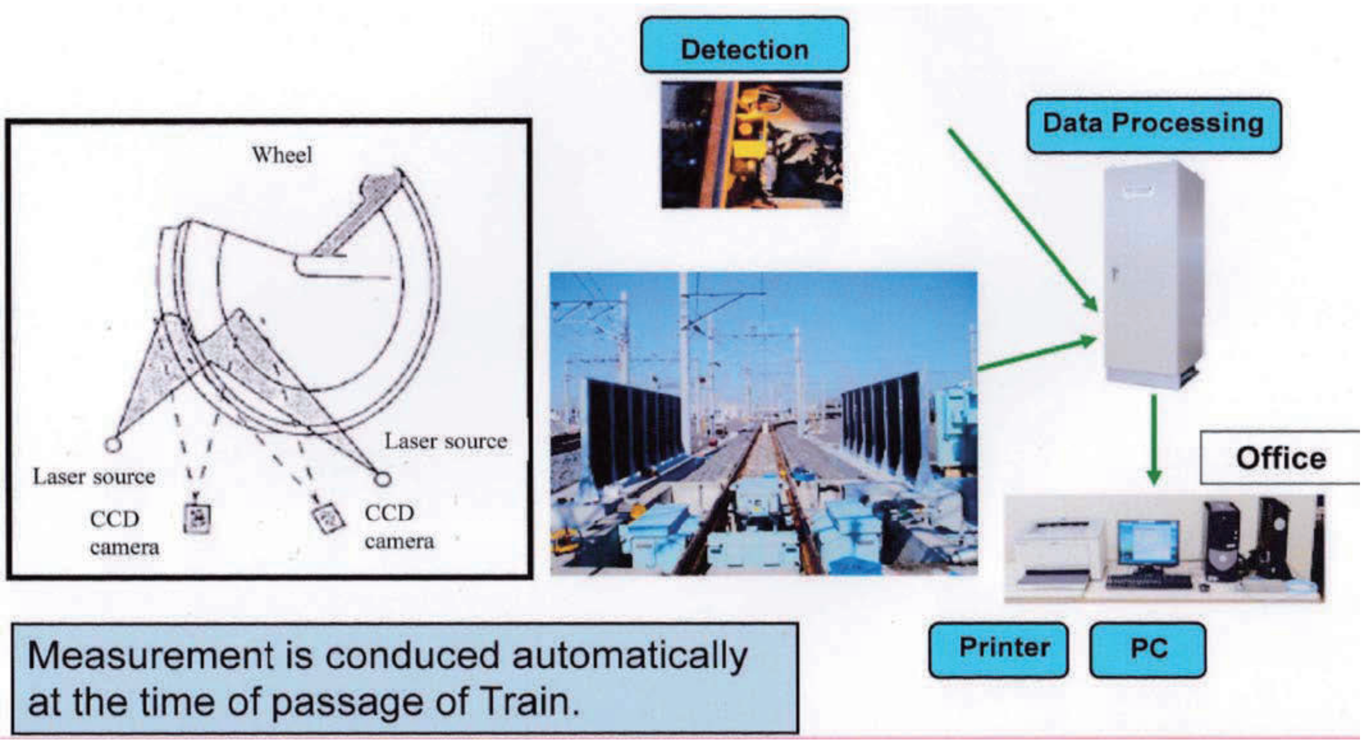


Figure 9.9-3 Measuring Equipment for Wheel Profile

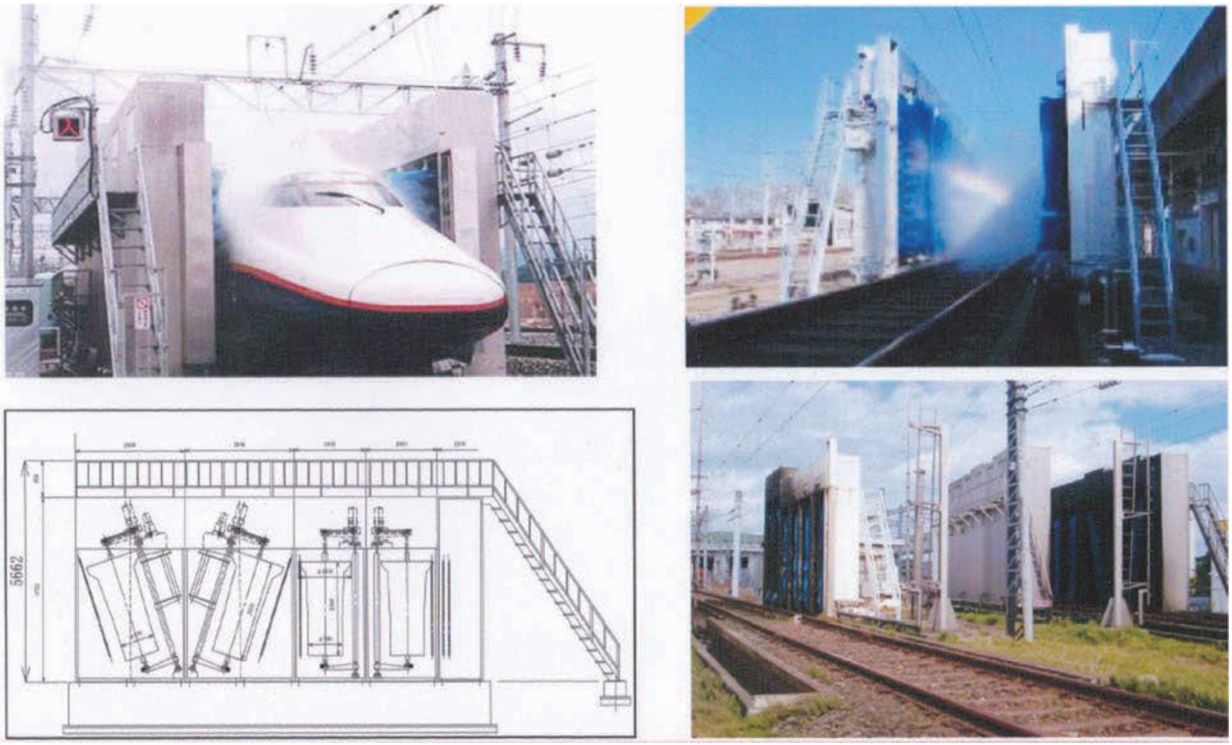


Figure 9.9-4 Automatic Car Body Washing Machine

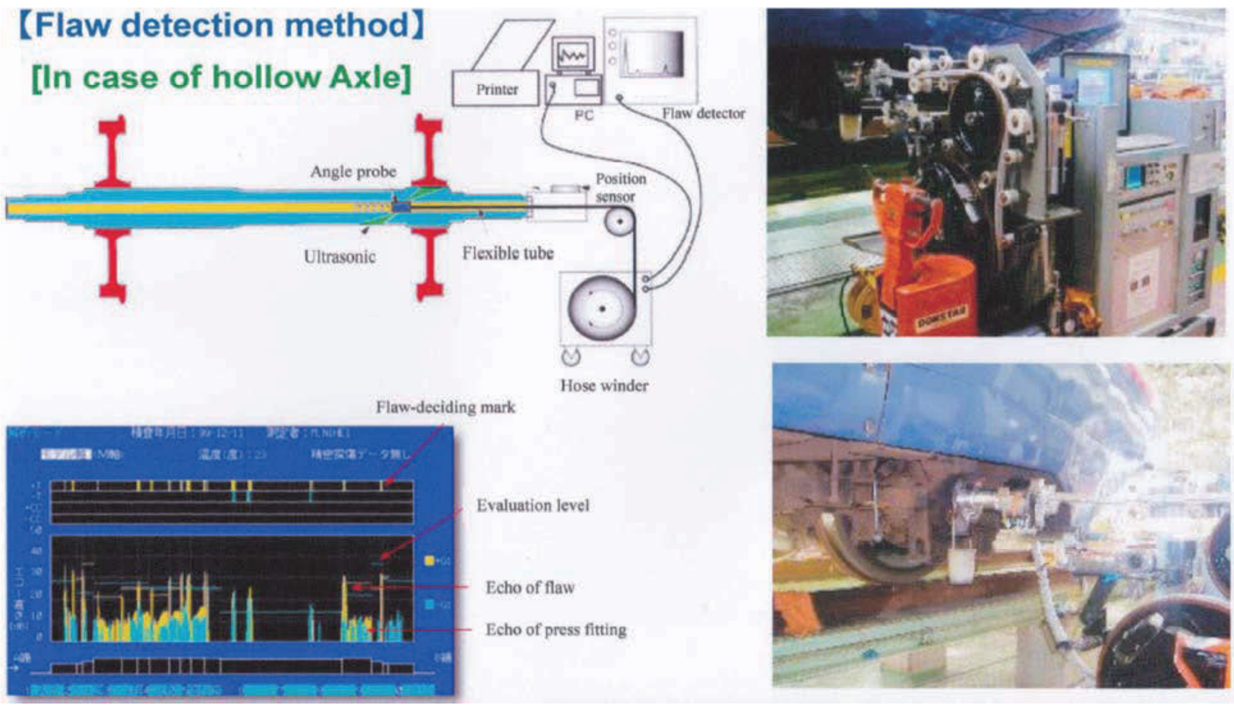


Figure 9.9-5 Automatic Axle Ultrasonic Flaw Detector

(2) Other Maintenance

Figure 9.9-6 Major Facility for Other Maintenance

(3) Heavy Maintenance

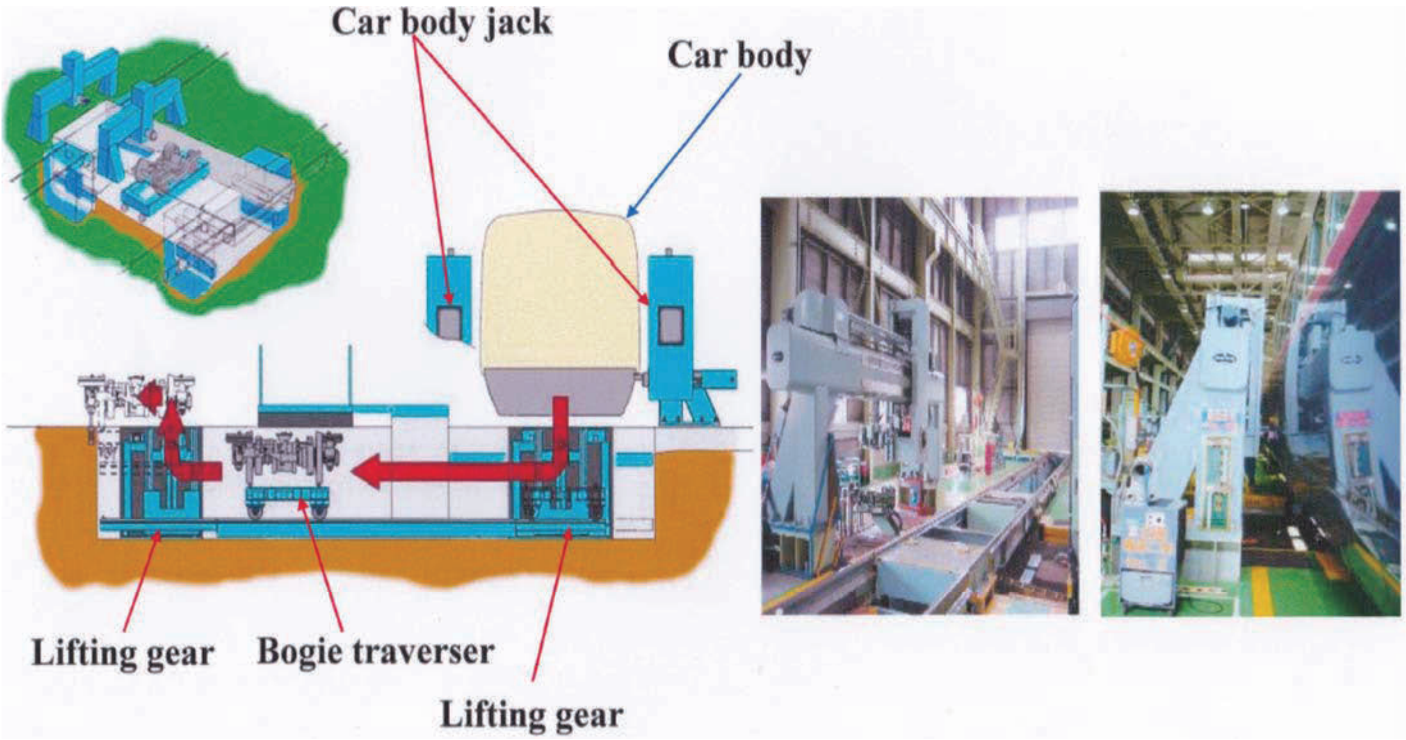


Figure 9.9-7 Bogie Changing Machine (for Bogie Inspection)

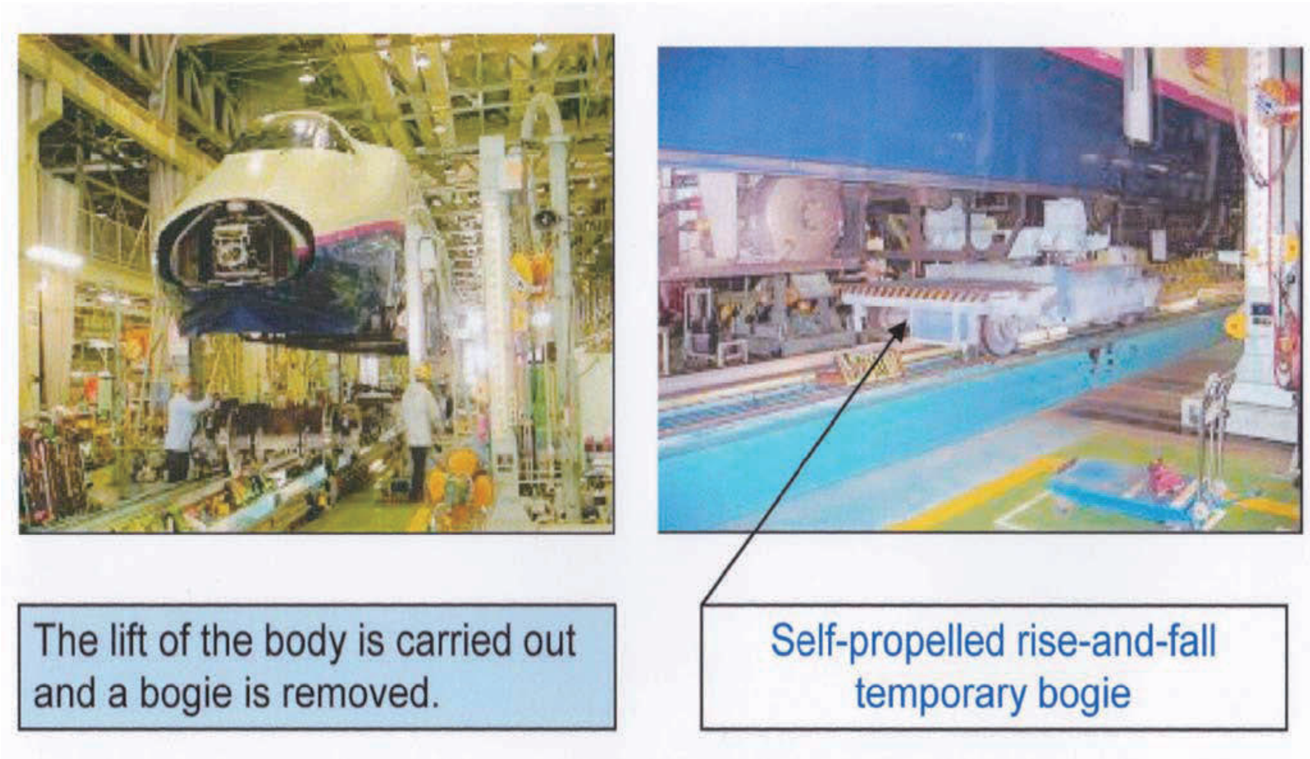


Figure 9.9-8 Bogie Removal Equipment (for General Inspection)

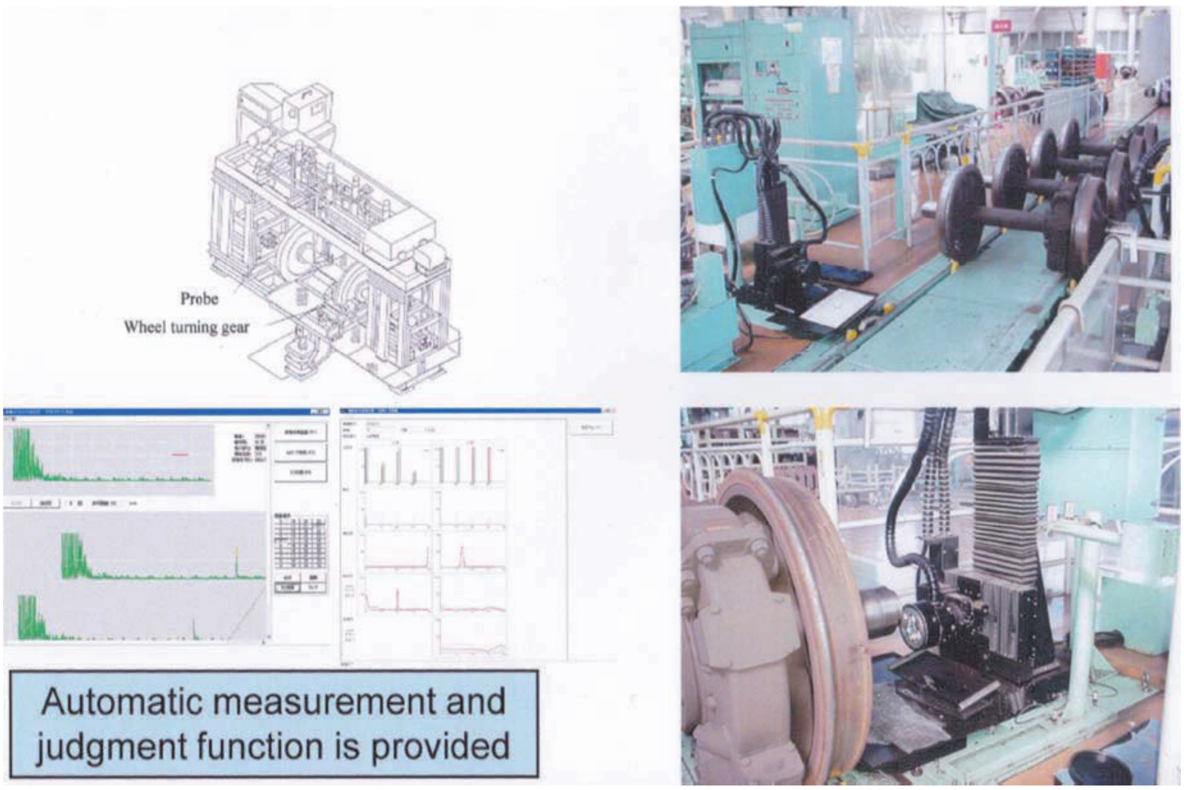


Figure 9.9-9 Ultrasonic Flaw Detector (for Bogie & General Inspection)

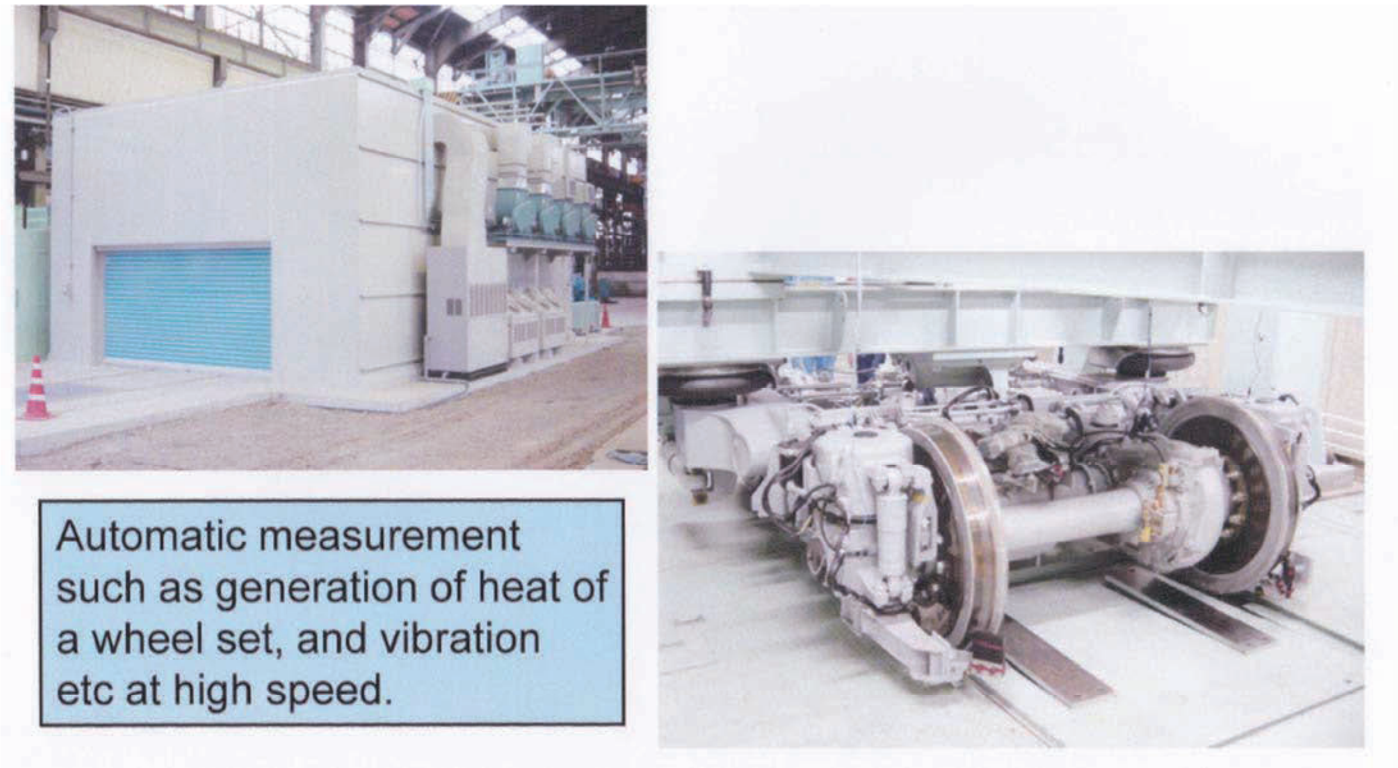


Figure 9.9-10 Bogie High-speed Rotation Test Equipment

Figure 9.9-11 Airtightness Hold Test Equipment

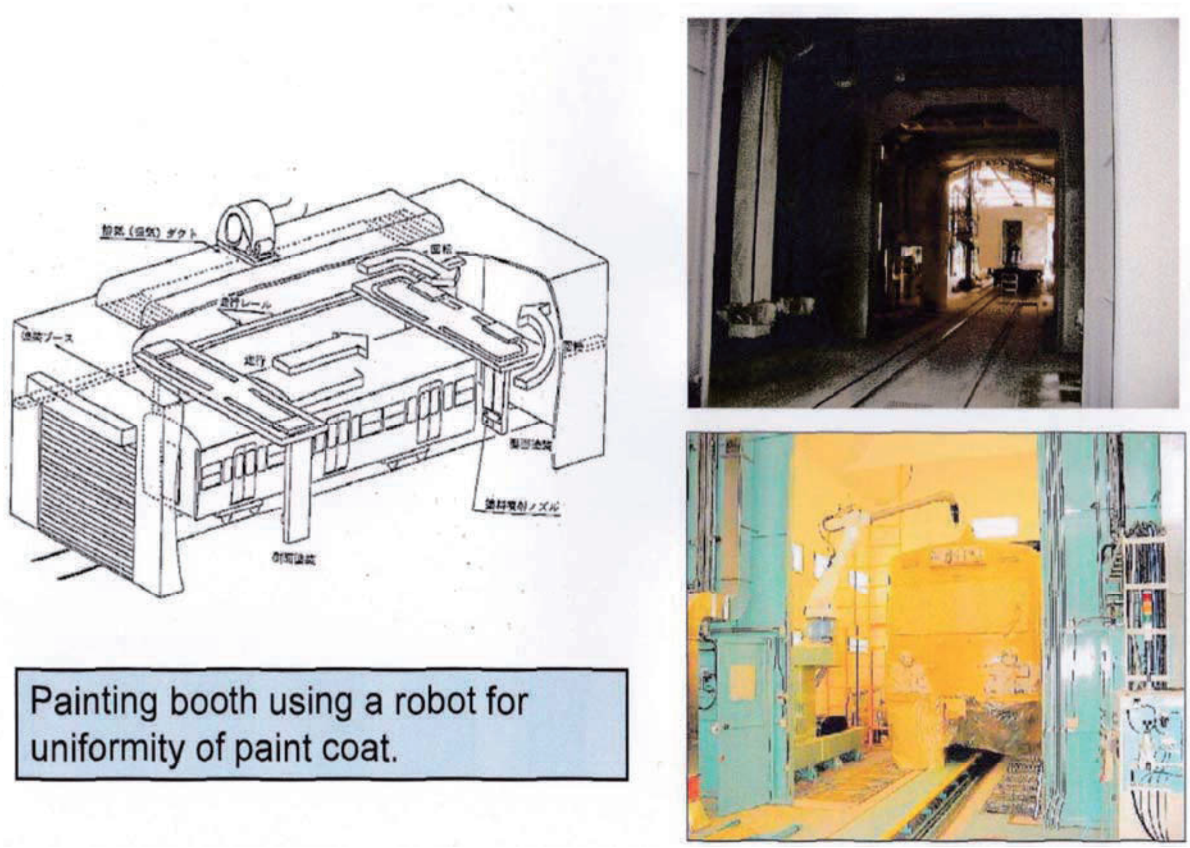


Figure 9.9-12 Car-body Painting Machine

9.9.5 Functions and Scales of Facilities at Car Depot and Workshop

For efficient traffic control, Study team will set up the car depots and workshop near terminal stations that serve as the starting and ending points of train services in order to facilitate preparation of the first trains and storing of the last trains. Based on the maintenance flow and size of the maintenance facilities, the workshop will be designed to carry out the demanded maintenance level. The image of the Car depot and work shop is shown in Figure 9.9-13.

Source: JRTT

Figure 9.9-13 The Image of the Car Depot and Workshop

Specifically, the following two locations are planned where the necessary land sites can be secured: the Thane Depot near the end of the Mumbai – Thane section, Sabarmati Depot and Workshop in the Ahmedabad – Sabarmati section.

(1) Function and Inspection Classification at Car Depot and Workshop

The car depots are divided into two types: the ones that store trains and perform daily inspection, regular inspection, and unscheduled maintenance and the ones that have workshop facilities to perform bogie inspection and general inspection.

Table 9.9-2 shows the functions and roles of the various depots in this plan.

Table 9.9-2 Function and Inspection Classification

	Function		Inspection Classification			
	Depot	Workshop	General Inspection	Bogie Inspection	Daily Regular Inspection	Unscheduled Maintenance
Thane Depot	○				○	○
Sabarmati Depot/ Workshop	○	○	○	○	○	○

Source: Study team

(2) Inspection Cycle

The function allocated to the depots mentioned above are based on an optimal rolling stock maintenance and management system implemented for the Japanese shinkansen to enhance safe and reliable train operation. They are planned based on the inspection cycle as shown in Table 9.9-3

Table 9.9-3 Inspection Cycle

Kind of Inspection	Daily Inspection	Regular Inspection	Bogie Inspection	General Inspection
Interval	48 hours	30,000 km or 30 Days	600,000 km or 1.5Years	1,200,000 km or 3Years

Source: Study team based on Japan Shinkansen Maintenance system

(3) Schedule on each Inspection

Following described are the numbers of yearly working days, working hours and inspection/repair processes of different inspection/repair categories compiled in consideration of the labor environment in India.

Table 9.9-4 Schedule on Each Inspection

Kind of Inspection	Schedule on inspection				Work days (day/week)
	2023	2033	2043	2053	
Train Preparation	2 h				7
Daily Inspection	1 h				7
Regular Inspection	2 days	2 days	1 day	1day	5
Bogie Inspection	8 days		6 days		5
General Inspection	24 days	20 days	17 day	15 days	5
Wheel Re-profiling	2 days (48 h)				7

Source: Study team

Table 9.9-5 Yearly Work Days and Work Hours

Kind of Inspection	Work days / year	Work days / hours	Remark
Train Preparation	365 days / year	24 hours / day	
Daily Inspection			
Wheel Re-profiling			
Regular Inspection	300 days / year	8 hours / day	2400 hours / year
Bogie Inspection			
General Inspection			

Source: Study team based on the Indian environment and social system

Here, the yearly work days and work hours for unscheduled repairs are considered as same as the monthly inspection in general.

(4) Number of Cars

Study Team calculated the number of cars based on the results of Demand Forecast and Train Operation Plan.

Table 9.9-6 Required Number of Cars

Year		2023	2033	2043	2053
Train configuration		10 cars	10-16cars	16 cars	16 cars
Number of trains		35	51	64	105
Required train sets	10 Cars	24	24	-	-
	16 Cars	-	11	44	71
Number of Cars		240	316	704	1,136

Source: Study team

(5) Scale of equipment/facilities at different depots/workshops and equipment/facilities classified by inspection category

The scale of depots/workshops can be calculated from demand forecasting results based on the above preconditions. We plan the scale of each depots/workshops based on the particulars in Table 9.9-7.

Table 9.9-7 Size Required for Each Depot

		Stabling Track No. (2053)			Track					
		Use	Reserve	Total	Maintenance Track	Daily Inspection Track	Regular Inspection Track	Unscheduled maintenance Track	Wheel Re-Profiling Track	Car Washing Track
Mumbai	Station	3	0	3						
Thane	Depot	28	5	33	29	6	3	1	1	1
Surat	Station	2	0	2						
Sabarmati	Workshop /Depot	28	5	33	29	6	3	1	1	1
Total		61	10	71	58	12	6	2	2	2

Source: Study team

Table 9.9-8 shows major equipment/facilities required for daily inspection, regular inspection, bogie inspection, general inspection and other inspections.

Table 9.9-8: Major Items of Equipment/Facilities Classified by Inspection Category

	Daily Inspection	Regular Inspection	Bogie Inspection	General Inspection	
Main facilities	Inspection Deck	Inspection Deck	Bogie Changing Machine (Car-body support type)	Bogie Changing Machine (lifting jack type)	Car body Painting Machine
	Front car Inspection Deck	Front car Inspection Deck	Bogie and Wheel sets repair facilities	Bogie and Wheel sets repair facilities	Parts repair facilities
		Automatic hollow axle ultrasonic flow detector	Bogie high-speed rotation test equipment	Bogie high-speed rotation test equipment	Electronic parts repair facilities
	Digital-ATC Testing Device	Digital-ATC Testing Device		Disassembly and Assembly facilities	Digital-ATC etc. Testing and Inspection facilities
				Traction motor maintenance facilities	
	Sewage Removal Device	Automatic Car body Washing Machine		Car body repair facilities	Wheel Re-Profiling Machine
					Bogie changing machine and Unscheduler repair facilities

Source: Study team

(6) Layout of Depot and Workshop

See the following pages for the layouts of Sabarmati depot/workshop and Thane depot.

Shown figure 9.9-14 for the layout of Sabarmati Depot and Workshop.

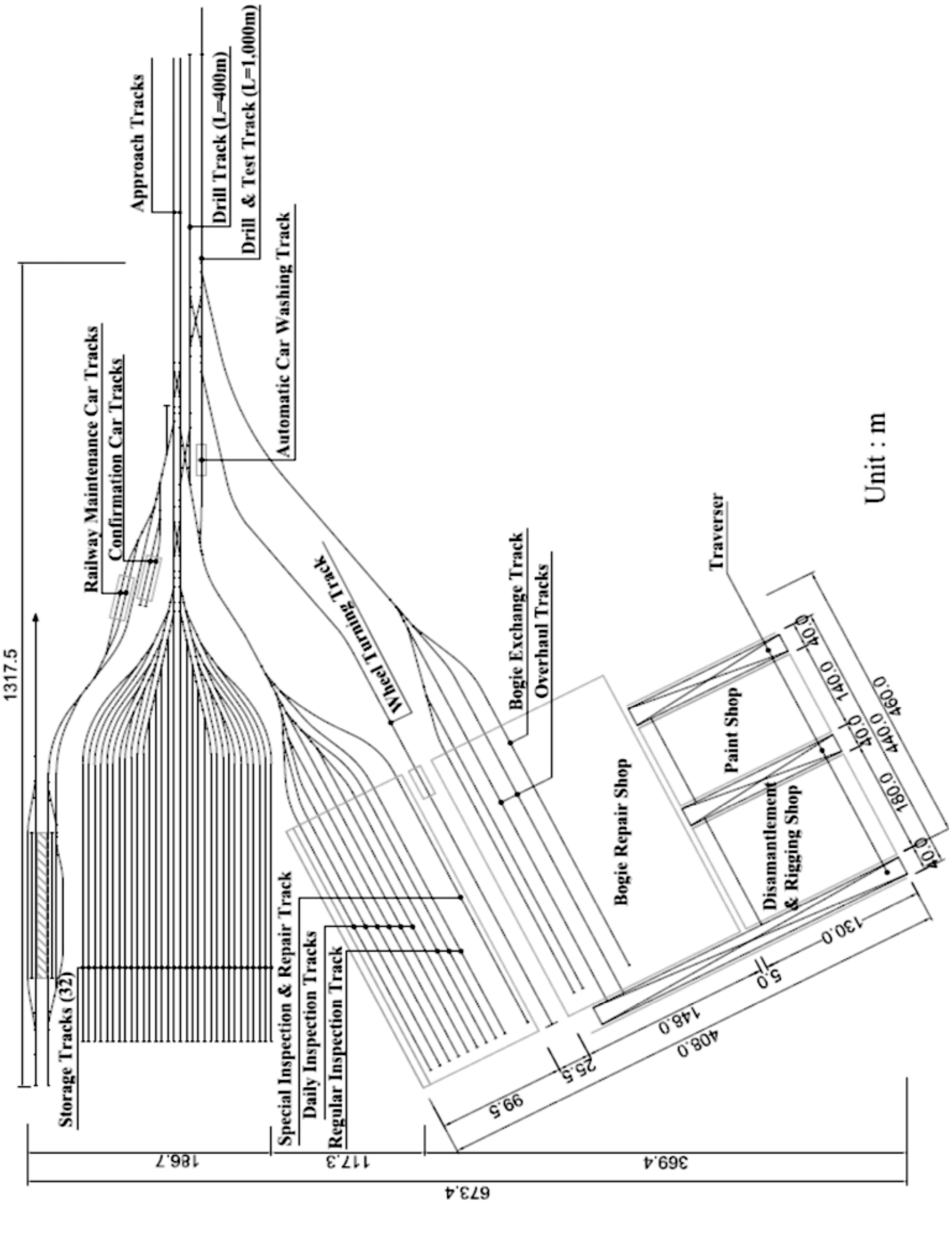


Figure9.9-14 Sabarmati Depot and Workshop

Shown Figure 9.9-15 for the layout of the Main Workshop.

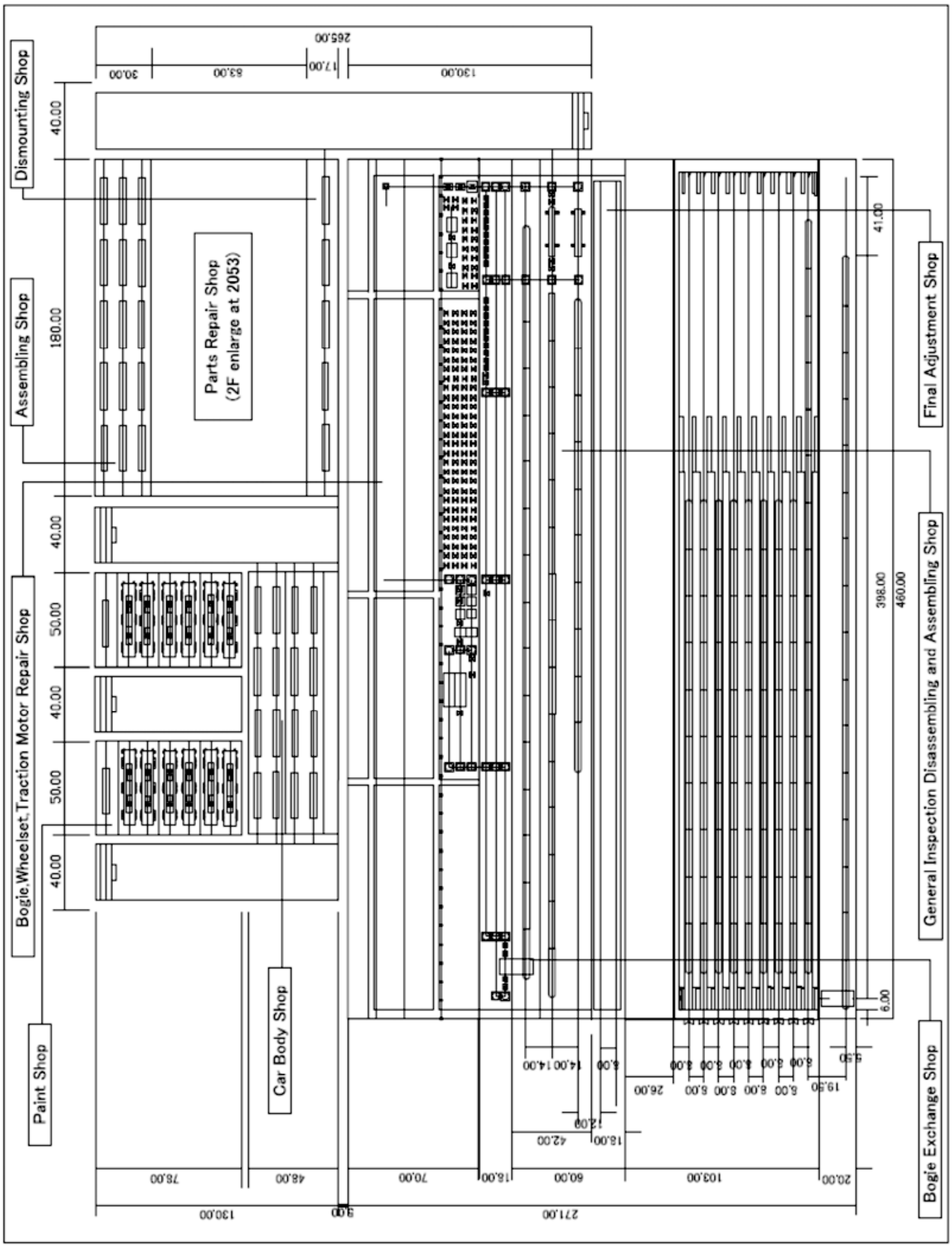


Figure 9.9-15 Main Workshop Layout

Shown Figure 9.9-16 for the layout of Thane Depot.

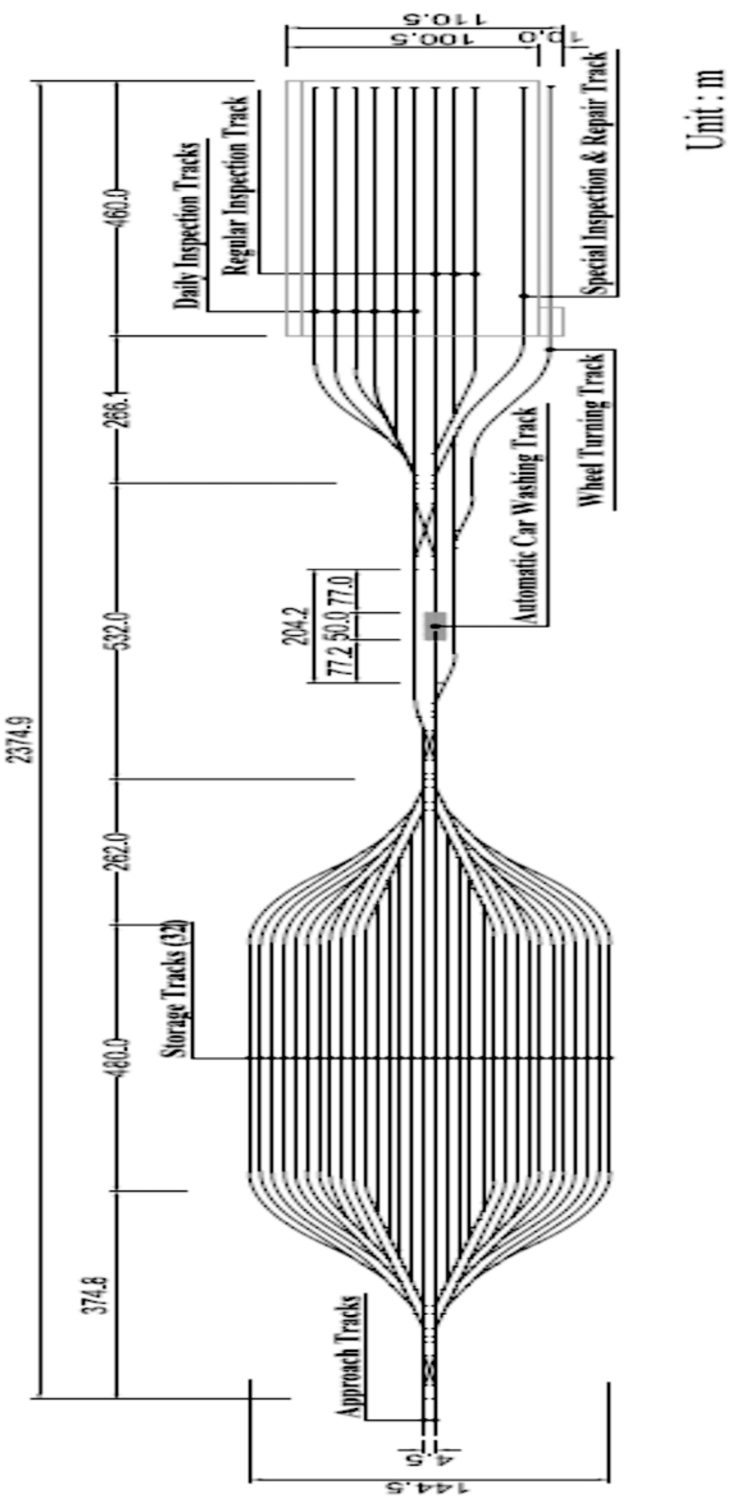


Figure 9.9-16 Thane Depot