Joint Feasibility Study for Mumbai-Ahmedabad High Speed Railway Corridor

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Contents

Volume 1	
Chapter 1 Overview of Study	
1.1 Objectives of Study ·····	
1.1.1 Study Background ······	····· 1-1
1.1.2 Purpose of the Study·····	···· 1-2
1.1.3 Region Targeted by the Study ······	····· 1-2
1.2 Contents of Study ·····	
1.2.1 Overall Organization of Study Operations ······	····· 1-3
1.2.2 Study Implementation Framework ······	····· 1-5
1.3 Schedule·····	····· 1-7
Chapter 2 Basic Route Information	····· 2-1
2.1 The Study Area ·····	····· 2-1
2.2 Administrative Structure ·····	2-2
2.3 Present Population ·····	2-3
2.4 Economic Condition ·····	2-7
2.4.1 GDP ·····	2-7
2.4.2 Number of Worker ·····	2-7
Chapter 3 Analysis of Relevant Data/Information	3-1
3.1 Review of HSR Plans ·····	
3.1.1 Indian Railways Vision 2020 ······	····· 3-1
3.1.2 High-speed Railway Vision ······	3-2
3.1.3 A Report by an Expert Committee	
on Modernization of Indian National Railway ·····	3-4
3.2 Review of HSR Study between Mumbai and Ahmedabad ······	3-5
3.2.1 Pre-feasibility Study Commissioned by	
the Indian Ministry of Railways Republic of India in 2009 ·········	3-5
3.2.2 Study Commissioned by the Ministry of Land, Infrastructure,	
Transport and Tourism of Japan in 2012 ·····	3-10
3.3 Review on Transport related Sector ·····	···· 3-16
3.3.1 Present Situation of Existing Traffic Mode and Future Plans	···· 3-16
3.3.2 Organization of Ministry of Railways, Republic of India (MOR)	3-22
3.3.3 Operation/Maintenance of MOR including Safety Management · · · · · ·	3-35
3.3.4 Procedure for Opening New Line in IR	3-54

3.4	Rev	iew of Existing Related Plans & Studies ······	3-57
3	3.4.1	Mumbai ·····	3-57
3	3.4.2	Surat·····	3-66
3	3.4.3	Vadodara·····	3-69
3	3.4.4	Ahmedabad ·····	3-71
3.5	Pub	lic Private Partnership - Legal, Institutional and Financing Framework \cdots	3-75
3	3.5.1	PPP History, Policy and Strategy in India	3-75
3	3.5.2	PPP Institutional Framework ······	3-76
3	3.5.3	PPP Project Application and Approval Process ·····	3-77
3	3.5.4	Project Approval to Bidding and Selection Flow	3-78
3	3.5.5	Railway Projects Open to Participation by Foreign Capital	3-79
3	3.5.6	Financing Sources under PPP ······	
3.6	The	Dedicated Freight Corridors (DFC) ······	3-83
3	3.6.1	Background ·····	3-83
3	3.6.2	Western Freight Corridor ·····	3-83
3	3.6.3	Eastern Freight Corridor ·····	3-85
3	3.6.4	Operation & Maintenance·····	3-88
3	3.6.5	Design Parameters · · · · · · · · · · · · · · · · · · ·	3-88
3	3.6.6	Estimated Cost & Funding Pattern ·····	3-89
3	3.6.7	Business Plan·····	3-90
3	3.6.8	The Dedicated Freight Corridor & The High Speed Railway Corridor	
		- Some Common Objectives·····	3-91
3.7	Plar	n for Semi High Speed Train on India Railways······	3-93
3	3.7.1	The Quest for Speed ·····	3-93
3	3.7.2	Progress of Speed in Rail Transport – Global Experience ······	3-93
3	3.7.3	Progress of Speed in Rail Transport – Indian Railway Experience ·······	3-95
3	3.7.4	Present Policy Regarding Increasing Speed	
		of Passenger Services on IR·····	3-95
3	3.7.5	Plan for Introducing Semi High Speed Trains with	
		Maximum Speed of 160 Kmph ······	3-96
3	3.7.6	Augmenting Infrastructure for Up-gradation to 160 Kmph······	3-97
Ch	apte	r 4 Formulation of HSR Basic Plan in India·····	4-1
4.1		nition of High Speed·····	
4.2	Nec	essity of HSR System in India ······	
4	1.2.1	Role of High Speed Rail	4-4

4.2.2	High Speed Rail System is Quite Different System
	from Conventional Line System · · · · · 4-4
	Necessity of HSR in India4-5
4.3 Bas	ic Characteristics of HSR System in the World ······· 4-8
4.3.1	Overview of Main Characteristics 4-8
	Construction Method · · · · 4-13
4.3.3	Operation Method······ 4-14
4.4 Inte	roperability and Gauge Selection ······ 4-18
4.4.1	Interoperability · · · · · 4-18
	Gauge Selection · · · · 4-27
4.5 Rec	uired Levels on Services / Facilities · · · · · 4-31
4.5.1	Maximum Operation Speed · · · · · 4-31
4.5.2	Traffic Frequency4-32
4.5.3	Countermeasures against Earthquakes and Natural Disasters ······ 4-33
4.6 Bas	ic Technical Standard and System Selection ······ 4-38
4.6.1	Schedule of Dimension for Mumbai-Ahmedabad
	High Speed Railway Corridor · · · · · 4-39
4.6.2	Proposed Primary SOD for Mumbai-Ahmedabad
	High Speed Railway Corridor · · · · · 4-42
4.6.3	Track Structure ······ 4-61
4.6.4	Electric Power Equipment · · · · · 4-67
4.6.5	Signaling/Telecommunications · · · · 4-73
4.6.6	Rolling Stock · · · · 4-79
4.7 Alig	nments & Station Location · · · · · 4-87
4.7.1	Workflow of Comparison of Alignments and Station Locations 4-87
4.7.2	Site Survey and Meeting with State Government and Local
	Railway Bureaus ······ 4-87
4.7.3	Overall Alignment and Station Locations4-92
4.7.4	Preliminary Survey of Alignment · · · · · 4-172
Chapte	r 5 Review of Travel Demand Forecasts
	and Setting of Fare Levels 5-1
5.1 Traf	fic Surveys ····· 5-1
5.1.1	Introduction 5-1
5.1.2	Willingness-To-Pay (WTP) Survey ····· 5-1
5.1.3	Classified Volume Count (CVC) Survey 5-4

5.1.4	l Car O-D Survey ······	⋯ 5-4
5.2 O	ptimum Fare Study for HSR ······	. 5-7
5.2.1	Cross Country Study ·····	·· 5-7
5.2.2	2 Fare Level for Other Transportation Modes ·····	·· 5-8
5.2.3	Recommendation ·····	·· 5-12
5.3 Re	eview of Travel Demand Forecast ······	·· 5-13
5.3.1	Principles for the Review of Demand Forecast	·· 5-13
5.3.2	Precondition for Demand Forecast ······	·· 5-14
5.3.3	Socio-economic Framework ······	·· 5-16
5.3.4	Transportation Network······	·· 5-18
5.3.5	Base Year Origin-Destination (OD) Development ······	5-22
5.3.6	S Trip Production ·····	5-25
5.3.7	7 Trip Generation / Attraction ······	5-26
5.3.8	3 Trip Distribution·····	·· 5-27
5.3.9	•	
	10 Traffic Assignment ······	
5.4 St	udy for Multi-Class Fare System ······	·· 5-37
5.4.1	Cross Country Study for Fare Level by Seat Class ······	·· 5-37
5.4.2	2 Discount Ticket ·····	5-38
Volum	<u>ne 2</u>	
Chapt	er 6 Natural Condition Surveys ·····	·· 6-1
6.1 To	pological Condition·····	·· 6-1
6.1.1	General Topography ······	·· 6-1
6.1.2	2 Topographical Digital Mapping · · · · · · · · · · · · · · · · · · ·	·· 6-4
6.1.3	B Control Survey Work ······	·· 6-14
6.1.4	Detailed Field Topographic Survey ······	·· 6-22
6.1.5	Satellite Image Processing and Digital Elevation Model Creation	·· 6-29
6.2 G	eological Information·····	·· 6-35
6.2.1	Outline of Geology and Soil in India·····	·· 6-35
6.2.2	Plan of Geological Survey ······	·· 6-41
6.2.3	,	
6.2.4	Summary of Geotechnical Survey·····	·· 6-47
6.2.5	Summary of Special Condition Ground ······	·· 6-49
6.2.6	Geological Data Collection for Preliminary Survey of Alignment·······	·· 6-52
6.3 Hy	ydrological Condition ······	·· 6-71

6.3.1	River System ·····	6-71
6.3.2	Meteorological Condition ······	····· 6-10
6.3.3	Ground Water Level ·····	····· 6-10
6.3.4	Water Quality·····	6-115
6.3.5	Hydrological Data Collection for Preliminary Survey of Alignment	6-120
6.4 Wa	ater Depth in Thane Creek······	····· 6-12
6.4.1	Mean Sea Level ·····	····· 6-12
6.4.2	Tidal Level ·····	6-124
Chapte	er 7 Environmental and Social Considerations	····· 7-1
7.1 Pro	ject Description ······	····· 7-1
7.1.1	The Project Location ······	····· 7-1
7.1.2	Project Background ······	····· 7-1
7.1.3	Importance of the Project ······	····· 7-2
7.1.4	Objective of the Project·····	7-4
7.1.5	Willingness to Pay ·····	7-4
7.1.6	The Executing Agency of the Project ······	····· 7-4
7.2 Pre	sent Natural and Social Condition······	····· 7-5
7.2.1	Climate and Temperature ······	····· 7-5
7.2.2	Air Quality ·····	····· 7-9
7.2.3	Water Quality·····	····· 7-10
7.2.4	Soil Quality ·····	····· 7-11
7.2.5	Waste Management ······	····· 7-15
7.2.6	Noise and Vibration·····	····· 7-20
7.2.7	Ground Subsidence ·····	7-24
7.2.8	Offensive Odors ·····	····· 7-25
7.2.9	Topography ·····	····· 7-25
7.2.10	Bottom Sediment ·····	····· 7-26
7.2.11	Biota and Ecosystem ······	····· 7-26
7.2.12	Pydrology ·····	····· 7-31
7.2.13	Protected Area ······	7-34
7.2.14	Demography ·····	7-51
7.2.15	Employment and Livelihood ······	7-51
7.2.16	Literacy ·····	7-51
7.2.17	Water Use ·····	7-52
7.2.18	Current Land-use·····	7-54

7.2.19	Cultural Heritage ·····	···· 7-54
7.2.20	Indigenous or Ethnic Minority ······	···· 7-56
7.2.21	Social Infrastructures and Decision-making Institutions······	···· 7-56
7.2.22	Health Care Facilities · · · · · · · · · · · · · · · · · · ·	···· 7-57
7.2.23	Educational Institutions ·····	···· 7-57
7.2.24	HIV/AIDS ·····	···· 7-58
7.2.25	Gender ·····	···· 7-59
7.2.26	Children's Rights · · · · · · · · · · · · · · · · · · ·	···· 7-60
7.2.27	Climate Change ·····	···· 7-61
7.2.28	Landscape ·····	···· 7-61
7.2.29	Accident ·····	···· 7-61
7.3 EIA	System in India ·····	···· 7-63
7.3.1	Law and Regulations in India ·····	···· 7-65
	Role of Concerned Authorities · · · · · · · · · · · · · · · · · · ·	
	ysis of Alternatives ······	
7.4.1	Comparison of Alternatives ······	···· 7-75
	No Action Plan ·····	
	oing and TOR on EIA ······	
7.5.1	Predicted Impact and Scoping·····	···· 7-90
7.5.2	TOR for EIA and RAP Census, Socio-economic Survey ······	···· 7-96
7.6 Resu	ılt of EIA Survey·····	···· 7-100
7.7 Asse	essment of Impacts ······	···· 7-109
7.8 Mitig	ation Measures and its Cost ······	···· 7-114
7.9 Envi	ronmental Monitoring Plan (EMP)······	···· 7-123
7.10 Lar	nd Acquisition and Resettlement ······	···· 7-129
7.10.1	Necessity of Land Acquisition and Resettlement······	···· 7-129
7.10.2	Legal Framework of Land Acquisition and Resettlement ······	···· 7-129
7.10.3	Gaps between JICA's Guidelines and related Ordinance in India \cdots	···· 7-130
7.10.4	Census and Socio-economic Survey·····	···· 7-133
7.10.5	Eligibility Policy and Entitlement Matrix······	···· 7-142
7.10.6	Implementation Organization·····	···· 7-148
7.10.7	Implementation Schedule ······	···· 7-152
7.10.8	Resettlement and Compensation Cost & Budget ······	···· 7-154
7.10.9	Monitoring and Evaluation ·····	
7.11 Loc	al Stakeholder Meeting ······	
7.11.1	Stakeholder Meeting in 1 st Stage ······	···· 7-170

7.11.2 Stakeholder Meeting in 2 nd Stage ·······	····· 7-177
7.11.3 Stakeholder Meeting in 3 rd Stage······	····· 7-186
7.12 Land Acquisition and Resettlement ······	····· 7-193
7.12.1 Contents of the Report ·······	····· 7-193
7.12.2 Location of Affected IP Groups ······	····· 7-194
7.12.3 IPP Budget · · · · · · · · · · · · · · · · · · ·	····· 7-194
Volume 3	
Chapter 8 Train Operation Plan	8-1
8.1 Basic Conditions for The Train Operation Plan	····· 8-1
8.1.1 Basic Concept ······	
8.1.2 Route Length and Stations	8-2
8.1.3 Restricted Train Speed (Curve and Down-gradient Sections)	8-2
8.2 Train Operation Plan	8-3
8.2.1 Demand Forecast ······	8-3
8.2.2 Stop Pattern ·····	8-3
8.2.3 Traveling Time ······	8-4
8.2.4 Train Capacity ······	8-5
8.2.5 Train Operation Plan ······	8-9
8.3 Number of Required Train-Sets (Number of Cars) and Storage Location	s ·· 8-13
8.3.1 Number of Required Train-Sets (Number of Cars) ······	8-13
8.3.2 Storage Locations ······	8-14
8.4 Option Plan for Low-fare Passengers · · · · · · · · · · · · · · · · · · ·	8-14
8.4.1 Introduction of Low-fare Seat Trains	8-14
8.4.2 Others	8-16
Chapter 9 High Speed Railway Construction Plan	····· 9-1
9.1 Basic Specification and Track Layout of the High Speed Railway	
for HSR1 Construction Plan·····	···· 9-1
9.1.1 Basic Track Layout ······	····· 9-1
9.1.2 Basic Policy for Designing Civil Structures	····· 9-19
9.2 Embankment and Cut Structure ······	9-22
9.2.1 Embankment ······	9-22
9.2.2 Cut Structure ·····	9-35
9.2.3 Box Culvert ······	9-38
9.3 Viaduct	····· 9-41

9.4	Bridg	ge	9-48
9.5	Tunr	nel	9-62
9	.5.1	Planning of Location for Tunnels	9-62
9	.5.2	Geological Aspects ·····	9-66
9	.5.3	Tunnel Configuration and Cross Section ·····	9-74
9	.5.4	Civil Work Aspects ·····	9-82
9	.5.5	Recommendations·····	9-87
9.6	Stati	on	9-90
9	.6.1	Station Facilities · · · · · · · · · · · · · · · · · · ·	9-90
9	.6.2	Station Concept ·····	9-92
9	.6.3	Station Structure ·····	9-111
9	.6.4	Station Square ·····	9-113
9	.6.5	Parking Space at the Stations ······	9-115
9	.6.6	Station and Station Square Plan · · · · · · · · · · · · · · · · · · ·	9-118
9	.6.7	Transport Connectivity of HSR and Other Modes in Station Area·······	9-148
9	.6.8	Summary of Station Elements · · · · · · · · · · · · · · · · · · ·	9-153
9.7	Trac	k	9-155
9	.7.1	Detailed Track Structure ·····	9-155
9	.7.2	Track Work Schedule ·····	9-174
9.8	Rolli	ng Stock ·····	9-190
9	.8.1	General Concept ·····	9-190
9	.8.2	Formation/Dimensions and Basic Performance·····	9-190
		Recommendation for Rolling Stock Plan·····	
9.9	Main	tenance Facilities for Rolling Stock······	9-205
9	.9.1	Maintenance System and Equipment/Facilities for HS Rolling Stock \cdots	9-205
9	.9.2	Maintenance System·····	9-206
9	.9.3	Policy of the High-speed Rolling Stock Safety Control System	
		and Features of Maintenance·····	9-209
9	.9.4	Introduction of Japanese Maintenance for Shinkansen · · · · · · · · · · · · · · · · · · ·	9-211
9	.9.5	Functions and Scales of Facilities at Car Depot and Workshop ··········	9-216
9.10) Pov	wer-related Facilities ·····	9-224
9	.10.1	Power Supply Installation ·····	9-224
9	.10.2	Overhead Equipment (OHE) ·····	9-239
9	.10.3	Lights and Electrical Facilities·····	9-250
9.11	Sig	naling/Telecommunications ······	9-252
9	.11.1	Signalling ·····	9-252

9.1	1.2	Telecommunications ·····	9-273
9.1	1.3	Cost Comparison of S&T Systems······	9-281
9.12	Ope	ration Management System ······	9-282
9.1	2.1	Roles and Requirements of Operational Control Center · · · · · · · · · · · · · · · · · · ·	9-282
9.1	2.2	Historical Progress of Train Operation Controlling System · · · · · · · · · · · · · · · · · · ·	9-282
9.1	2.3	Example of Operation Controlling System · · · · · · · · · · · · · · · · · · ·	9-283
9.1	2.4	Modern and Robustness System Configuration ······	9-287
9.1	2.5	Controlling Center Management ······	9-290
9.1	2.6	Proposed Train Operation Controlling System·····	9-293
9.1	2.7	OCC Building · · · · · · · · · · · · · · · · · · ·	9-296
9.1	2.8	Backup Function of OCC ······	9-297
9.13	Ticke	eting System·····	9-298
9.1	3.1	Ticketing System Structure ·····	9-298
9.1	3.2	Processes Handled by the Ticketing System ······	9-299
9.1	3.3	Ticketing Systems for High Speed Railways in Other Countries · · · · · · · ·	9-300
9.1	3.4	Ticketing System for High Speed Railway in India ······	9-302
9.14	Com	parison between Recommended Systems and Alternatives ······	9-314
9.1	4.1	System Integration and Total Design Management · · · · · · · · · · · · · · · · · · ·	9-314
9.1	4.2	Comparison from the View Point of Cost and Technical Aspect········	9-315
9.15	Sum	mary of Workshop for HSR on Subsystem ·····	9-318
9.1	5.1	Date, Time, Place and Number of Participants · · · · · · · · · · · · · · · · · · ·	9-318
9.1	5.2	Program ·····	9-318
9.1	5.3	Output and Effect of Workshop ······	9-318
<u>Volu</u>	me 4	<u>4</u>	
Cha	pter	10 Station Area Development	10-1
		an Planning around Station Area ·····	
10.2	Stati	ion Area Development ······	10-2
10	.2.1	Secure Convenience for HSR Passenger ······	10-2
10	.2.2	Harmonization with Urban and Regional Planning	10-6
10.3	Valu	e Capture Models·····	10-18
10	.3.1	Existing Market Status and Regulations, etc. ·····	10-18
10	.3.2	Around Station Development·····	10-25
10	.3.3	Land Value Capture Flow for HSR·····	10-36
10.4	Non	Railway Business·····	10-39
10.5	Reco	ommendation ·····	10-43

		11 Operation and Maintenance Plan	
		ety Management Plan ·····	
11	.1.1	Safety Management in High-speed Railway·····	11-1
11.2	Ope	ration and Maintenance Plan ······	11-7
11	.2.1	Importance of Cooperation between Operation and Maintenance······	11-7
11	.2.2	Recommended Structure Type of O&M Organization ······	11-7
11	.2.3	Organization for Management, Indian HSR Line1 ·····	11-7
11	.2.4	Structure of Operation and Maintenance	
11	.2.5	Offices and Staff for Operation and Maintenance · · · · · · · · · · · · · · · · · · ·	
11	.2.6	Major Systems and Machines Required for Maintenance ······	
11	.2.7	Operation and Maintenance Costs·····	
11.	.2.8	Investment after Starting Operation ·····	11-36
		12 Project Cost of the High-speed Railway System ····	
		l Project Cost·····	
		Composition of Project Cost·····	
		Basic Policy of Project Cost Estimation ·····	
		culation of Project Cost ······	
		Construction Cost ·····	
12	.2.2	Calculation of Project Cost·····	12-12
		Cost Comparison between the Joint F/S and the Pre-F/S ······	
		Cost Comparison with Formation Level Width·····	
12.3	Ann	ual Investment Plan······	12-17
Cha		13 Project Implementation Plan	
13.1		struction Stage Structure and its Scope·····	
13.2		rall Framework for Project Implementation ······	
13.3	Prod	curement Planning······	
13	.3.1	Role of Procurement Planning · · · · · · · · · · · · · · · · · · ·	
13	.3.2	Procurement Methods ·····	
13	.3.3	Priority for Procurement Planning · · · · · · · · · · · · · · · · · · ·	
13	.3.4	Basic Framework of Procurement · · · · · · · · · · · · · · · · · · ·	
13	.3.5	Main Object of Procurement·····	13-9
13	.3.6	Development of Business Environment for Procurement	13-14

Cł	nap	oter	14 Project Scheme Financial Option	14-1
14.	.1	High	Speed Railway Project Implementation around the World ······	14-1
14.	.2	Metr	o Rail Projects around the World ······	14-3
	14.	2.1	Metro Rail Projects under PPP ······	14-3
14.	.3	Rail	way Projects in India·····	14-10
	14.	3.1	Railways and its Group ······	14-10
14.	.4	Metr	o Rail Projects in India ······	14-15
	14.	4.1	Case Study 1: Mumbai Metro Line 1 ······	14-15
14.	.5	Fina	ncing Sources for HSR Projects ······	14-20
	14.	5.1	Financing Sources in India·····	14-20
	14.	5.2	Finance Sources from Japan·····	14-25
			Other Finance Sources ·····	
14.	.6	Pos	sible Project Scheme Considerations ······	14-26
	14.	6.1	PPP Project Structuring Schemes ·····	14-26
			Contract Patterns ·····	
	14.	7.1	PPP Project Risks·····	14-29
	14.	7.2	Metro Rail Project in India Case Studies ······	14-34
14.	8.	Tent	ative and Possible Forms of	
			HSR Project Implementation and Operation ······	
	14.	8.1	Introduction ·····	
	14.	8.2	HSR, a New Modality of Railway·····	
	14.	8.3	Possible Project Schemes ·····	
	14.	8.4	Financial Instruments Supporting Project Scheme ······	14-45
14.	.9	Key	Considerations for Future ······	14-51
Cł	nap	oter	15 Economic and Financial Analysis	15-1
15.	.1	Meth	nodology ·····	15-1
	15.	1.1	Outline ·····	15-1
	15.	1.2	Methodology of Economic Analysis · · · · · · · · · · · · · · · · · ·	15-1
	15.	1.3	Methodology of Financial Analysis·····	15-4
15.	.2	Eco	nomic analysis·····	15-5
	15.	2.1	Economic Benefits · · · · · · · · · · · · · · · · · · ·	15-5
	15.	2.2	Economic Costs ·····	15-7
	15.	2.3	Result of Economic Evaluation ·····	15-8
	15	2 4	Indirect Economical Benefit·····	15-11

15.3	3 Fina	ancial analysis ·····	15-14
1	15.3.1	Revenue·····	15-14
1	15.3.2	Financial Costs ·····	15-14
1	15.3.3	Result of Financial Evaluation ·····	15-15
Ch	apter	16 Legal Systems and Technical Standard	16-1
16.	1 Hig	h Speed Railway Line Construction Procedure in Japan ·····	16-1
1	16.1.1	Japanese Institute and Procedure for Public Work (Council System) $\cdot\cdot$	16-1
1	16.1.2	Japanese High Speed Railway Construction Procedure · · · · · · · · · · · · · · · · · · ·	16-1
1	16.1.3	Land Acquisition Procedure and the Role of Local Government ········	16-3
16.2	2 Jap	anese Legislation for High Speed Railway Construction and Operation	16-5
1	16.2.1	Laws Related High Speed Railway Construction and Operation ·······	16-5
1	16.2.2	Laws for Land Control and Land Acquisition ·····	16-8
1	16.2.3	Technical Standards for Railway ·····	16-11
16.3	3 Or	ganization of Indian Government and Railways-related Institutions ······	16-15
1	16.3.1	Organization of Indian Government ······	16-15
1	16.3.2	Railway-related Institutions ······	16-16
1	16.3.3	Railway Safety Commissioner ······	16-27
16.4	4 Rai	lway Technical Standards in India·····	16-28
1	16.4.1	Authentication of Technologies ······	16-28
1	16.4.2	Railway Technical Standard ······	16-29
1	16.4.3	Existing Schedule of Dimensions ······	16-30
1	16.4.4	Policy Circular ·····	16-31
1	16.4.5	Standards of Construction ·····	16-31
1	17.4.6	Current Situation of Bridge Design Process······	16-32
1	17.4.7	Electrical Facilities ······	16-32
16.	5 Effc	orts and Procedures Required for Introduction of High-Speed Railways	
		in the Future ·····	16-33
1	16.5.1	Establishment of Legal System and Technical Standard	
		for HSR in India·····	16-33
1	16.5.2	Reinforcement of the Institute of High Speed Railway Project	
		Implementation ·····	16-34
1	16.5.3	Necessity of the Regulation Enactment in the Future······	16-34
1	16.5.4	Schedule of Institute Preparation ·····	16-36
1	16.5.5	Decrees Instituting Process ·····	
16 6	6 Rec	commendation ······	16-38

Chapt	er 17 Human Resource Development Plan ······ 17-1
17.1 E	Basic Policy of Developing Human Resource · · · · · · 17-1
17.2 T	he Technology Required for Operation/Maintenance of India HSR
E	Based on Current Railway Technology Level in India and the Core
٦	Fechnology to Ensure Safety of HSR · · · · · 17-2
17.2	.1 Current State of Railway Technology Level in India · · · · · 17-2
17.2	2 The Technology Required for Operation/Maintenance of HSR · · · · · 17-2
17.2	.3 The Core Technology to Ensure Safety for Operation/Maintenance · · · · 17-3
17.3	Set-up Time of the Organization Concerned/the O&M Company
f	or HSR and Schedule of Human Resource Development17-4
17.3	.1 Set-up Time of the Organization Concerned / the O&M Company
	for HSR · · · · · 17-4
17.3	2 Technology Transfer during Construction Period······ 17-6
17.4	Specific Program for Human Resource Development ······ 17-8
17.4	.1 Human Resource Development for Operation/Maintenance········· 17-8
17.4	2 Object Trainees and Training Methods for Human Resource
	Development······ 17-9
17.4	· · · · · · · · · · · · · · · · · · ·
17.4	.4 Training in India······ 17-11
17.4	.5 Follow-up Education/Training during One Year after Opening······ 17-14
17.5 C	Other Issues of Human Resource Development ······ 17-15
17.5	.1 The Education/Training of Safety to Ensure the Safety in Indian HSR · 17-15
17.5	2 Recruiting of Human Resource for Operation/Maintenance of HSR ···· 17-16
17.5	.3 Technical Independence of Indian HSR · · · · · 17-16
17.5	.4 Other Considerations 17-18
17.6	Set-up Plan of the HSR Training Institute in India · · · · · · · · · · · · · · · · · · ·
17.6	.1 Organization of the HSR Training Institute······ 17-20
17.6	2 Facilities/Equipment of the HSR Training Institute
17.6	
17.6	.4 Education/Training Curriculums and Training Period of Main
	Related Employees · · · · 17-26
17.7	Overall Roadmap of Human Resource Development · · · · · 17-26
Chapt	er 18 Conclusion 18-1

<u>VOI</u>	<u>ume</u>	<u>: 5</u>	
		dix 1 Comparison of Alternative Route	
1.1	Trav	vel Demand Forecasts·····	A1-1
1	.1.1	Outline ·····	
1	.1.2	Alternative Plan·····	A1-1
1	.1.3	Demand Forecast by Alternative Plans·····	A1-2
1.2	Trai	n Operation Plan ·····	A1-11
1	.2.1	Number of Trains·····	
1	.2.2	Number of Required Train Sets (Cars) ······	A1-12
1.3	Eco	nomic Analysis ·····	A1-13
1	.3.1	Objective ·····	A1-13
1	.3.2	Methodology ·····	A1-13
Apı	oend	dix 2 Workshop for HSR Subsystem ·····	A2-1
2.1		-line·····	
2.2	The	Official Letter Concerning Workshop ·····	A2-2
2.3	Par	ticipants List·····	A2-3
2.4	Spe	ech and Presentation ······	A2-5
Apı	oend	dix 3 Workshop for SOD for HSR ·····	A3-1
3.1		ective of SOD Workshop·····	
3.2	The	Official Letter for Workshop on Proposed SOD for HSR ·····	A3-1
3.3	Sch	edule of SOD Workshop·····	A3-2
3.4	Pro	gramme ·····	A3-2
3.5	Atte	endance List ·····	A3-3
3.6	Pho	otos·····	A3-4
Арј	oend	dix 4 Environmental Impact Assessment·····	A4-1
	ume		
Apı	oend	dix 5 Preparation of Resettlement Action Plan ······	A5-1
Apı	oend	dix 6 Preparation of Indigenous People Plan ······	A6-1
Apı	oend	dix 7 Financial Model Scenarios (Summary)·····	A7-1

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			
СВ	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			
L	1 P. 1			

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		
	ŭ		
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	Intrastructure Leasing & Financial Services Limited 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 Indian Standard		
JETRO	Japan External Trade Organization		
JICA	Japan International Cooperation Agency		
JNR	Japanese National Railways		
JR IDEE	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 SEA	Synchronous Digital Hierarchy		
SEAC	Strategic Environmental Assessment		
SEIAA	State Level Expert Appraisal Committee, India 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 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	IJ	under 6000 m	310	
3500 m	IJ	under 4000 m	275	
3000 m	IJ	under 3500 m	260	
2800 m	IJ	under 3000 m	250	
2500 m	IJ	under 2800 m	235	
2200 m	IJ	under 2500 m	220	
2000 m	IJ	under 2200 m	210	
1800 m	IJ	under 2000 m	200	
1500 m	IJ	under 1800 m	185	
1200 m	IJ	under 1500 m	165	
1000 m	IJ	under 1200 m	150	
900 m	IJ	under 1000 m	140	
800 m	IJ	under 900 m	135	
700 m	IJ	under 800 m	125	
600 m	IJ	under 700 m	115	
500 m	IJ	under 600 m	105	
400 m	IJ	under 500 m	95	

^{*320}km/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	

^{*320}km/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 evaluation 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.

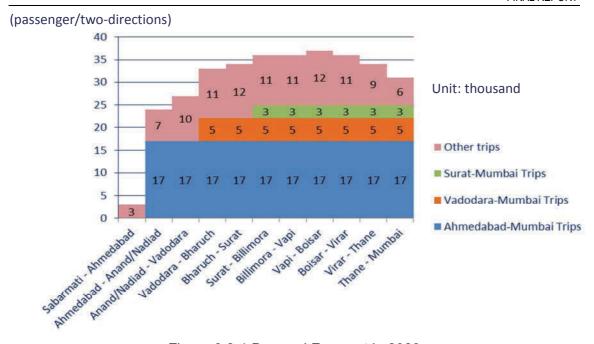


Figure 8.2-1 Demand Forecast in 2023

Table 8.2-1 shows stopping station by train type.

Table 8.2-1 Stopping Station by Train Type

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

(o: 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	Stopping station			
Station	(km)	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

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.

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



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 shoul 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 recomended 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 Capaci	tv. Train	Configur	ration and	Number of	of trains in 2023
14510 0.2	Train Capaci	.,		ation and	1 10111001	, uanio in 2020

	o mani capacity,		***************************************	71 01 traine in 2020
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.

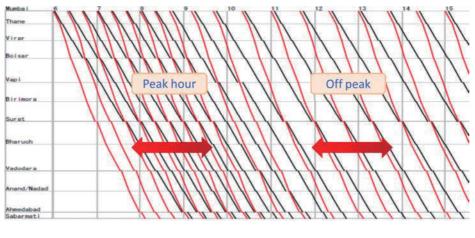


Figure 8.2-3 Diagram Image (6 cars)

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.

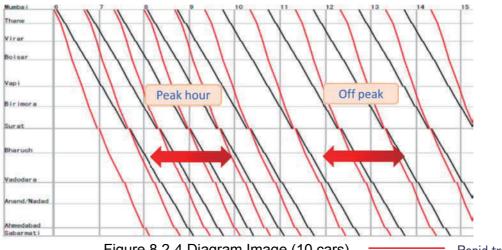


Figure 8.2-4 Diagram Image (10 cars)

Rapid train Each stop train

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)

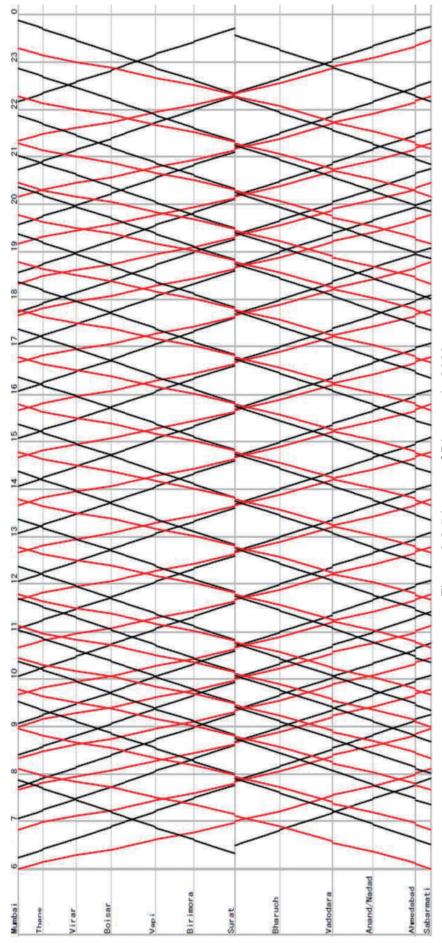
Year	2023	2033	2043	2053	
Train configuration	10 10 • 16		16	16	
Train capacity	Approx. 750	Approx. 750, 1,250	Approx. 1,250	Approx. 1,250	
Trafficvolume (day/one-direction)	17,900	31,700	56,800	92,900	
Number of trains (day/one-direction)	35	51	64	105	
Number of trains (train/hour/one-direction) Peak 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.



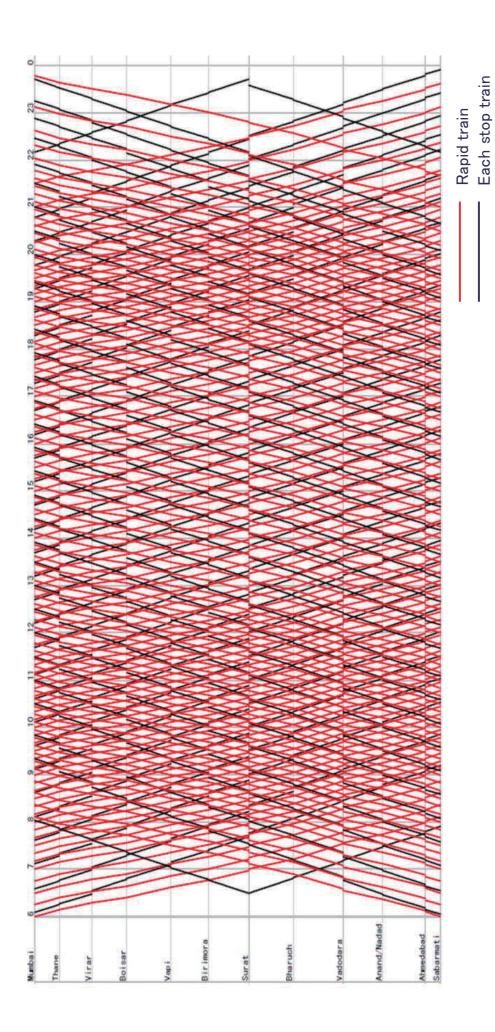


Figure 8.2-6 Image of Diagram in 2053

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

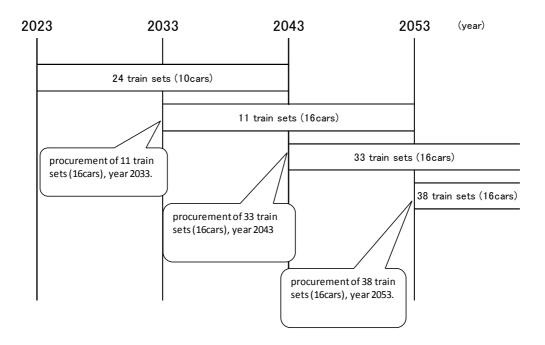


Figure 8.2-7 Image of procurement plan for rolling stock

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 significantly 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.

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 3-1 Train Kilometers

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 (train/one-direct		35	51	64	105	
Number of	10 cars	24	24	-	1	
train sets	16 cars	1	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				
Location	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 ca	ars, 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.

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

Table 8.4-1 Comparison of Train Capacity

(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.

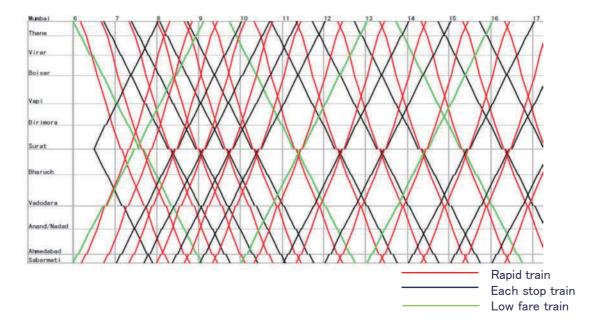


Figure 8.4-2 Image of Diagram of Low-fare train (In 2023)

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

	Distance	•	Stopping station	
Station	(km)	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.

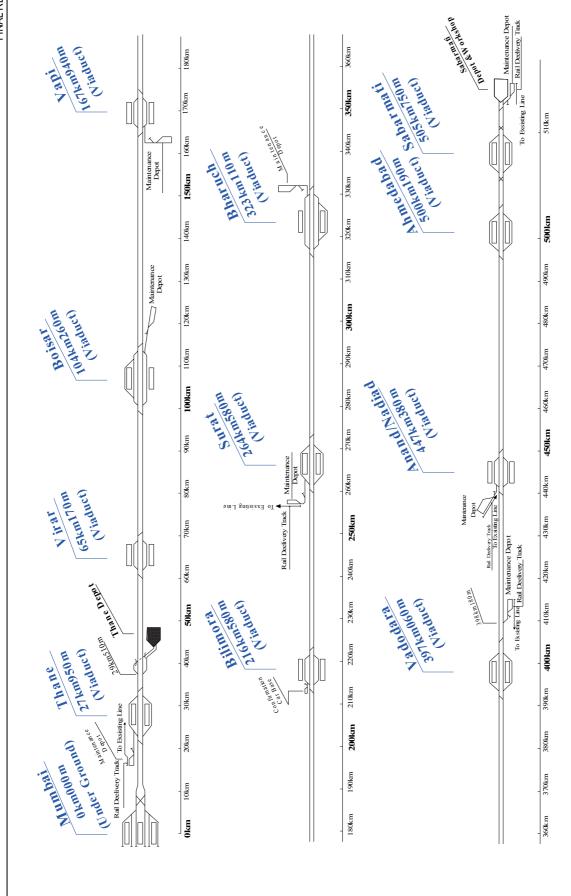


Figure 9.1-1 Distribution of Stations, Depots, Workshops and Maintenance Depots for Rolling Stock along the Whole HSR1 Line

(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 mThe 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.

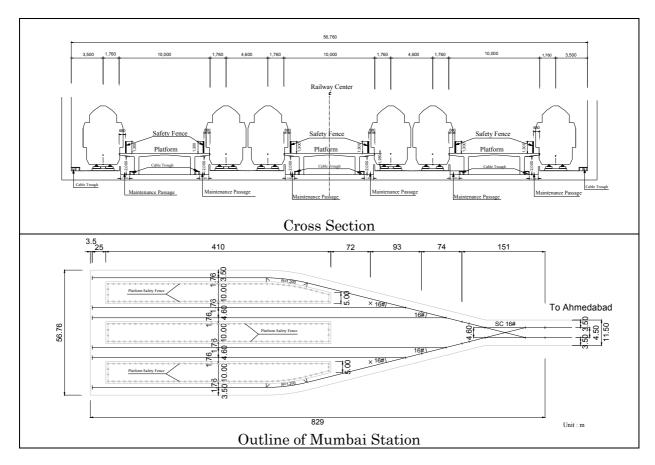


Figure 9.1-2 A Cross-section and a Schematic Drawing of the Track Layout, Mumbai Station

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.

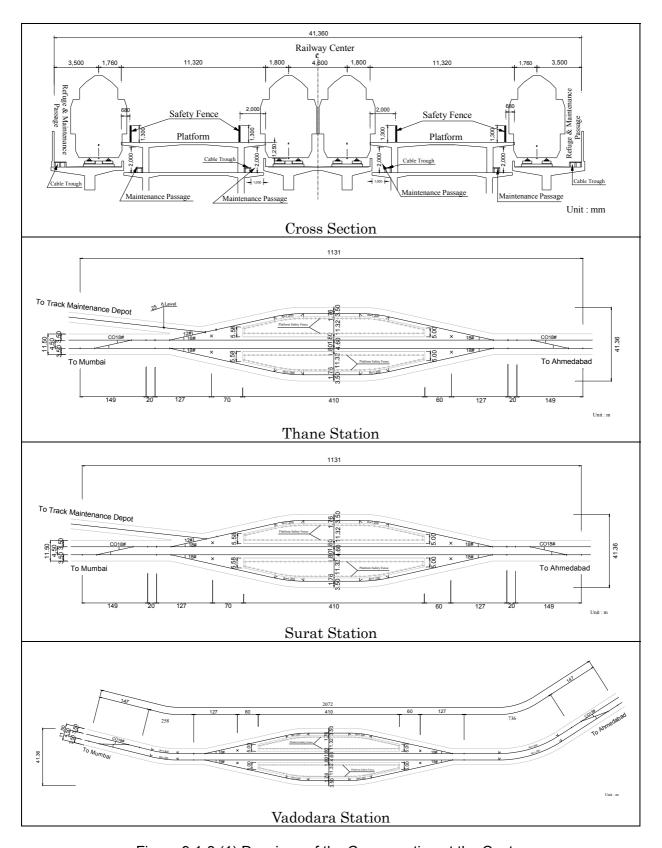


Figure 9.1-3 (1) Drawings of the Cross-section at the Center and Schematic Drawing of the Track Layout of Different Stations

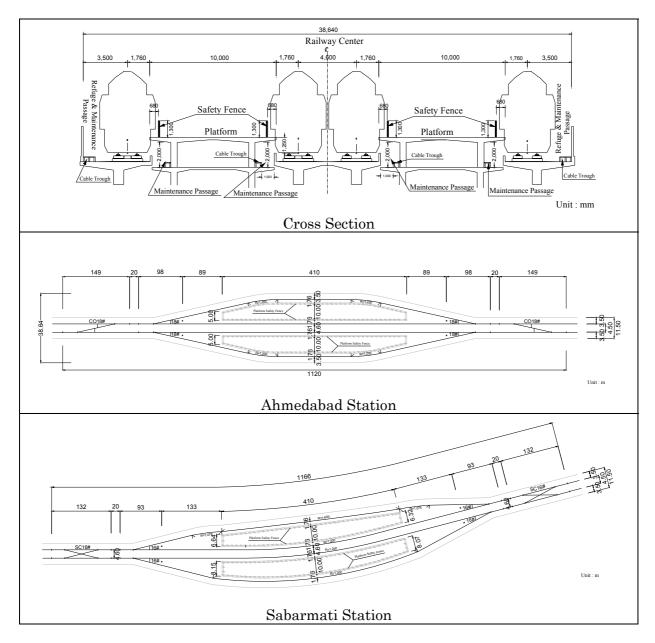


Figure 9.1-3 (2) Drawings of the Cross-section at the Center and Schematic Drawing of the Track Layout of Different Stations

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.

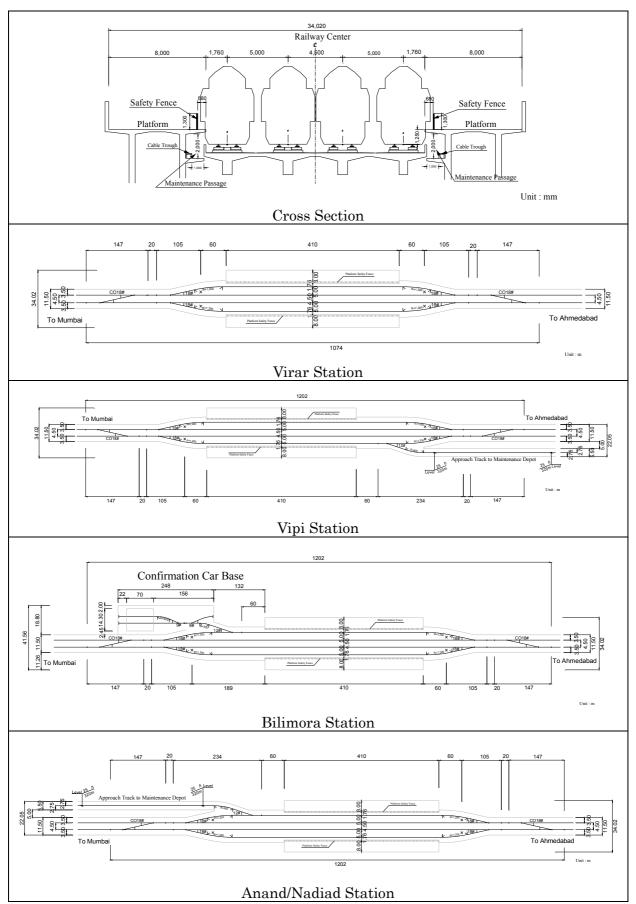


Figure 9.1-4 (1) Drawings of the Cross-section at the Center and Schematic Drawing of the Track Layout of Different Stations

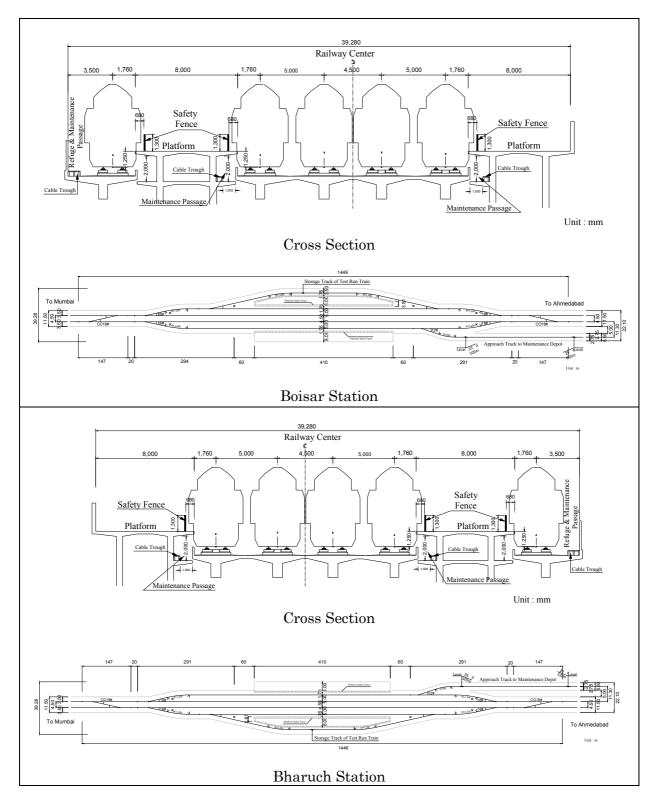


Figure 9.1-4 (2) Drawings of the Cross-section at the Center and Schematic Drawing of the Track Layout of Different Stations

(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

Year		2023		2033		2043		2053	
Items	Than	Sabarmat	Than	Sabarmat	Than	Sabarmat	Than	Sabarmat	Remark
Rems	e	i	e	i	e	i	e	i	S
Depot		1		1		1	C	1	
Storage									L=480
Tracks	13	11	15	13	23	22	29	29	
									m
Daily	2	2	3	3	3	3		(
Inspection	2	2	3	3	3	3	6	6	
Tracks									
Regular	•	2	2	2	•		2	2	
Inspection	2	2	3	2	2	2	3	3	
Tracks									
Special									
Inspection	1	1	1	1	1	1	1	1	
& Repair	-	-	-	-	-	_	-	_	
Track									
Wheel									
Re-profilin	1	1	1	1	1	1	1	1	
g Track	1	1	1	1	1	1	1	1	
Track									
Car									
Washing	1	1	1	1	1	1	1	1	
Track									
Drill Track		1		1		1		1	
(L=400m)		1		1		1		1	
Workshop									
Overhaul		2		2		2		2	
Tracks		2		2		2		2	
Bogie									
Exchange		1		1		1		1	
Track									
Assembly								_	
Tracks		2		2		2		2	
Bogie									
Repair		88m		88m		88m		88m	
Shop		×460m		×460m		×460m		×460m	
(W×Lm)		100111		100111		100111		100111	
Rigging									
Shop		130m		130m		130m		130m	
(W×Lm)		×180m		×180m		×180m		×180m	
Paint Shop		130m		130m		130m		130m	
(W×Lm)		×140m		×140m		×140m		×140m	
Traverser									
(Set)		4		4		4		4	
Drill &									
Test Track									
		1		1		1		1	
(L=1,000m									
J									

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 m² for approach tracks and approximately 324,420 m² 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 m² for approach tracks and approximately 673,260 m² 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.

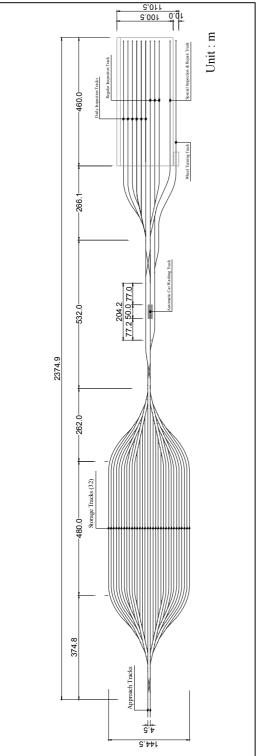


Figure 9.1-5 (1) Schematic Drawing of the Track Layout, Thane Rolling Stock Depot

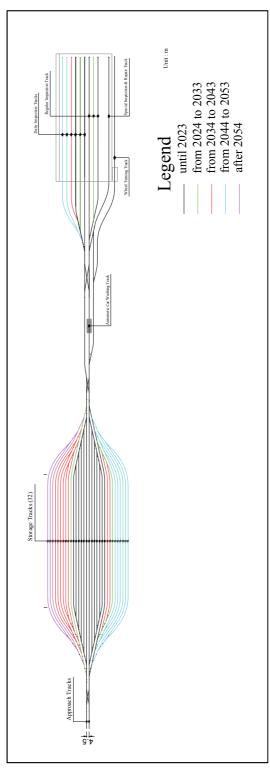


Figure 9.1-5 (2) Track Layout of the Thane Rolling Stock Depot in Different Fiscal Years

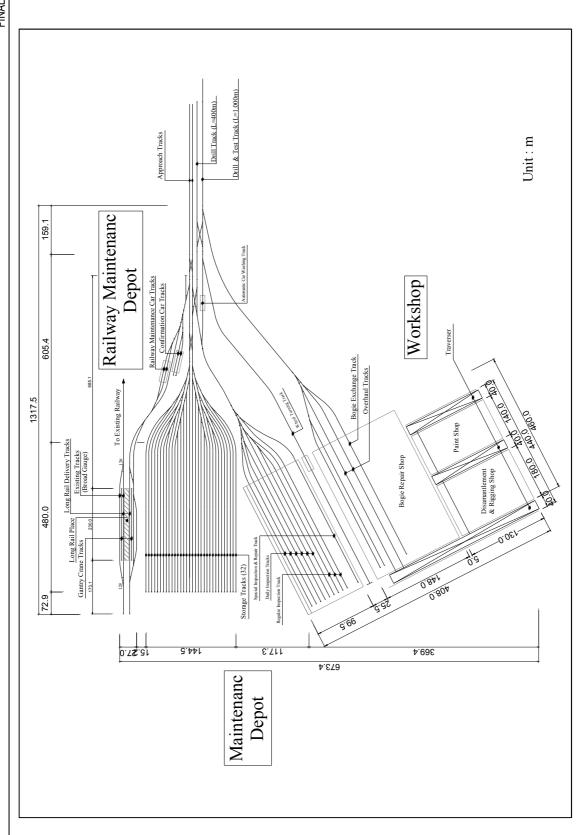


Figure 9.1-6 (1) Schematic Drawing of the Track Layout Sabarmati Rolling Stock Depot and Workshop

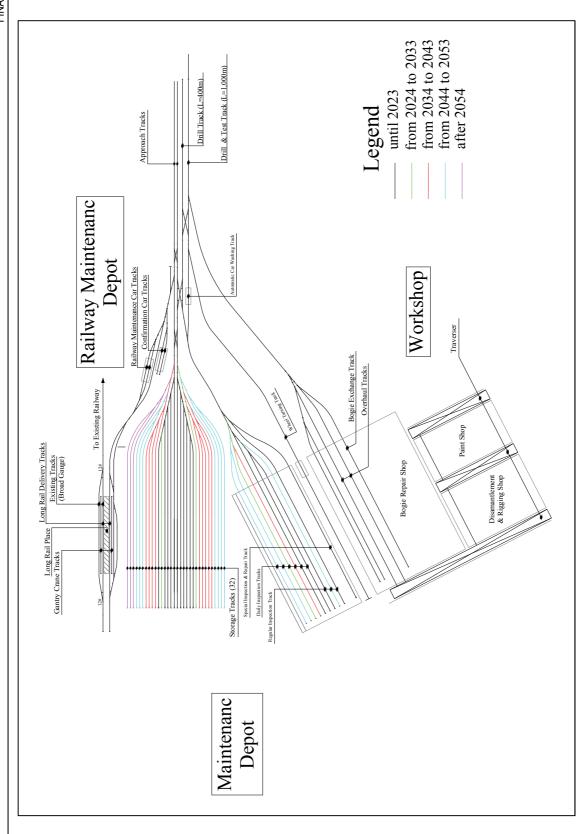


Figure 9.1-6 (2) Chronological Changes in the Track Layout, Sabarmati Rolling Stock Depot and Workshop

(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 (m²)

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 Ca	r Depot & Workshop		Connected to an existing
				line
Total	243,150	23,870	267,020	

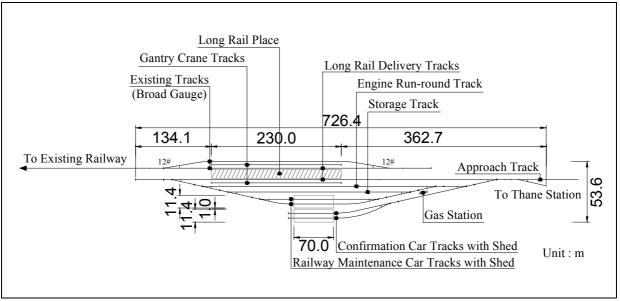


Figure 9.1-7 (1) Schematic Drawing of Track Layout, Thane Track Maintenance Depot

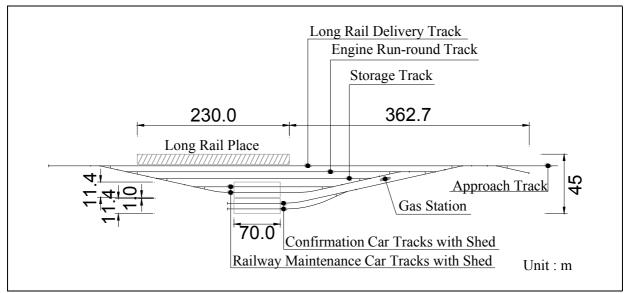


Figure 9.1-7 (2) Schematic Drawings of Track Layout, Boisar, Vapi and Thane Track Maintenance Depots

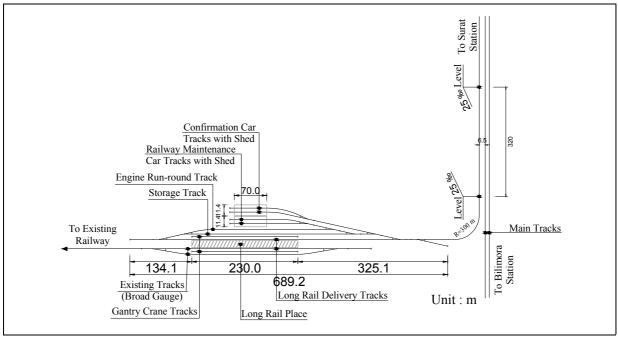


Figure 9.1-7 (3) Schematic Drawing of Track Layout, Surat Track Maintenance Depot

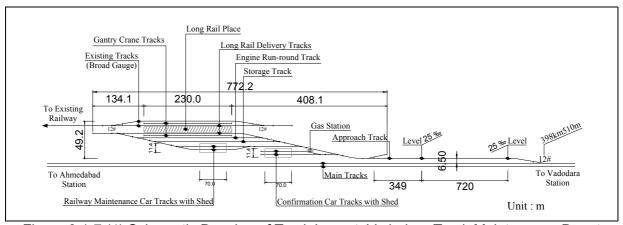


Figure 9.1-7 (4) Schematic Drawing of Track Layout, Vadodara Track Maintenance Depot

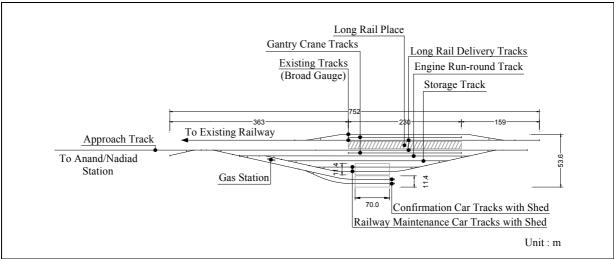


Figure 9.1-7 (5) Schematic Drawing of Track Layout, Anand/Nadiad Track Maintenance Depot

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	■ DBE (Design Basis Earthquake)				
Earthquake	Reasonably be expected to occur at least once during the design life of structure.				
Motions	The design horizontal seismic coefficient A _h for a structure shall be determined by the				
(DBE)	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	MCE (Maximum Considered Earthquake)			
Earthquake	The most severe earthquake effects.			
Motions (MCE)	$A_{h} = (Z \cdot I \cdot S_{a}) / (R \cdot g)$			
Set of the	■ For DBE (Design Basis Earthquake)			
Damage Level	Structure would undergo deformation beyond its yield limit.			
of Members	■ 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

	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 _α) (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 α(=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 length between stations.

Length Embankment Rate No. Station (km) Structures(km) (%)Mumbai st. - Thane st. 27.8 2.8 10 Thane st. – Virar $\overline{st.}$ 2 37.0 4.8 13 3 Virar st. - Boisar st, 39.4 23.8 61 Boisar st. – Vapi st. 4 64.748.0 76 Vapi st. – Bilimor st. 5 48.243.8 93 Bilimor st. - Surat st. 6 47.3 33.0 717 Surat st. - Bharuch st. 58.666 38.0 8 Bharuch st. - Vadodara st. 74.0 60.4 83 Vadodara st. - Anand/Nadiad st. 9 50.0 35.1 7110 Anand/Nadiad st - Ahmedabad st. 23.352.74511 Ahmedabad st. - Sabarmati Depot. 0.0 0 8.8 TOTAL 508.5 313.0 63

Table 9.2-1 List of Embankment Structures

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.

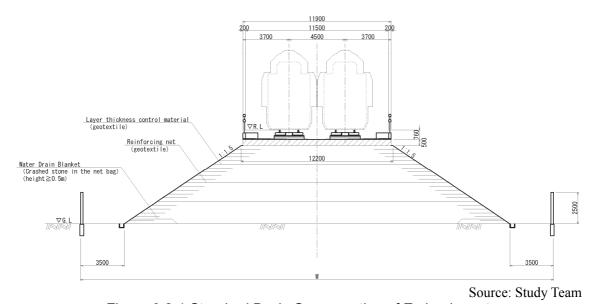
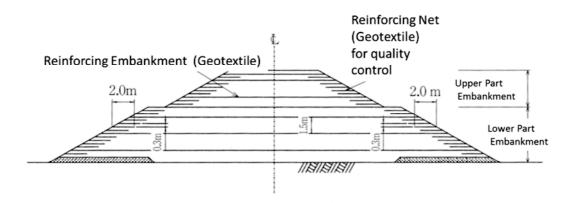


Figure 9.2-1 Standard Basic Cross-section of Embankment

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.

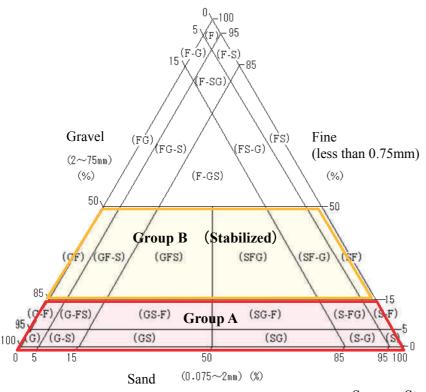
Embankment having a height of 6 m or over is separated into the upper part embankment and lower part embankment. For the materials to construct upper/lower embankments, see Table 9.2-2.

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/m³ (lower limit :70 MN/m³)
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

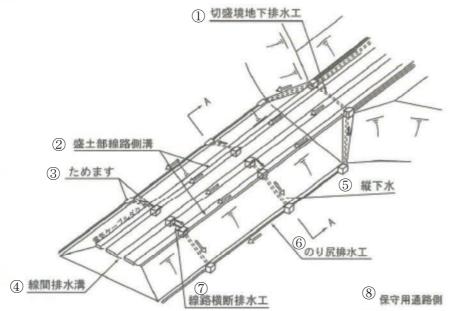
To prevent surface erosion, strengthen the surface layer soil and preserve the environment by greening, Study team propose sodding planting that suit the climates of the Gujarat and Maharashtra states and has been adopted for the embankments of existing railways.

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 0.3×0.3 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.



- 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
- 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



Figure 9.2-6 Distribution Area of BCS 2

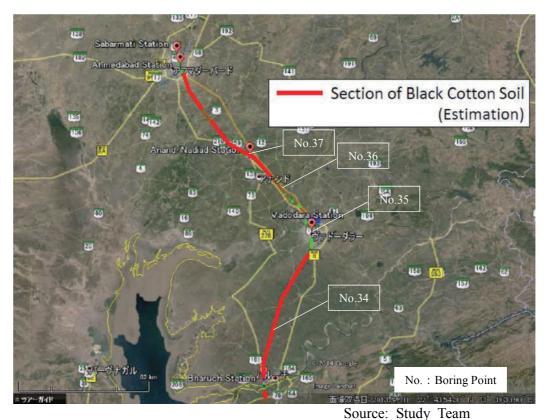


Figure 9.2-7 Distribution Area of BCS 3

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.

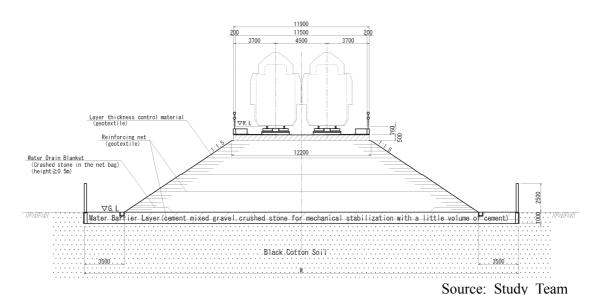


Figure 9.2-8 A standard Basic Cross-section of Reinforced Embankments (Cement-improved Gravelly Soil + Geotextile)

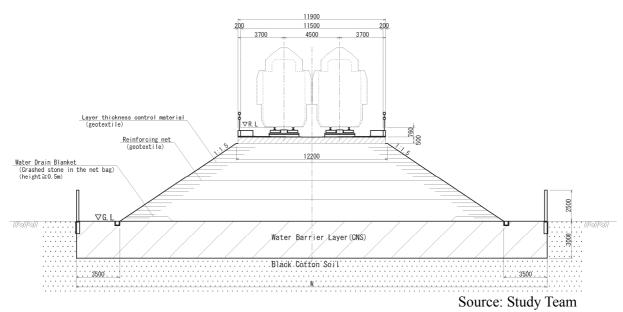


Figure 9.2-9 A standard Basic Cross-section of Reinforced Embankments (CNS Layer)

(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, Nvalue 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.

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 following ①, 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

Gı	Grain		Sieve name (mm)								
Designation	Percentage in weight of the sieve passing grains (%)										
(mm)	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

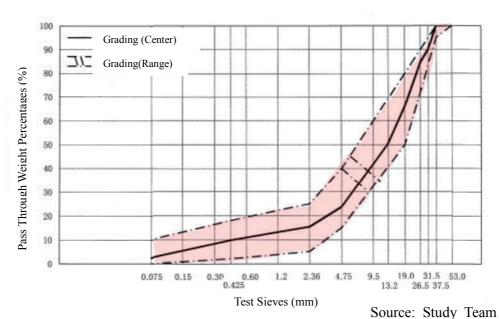


Figure 9.2-10 M-40 Percentage in Weight of the Sieve Passing Grains of the Crushed Stone in a Cement-improved Gravelly Soil Sieving Test

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 measures ①, 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.

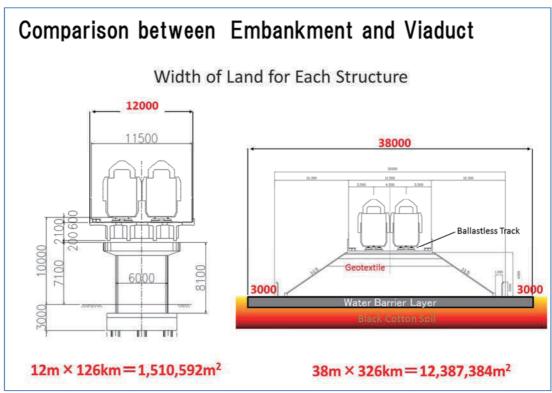


Figure 9.2-11(1) Comparison between Embankment and Viaduct
Source: Study Team

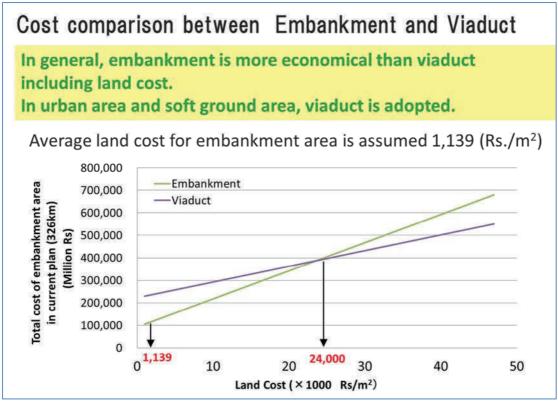


Figure 9.2-11(2) Cost comparison between Embankment and Viaduct
Source: Study Team

(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



Figure 9.2-12 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

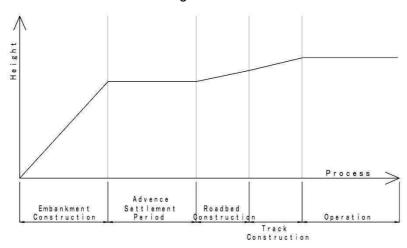


Figure 9.2-13 Process of the Construction Stage

- "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.

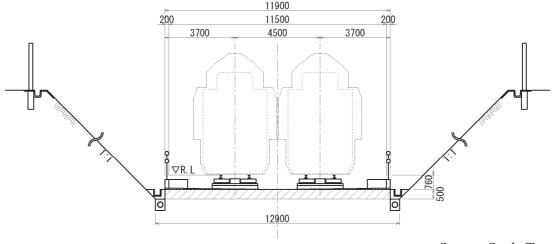
9.2.2 Cut Structure

(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 $\geq 110 \text{ MN/m}^3$ at the subgrade surface.



Source: Study Team

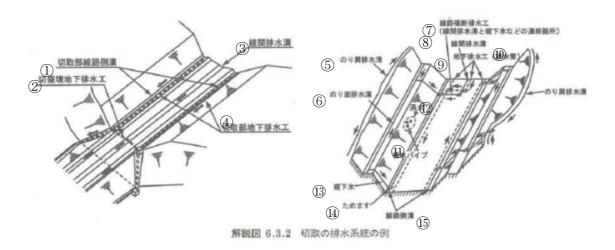
Figure 9.2-14 Standard Cross-section of the Cut for Slab Tracks.

(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.



- 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
- ⑤ Slope drainage work
- 7 Track crossing drainage work
- Soint between underground sewage and drainage between tracks
- 9 Underground drainage work
- 10 Drainage piping
- ① Drainage pipe
- Spring water
- 13 Longitudinal sewage
- (14) Catch basin
- 15 Track side ditch

Source: Study Team

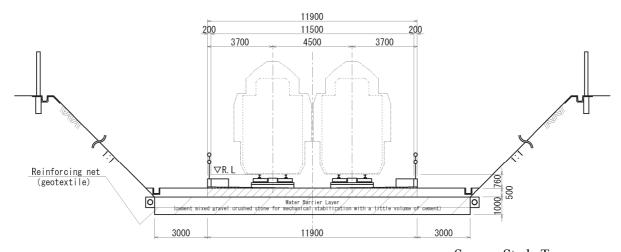
Figure 9.2-15 Drawings of Cut Ditch

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 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

	Tallet and the second of the s						
Box	Туре	Type GL-RL (m) Rea		applic	ation	Quantity (No. of places of application)	
Culvert	H 3.6-4.8×W 10 m	6.0-7.0	Results surveys	of	site	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

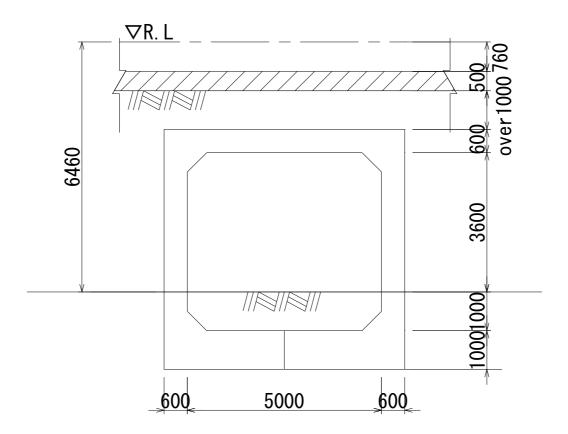
Box Culvert	Dimens	sions	Quantity
Farm road	H 3.6 m	W 5.0 m	939
Small canal	H 1.5 m	W 1.5 m	626

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)

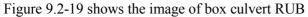




Figure 9.2-19 An Image of Box Culvert RUB

(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	Туре	GL∼RL (m)	Reason of application
Culvert	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)

		Box Curvert	Deligin Tom (milet 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.

Joint Feasibility Study for Mumbai-Ahmedabad High Speed Railway Corridor FINAL REPORT

	PC U-shaped Girder (Kyusyu-Shinkansen)		L = 10 - 60 (m)	1/12.2	Cast - in – place Pre – cast (segmental)	Used only where under clearance is limited
faduct and Bridge	PC Box Girder (Kyushu-Shinkansen)		L = 45 – 60 (m)	1/15.3	Cast - in – place Pre - cast	PC-Box Girder can be applied to various construction methods and has relatively strong rigidity to support HSR.
Table 9.3-1 Main Structure Types for Viaduct and Bridge	PC T-shaped Girder (Kyushu-Shinkansen)		L = 20 - 45 (m)	1/13.9	Cast - in - place Pre – cast	PC-T Girder can be applied to various construction methods and has relatively strong rigidity to support HSR.
Table 9.	RC Girder (Kyushu-Shinkansen)		L = 0 - 20 (m)	1/9.5	Cast - in - place Pre – cast	Construction cost is the lowest but applicable span is shorter.
	Items / Structures (Project referred from)	General Sections	Applicable Span	Span / Girder Height	Applicable Construction Method	Note

(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 SpansIncremental LaunchingCast-in-Place	
Note	Both slab and ballast track can be applicable track can be applicable The connection was at		 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)





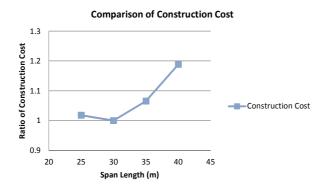


Source: http://www.pcken.or.jp

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:

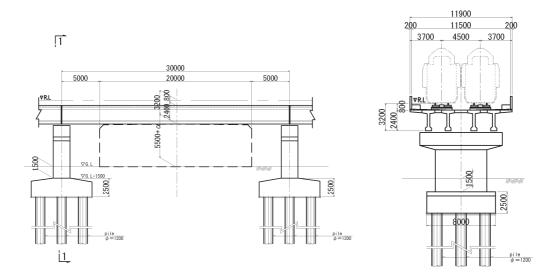
- Four options as L=25(m), 30(m), 35(m), 40(m) are compared,
- These options are compared under the same situation of girder erection method, height of R.L. and soil condition,
- Bridge length for case study is 1050 (m). (L=25m with 42-spans, L=30m with 36-spans, L=35m with 31-spans, and L=40m with 26-spans).

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

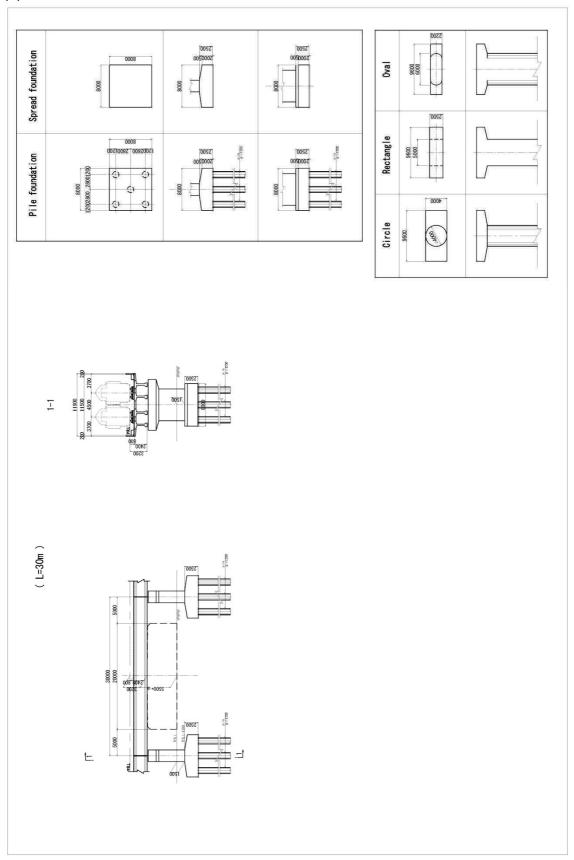


Figure 9.3-5 Drawing for Standard Structure Type of viaduct (2)

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).

Structure Type Side View / Note PC Continuous Bridge of Simple I-shaped Box or Girders PM 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. • Widely used for a River Bridge not only for the Japanese Shinkansen but also Continuous Bridge of PC for the European HSR. Box Girder • 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. 100000 100000 100000 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.

Table 9.4-1 Major Structure Types for River Bridge

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 - 2	Continuous Bridge of Steel Through Truss Girder with Concrete Slab	80000 80000 100000 100000 5400000 80000 100000 100000 800000 100000 100000 100000 800000 100000 100000 100000 800000 100000 100000 100000 100000 100000 100000 100000 100000 100000 100000 1000000	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	1.12	Traveller Crane Method, Track Crane/Bent, Incremental Launching.	Approximately 30 (months) (The schedule may change based on conditions of river)	Less Maintenance (weathering steel with concrete slab)	Seldom (no experience on the through truss girder with concrete slab)	Noise from steel bridge is bigger than the concrete bridge	4
Case - 1 Case - 2	Continuous Bridge of PC – Box Girder using Cantilever Method	360000 360000 57000 82800 B 82000 570000 57000 57000 57000 57000 57000 57000 57000 57000 57000 57000 57000 57000 57000	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	1.00	Cast-in-Place / Cantilever	Approximately 24 (months)	Less Maintenance(concrete bridge)	Popular (many of experiences for railway project)	Less noise impact	
Case	Structure Type	Side and Cross Section View (with Sample Span)	Quantity of Main Materials	Cost	Construction Method	Schedule	Maintenance	Applicability in India	Environmental impact	Evaluation

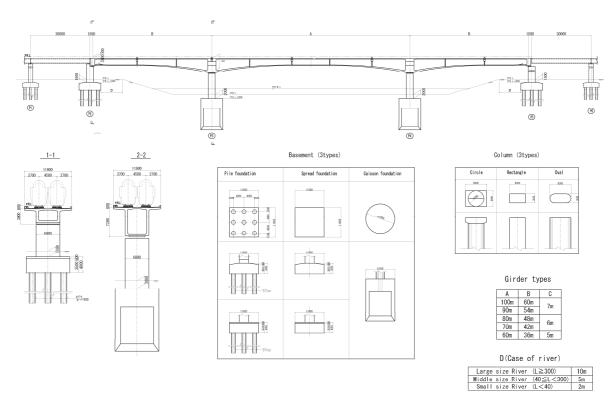


Figure 9.4-3 Drawing of Standard Structure Type for Bridge, Continuous Bridge of PC Box Girder (Cantilever Method).

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

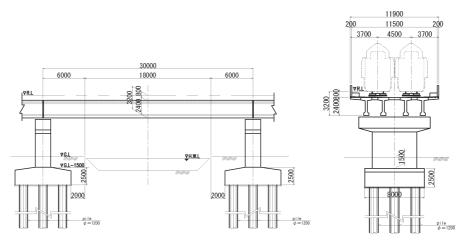


Figure 9.4-7 Bridge (PC I-shaped Girder) (L=30m)

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.

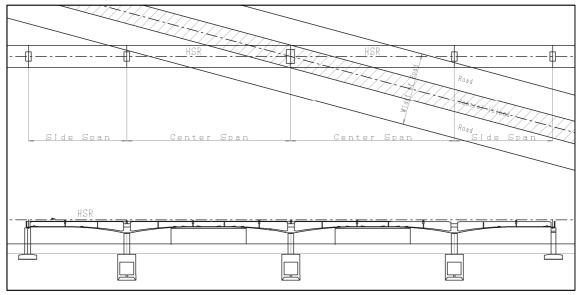


Figure 9.4-8 Bridge (PC-girder (Cantilever erection method))

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.

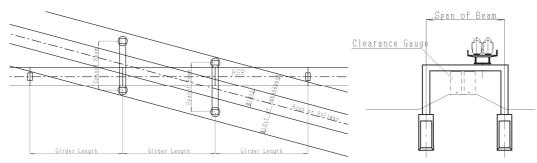


Figure 9.4-9 Bridge (Gantry Type Pier)

Source: Study Team

(3) GAD for Standard Structure Spread foundation Oval Rectangle Pile foundation Circle

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

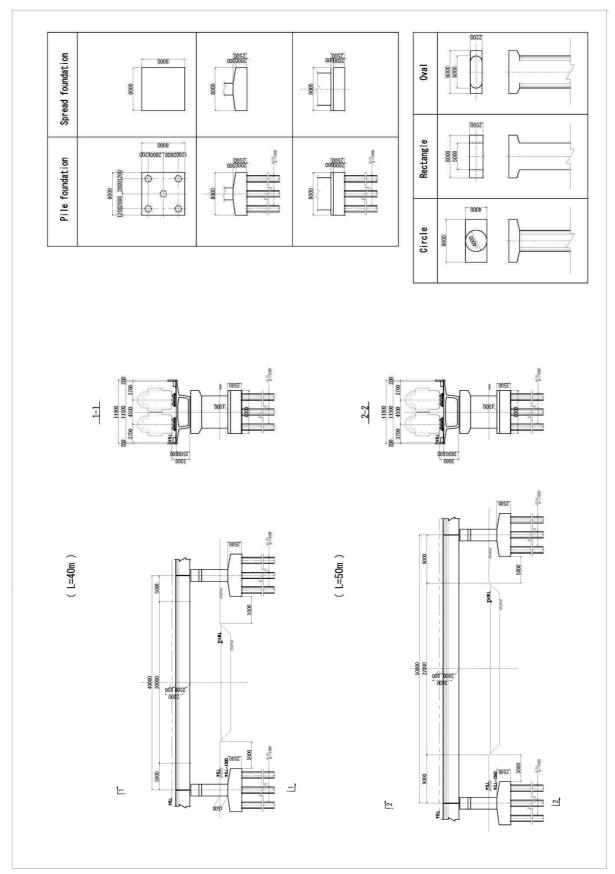


Figure 9.4-11 Drawing of Standard Structure Type for Bridge, Simple-girder, 1-span(2)

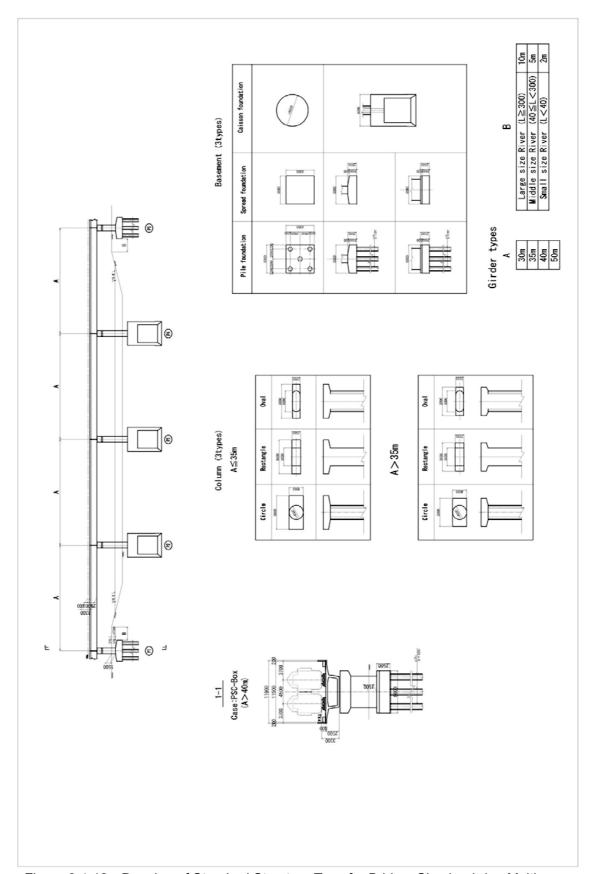


Figure 9.4-12 Drawing of Standard Structure Type for Bridge, Simple-girder, Multi-span

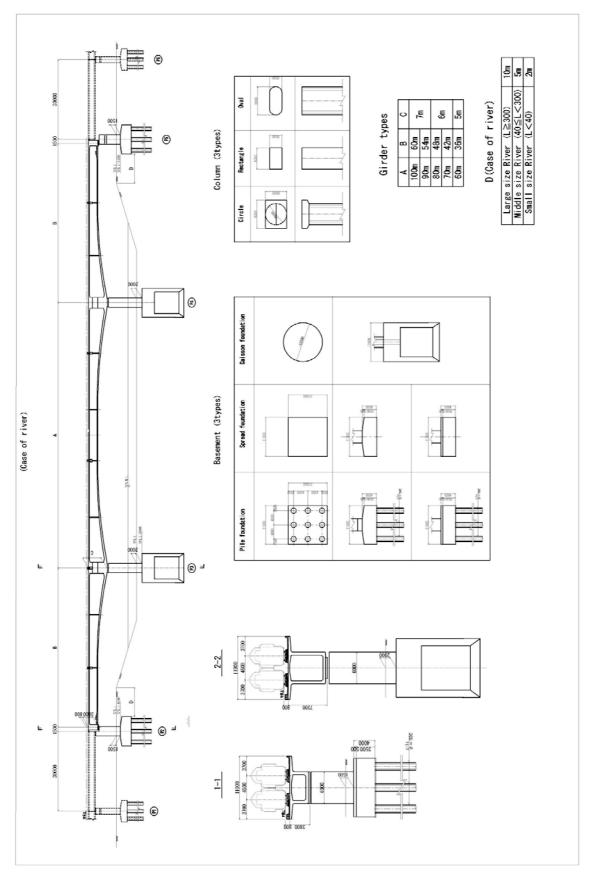


Figure 9.4-13 Drawing of Standard Structure Type for Bridge, Cantilever erection method

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	Mumbai area and Thane Creek
2	5.77	13.62	7.85	Undersea	East side of Thane Creek
3	13.62	21.10	7.48	tunnel	Navi Mumbai area
4	52.50	53.30	0.80		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	Mountain	Saravali (Between Virar and Boisar)
9	125.45	125.90	0.45		Gaurwadi (Between Boisar and Vapi)
10	127.70	128.25	0.55	tunnel	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.

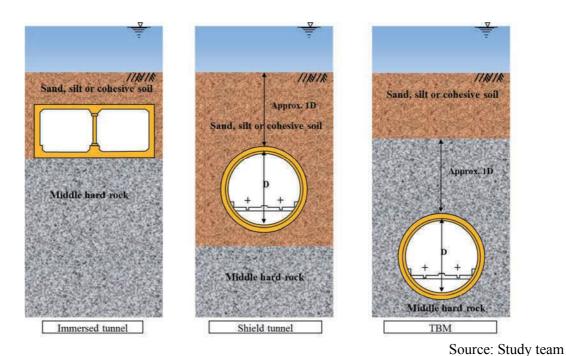


Figure 9.5-4 Relationship between Tunnel Types and Topography at Seabed

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.

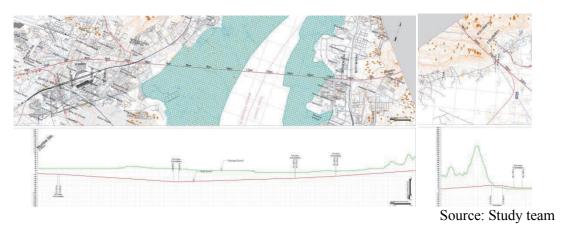
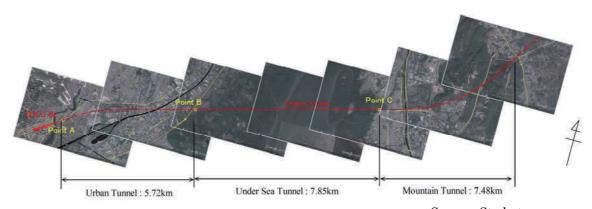


Figure 9.5-5 Plane and Profile Drawing

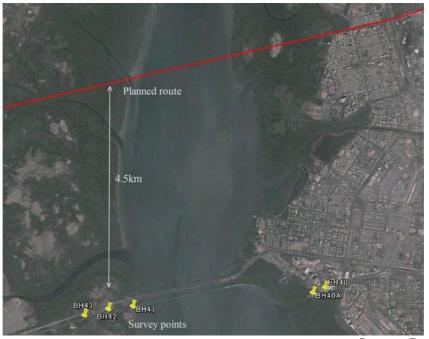


Source: Study team

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

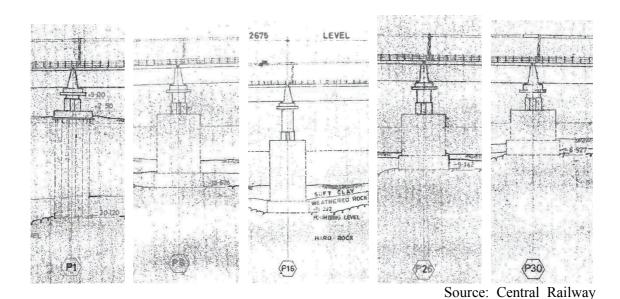


Figure 9.5-8 General (Side) View of Vashi Bridge

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.

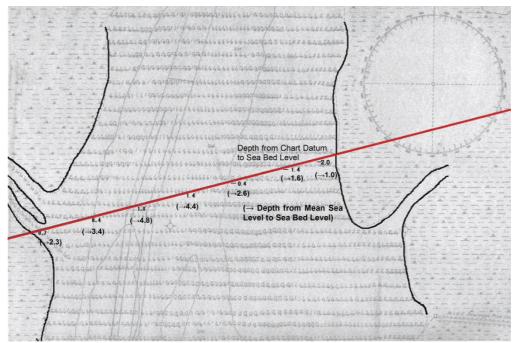
Table 9.5-2 General View of Geological Date

	Elevation of	Thickness of	Thickness of clay	Water		
	Rock	weathered basalt	layer(m)	depth(m)		
	Layer(m)	rock layer(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 9^{th} Feb to 8^{th} Mar and 16^{th} Mar to 20^{th} 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 $31 \rightarrow Ground$ class DII Bed rock layer: RQD = 41 to $48 \rightarrow Ground$ 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

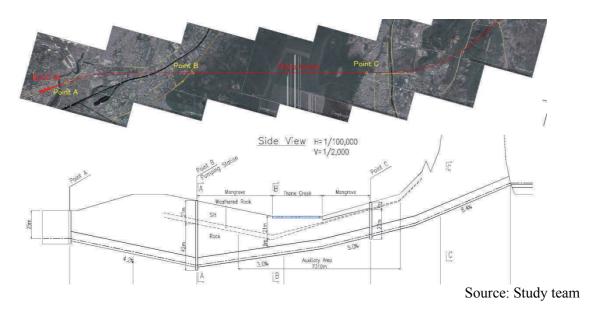
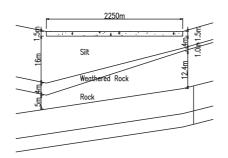


Figure 9.5-10 Topography, Geology and Water Depth Setting for Thane Creek Undersea Tunnel



Ground Assumptions	
Silt	N=8
Weathered Rock	DI
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.

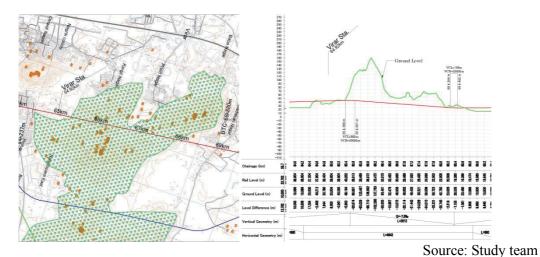
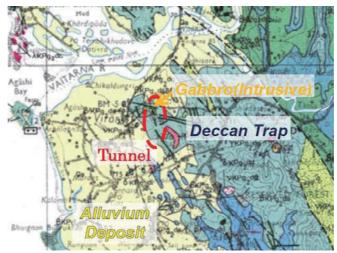


Figure 9.5-12 Outline of Topography (Thane-Virar)

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

- 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.

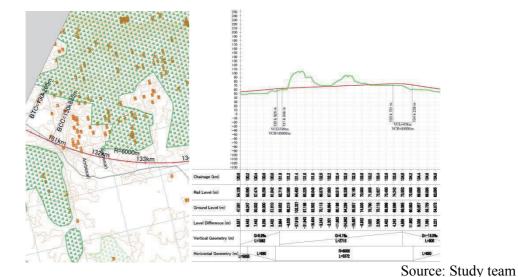


Figure 9.5-14 Outline of Topography (Boisal-Vapi)

• 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.

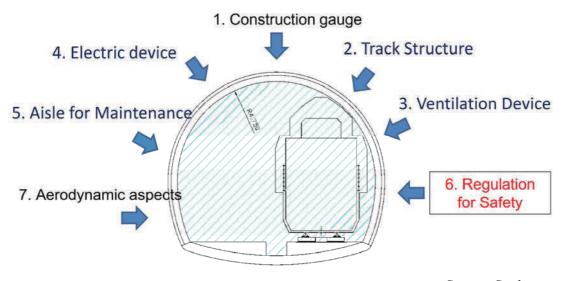
The tunnel profiles are broadly divided into the following two:

- 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.

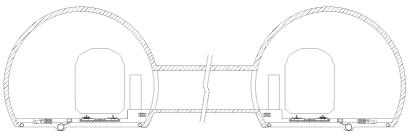
3) Single-bore double track tunnel and twin-bore single track tunnel

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.



Source: Study team

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



55 m²+55 m²+connectin tunnel $\alpha = 110 + \alpha$ m²

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 m².

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

Ground facilities

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	Installation of leakage coaxial cables
facilities	• Installation of wayside telephones at equipment/materials pits at
	intervals of 500 m (with location indicating lamps normally on)
Fire extinguishing	Installation of 10 to 20 fire extinguishers at each
facilities	equipment/materials pit
Illumination	• Installation of illuminators on both sides at intervals of 15 to 20 m
facilities	
Distance displays	Installation of information panels to indicate the distance to tunnel
	exits on tunnel walls at intervals of 100 m
Power supply	Introduction of heat resisting trolley and messenger wires into the
facilities	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	• Installation of train protection switches on the maintenance pass side
equipment	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	Cars are extremely fire-resistant as incombustible or fire-resistant		
structure	materials and those applied with equivalent treatment are used for		
	outside plates, linings, seats and curtains.		
Fire extinguishing	Passenger cabins are all installed with two to four reinforcement liquid		
equipment	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 m², (homogeneous sound rock ground: concrete bed, other part invert)

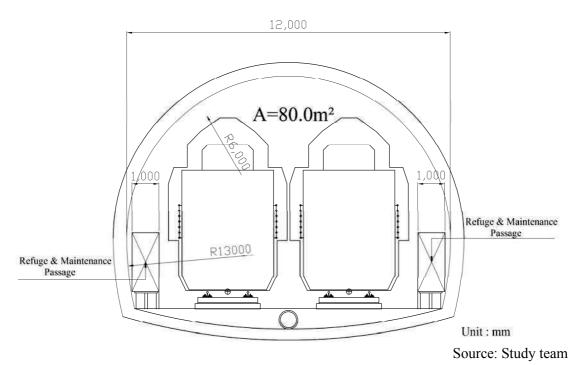


Figure 9.5-18 NATM Cross-Section for Double Tracks (A=80 m²)

NATM cross-section for single track in parallel
 Maintenance/evacuation passage 1.0 m on one side, bore cross-sectional area 46m², (homogeneous sound rock ground: concrete bed, other part invert)

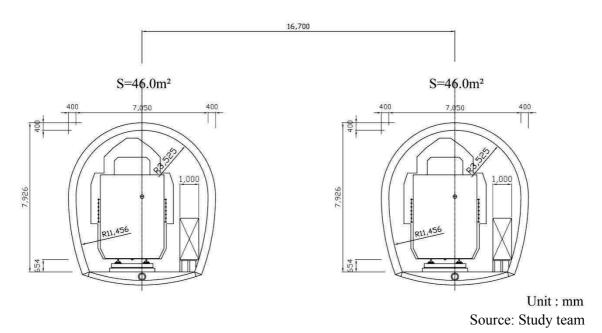
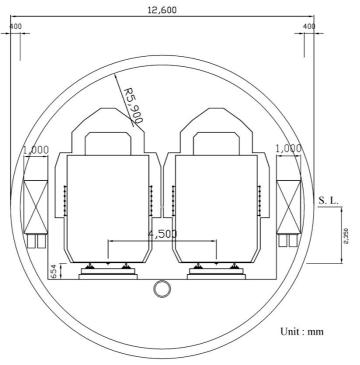


Figure 9.5-19 NATM Cross-Section for Single Track in Parallel (A=46+46 m²)

• TBM for double tracks
Distance between track centers 4.5 m, maintenance/evacuation passage 1.0 m on both sides,
bore cross-sectional area 109m², (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

Source: Study team

cross-sectional area 50m², (homogeneous sound rock ground: concrete bed, other part invert)

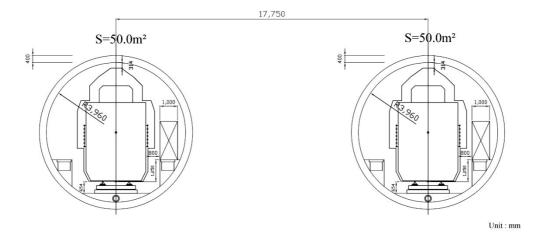


Figure 9.5-21 TBM for Single Track in Parallel (A=50+50m²)

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.

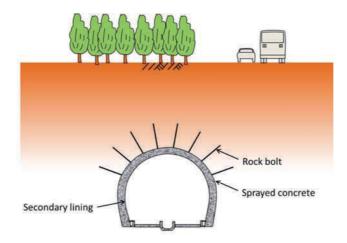
The following are the advantages/disadvantages of the tunneling methods:

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.

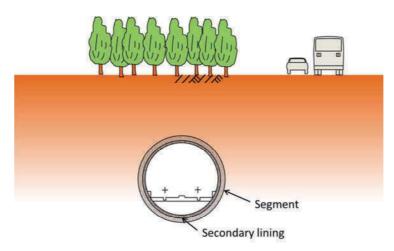
The following are the advantages/disadvantages of the tunneling methods:

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

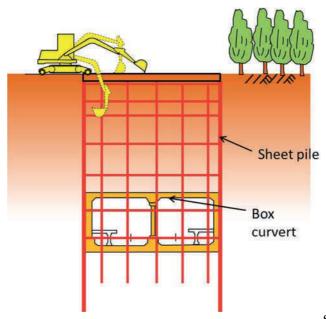
This is a method to excavate the ground from the surface to construct structures in the tunnel and refill afterword, which is used to excavate the portion near the ground surface or to construct stations and other large-scale facilities. The following are the advantages and disadvantages of this construction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

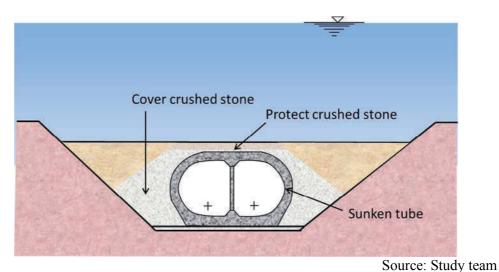


Figure 9.5-24 Conceptual Drawing for Sunken Tube Method

(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

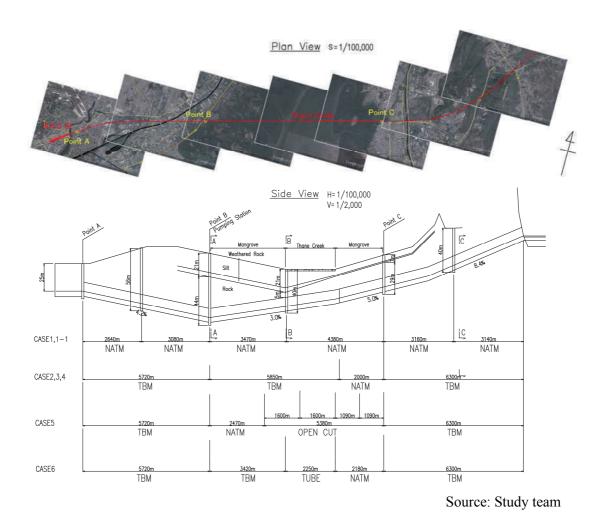


Figure 9.5-25 Classification of the Construction Method for Each Case

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.

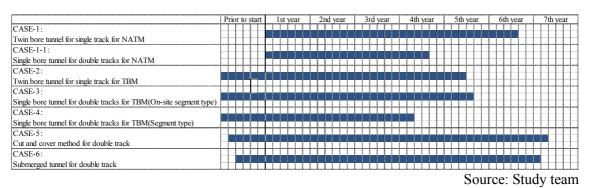


Figure 9.5-26 Comparison of Construction Period for Each Case

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.

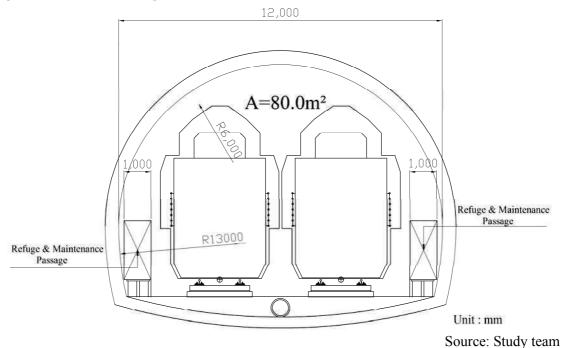


Figure 9.5-27 Basic Cross Section Drawing for NATM

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	Mumbai area and Thane Creek
2	5.77	13.62	7.85	Undersea	East side of Thane Creek
3	13.62	21.10	7.48	tunnel	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.

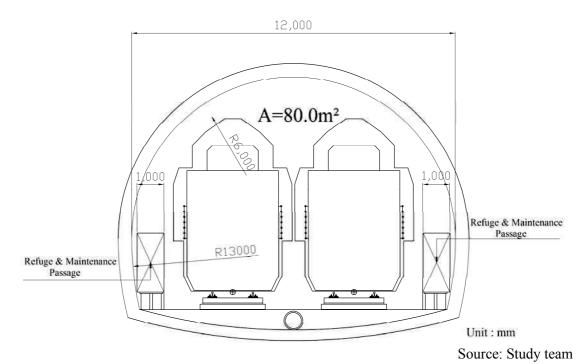


Figure 9.5-28 Basic Cross Section Drawing for NATM

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		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	Mountain	Saravali (Between Virar and Boisar)
9	125.45	125.90	0.45	tunnel	Gaurwadi (Between Boisar and Vapi)
10	127.70	128.25	0.55	tuiniei	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

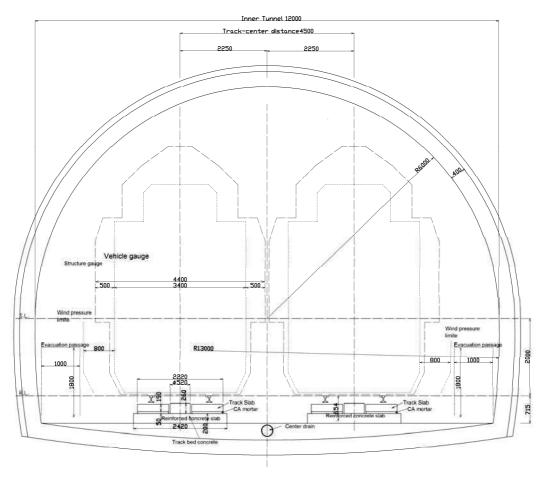


Figure 9.5-29 GAD for NATM Cross Section

9.6 Station

9.6.1 Station Facilities

(1) Station Facilities

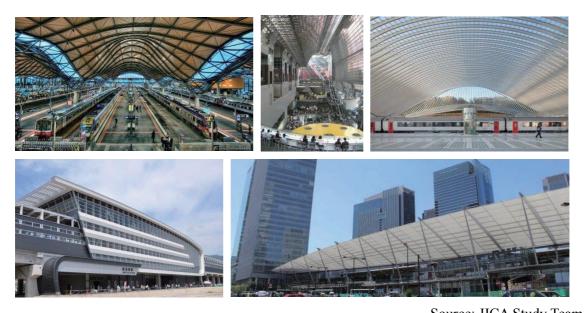
HSR stations will become the gateway of the region. The principals of station planning are described in this Chapter 9.6.

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

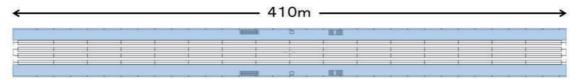
The facilities listed above will be designed under the engagement of universal design which is nowadays the international standards for India HSR operation. The universal design basic policies for the HSR stations are presented below.

- 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.

 $5m \text{ extra} + 25m \times 16 \text{ trains} + 5m \text{ extra} = 410m$



Source: JICA Study Team

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



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.

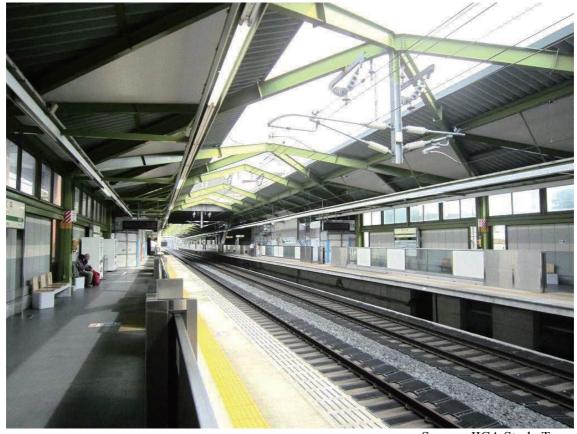
(1) Placing the essential station facilities for HSR operation in an appropriate position

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

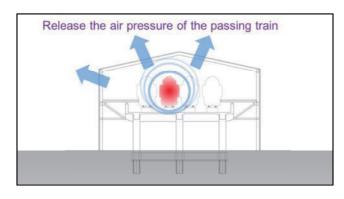
a) Windbreak screen

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



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.





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

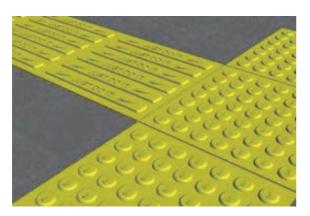
e) Universal Design / Lifts and Escalator

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.



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.

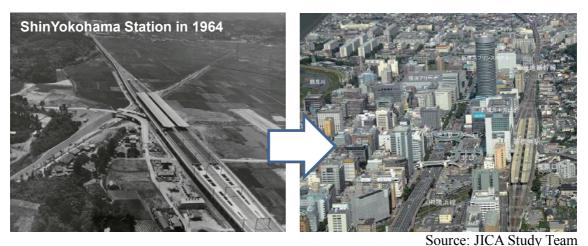


Figure 9.6-13 Development around Shin-Yokohama Station during these 50 years.

(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

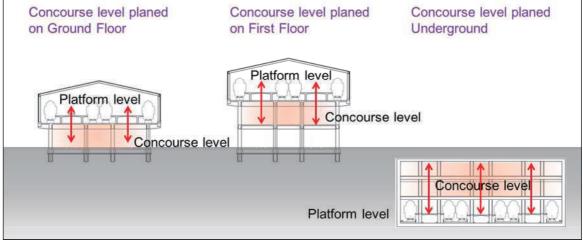
Reflecting the philosophical Station concept written above, the station layout will be designed as follows,

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	

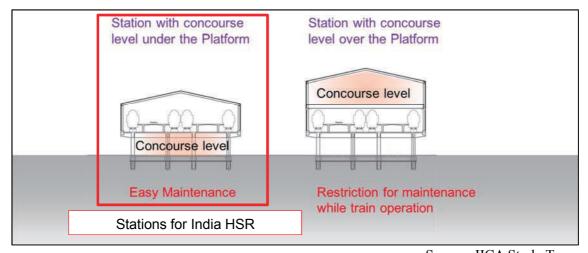
The Concourse level on the first floor will be connected to the ground floor with stairs, Escalators and Elevators, to approach to the station squares. In all stations, the concourse level is connected to the platform level from the paid concourse with stairs and Escalators as well as Elevators.



Source: JICA Study Team

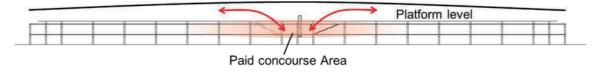
Figure 9.6-14 Difference of Concourse Level

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.



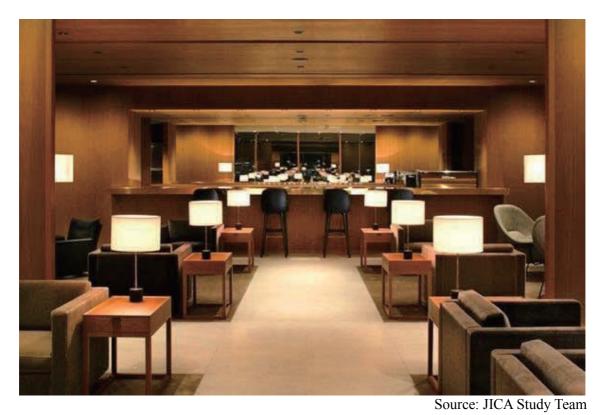
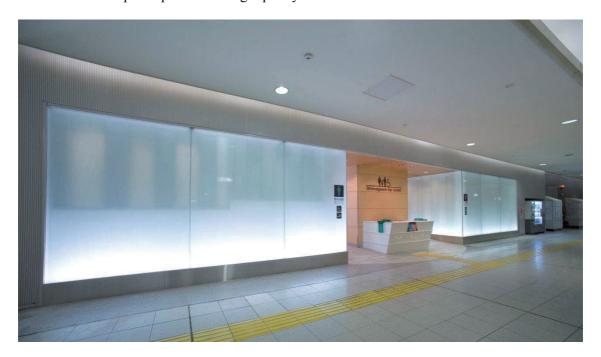


Figure 9.6-18 Image of Waiting Room for Business Class Passengers



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.



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





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.



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.

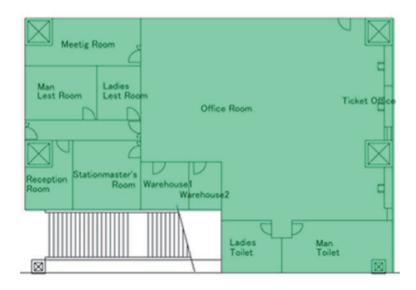


Figure 9.6-26 Image of Station Office for Small HSR Station

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.



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.

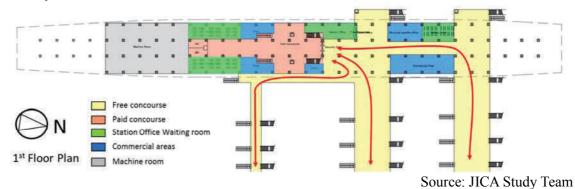


Figure 9.6-29 Connection to the Existing Railway Station (Vadodara Station)

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



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.



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







Figure 9.6-37 Examples of Beautiful Stations around the World

9.6.3 Station Structure

(1) Standard Structure Type for Elevated Stations

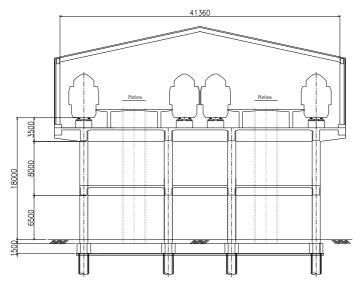
Structure types for elevated stations are categorized into two types based on the platform type of each station which could be reconsidered after following stage survey. Table 9.6-1 below shows the structure types of elevated station.

rable of a reduction rypes of Elevation 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	

Table 9.6-1 Structure Types of Elevated Station

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.

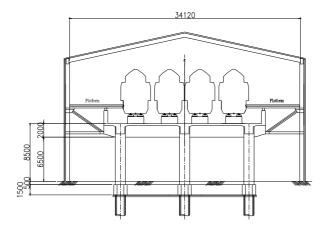


Source: JICA Study Team

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

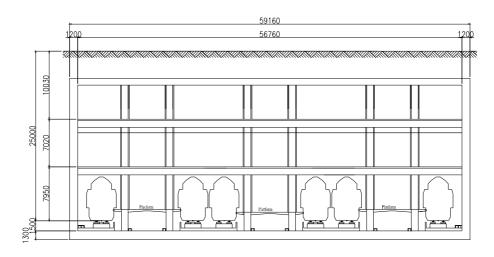


Figure 9.6-40 Typical Section of Station Structure (Underground Station)

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 5000m² as a minimum demanded area for the HSR stations in India.

Table 9.6-2 Formula of Area Calculation of Station Square

I Innar limit	$A = 0.271 \times B + 11.22 \sqrt{B} (B \le 30,000)$
Upper limit	$A = 58.90 \text{ x } \sqrt{B} \text{ (B } \ge 30,000)$
Normal	$A = 0.238 \times B + 9.85 \sqrt{B} (B \le 30,000)$
	$A = 51.65 \times \sqrt{B} (B \ge 30,000)$
Lower limit	$A = 0.217 \times B + 8.99 \sqrt{B} (B \le 30,000)$
	$A = 47.16 \times \sqrt{B} (B \ge 30,000)$

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)

- \triangleright Area of Station Square is rounded up to the nearest 1,000 m².
- 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.



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:

$$A \times 1/2 \times B \times C = D$$

- 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
$$30 \text{ m}^2/\text{car}^* = \text{E}$$

- *: Required parking space per a car (based on the manual for design and implementation of station square in Japan)
- E: Required parking area (m²)

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.

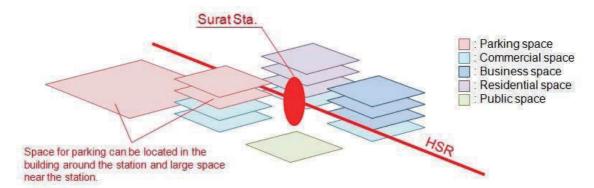


Figure 9.6-43 Image of Parking Space Distribution at Surat Station

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

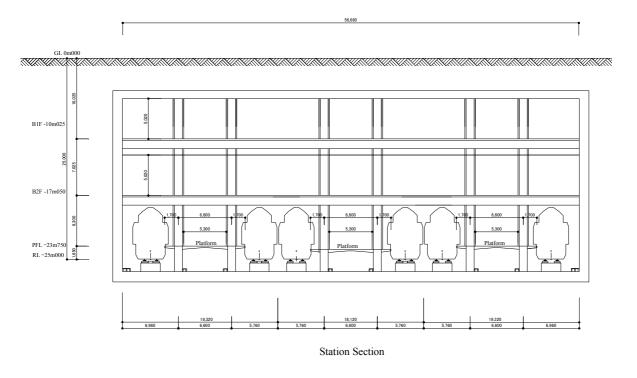
9.6.6 Station and Station Square Plan

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

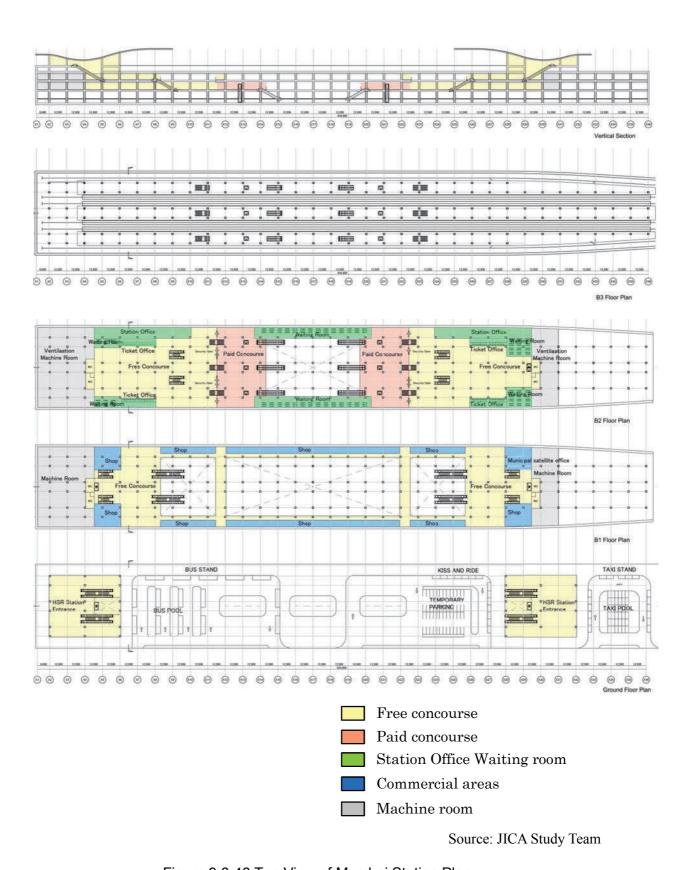


Figure 9.6-46 Top View of Mumbai Station Plan

(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.

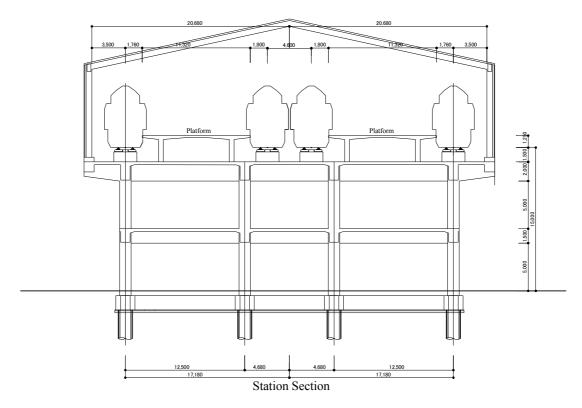


Figure 9.6-47 Cross-sectional View of Thane Station

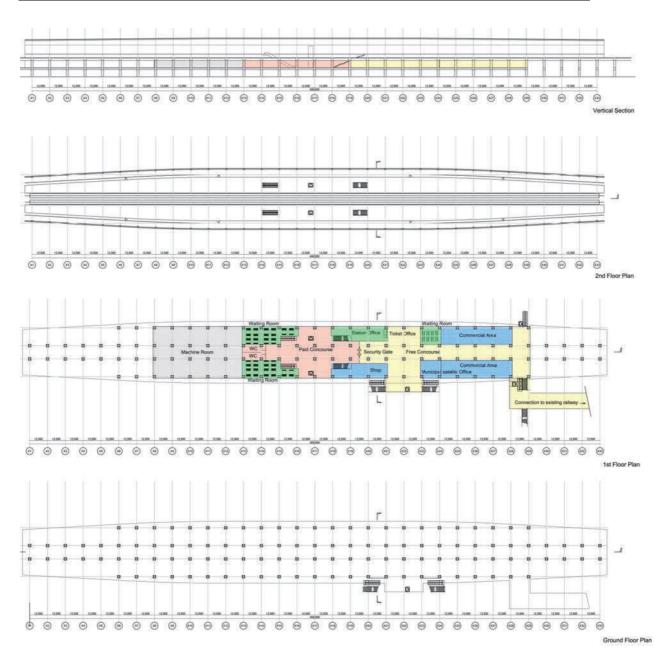
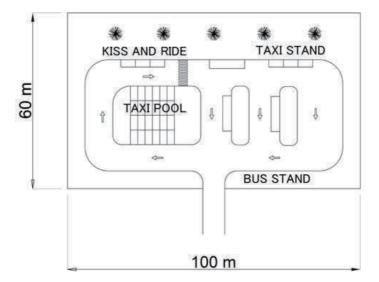


Figure 9.6-48 Top View of Thane Station Plan

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





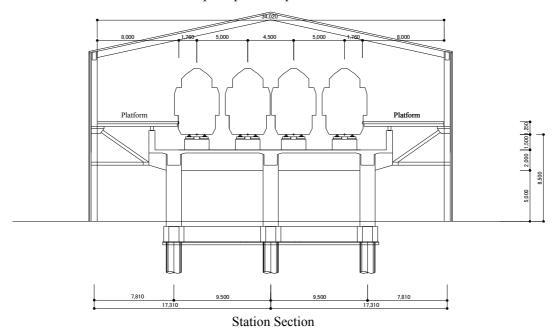
^{*} The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

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

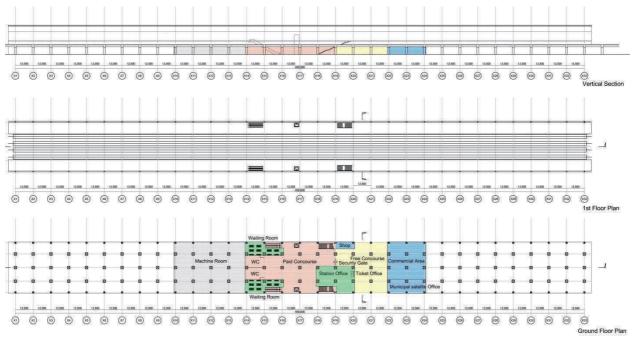
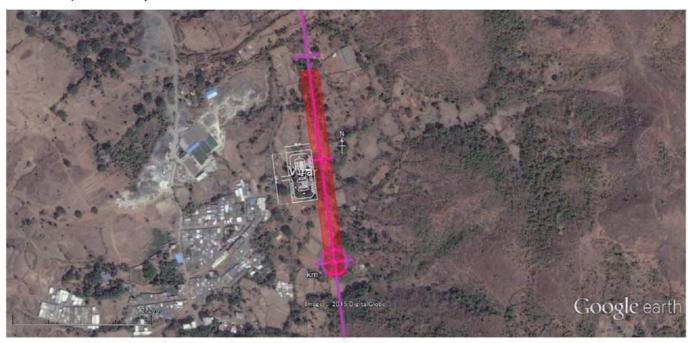
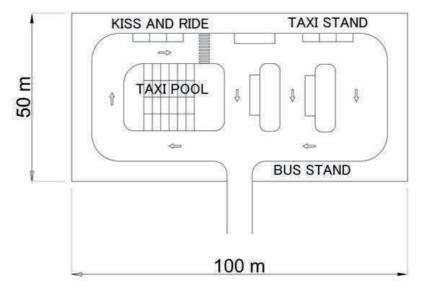


Figure 9.6-51 Top View of Virar Station Plan





* 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.

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.

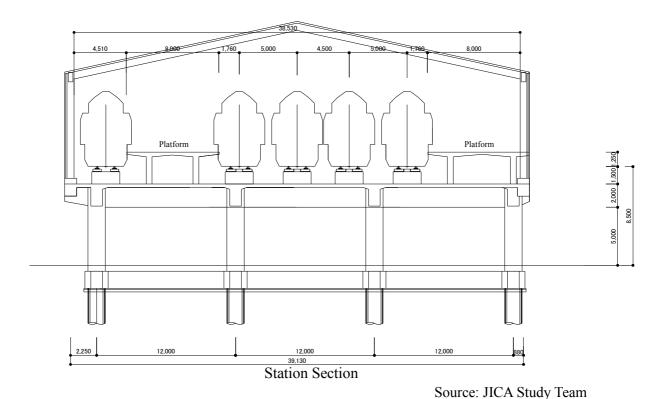


Figure 9.6-53 Cross-sectional View of Boisar Station

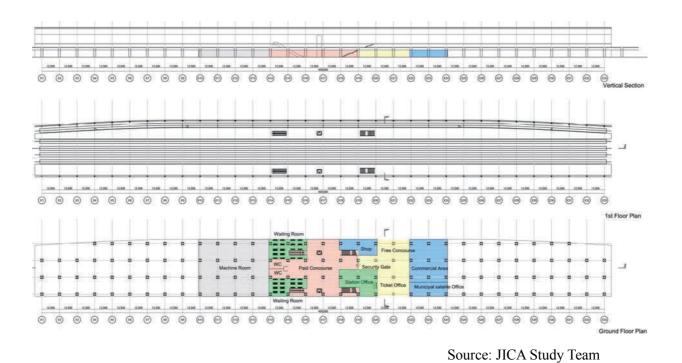
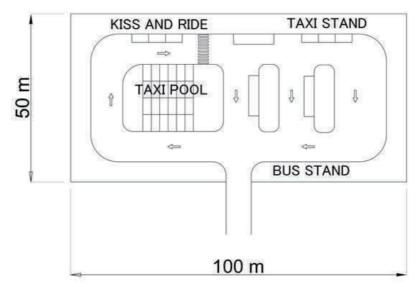


Figure 9.6-54 Top View of Boisar Station Plan





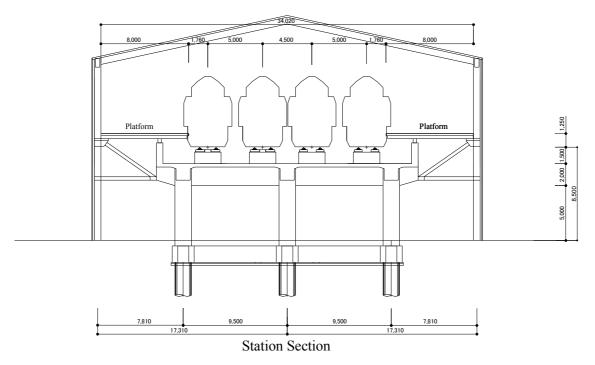
* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

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

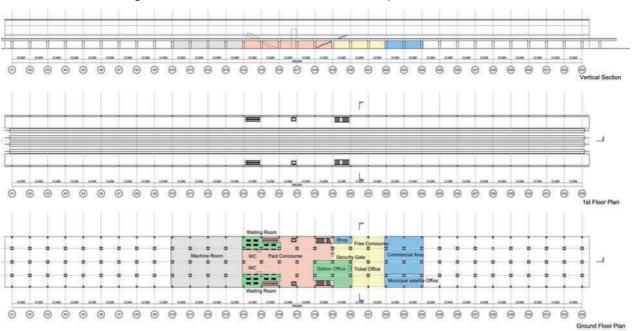
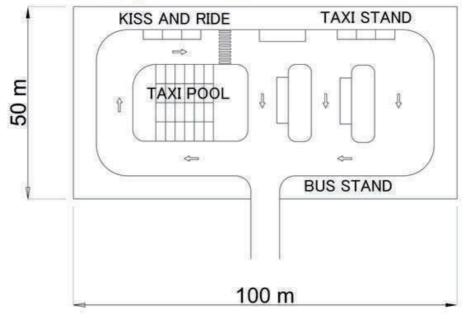


Figure 9.6-57 Top View of Vapi Station Plan





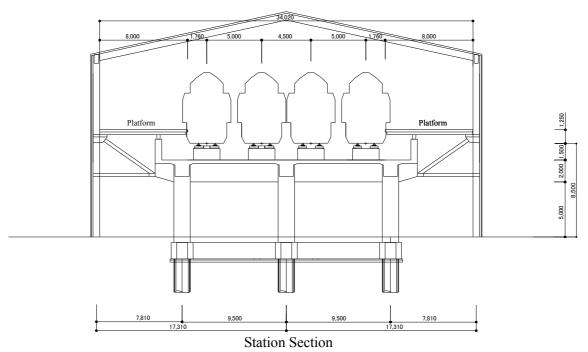
* The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

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

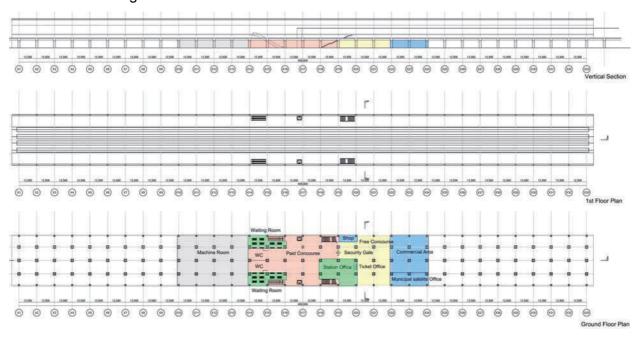
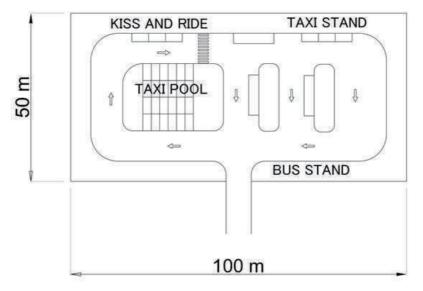


Figure 9.6-60 Top View of Bilimora Station Plan





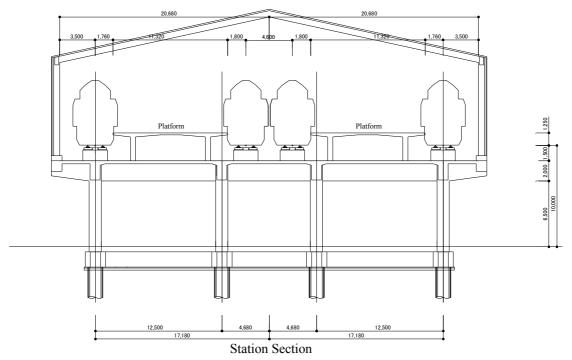
^{*} The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

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.



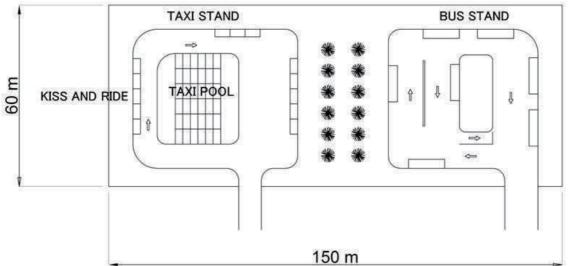
Source: JICA Study Team

2nd Floor Plan

Figure 9.6-62 Cross-sectional View of Surat Station

Figure 9.6-63 Top View of Surat Station Plan





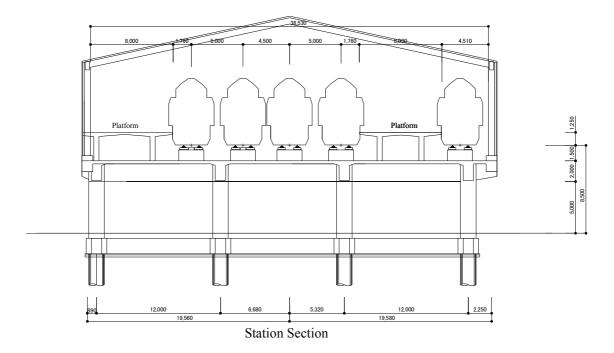
^{*} The minimum required area for station square based on Japanese experience is proposed here but the business and commercial development of station area in future and facility for connectivity with metro and BRT service should be discussed with local governments and municipalities and planned.

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.



Source: JICA Study Team Figure 9.6-65 Cross-sectional View of Bharuch Station

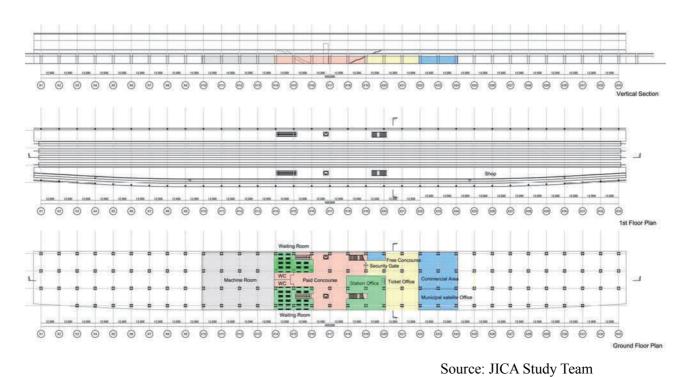
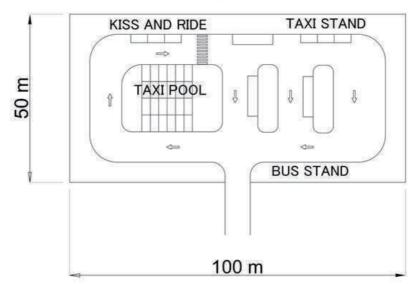


Figure 9.6-66 Top View of Bharuch Station Plan





* 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.

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.

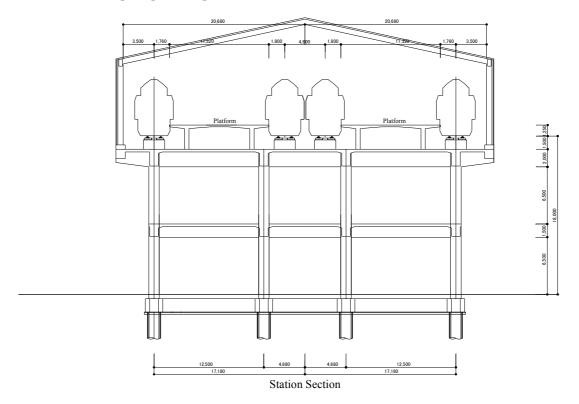


Figure 9.6-68 Cross-sectional View of Vadodara Station

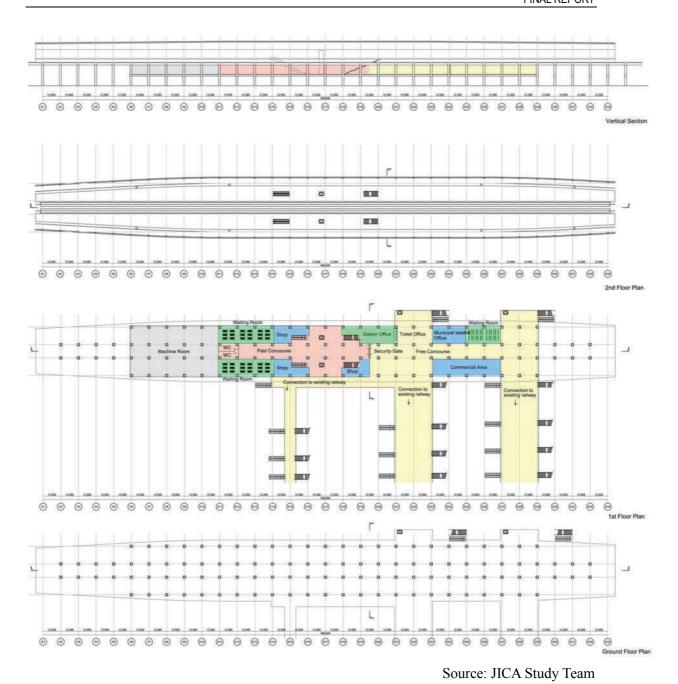
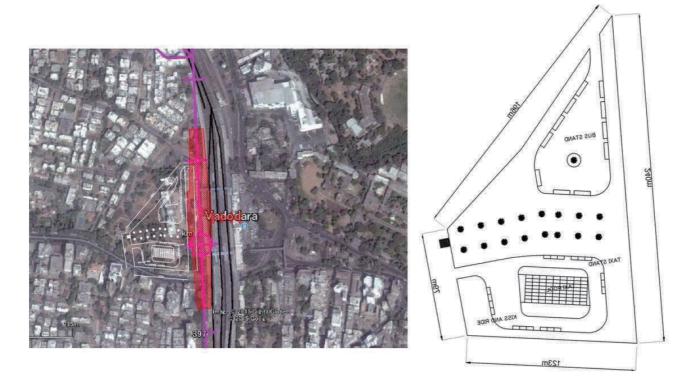


Figure 9.6-69 Top View of Vadodara Station Plan

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.

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.

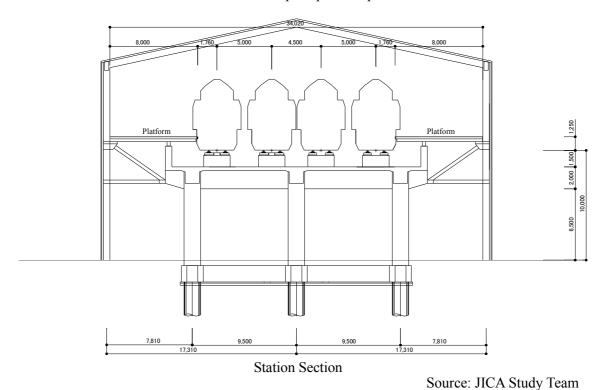


Figure 9.6-71 Cross-sectional View of Anand/Nadiad Station

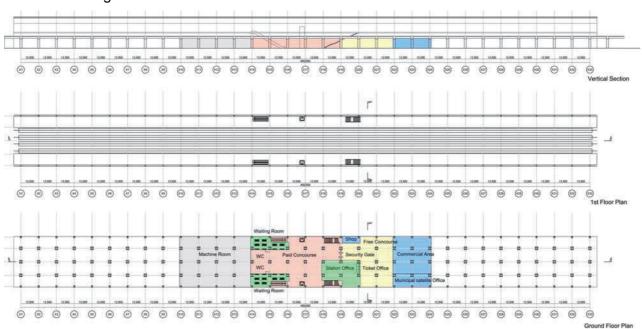
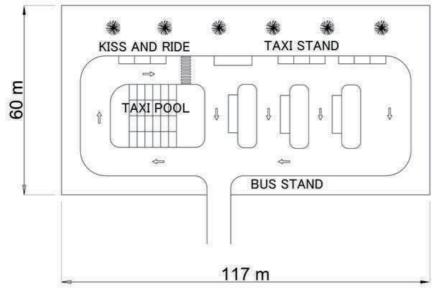


Figure 9.6-72 Top View of Anand/Nadiad Station Plan





^{*} 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.

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.

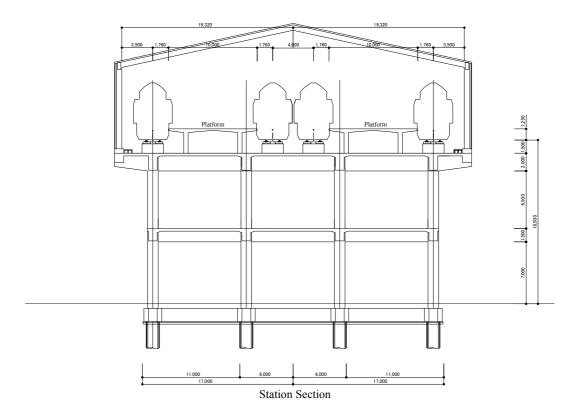


Figure 9.6-74 Cross-sectional View of Ahmedabad Station

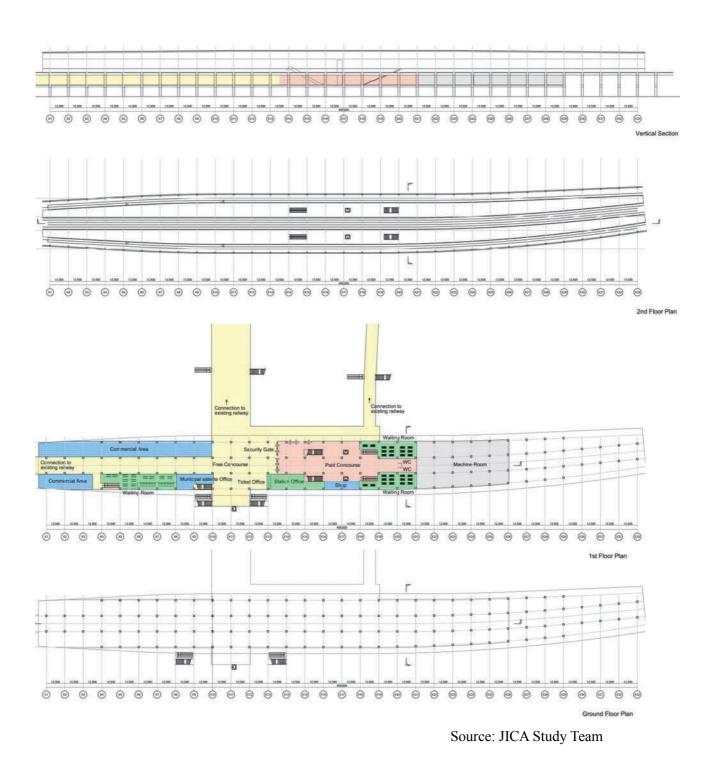
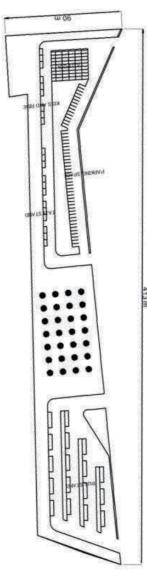


Figure 9.6-75 Top View of Ahmedabad Station Plan

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.

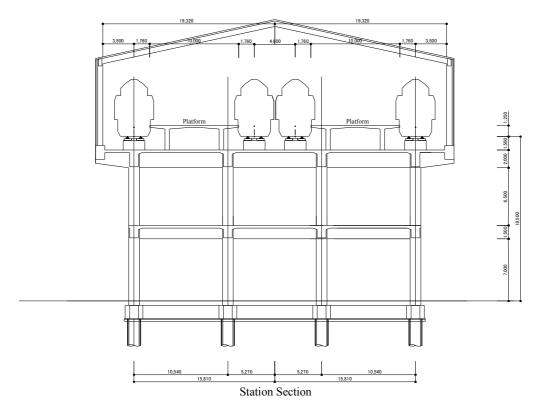
Source: JICA Study Team

Figure 9.6-76 Top View of Ahmedabad Station Square

(12) Sabarmati

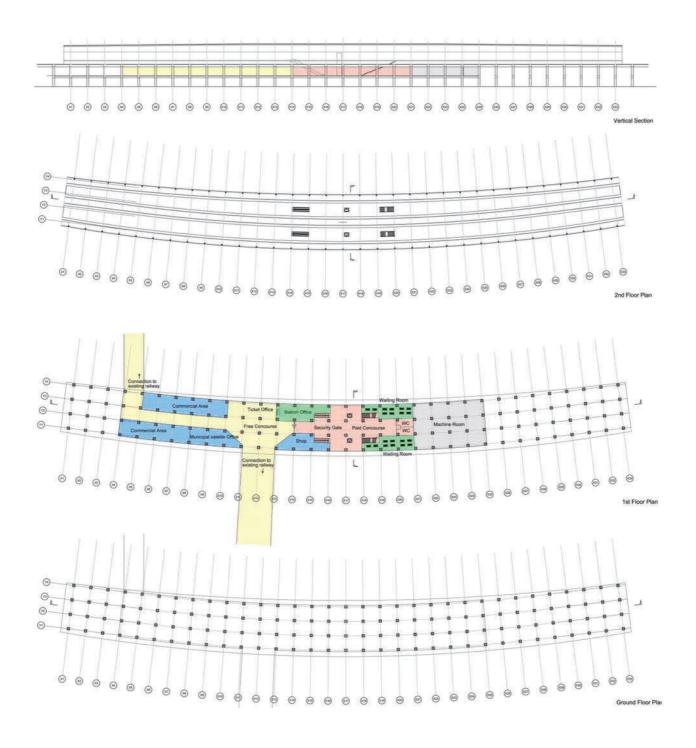
1) Station Building

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.



Source: JICA Study Team

Figure 9.6-77 Cross-sectional View of Sabarmati Station

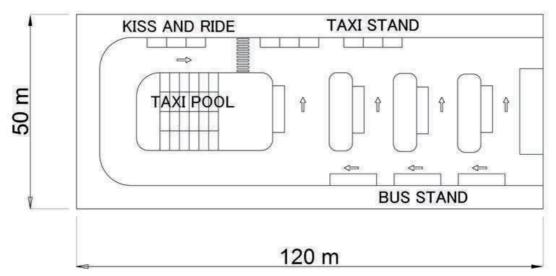


Source: JICA Study Team

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

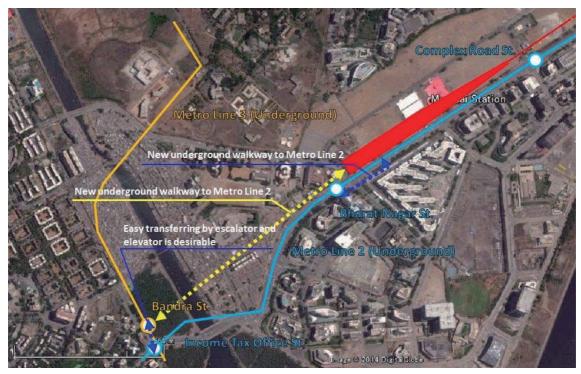
Mumbai is the largest city in India and the center of its economic. Proposed HSR station locates in the center of BKC area which is one of CBDs in Mumbai and lots of major companies operatesaround the station and the stations of planned Mumbai metro also are located near HSR station.

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.



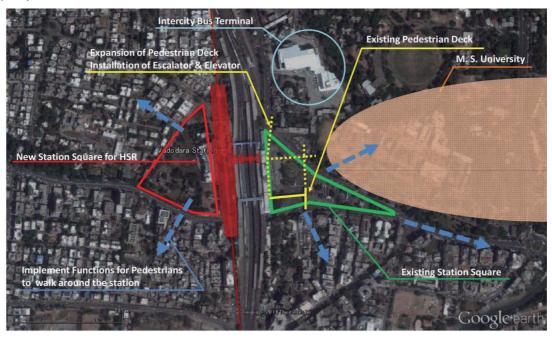
Source: Compiled with Google Earth by Study Team

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	Undergroun d	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.

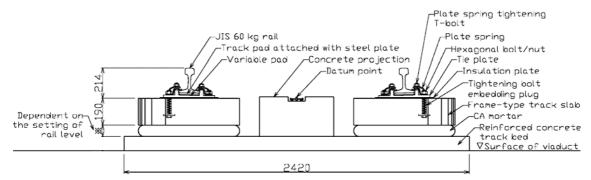


Figure 9.7-1 Standard Cross-section of the Tracks in Viaduct/Bridge Sections

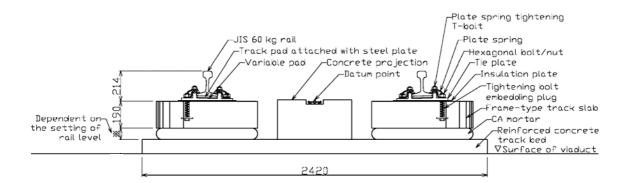


Figure 9.7-2 Standard Cross-Section of the Tracks in Embankment Section

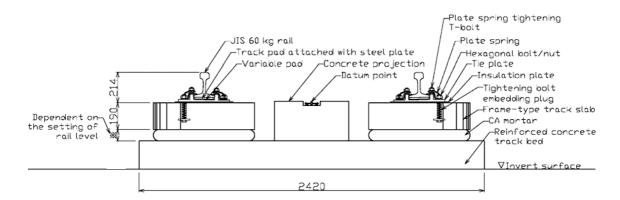


Figure 9.7-3 Standard Cross-Section of the Tracks in Tunnel Sections

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.

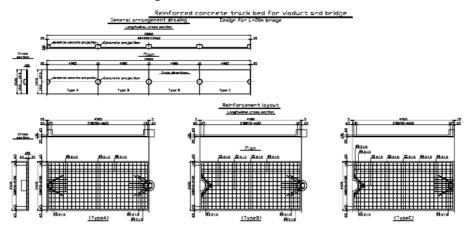


Figure 9.7-4 Reinforced Concrete Track Bed (Viaduct/Bridge Sections)

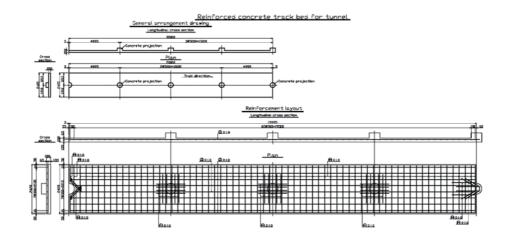


Figure 9.7-5 Reinforced Concrete Track bed (Tunnel Section)

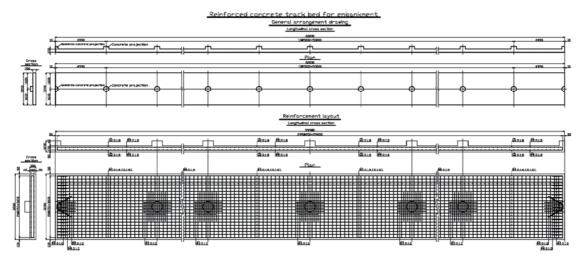


Figure 9.7-6 Reinforced Concrete Track Bed (Embankment Section)



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.

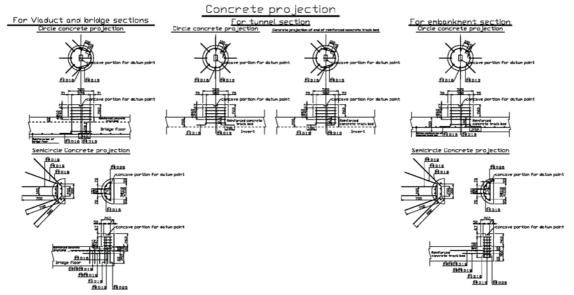


Figure 9.7-8 Drawings of Concrete Projection



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.

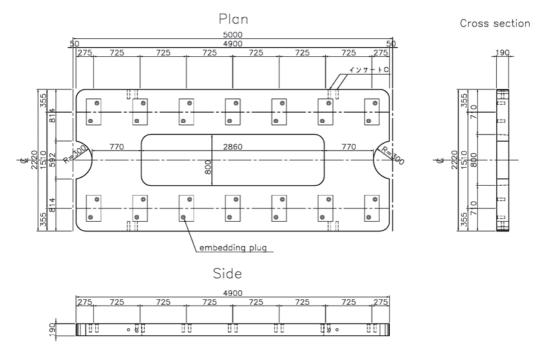


Figure 9.7-11 Drawing of the Frame-type Track Slab

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.

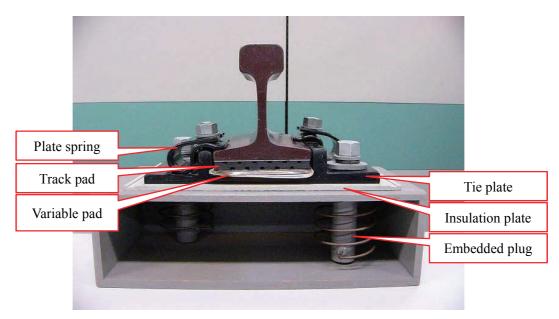
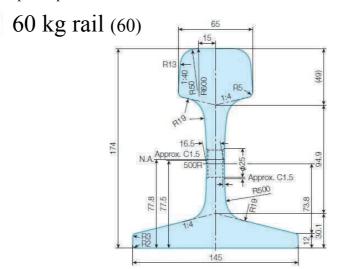


Figure 9.7-12 Direct Fixing Type 8 Fastener

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.

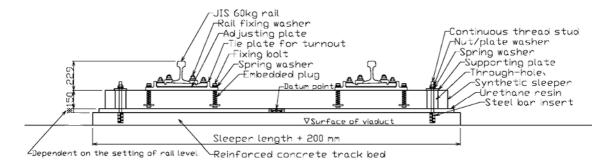


Figure 9.7-15 Standard Cross-section of the Track Structures at Turnouts in Viaduct/Bridge sections.

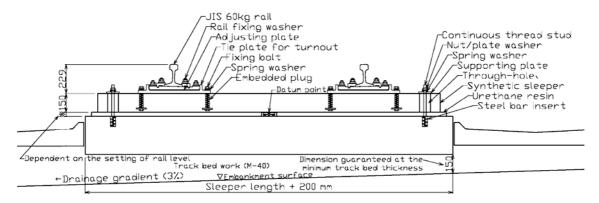


Figure 9.7-16 Standard Cross-section of the Track Structure at Turnouts in Embankment Sections.

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.

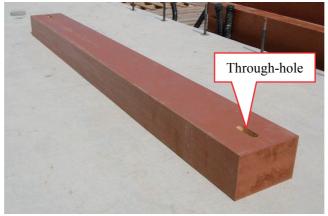


Figure 9.7-18 Synthetic Sleeper

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.

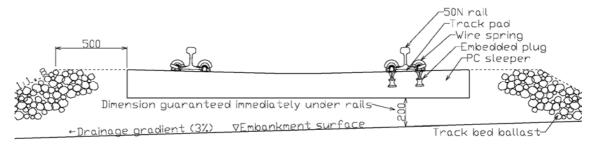


Figure 9.7-20 Standard Track Cross-section at Rolling Stock Depot.

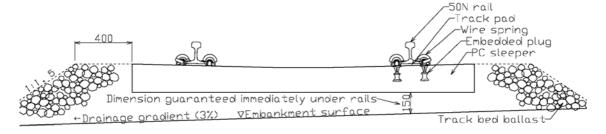


Figure 9.7-21 Standard Track Cross-section at Maintenance Depot.

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.

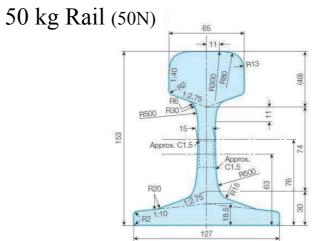


Figure 9.7-22 Cross-section of 50N Rail (Source: Nippon Steel & Sumitomo Metal Corporation)

(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.

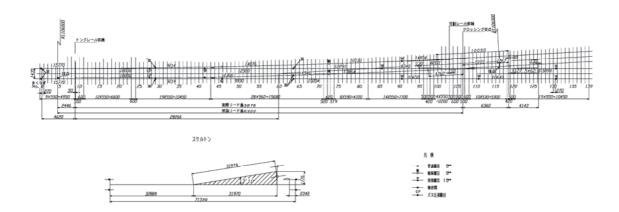


Figure 9.7-23 Drawing of Simple Turnout T-No.18

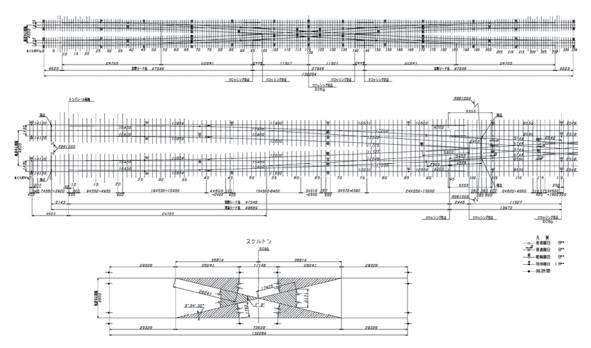


Figure 9.7-24 Drawing of Scissors Crossing Turnout SC-No.16.



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	Fotal 8					85		

Table 9.7-2 List of the Quantities of Mainline Turnouts

(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

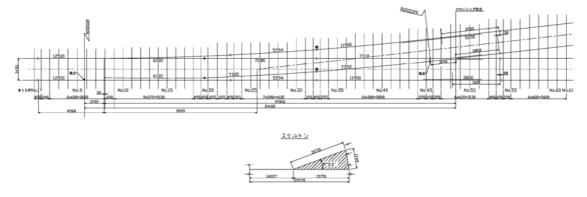


Figure 9.7-29 Drawing of simple turnout T-No.9

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.

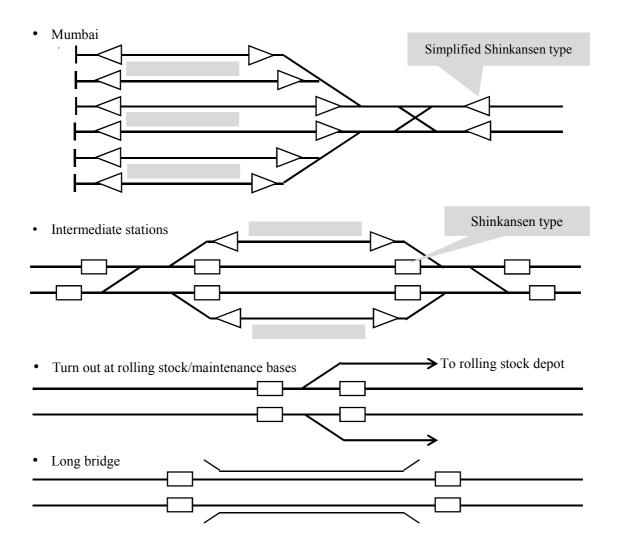


Figure 9.7-30 A Schematic Presentation of the Locations of Expansion Joints

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.

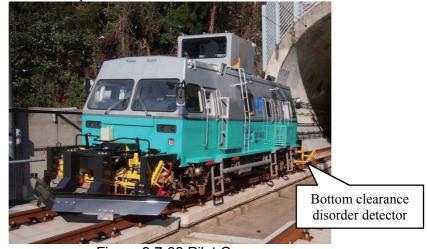


Figure 9.7-33 Pilot Car

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	0	0	0
104 k 350 m	Boisar	0	0	
168 k 900 m	Vapi	0	0	
217 k 300 m	Bilimora	0		
265 k 480 m	Surat	0	0	0
322 k 950 m	Bharuch	0	0	
398 k 180 m	Vadodara	0	0	0
446 k 980 m	Anand/Nadiad	0	0	0
506 k 000 m	Sabarmati	0	0	0

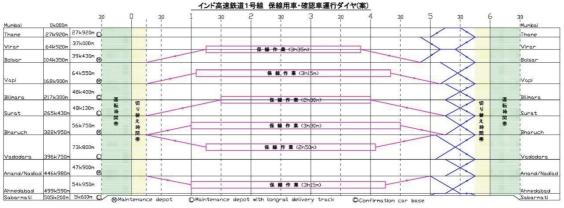


Figure 9.7-34 Maintenance Work and Pilot Car Operation Diagram

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 per day x day/night execution x 25 days/mon		35 km
Laying of track slabs	Track slab transport, laying, adjustment, CA mortar grouting	40 track stabs (for track length 200 m) per day x	
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	
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
В	27 k 920 m	80 k 000 m	52 k 080 m	Thane M. base	Const. base No.1
С	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
Е	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
Н	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

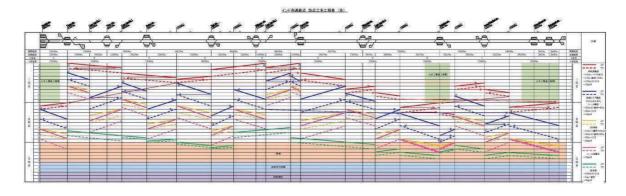


Figure 9.7-36 Track Construction Work Schedule

(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 $1,034.5 \times 2 = 2,069$ 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 Figure 9.7-40 Track Slab Manufacturing Plant (External View)

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.

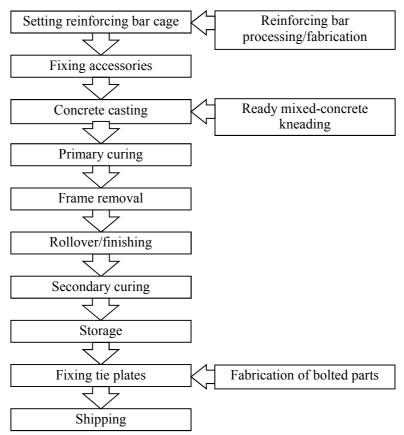


Figure 9.7-41 Flow of Track Slab Manufacture

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 9.7-48 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.

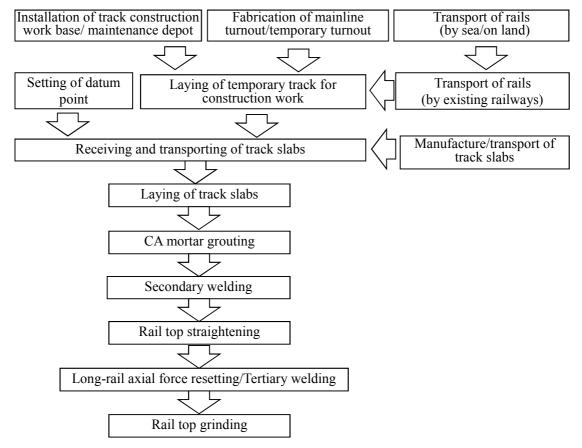


Figure 9.7-53 A flow of Slab Track Construction Work

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.



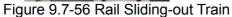




Figure 9.7-57 Rail Sliding-out Operation

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
В	3	27	1	1	1
С	3	27	1	1	1
D	3	27	0	1	1
Е	6	54	1	1	1
F	3	27	0	1	1
G	3	27	0	1	1
Н	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



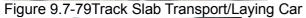




Figure 9.7-80Rail Sliding-out Car



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.

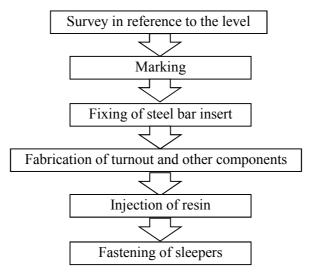


Figure 9.7-83 CA Mortal Plant Car

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.



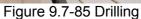




Figure 9.7-86 Planting of Steel Bar Insert

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.

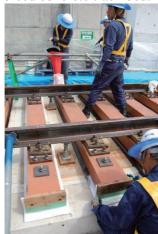


Figure 9.7-89 Injection of Resin



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

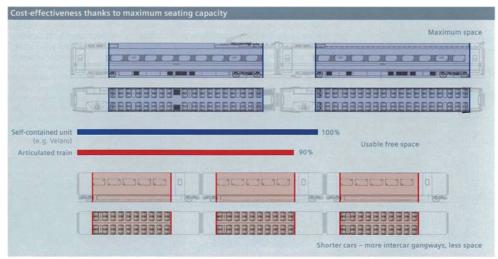
Based on these, other items are compared and analyzed at the outset and the detailed dimensions and specifications are investigated.

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

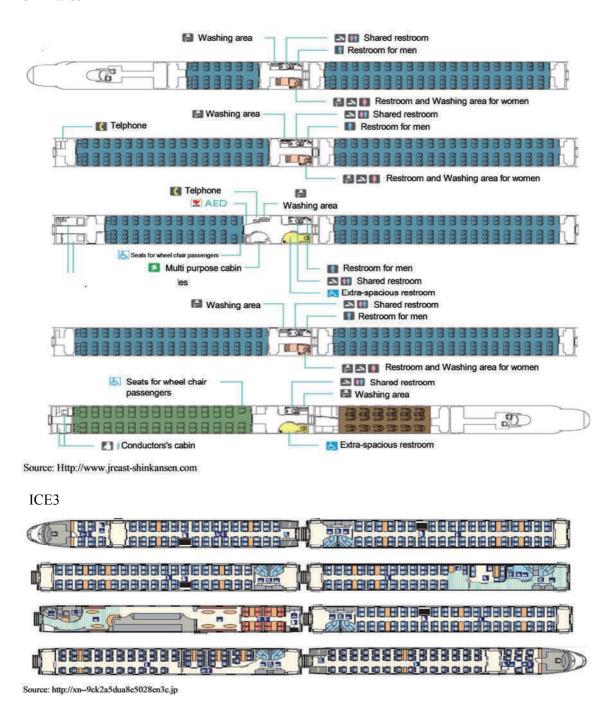


Figure 9.8-2 Typical Passenger Room Layouts of Shinkansen and ICE3

Table 9.8-2 Comparison of Floor Layout

Class	Japan	France	German
Class	Series E5	TGV-R	ICE3
Туре	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	_	0	0
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	0	0
Seat type	Rotating and	Fixed and	Fixed and
(standard class)	reclining seat	non reclining seat	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.

Table 9.8-3 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 sections with 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

	Jaj	oan	Fra	nce	Ger	man	Ita	ıly	Sp	ain		China		Taiwan	South	Korea
Class	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	750 persons: 10-car train set	2-class system Seat pitch:		
(Approx.)	1,200 persons: 16-car train set	1000~1040 mm (standard class) 1,160mm(bisiness class)		
Seat arrangement	5-seat(2+3) arrangement	Standard class 6-seat(3+3) arrangement is possible		
Sout arrangement	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.

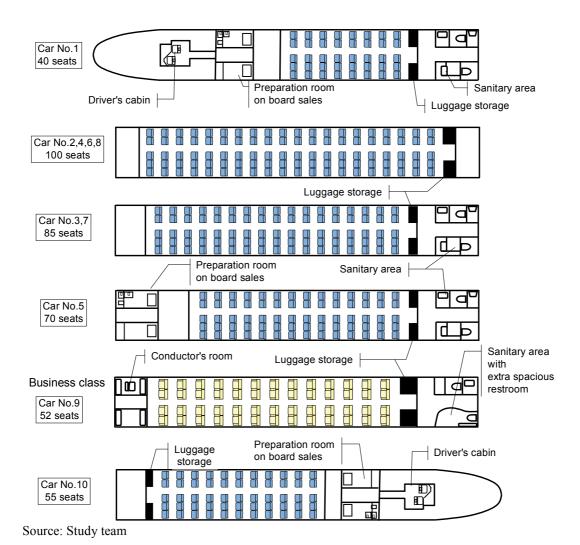
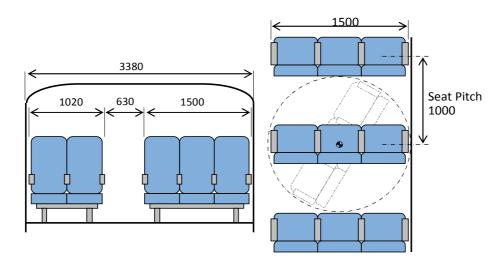


Figure 9.8-3: Recommendation for Rolling Stock Dimensions Specifications



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	000mm 1000mm 920mm		Total					
standard	52seats	735seats			787seats					
train set	(1car)	(9cars)			/0/Scats					
low fare		410seats	462seats		892seats					
train set		(5cars)	(5cars)		692SeatS					
more low fare		410seats		528eats	938seats					
train set		(5cars)		(5cars)	9308Cat8					

120 seats (seat pitch 1000mm)

126 seats (seat pitch 920mm)

- 1000

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

	Japan	German	Italy	China	China	Taiwan
Class	Serise E5	ICE3	AGV-Italo	CRH-2C	CRH-3	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.

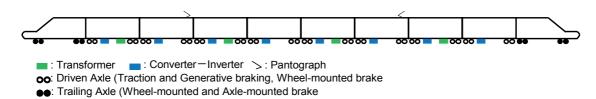
Except for 700T with which three-unit composition is readily possible for 12-car train sets, a traction unit is composed of two converter-inverter sets, each controlling four traction motors, installed in combination under a transformer, thereby driving eight traction motors in total. As shown in Table 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

	10010 0.0 0	inpariouri or Braining	g Cycloin for Livio	
Series	Japan	German	China	Taiwan
Series	Serise E5	ICE3 Regenerative brake neumatic brake ddy current brake Wheel mounted disk Wheel mounted disk CRH-2C Regenerative brake Pneumatic brake Regenerative brake Pneumatic brake Wheel mounted disk Wheel mounted disk Wheel mounted disk Wheel mounted disk Wheel mounted disk	700T	
	Regenerative brake	Regenerative brake	Dagamamatirya brodea	Regenerative brake
Braking system	_	Phelimatic hrake	~	Pneumatic brake
	Pneumatic brake	Eddy current brake	Pheumatic brake	Eddy current brake
Driven axle	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk
Tueiline enla	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk	Wheel mounted disk
Trailing axle	Axle mounted disk	Axle mounted disk	Axle mounted disk	Eddy Cirrent disk
For earthquakes	0	_	_	_

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

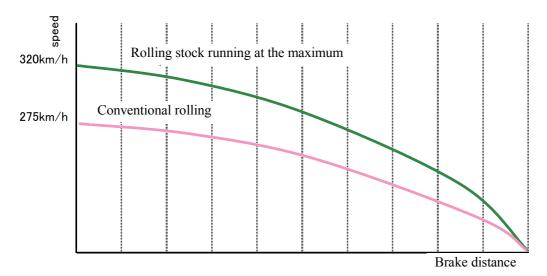
^{*} Frequency of earthquake occurrence indicates the number of earthquakes, 6 or over on the Richter scale, in and after 2000.

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 bogic frames larger to increase bogic 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	Spain S103	China CRH-2C	China CRH-3	Taiwan 700T	South Korea KTX-II
				-Italo					
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	Air spring and Lateral damper	Secondary suspension			
bogie frame and car body	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

	Jap	oan	Fra	ince	Ger	man	Italy	Sp	ain	Ch	ina	Taiwan	South Korea
Class	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		0				0	0		0		0		
Underfloor	0		0					0		0		0	0
Others				0	0								

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 $1\frac{1}{2}$ 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

Train Preparation After each leg Daily Inspection Daily Inspection After each leg Daily Inspection After each leg Daily Inspection After each leg Car cleaning, servicing, water supply, removal og sewage, other work Check status of bogic, 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. Train function test through the driving-cab monitoring system. Inspect/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. Principal bogic components are disassembled. Inspect the wheel sets, wheels, axles, driving gears, traction motors and riggings. 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 bogic inspection, each bogic is subjected is to a car running test as a final check under the same conditions as those of actual train operation. The general inspections conducted on every part of cars. Bogies and all major components are exchanged with spares that have already been inspected and maintained under a spare component circulating system. Also perform on board day leg inspector of function			1	1 Periodic Maintenance			
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Ultrasonic Flaw or inspection is performed to check for any flaws.			-	inspection is performed to check for any flaws.			
Inspection 30 days		inspection	30 days				
Wheel Use wheel profiler to correct wheel shape and maintain		Wheel	100.0001				
Reprofiling 100,000 km ride comfort lever.			100,000 km	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.

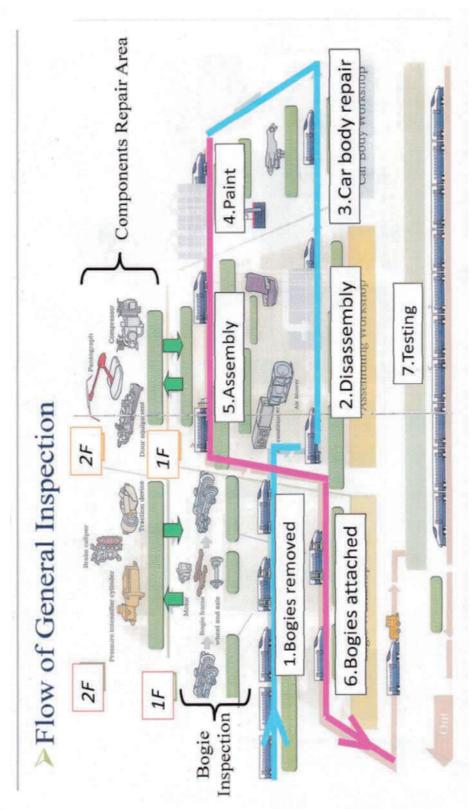


Figure 9.9-1 Example of HSR Rolling Stock Workshop

9.9.4 Introduction of Japanese Maintenance for Shinkansen

- (1) Light Maintenance
- 1) Major facility for light maintenance

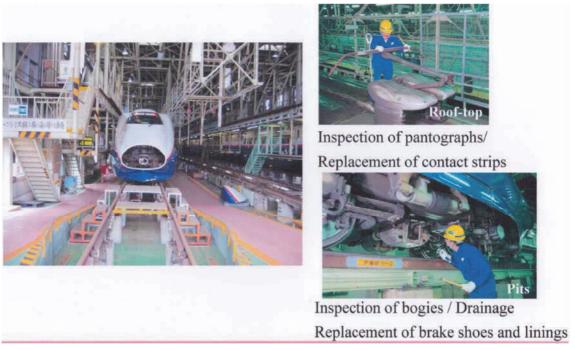


Figure 9.9-2 Inspection Deck

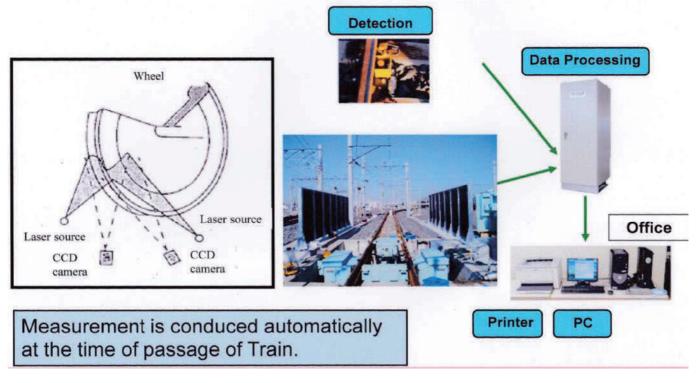


Figure 9.9-3 Measuring Equipment for Wheel Profile

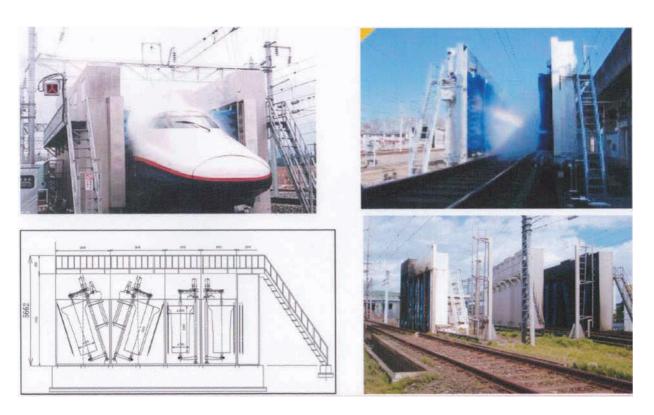


Figure 9.9-4 Automatic Car Body Washing Machine

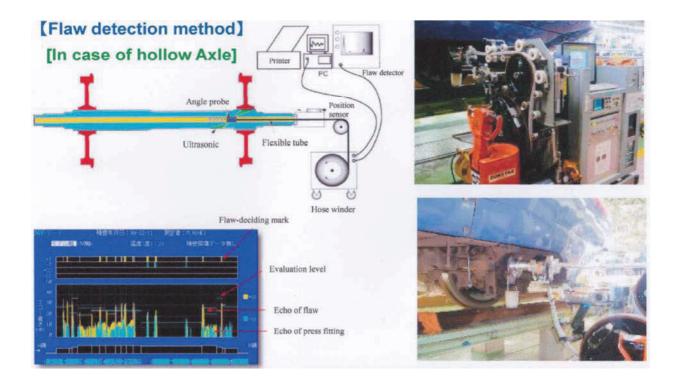


Figure 9.9-5 Automatic Axle Ultrasonic Flaw Detector

(2) Other Maintenance



Figure 9.9-6 Major Facility for Other Maintenance

(3) Heavy Maintenance

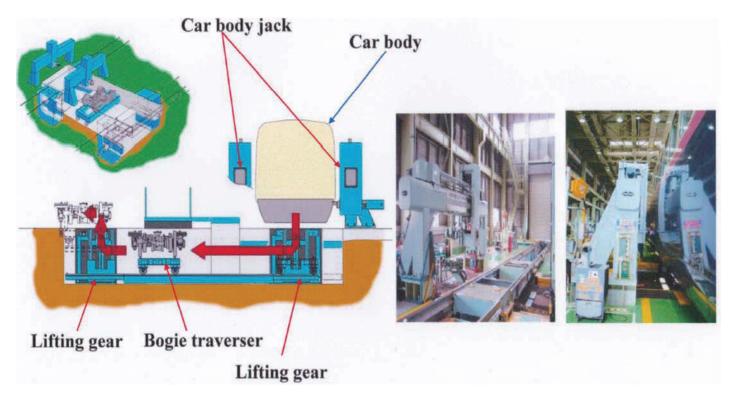


Figure 9.9-7 Bogie Changing Machine (for Bogie Inspection)





The lift of the body is carried out and a bogie is removed.

Self-propelled rise-and-fall temporary bogie

Figure 9.9-8 Bogie Removal Equipment (for General Inspection)

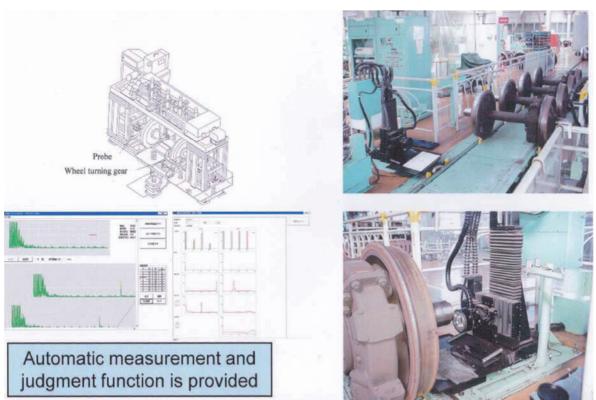


Figure 9.9-9 Ultrasonic Flaw Detector (for Bogie & General Inspection)



Automatic measurement such as generation of heat of a wheel set, and vibration etc at high speed.



Figure 9.9-10 Bogie High-speed Rotation Test Equipment



Figure 9.9-11 Airtightness Hold Test Equipment

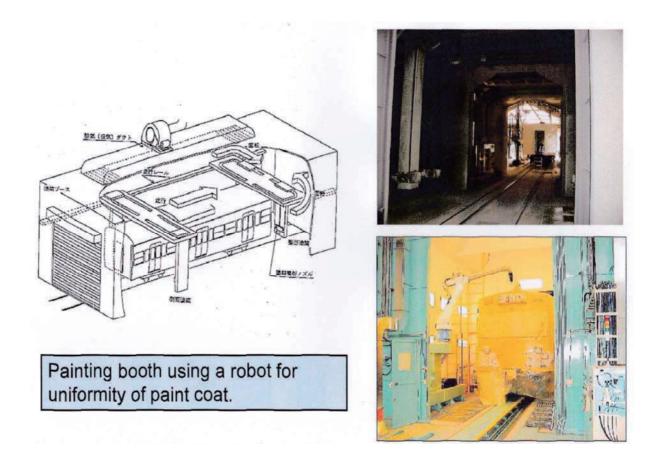
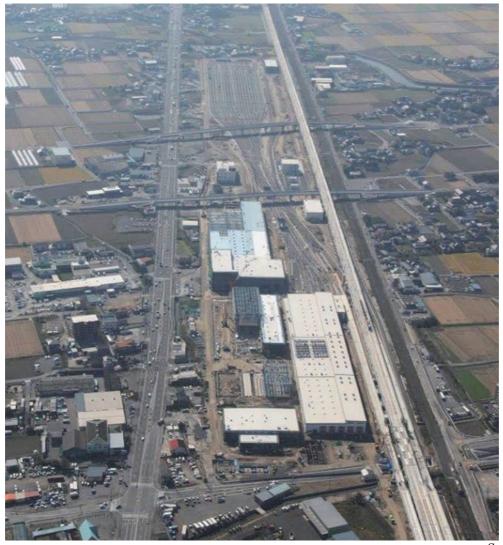


Figure 9.9-12 Car-body Painting Machine

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	0				0	0		
Sabarmati Depot/ Workshop	0	0	0	0	0	0		

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

-	Table 515 5 maps and Table							
	Kind of	Daily Inspection	Regular	Bogie Inspection	General			
	Inspection		Inspection		Inspection			
			30,000 km	600,000 km	1,200,000 km			
	Interval	48 hours	or	or	or			
			30 Days	1.5Years	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		Work days				
Kind of hispection	2023	2033	2043	2053	(day/week)	
Train Preparation		2 h				
Daily Inspection		7				
Regular Inspection	2 days	2 days	1 day	1day	5	
Bogie Inspection	8 days		6 da	5		
General Inspection	24 days	20 days	17 day	15 days	5	
Wheel Re-profiling		7				

Table 9.9-5 Yearly Work Days and Work Hours

Table 5.5-5 Tearly Work Days and Work Hours							
Kind of Inspection	Work days / year	Work days / hours	Remark				
Train Preparation							
Daily Inspection	365 days / year	24 hours / day					
Wheel Re-profiling							
Regular Inspection							
Bogie Inspection	300 days / year	8 hours / day	2400 hours / year				
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
D 1 1 1 1 1 1	10 Cars	24	24	9 4 6	
Required train sets	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

	Table 5.5-7 Gize Required for Each Depot									
		Stablii	ng Track No.	(2053)		Track				
		Use	Reserve	Total	Maintenance	Daily	Regular	Unscheduled	Wheel	Car
					Track	Inspection	Inspection	maintenance	Re-Profiling	Washing
						Track	Track	Track	Track	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

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		nspection
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.

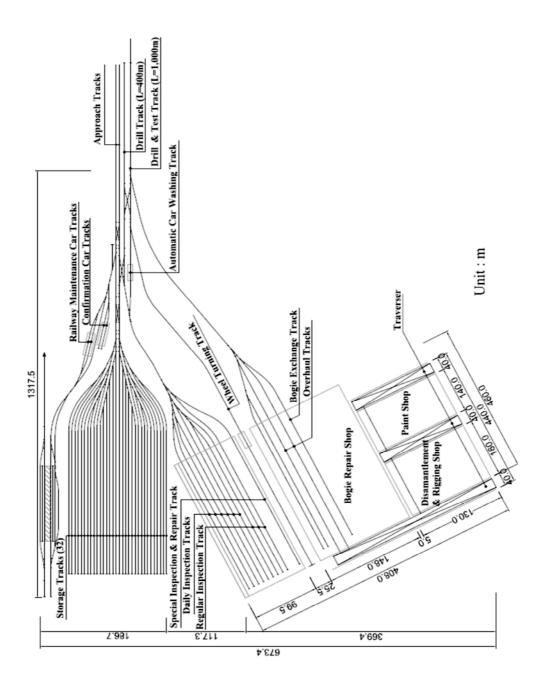


Figure 9.9-14 Sabarmati Depot and Workshop

00.71 Dismounting Shop Final Adjustment Shop Parts Repair Shop (2F enlarge at 2053) Assembling Shop General Inspection Disassembling and Assembling Shop 398.00 Bogie, Wheelset, Traction Motor Repair Shop 50,00 40.00 Car Body Shop Bogie Exchange Shop Paint Shop 103'00 00,87 00'09

Shown Figure 9.9-15 for the layout of the Main Workshop.

Figure 9.9-15 Main Workshop Layout

130,00

Shown Figure 9.9-16 for the layout of Thane Depot.

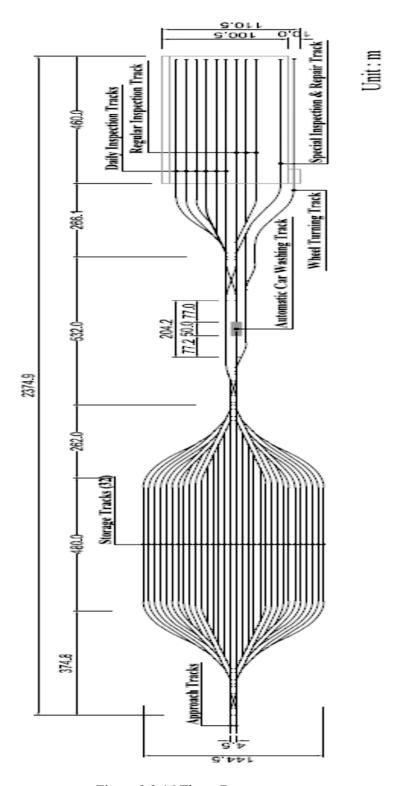


Figure 9.9-16 Thane Depot

9.10 Power-Related Facilities

9.10.1 Power Supply Installation

(1) Basic Method

As discussed in Chapter 4, the basic plan for the power supply installation (PSI) is as follows.

Incoming Method

It is powered by double lines taken from the transmission network of 132/220kV, which is the main transmission system of Electric Power companies.

➤ Feeding system

The feeding system will be single-phase AC, 50Hz, 2x25kV.

Feeding Voltage

The standard voltage of the system is 25kV. The maximum allowable voltage is 30kV and minimum allowable voltage is 22.5kV. In addition, there is a minimum voltage of 20kV for short durations.

Substation System

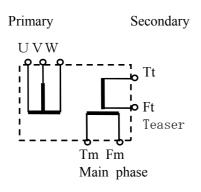
The substation system shall be as follows:

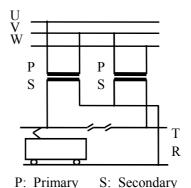
There will be a spacing of 50 to 60km between the traction substations (TSS).

There will be 25 to 30km interval between TSS and the sectioning and paralleling post (SP). And, there will be sub-sectioning and paralleling post (SSP) in the midway of the SP and TSS.

(2) Connection Method of Traction Transformers

The connection methods of traction transformer are Scott connection method and the V- connection method. The connection method is shown in Figure 9.10-1 and Figure 9.10-2 respectively.





Source Study team

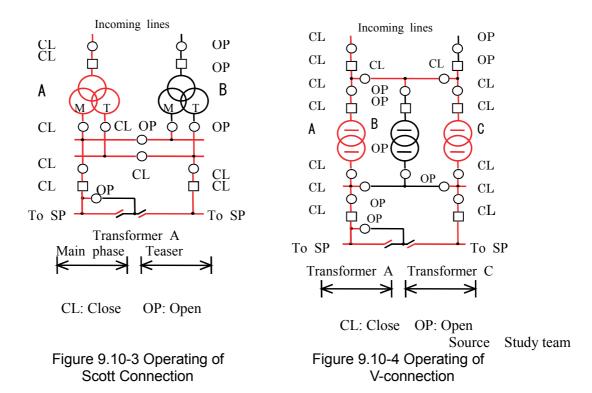
Figure 9.10-1 Scott Connection Method

Figure 9.10-2 V-connection Method

1) Connection of Feeding Transformers and Operating Method

Scott connection method is installed using two transformers, one for operation and other for stand-by, as shown in Figure 9.10-3.

V-connection method is installed using three transformers, two for operation and third for stand-by, as shown in Figure 9.10-4.



2) Connection Method of Traction Transformers and Voltage Unbalance Rate

The following formula is used for calculating voltage unbalance rate due to the connection method of the transformers.

a) Single phase transformer

 $u=(Es\times I)/Ps)\times 100$ (%)

b) V-connection transformer

 $u=(E_S\times SQR(I_a^2+I_b^2-I_a\times I_b)/P_S)\times 100(\%)$

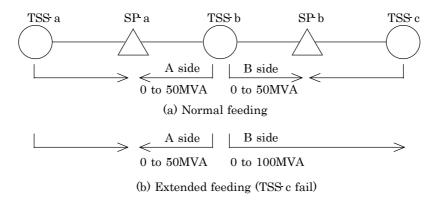
c) Scott connection transformer

 $u=(E_s\times|(I_m-I_t)|/P_s)\times100(\%)$

However, u : Voltage unbalance rate (%)
Es : Line voltage (kV)
Ps : Short current apparent power (kVA)
I : Line current (Single phase) (A)
Ia, Ib : Line current (V-connection) (A)
Im, It : Line current (Scott connection) (A)

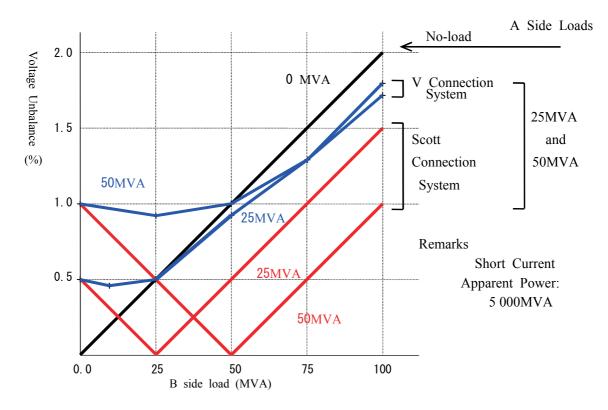
3) Calculation of Voltage Unbalance Rate

The calculation is done depending on the load conditions as shown in Figure 9.10-5. The Figure 9.10-6 shows the calculation result of the unbalanced rate. Voltage unbalance rate is the same in any connection when the load in one direction only. However, if there are loads in both directions, the unbalanced rate is smaller than V-connection in case of Scott connection.



Source Study team

Figure 9.10-5 Load Conditions



Source: Study team Figure 9.10-6 Connection Method of Traction Transformers and Voltage Unbalance Rate

4) Connection Methods adopted for high-speed rail

Table 9.10-1 shows the connection methods adopted for different high-speed rails. South Korea high-speed rail (KTX) was constructed by introducing the technology of France. However, Scott connection method is same as used for Shinkansen in Japan.

Table 9.10-1 Connection Methods Adopted for High-speed Rail

Type of Connection Method	Name of Country
Scott Connection	Japan, Taiwan, South Korea
V-connection	France, Spain, U.K., Italy, China

Source: Study team

5) Recommendation

Scott connection method is proposed for the following reasons.

- a) The incoming circuit can be simplified.
- b) The number of traction transformers is reduced.
- c) The power supply voltage unbalance is reduced.

(3) System Voltage and Voltage Regulation

Table 9.10-2 shows the system voltage and voltage regulations. The highest voltage is same for Indian railways and Shinkansen. However, the minimum voltage is higher to ensure the power supply to the Shinkansen train.

Table 9.10-2 System Voltage and Voltage Regulation

		Nominal	Maximum	n voltage (kV)	Minimum voltage (kV)	
Name of	Kinds of Lines	voltage	Short	Continuous	Continuous	Short
Country		(kV)	term			term
Japan	Shinkansen	25.0		30.0	22.5	20.0
	(High-Speed)					
India	Conventional	25.0	30.0	27.0	18.5	17.5
IEC		25.0		27.5	19.0	17.5

Source: Study team

(4) Plan of Incoming Lines

1) Incoming Voltage

Table 9.10-3 shows Incoming voltage of traction substation (TSS) that has been adopted for Indian Railways. The 132/220kV system is desirable as the incoming voltage for the high-speed rail. The reason, short current apparent power is larger than that of the 66kV to 132/220kV. There is also an advantage that voltage unbalance rate is reduced by this.

Table 9.10-3 Incoming Voltages of TSS

System voltage (kV)	66kV, 110kV, 132kV, 220kV
---------------------	---------------------------

Source: Study team

(5) Passing method for Neutral Section

For passing neutral section (NS), changeover section system is adopted in which there is no effect on operation of trains. In this system, the train is also the regenerative breaking or powering, can pass directly.

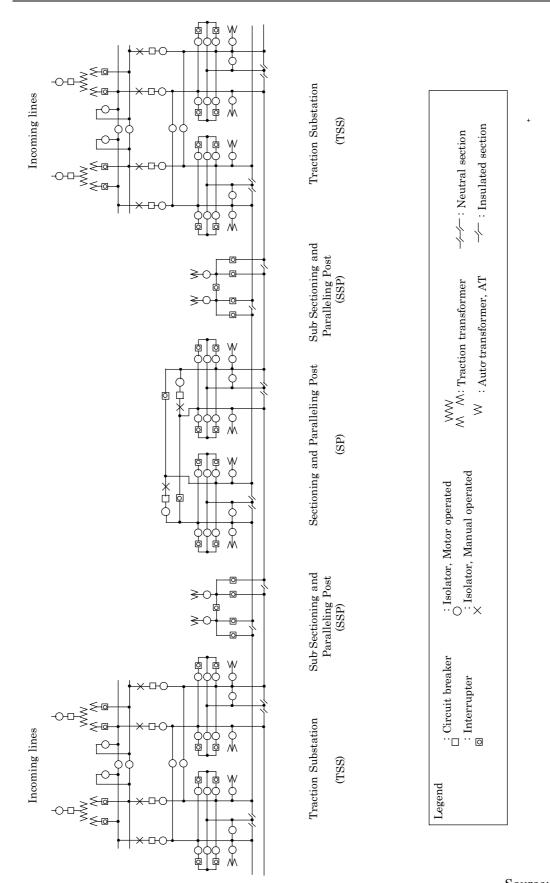
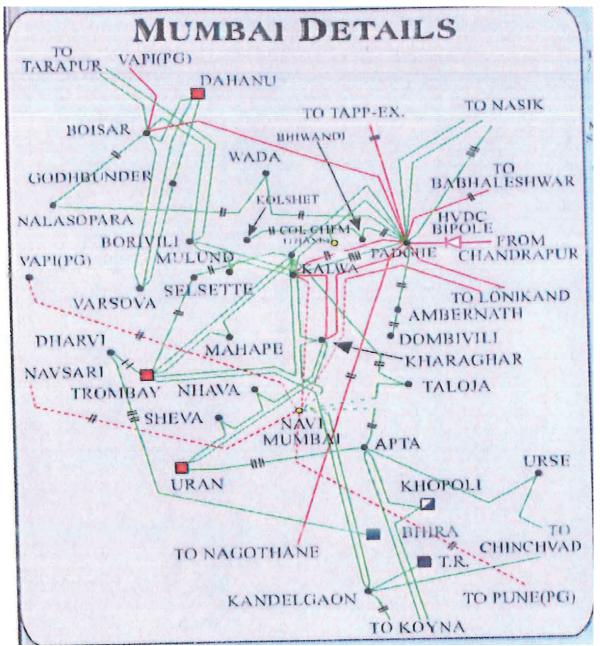


Figure 9.10-7 Standard Power Supply Network

(6) Incoming Plan

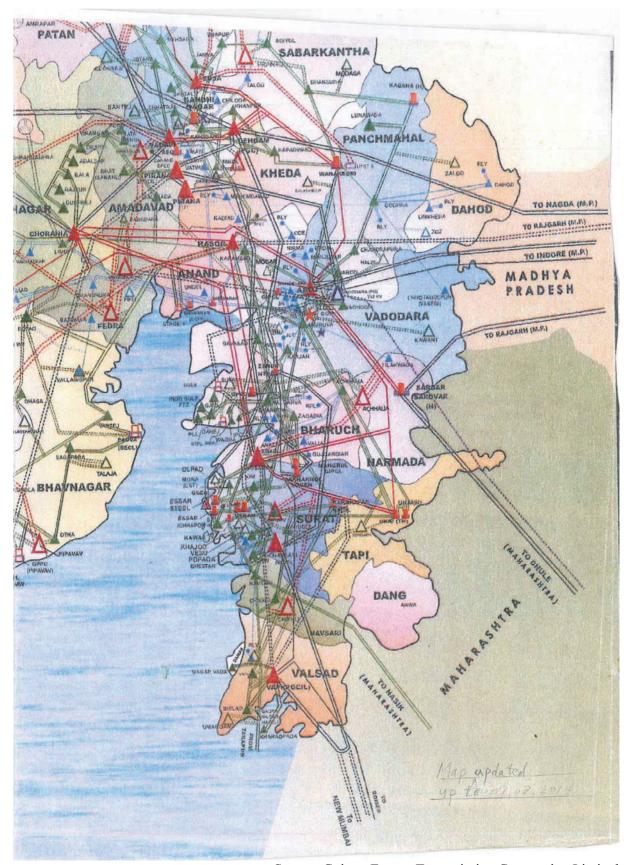
For the incoming plan, the incoming voltage is taken as 132/220kV. Scott connection method is proposed because it gives only small voltage unbalance to the power source, when compared to the V connection method. Japan, Taiwan and Korea have adopted the Scott connection.

The power transmission map of Mumbai and Gujarat is shown in Figure 9.10-8 and Figure 9.10-9 respectively. The transmission system of the Power Authority in the project area is 66/132/220/400kV. The supply to TSS for high-speed rail will be coming from the grid substations (GSS) or the power stations (PS) of the Power Authority.



Source: Major Transmission Network of India, Central Electricity Authority

Figure 9.10-8 Power Map of Mumbai Details



Source: Gujarat Energy Transmission Corporation Limited Figure 9.10-9 Power Map of Gujarat (Project Section)

On the basis these maps, the locations of TSS are shown in Table 9.10-4, when the distance between the TSS is set to 50 to 60 km interval.

For determining the exact locations of TSS, field surveys are required to check whether it is possible to draw transmission circuits from the GSS/PS or if there is any obstruction in the route of transmission lines to the planned TSS sites.

Table 9.10-4 Location Plan of Traction Substations (Tentative)

	Traction Substation	Total Length	Grid Substation (GSS) or Power Station		
No	(TSS) Name	(km)	(PS) of Power Supply Authority		
01	Mumbai	7	Muland/GSS		
02	Virar	59	Vasai/GSS		
03	Boisar	114	Dahanu/PS		
04	Vapi	167	Vapi(new)/GSS		
05	Bilimora	220	Ambipa/GSS (New)		
06	Surat	275	Utran/PS		
07	Bharuch	330	Vadidla/GSS		
08	Vadodara	385	Jambura/GSS		
09	Anand	440	Karmsad/GSS		
10	Ahmedabad	492	Vatwa/GSS (132kV)		

A field survey was conducted from Ahmedabad to Mumbai to confirm the plan shown in Table 9.10-4. From the results of the field survey, it was found that it is possible to provide power to all the ten TSS locations, although some locations were found to be different than originally expected. The final incoming point will be decided by discussions with the Power Authority, and the incoming plan prepared here could be an important document for the discussions.

Here is an example from the field survey. This example is for Vapi/TSS. As per the map, the Vapi/GSS is a 132/220kV GSS. Figure 9.10-10 shows the surrounding area near Vapi. However from the field survey, Study team came to know that it is actually a 66kV Electricity Board SS (EBSS) as shown in Figure 9.10-11. So Study team surveyed the area and were able to find a 400/220kv station of Power Grid Corporation of India LTD (PGCIL) as shown in Figure 9.10-12 and 9.10-13. As per the map, this station was located at far-east of Vapi city, however for the field survey Study team found out that it is only 15 min from the 66kV EBSS.

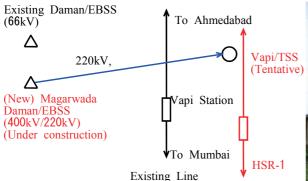




Figure 9.10-10 Location Map of Vapi

Figure 9.10-11 Daman/EBSS







Source: Study team Figure 9.10-13 400kV Incoming Lines

Figure 9.10-14 shows the minimum distance of transmission line from GSS/PS, the location of SP at midpoint and the name of proposed HSR station. The location of each TSS/SP/SSP and the distance between them is shown in Figure 9.10-15.

As per the arrangement shown in Figure 9.10-16, the spacing between each TSS will be 50 to 55 km and spacing between each post will be about 13-14 km. These spacing are within the desirable spacing of 50-60 km for TSS and 13-17 km for each posts.

GSS or PS of Power Supply Authority	Muland	Vasai	Dahanu/PS	Vapi (New)	Ambipa
Minimum Distance of Incoming line	8km	7 km	2km	9km	13km
Traction Substation Name	01_Mumbai 7km	02_Virar 59km	03_Boisar 114km	04_Vapi 167km	05_Bilimora 220km
Station Name	Mumbai Thand 0.0km 27.9k		Boisar 104.4km	Vapi 168.9km	Bilimora 217.3km

GSS or PS of Power Supply Authority	Utran/PS Vadadla Jambura Karmsad Vatwa (132kV)
Minimum	121 21 21 21
Distance of Incoming line	12km 2km 2km 6km 2km
Traction	06 Surat 07 Bharuch 08 Vadodara 09 Anand 10 Ahmedabad
Substation	275km 330km 385km 440km 492km
Name	
Station Name	Surat Bharuch Vadodara Anand/Nadiad Ahmedabad Sabarmati 264.5km 323.1km 396.9km 447.1km 499.8km 505.4km 507km
	Workshop
-	Remarks GSS: Grid Substation PS: Power Station

Figure 9.10-14 Map of Planned Traction Substations (Tentative)

Station	TSS	SP	SSP	Total	TSS	TSS to SP	Post to
							Post
				Length	Interval	Interval	Interval
Name	Name	Name	Name	(km)	(km)	(km)	(km)
Mumbai				0			
	01_Mumbai			7			7
			21	21		26	14
Thane				27.9			
		11		33	52		12
			22	46		26	13
	02 Virar			59	7		13
Virar				64.9			
			23	72.75	7	27.5	13.75
		12		86.5	55		13.75
			24	100.25	7	27.5	13.75
Boisar				104.4	7		
	03 Boisar			114	7		13.75
	_		25	127.25		26.5	13.25
		13		140.5	53		13.25
			26	153.75	7	26.5	13.25
Vapi				168.9	7		
•	04 Vapi			167	7		13.25
			27	180.25		26.5	13.25
		14		193.5	53		13.25
			28	206.75	7	26.5	13.25
Bilimora				217.3	7		
	05 Bilimora			220	7		13.25
	_		29	233.75		27.5	13.75
		15		247.5	55		13.75
			30	261.25	7	27.5	13.75
Surat				264.5	7		
	06 Surat			275			13.75
	_		31	288.75		27.5	13.75
		16		302.5	55		13.75
			32	316.25	7	27.5	13.75
Bharuch				323.1	7		
	07 Bharuch			330			13.75

Figure 9.10-15 Location Plan of TSS/SP/SSP (Tentative)(1/2)

Station	TSS	SP	SSP	Total	TSS	TSS to SP	Post to
							Post
				Length	Interval	Interval	Interval(km
Name	Name	Name	Name	(km)	(km)	(km))
	07_Bharuch			330			13.75
			33	343.75		27.5	13.75
		17		357.5	55		13.75
			34	371.25		27.5	13.75
	08_Vadodara			385			13.75
Vadodara				396.9			
			35	398.75		27.5	13.75
		18		412.5	55		13.75
			36	426.25		27.5	13.75
	09_Anand			440			13.75
Anand/							
Nadiad				447.1			
			37	453		26	13
		19		466	52		13
			38	479		26	13
·	10_Ahmedada						
	d			492			13
Ahmedbad				499.8			
Sabarmati				505.4			
			39	506			14

Source: Study team

Figure 9.10-16 Location Plan of TSS/SP/SSP (Tentative)(2/2)

(7) Substation Facility Planning

The Indian Railways has 18 years of experience in operating the 2x25kV feeding system for the 724 km long Bina – Katni – Anupur - Bishrampur/Chirimiri line which was opened in the year 1996. Also, the 2,635km long Dedicated Freight Corridor (DFC) project, which is under construction, has adopted the 2x25kV system. Here, the 2x25kV system is compared with the conventional system with regard to the system requirements for the High speed rail.

There is a need to increase the capacity of transformer substation facility, of which there is the auto-transformer (AT) and traction transformer (TTr). In addition, Study team proposes to adopt the changeover switch. These are described as follows.

1) Traction Transformer

Maximum power current of conventional lines is 600A to 700A as compared to 1000A for High speed rails. Therefore, it is necessary to have larger traction transformer capacity for HSR-1 than for the conventional lines. The traction transformer capacity is 50MVA (2x25MVA) in Conventional lines but, 120MVA (2x60MVA) is required in HSR-1.

If fluctuations in the incoming voltage is large traction substation, installed the OLTC (On-load tap changer).

2) Auto Transformer

It is necessary to increase the capacity of auto transformer (AT) for the same reason as traction transformer. For this reason, AT capacity is 8MVA in conventional lines but 15MVA for HSR-1.

3) Changeover Section System

For neutral section (NS), changeover section system is adopted. In this system, the train is also the regenerative breaking or powering, can pass directly. This system has 50 years of experience in the

Japanese Shinkansen.

The structure of the NS is to be described in detail in 9.10.2(3).

(8) Schematic Diagram of TSS/SP/SSP

The schematic diagram of TSS/SP/SSP is shown in Figures 9.10-18 to 9.10-20 is applied to HSR-1. The name and letter symbol of the schematic diagram is shown in Figure 9.10-17.

Symbol	Name	Symbol	Name
	Scott connected Transformer		Changeover switch
	Auto-transformer (AT)	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Isolator (Motor operated)
	LT Supply transformer		Isolator (Manual operated)
35	Voltage transformer (VT)	<u> </u>	Lightning arrester (LA)
₹	Current transformer (CT)	-//-	Neutral section
/-/-M	Circuit breaker		Isolated section
//M	Interrupter		

Figure 9.10-17 Name and Letter Symbol of Schematic Diagram

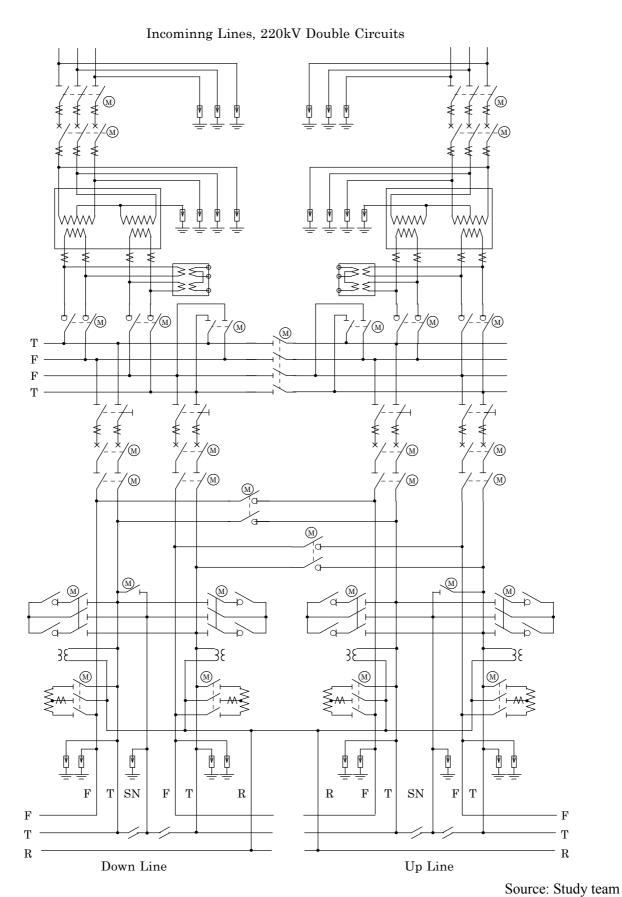
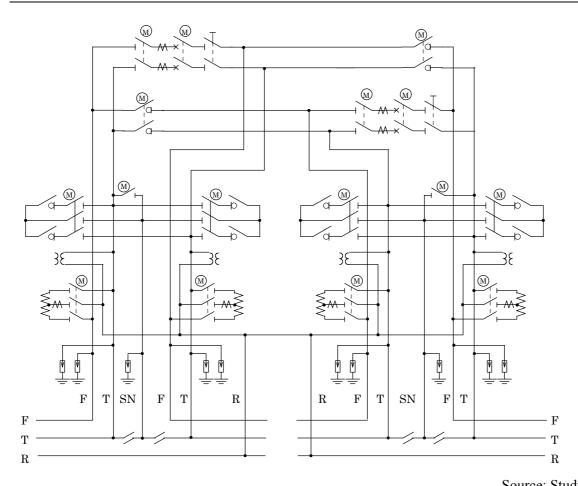


Figure 9.10-18 Schematic Diagram of Traction Substation (Tentative)



Source: Study team Figure 9.10-19 Schematic Diagram of Sectioning and Paralleling Post (Tentative)

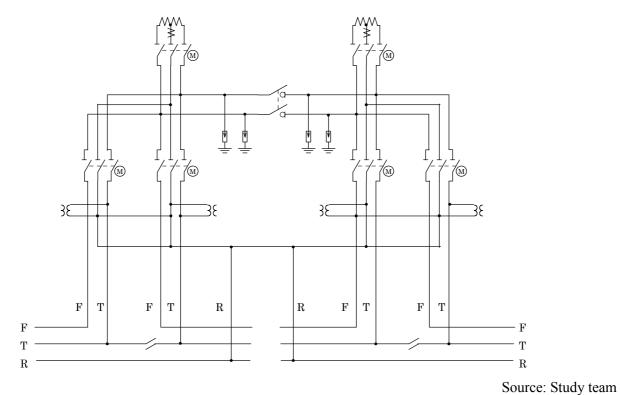


Figure 9.10-20 Schematic Diagram of Sub-Sectioning and Paralleling Post (Tentative)

9.10.2 Overhead Equipment (OHE)

(1) Type of Overhead Equipment

The type and characteristics of overhead equipment used for high-speed rails in different countries is shown in Figures 9.10-21 to 9.10-23. The Table 9.10-5 shows the type of OHE used by countries that operate high-speed trains at 300km/h or above. Japan has been using compound catenary and simple catenary as OHE. The compound catenary is used when the traffic volume is high and simple catenary is used when traffic volume is not very high.

The TGV Paris South-East (PSE) of the French Railways (SNCF) line, which was opened in 1981, uses simple catenary system with stitch wire, in order to improve the current collecting performance. However, since the adjustment of the OHE is difficult, SNCF has adopted the simple catenary system in the new lines that was built since then. In addition, the PSE line has also been changed to the simple catenary system in section with speed of 270km/h or more.

The Beijing-Tianjin line in China, which opened in 2008, has also adopted the simple catenary system. However, with the introduction of German technology, the new lines which were opened thereafter, have adopted the simple catenary with stitch wire system.

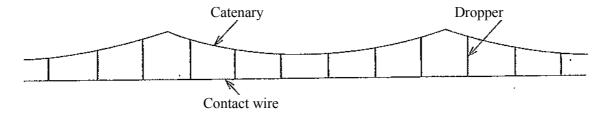


Figure 9.10-21 Simple Catenary System

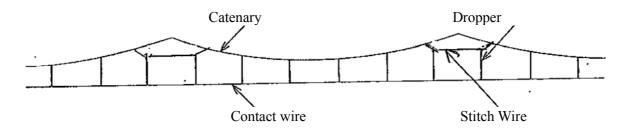
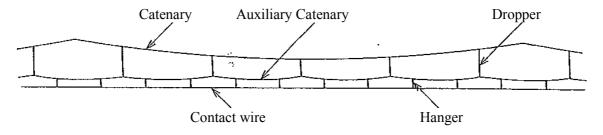


Figure 9.10-22 Simple Catenary with Stitch Wire System



Source: Study team

Figure 9.10-23 Compound Catenary System

Table 9.10-5
Overhead Equipment Adopted in the main Countries which Operate High Speed Rail

Type of Over Head Equipment	Name of Country
Simple Catenary	Japan, France, U.K., Italy, China, South Korea
Simple Catenary with Stitch Wire	France, Spain, Germany, China,
Compound Catenary	Japan, Taiwan

Source: Study team

Table 9.10-6 shows the characteristics of OHE as adopted in different countries. Only Japan and Taiwan are using the compound catenary system whereas other countries use simple catenary system. Since the traffic volume is large in the Japanese Shinkansen, it is necessary to supply large amount of current. The allowable current of compound catenary is 1000A and simple catenary is 800A. The material of the OHE is copper except for the catenary cable, for which it is steel.

The contact wire had used hard copper in Tokaido Shinkansen when it was opened in 1964. At that time maximum speed was 210km/h. The speed of the train becomes 270km/h as the PSE line of France, increased tension of the contact wire. For this reason, it began to use copper alloys such as bronze of high tensile strength. At present, contact wire made of alloy of copper with the addition of 0.1 to 0.5% Magnesium (Mg) or silver (Ag) has also been used in France, Germany, and China.In Japan, the standard span length is 50m, but there are cases of 60m also in the Tokaido Shinkansen. However, considering accident prevention due to heavy winds, span length is kept at 50m. In France, 54m is the standard span, and the maximum is set to 63m. However, in the Mediterranean TGV line, span length is 45m to 50m in areas of heavy winds. In Germany, span is set to 65m if wind speed is low.

Table 9.10-6 Overhead Equipment of High-speed Rail

		verneau Equipment o		
Name of	Japan	China	France	Germany
country				
Overhead	Compound	Simple catenary	Simple	Simple catenary with
Equipment	Catenary	with stitch wire	Catenary	stitch wire
Catenary wire	Galvanizing	Bronze	Bronze	Bronze
	steel			
	180mm ²	120mm ²	116mm ²	120mm ²
	2 450daN	2 100daN	2 000daN	2 100daN
Auxiliary	Hard-Drawn	Bronze		Bronze
catenary wire or	cupper		None	
stitch wire	150mm ²	35mm^2		35mm ²
	980daN	350daN		350daN
Contact wire	Bronze	CuMg	Bronze	CuMg
	170mm^2	150mm ²	150mm ²	120mm ²
	1 960daN	3 000daN	2 600daN	2 700daN
Span length	50m	60m	54m	65m
Maximum	320km/h	300km/h	320km/h	300km/h
operational				
speed				
Allowable				
current	1 000A		800A	

(2) Overhead Equipment for HSR-1

1) Natural Environment Conditions

Table 9.10-7 shows the ambient air temperature conditions of India and Japan. Table 9.10-8 also shows the wind speed in Japan. The maximum temperature is 40 degree centigrade in Japan and 50 degree centigrade in India. So it is necessary to take this into account, because it affects the allowable current of OHE. As for wind speed, it should be compared with the situation of winds in the western region of India.

Table 9.10-7 Ambient Air Temperatures (deg. C)

Item	Japan	India
Maximum	40	50
Minimum	-10	-10

Table 9.10-8 Winds Speeds (m/s)

Conditions	Japan	
Heavy	50	
Normal	40	

Source: Study team

2) Arrangement of OHE

Table 9.10-9 shows the arrangement of the general region. Compound catenary is adopted into high density high-speed line due to its high current capacity. In this project its potential traffic volume in the future is estimated to be high, therefore compound catenary should be recommended. However, simple catenary is adopted for sub-main lines and depots. Maximum operation speed on rigid OHE is restricted under 160 km/h, therefore adopting it in tunnels should not be selected and compound catenary should be selected even in tunnels for high speed operation. The arrangement of OHE in tunnel section and disaster prevention region is given in Table 9.10-10 Wire and cable type having excellent heat resistance is adopted in tunnel section and disaster prevention regions.

OHE with a standard span of 50m is proposed. This is because the project section is located in a strong wind area.

Table 9.10-9 Arrangement of OHE (General Region)

	3 /	
Item	Main Line	Sub-Main Line / Depot
Type of Overhead equipment	Compound catenary	Simple catenary
(OHE)		
Catenary wire	Galvanizing steel	Cadmium copper 65mm ²
	180mm ²	
	2 450daN	980daN
Auxiliary catenary wire	Hard-drawn cupper	None
	150mm ²	
	980daN	
Contact wire	Bronze 170mm ²	Hard drawn copper 107mm ²
	1 960daN	980daN
Negative Feeder	Hard-drawn	None
(AT Feeder)	Aluminum 300mm ²	
	392daN	
Standard Span	50m	50m

Table 9.10-10 Arrangement of OHE (Tunnel Section and Disaster Prevention Region)

Item	Main Line		
Type of Overhead equipment (OHE)	Compound catenary		
Catenary wire	Galvanizing steel 180mm ² 2 450daN		
Auxiliary catenary wire	Silver-containing Hard-drawn copper 150mm ² 980daN		
Contact wire	Silver-containing Hard-drawn copper 170mm ² 1 960daN		
Negative feeder (AT Feeder)	ACSR 330mm ² 1 470daN (Aluminum Cable Steel Reinforced)		

Source: Study team

Table 9.10-11 shows the standard spacing of droppers and hanger on the OHE. Also, Table 9.10-12 shows height and gradient of contact wire.

Table 9.10-11 Standard Spacing of Hanger and Dropper

Item	Hanger	Dropper
Compound catenary	5 m	10 m

Source: Study team

Table 9.10-12 Height and Gradient of Contact Wire

Section	Height of Contact Wire	Gradient
High-speed		Less than 1/1000
Less than 110km/h	5m +/- 0.1m	Less than 3/1000
Depot/Workshop		Less than 5/1000

Source: Study team

(3) Automatic Tensioning Devices (ATDs)

Automatic tensioning device (ATD's) is used to maintain constant tension automatically and thus maintain good performance for current collection. In Tokaido Shinkansen, since it's opening in 1964, pulley type ATD has been used. The picture is shown in Figure 9.10-24. However, in this method, there is a need to apply oil to the cable that connects the weight and pulley. In addition, wire breakage due to aging of the cable also occurs.

To replace this method, spring tension adjustment "spring type ATD" was developed. The picture is shown in Figure 9.10-25. It is compact as compared to the pulley type. Weight is also lighter than the 1500kg of pulley type.



Figure 9.10-24 Pulley type ATD



Source: Study team

Figure 9.10-25 Spring type ATD

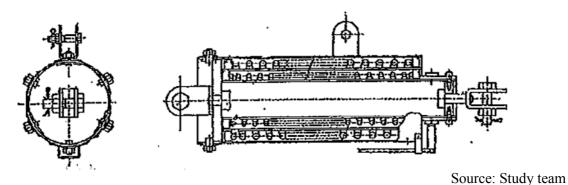


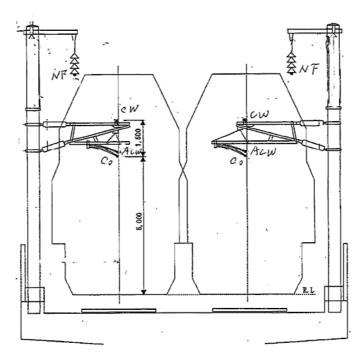
Figure 9.10-26 Internal Structure of Spring

Figure 9.10-26 shows the internal structure of the spring. The spring has large stroke and is compact due to the two-stage structure of the coil spring.

Currently, conversion from pulley type to spring type is being promoted in Japan's Shinkansen. After confirming weather conditions of the project area, the spring type is proposed for adoption.

(4) Standard Arrangement of OHE

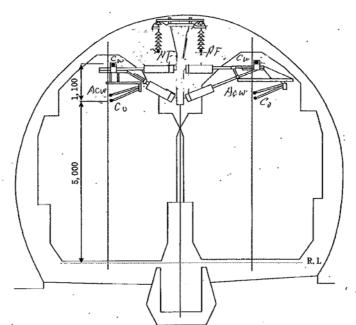
The standard arrangement of OHE for viaduct section is shown in Figure 9.10-27, and for tunnel section, it is shown in Figure 9.10-28. In this arrangement, distance of contact wire (Co) and catenary wire (Cw) at bracket is 1500mm. And, distance of contact wire (Co) and auxiliary wire (Acw) is 150mm. In tunnel section, distance of Cw and Co is 1100mm at bracket. Distance of Co and Acw is same as that for viaduct section



Cw: Catenary wire Acw: Auxiliary catenary wire Co: Contact wire NF: Negative feeder

Source Study team

Figure 9.10-27 Standard Arrangement of OHE (Viaduct Section)



Cw: Catenary wire Acw: Auxiliary catenary wire Co: Contact wire

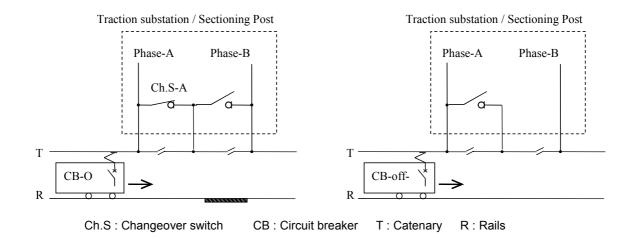
NF: Negative feeder

Source Study team Figure 9.10-28 Standard Arrangement of OHE (Tunnel Section)

(5) Neutral Section

1) Type of Neutral section

Neutral sections (NS) are of two types. One is power supply installation (PSI) side switching method, and other is on-board circuit breaker (CB) off method. They are show in Figure 9.10-29.



- (a) Power Supply Installation side switching Method
- (b) On-board CB Off Method

Source: Study team

Figure 9.10-29 Type of Neutral Sections

The PSI side switching method is called "the changeover section system". In this system, the train is also the regenerative breaking or powering, can pass directly. This system has 50 years of operational experience in the Japanese Shinkansen. In the on-board CB off method, there is "Long neutral section system" (being used the TGV Paris-South-East (PSE) since 1981) and the "Split neutral section system" which has been developed in recent years. The split neutral section system is used LGV Est in France since 2007. Figure 9.10-30 shows type of neutral section.

The changeover section system has been adopted in Japan and Taiwan, and on-board CB off system has been adopted in Korea, France, the U.K., and Italy.

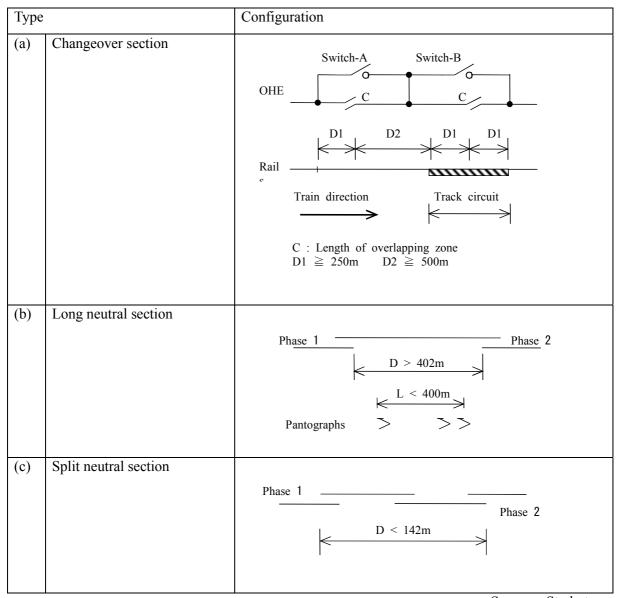


Figure 9.10-30 Type of Neutral Section(NS)

2) Configuration of the Neutral Sections for the Changeover Section

The changeover section has the configuration as shown in Figure 9.10-31. The main devices are the track circuit, switch-A, switch-B, section-A, and section-B. The figure illustrates the down direction for, switch-A is normally on mode, switch-B is normally off mode. Figure 9.10.2.10 shows the power outage state of the train in the changeover section system. The power outage time is about 0.3 seconds, the running speed of the train is about 27m is power outage mileage in the case of 320km/h.

Item		Operation of the train and switches	
(a)	Passing train is before the section-A	31A Q 31B	
(b)	Train passed the section-A	T R 231B	
(c)	Track circuit detected the train (Switch-A off)	T R 231B	
(d)	On switch-B after switch-A Off	T R 31A 0 31B	
(e)	Train passed the track circuit	T R 31A 0 31B	
(f)	Go back the state (a)		

Figure 9.10-31 Operation of the changeover switches when the train passes the changeover section

Table 9.10-13 shows main specification of the changeover switch. Also, Figure 9.10-32 shows photo of vacuum interrupter type changeover switch. The medium high-voltage load break switch (Interrupter) of general, main circuit opening and closing operation recommended numbers is 10 000 times. However, the changeover switch is guaranteeing the operation of 200 000 times in the mechanical life and 100 000 times in electrical life.

Table 9.10-13 Specifications of Changeover Switch

Item	
Rated Voltage	42kV
Rated Current	1 200A
Rated Frequency	50/60Hz
Rated Closing Current	31.5kA
Rated Short Time	12.5kA
Current	
Rated Closing	DC100V
Operation Voltage	
Duty of Operations	O-1secC,
	C-1secO
Power Frequency	
Withstand Voltage	
Phase to Earth	70kV, 1 min.
Terminal to Terminal	84kV, 10 min.
Switching impulse	250kV
withstand voltage	
Capable of Continuance	
Closing/Opening	
Mechanical	200 000 times
Electrical	100 000 times

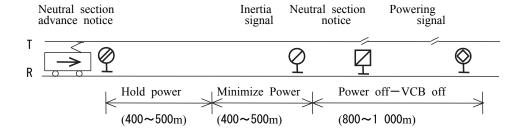
Source: Study Team



Figure 9.10-32 Vacuum Interrupter type Changeover Switch

3) Configuration of the Neutral Sections for the Long neutral Section

The Korea Train eXpress (KTX) as an example where long neutral section (LNS) system is employed. Figure 9.10-33 shows the LNS passing situation. The coasting distance of the train which is the sum of power off-VCB off time and minimum power length is 1 200m to 1 500m, power off mileage has become 800 to 1 000m. Also, the running speed of the train is converted to time in the case of 320km/h, the coasting time is 13 to 16 seconds, and it is 9 to 11 seconds power off time. Auxiliary equipment such as air conditioning also stops power off during this time.



Source Study team Figure 9.10-33 Neutral Section Passing Situation in Korea Train express (KTX)

Problems of on-board CB off method

- (a) Many problems have occurred due to operational mistakes of motormans.
- (b) Speed may drop because the train is coasting in the NS.

For this reason, some countries have developed the changeover section. France carried out tests to install vacuum switch (VS) on the mast, but did not succeed. China and South Korea have also tested thyristor switch system, but have not been successful.

4) Performance results of two neutral sections

Table 9.10-14 shows the evaluation of the PSI side switching method and on-board CB open method.

Table 9.10-14 Performance Results of Two Neutral Sections

Item	PSI side switching	On-board CB Off
	Method	Method
Power Outage time	0.3 sec.	
(at 320km/h)		9 to 11 sec.
(at 160km/h)		18 to 22 sec.
Train Coasting Length		1 200 to 1 500 m
(at 320km/h)	27 m	
(at 160km/h)	14 m	

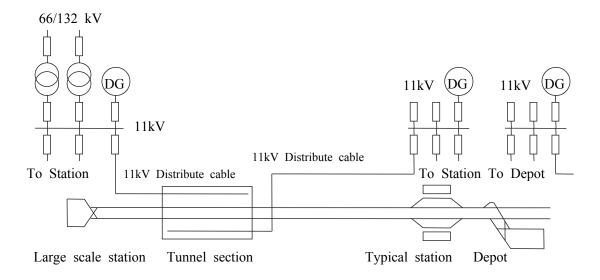
9.10.3 Lights and Electrical Facilities

(1) Overview of Lights and Electrical Facilities

The lights and electrical facilities used in high-speed rail are: (a) distribution facilities for stations, (b) distribution facilities for workshop and depots, (c) distribution cables between stations.

Figure 9.10-34 shows the overview of the distribution cable and high voltage (HV) distribution facilities. The double circuits of incoming 11kV serve as a power source for stations, workshop and depots, and a diesel engine generator (DEG) is also installed as a countermeasure for power outages. However, for large stations such as Mumbai station, an incoming voltage of 66/132kV is used because the power load is large in such stations.

For supplying power to maintenance vehicles, to signals and telecommunication equipment etc. an 11kV power line is installed. This is single circuit, but in order to improve reliability of power supply in long tunnels of 5km or more, double circuits drawn from different directions are installed.



Source Study team Figure 9.10-34 Overview of the Distribution Circuit and the High-voltage Distribution Equipment

(2) Power Distribution Facilities

Power distribution facilities are required for stations, depots, workshops and for drainage facilities of the Thane creek tunnel. Table 9.10-15 shows incoming plan of distribution facilities for stations and depots.

Table 9.10-15 Incoming Plan of Distribution Facility for Stations and Depots

Table 9.10-15 Incoming Plan of Distribution Facility for Stations and Depots						
Station/Depot/Workshop/Drainage		Total Length	Incoming	Nos. of Circuit		
post name		(km)	Voltage (kV)	(Nos.)		
01	Mumbai/station	0.0	66/132	2		
02	Thane creek/drainage post	6.9	11	2 (3)		
03	Thane/station	27.9	11	2		
04	Thane/depot	29.5	11	2		
05	Virar/station	64.9	11	2		
06	Boisar/station	104.4	11	2		
07	Vapi/station	168.9	11	2		
08	Bilimora/station	217.2	11	2		
09	Surat/station	264.5	11	2		
10	Bharuch/station	323.1	11	2		
11	Vadodara/station	396.9	11	2		
12	Anand/Nadiad/station	447.1	11	2		
13	Ahmedabad/station	499.8	11	2		
14	Sabarmati/Station	505.2	11	2		
15	Sabarmati/Centre	507.0	11	2		
16	Sabarmati/Workshop	507.0	66/132	2		
	*	•		•		

9.11 Signalling/Telecommunications

This section describes the proposed Signalling and Telecommunications (S&T) plan for the Mumbai-Ahmadabad HSR corridor. It gives alternative technological options and recommends the most suitable system for the project.

The present Joint Feasibility Study provides the main design features of the signalling and telecommunications for the operation of the line, as also the associated sub systems like passenger information systems and Facility-SCADA, etc. according to the requirements of the new HSR corridor, taking into account the proven systems of Shinkansen and European systems.

The signalling described for the design of the Mumbai-Ahmadabad HSR corridor are:

- Automatic Train Protection (ATP) system
- Fall-Back Block system
- Interlocking device
- Track Vacancy Detection system
- Electric Point Machine
- Systems to realize "Fail-safe" operation
- Power Supply of signalling
- Cable for signalling, and
- Monitoring for signalling

The telecommunications of the Mumbai-Ahmadabad HSR corridor consists of:

- Digital Train Radio system
- Backbone network using Optical Fiber Cable (OFC)
- Public Address (PA) system
- Closed Circuit Television (CCTV) system
- Passenger Information System (PIS)
- Telephone system
- Clock system
- Facility-SCADA (F-SCADA)
- Power Supply of telecommunications, and
- Cable for telecommunications

9.11.1 Signalling

The Signalling shall provide the highest security level to ensure that the operational activities are developed following strict safety requirements. At the same time it shall meet the requirements for efficient train operations and high quality of service.

(1) ATP system

1) ATP system suitable for HSR

Overlooking a wayside signal may cause a serious accident when high-speed trains with more than 250km/h run. It is necessary to indicate allowable maximum speed on on-board monitor continuously and also to control brake automatically in case of over speed.

As mentioned in Section 4.6.4, ATP systems are categorized as shown in Table 9.11-1.

Table 9.11-1 Categorization of ATP System

functions Transmission	attentiveness check, train stop function and others, but without brake supervision	with brake supervision, but without dynamic speed profile	dynamic speed profile
intermittent	Group 1	Group 2	Group 4
continuous	Gro	oup 3	Group 5

Source: "Railway Signalling & Interlocking", Eurailpress, 2009

The ATP Systems belonging to "Group 5" meets the requirement for HSR. Some examples of continuous ATC system with dynamic speed profile used on high speed lines in the world are:

- Digital-ATC
- ETCS Level-2
- CTCS Level-3
- TVM-430
- LZB

These have Continuous update of Movement Authority (hereinafter referred to as MA) & Cab Signaling. The Mumbai-Ahmadabad HSR will have state-of-the-art Cab signal and a continuous control with single-step brake supervision.

2) ATP system with Single-step brake pattern and comparison with Multi-steps brake patterns

Cab signal system is essential for HSR over 250km/h because of visibility and continuous brake control system has excellent responsiveness contributing high safety, high speed and high frequency. In continuous brake control type, conventional ATP system having multi-step brake transmits permitted speed information every block to the on-board device via analog signal sent from the ground. On the other hand, single-step brake type makes the ground equipment send MA including stopping point information by digital signal. The on-board device makes or retrieves single-step speed check profile (single-step braking pattern). And the on-board device compares the train speed and the train position with the speed check profile. Recent digital technology makes ATP system sophisticated. This type is better train control because the on-board device can deal with a lot of data. ATP system with single-step brake achieves better riding comfort for passengers and shortened operation headway which leads possibility for high density operation. (Figure 9.11-1)

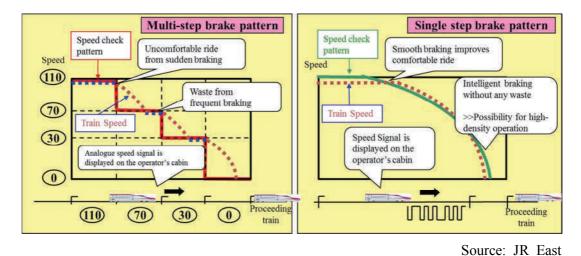


Figure 9.11-1 Difference between Multi-step Brake Pattern and Single-step Brake Pattern

Recommendation for ATP system of the Mumbai-Ahmedabad HSR Corridor

It is suitable for the Mumbai-Ahmedabad HSR to introduce a proven ATP system having continuous control with single-step brake supervision. Among the single-step brake type used in the world HSR, although there are some systems such as Digital-ATC, ETCS Level-2, TVM430 and LZB, the study team has extracted Digital-ATC and ETCS Level-2 from them because TVM430 and LZB are now being replaced with ETCS Level-2 step by step for interoperability among Europe countries based on the interoperability directive of European Union (EU). Comparison between Digital-ATC & ETCS Level-2 for featured elements is shown in Table 9.11-2.

Table 9.11-2 Comparison between Digital-ATC and ETCS Level-2

	Digital-ATC	ETCS Level-2
Safety Integrity Level	SIL-4	SIL-4
Block system	Fixed block	Fixed block
Type of signalling	Cab signalling	Cab signalling
Method for track	Track circuit	Track circuit (AFTC) or axle counter,
occupancy detection	(AFTC (Audio Frequency Track Circuit))	etc.
Transmission method	Rail	GSM-R
of MA		
Braking Pattern	Retrieval of single-step braking pattern	Calculation by on-board device
Deceleration Control	Smooth automatic braking when trains stop at stations	Automatic braking when trains stop at stations
Running distance when train stops	As same as ETCS L-2	As same as Digital-ATC
Line Capacity on new constructed project	As same as ETCS L-2	As same as Digital-ATC
New installation	A few number of equipment -ATC & Interlocking device -Track Circuit -Fixed balises	-Radio Block Centre (RBC) -GSM-R network (MSC and BTS, etc.) -Interlocking -Device for track occupancy detection
		-Fixed balises
In operation as of 2013	2,182km	2,281km
Comparison of cost	As same as ETCS L-2	As same as Digital-ATC

Source: Study Team

Digital-ATC should be recommended as ATP system of the Mumbai-Ahmadabad HSR due to the following reasons:

- Japan Shinkansen HSR with Digital-ATC has no fatality for 50 years.
- Digital-ATC has less equipment than ETCS Level-2, which reduces maintenance cost.
- Digital-ATC has higher safety, availability and reliability.
 - Digital-ATC Hazard Rate: order of 1 x 10⁻¹¹ [1/hour] (ETCS: 0.67 x 10⁻⁹ [1/hour])
 - Digital-ATC Design Specification of Availability: 99.998% (ETCS: 99.985%)
 - In Digital-ATC, all of the devices and networks in equipment room have redundancy configuration.
 - On Digital-ATC number of functional failure of signalling equipment during 2002-2013 is one in JR-East Shinkansen.

Although fall-back system with Digital-ATC is not essential, fall-back system can be provided using train radio system and axle counter if Indian Railways wants.

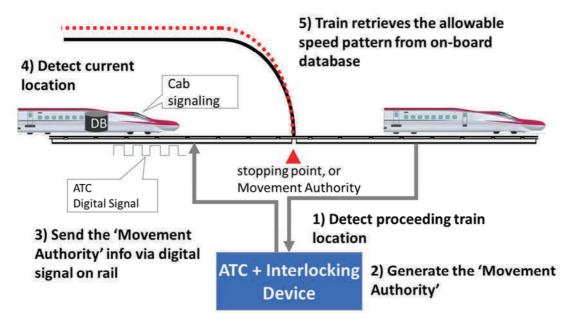
- Digital-ATC has brake pattern stored on high-speed trains, so response time is fast.
- With Digital-ATC, OCC dispatchers can directly send command to high-speed trains when temporarily needed.
- Cost of Digital-ATC and ETCS Level-2 is approximately same.
- ETCS Level-2 seems to be suitable in case of upgrading ETCS Level-1 section because equipment like track circuit can be re-utilized.
- In ETCS Level-2, GSM-R network is necessary to be installed as a sub-system of ETCS Level-2. However, Indian Railways GSM-R frequency band allotted is now only 1.6MHz (952.8-954.4/907.8-909.4MHz), which is not sufficient to control high-speed trains.
- In ETCS Level-2, GSM-R capability to support full requirements of ERTMS is limited, as a result new technological solutions, namely GPRS, are being tried for providing quasi-simultaneous communication with large numbers of trains in densely traffic areas.

4) Digital-ATC System

a) Overview

In Digital ATC system, MA is sent to on-board device of high-speed train via rail from signal equipment room. The on-board device retrieves single-step brake pattern based on the profiles such as running resistance, gradient and speed limits for turnouts and curves from the MA and the location of the train. If the train exceeds the speed indicated by the signal, the speed will be reduced automatically. By having optimal brake control according to individual train functions, the Digital-ATC system can minimize braking loss, shorten the scheduling time, and enhance riding comfort.

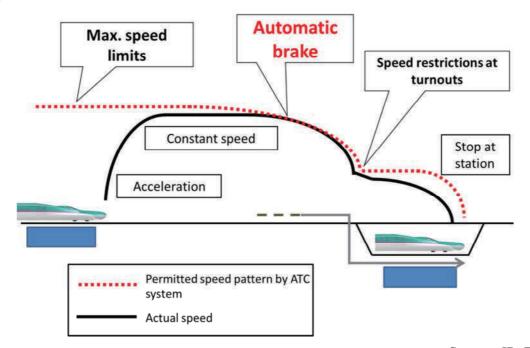
Figure 9.11-2 shows the flow of brake pattern generated by Digital-ATC.



Source: JR East

Figure 9.11-2 The Flow of Brake Pattern Generated by Digital-ATC

Digital-ATC has automatic deceleration up to 75km/h which is consideration of restriction speed of turnout in stations from the operation speed when train stops at stations as shown in Figure 9.11-3.



Source: JR East

Figure 9.11-3 Acceleration and Deceleration of Digital-ATC

As written above, the on-board device stores the profile on geographic condition and permanent speed limit like turnouts and curves in advance. On the other hand, as for temporary speed limit,

OCC dispatchers can directly send command to high-speed trains based on alarms of Disaster Detection and Warning System for rain, water level, wind, and rail temperature. They select the limited speed level and command to the train with assignment of the train number. The on-board system also has transition brake function. This is low-power brake which works before the train speed exceeds the normal brake pattern. Passengers don't feel shock and can have more comfort trip. (Figure 9.11-4)

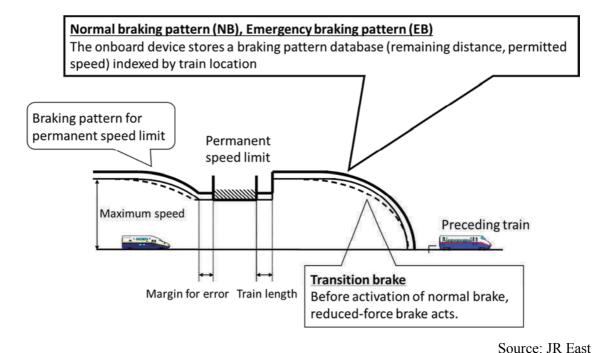


Figure 9.11-4 Brake Pattern of Digital-ATC

b) System function

i) System function

- Stop control for stop point
- Speed control for speed limit point (regular speed control, temporary speed limit for work-site, etc.)
- Cab signal aspect and other information indication

ii) Ground equipment functions

Train detection

Judges a track circuit occupied making with a reception level of ATC telegraphic messages and validity of them

Preparation of track circuit information on which train should stop

Decides a stop track circuit for each movement according to information of the track circuit, route configuration and train protection

Preparation of information for temporary speed limit

When a speed limit for work-site is set, prepares information of the temporary speed limit corresponding to the work site and speed.

ATC telegraphic message transmission

Edits its own track circuit number, stop track circuit number, speed limit for work-site information and others, adds CRC (Cyclic Redundancy Check, bits for error transmission detection) and a sequential number, and sends them to the track circuit. If the ground equipment detects train stop information, it sends an emergency stop signal to a relevant track circuit.

iii) On-board equipment functions

Position recognition

The on-board equipment recognizes a position of the train where it is installed according to signal from a tachometer generator continuously. Also, it corrects its train position according to position information from transponders (balises) installed on the ground.

Speed check patterns (unique function of Digital-ATC)

The on-board equipment has speed check patterns for all track circuits that may be a stop point in advance. The speed check patterns include a service brake pattern (NB pattern) and an emergency brake pattern (EB pattern).

Speed check

The on-board equipment searches a speed check pattern according to information received from rails such as a track circuit number on which train should stop (unique function of Digital-ATC). It compares the speed indicated by the speed check pattern and the speed of its own train, and controls braking.

Temporary speed limit

The on-board equipment searches a speed check pattern for a temporary speed limit according to information of the speed limit for work-site received from rails. It compares the speed indicated by the speed check pattern and the speed of its own train, and controls braking.

Speed indication

The on-board equipment indicates speed on a speed meter device of the cab.

Others

The on-board equipment indicates a pattern allowable speed and a goal on the speed meter device of the cab.

iv) Speed check patterns

Speed check patterns are given to each pair of remaining distance to a stop track circuit end and a pattern allowable speed at that point. A speed check pattern end (the point of which pattern allowable speed is 0 km/h) is a point with a margin for an error of its own train position from the track circuit end. Speed check patterns include the following estimated items.

- Set deceleration of each train type
- Fluctuation of electric brake and mechanical brake
- Running resistance of each train type
- Brake distance margin
- Gradient
- Regular speed limit such as of turnout and curve

The speed check patterns have the following types:

- Emergency brake pattern (EB pattern): Installed in the equipment in advance
- Service brake pattern (NB pattern): Installed in the equipment in advance
- Transition brake pattern : Calculated in each case according to normal speed check pattern

c) System specification

Safety Integrity Level of Digital-ATC system goes far beyond SIL 4 and all of the devices and networks of the system in equipment room has redundancy configuration to achieve tolerance in failure. Redundant configuration of devices and networks enables high reliability.

Digital-ATC can be combined with Electronic Interlocking System, which is multifunctional in small footprint. Carrier wave of Digital-ATC uses MSK (Minimum-Shift Keying) modulation and continuously transmits to on-board device via rail. Carrier frequencies of ATC wave are decided in consideration of harmonics occurred by traction power system using 50Hz. Example of frequency band applied on HSR is shown in Table 9.11-3.

Table 9.11-3 Frequency of ATC Signal Applied on HSR

Item		Frequency	Remarks	
ATC wave (Hz)	Southbound	1,000-1,500 band	ATC signal will be used both on section of track circuit with insulated joints (in stations) and that of non-insulated track circuit (between stations).	
(IIZ)			ATC signal and track circuit with insulated joints	
	Northbound	1,500-2,000 band	will be same wave in stations. ATC signal and non-insulated track circuit frequency between the stations will be different.	

Source: Study Team

Table 9.11-4 shows other basic specifications of Digital-ATC.

Table 9.11-4 Other Specifications of Digital-ATC Applied in the HSR

Table 3:11 + Other opecineations of Digital 71 o Applied in the Hork			
Telegram length	58 bit		
	(Frame length: 75 bit)		
Telegram sending cycle	1,350 m sec		

Source: Study Team

d) System configuration

i) Interlocking ATC integrated logic part

Equipment with interlocking logic and ATC logic: In addition to the interlocking logic, it prepares information of a stop track circuit and a temporary speed limit, and sends ATC telegraphic messages. It has a triple modular configuration (fail-sale configuration by 2 out of 3).

ii) Transmission control part

This part receives ATC telegraphic messages from the interlocking ATC integrated logic part, disassembles and sends them to each transmitter-receiver device. It receives a track circuit reception level and telegraphic message content from each transmitter-receiver, and decides track circuit occupancy. It has a triple modular configuration (fail-sale

configuration by 2 out of 3).

iii) Transmitter-receiver

It responds to each track circuit one-by-one, converts ATC telegraphic messages with MSK modulation, and sends them to each track circuit. Also, it demodulates signals from the track circuits and sends them along with levels to track circuit ground system. It has a double modular configuration.

iv) Integrated monitor

It records status of signals transmitting on track circuits, contents of telegraphic messages, and status of electric point machines

v) Gateway

It transmits necessary information with a neighboring ground equipment.

5) Conclusion

Digital-ATC has higher level of Safety, Availability and Reliability, fully meeting with the operational requirements of the Mumbai-Ahmadabad HSR corridor.

(2) Fall-Back Block system

As already mentioned above, Fall Back system for Digital-ATC is not essential because Digital-ATC has a high reliability and availability. But, if Indian Railways desire a Fall-Back Block system, it can be provided on the Mumbai-Ahmedabad HSR corridor, using axle counters and train radio system.

In case equipment for Digital-ATC fails and becomes unavailable, the Fall-Back Block system can temporarily be worked to maintain safety and smooth operation. When the Fall-Back Block system is operated, it is necessary to check no other trains exist in the protection area to keep safety operation at first. To detect trains between stations, axle counter device will be adopted instead of Audio Frequency Track Circuit (hereinafter referred to as AFTC) in Fall-Back mode as shown in Figure 9.11-5. The axle counter system has function to count a number of trains, to transmit data between equipment rooms, and to monitor the data such as log data on counting and voltage.

Source: JR East Figure 9.11-5 Axle Counter Device as Fall-Back System

In the Fall-Back Block system, the MA is transmitted to the on-board device by Leaky Coaxial Cable (LCX)/radio system based on train detection data by axle counter device. LCX will be laid along the HSR line as shown in Figure 9.11-6. And, LCX will also be used as a transmission method of digital train radio system. Ground signals will be used for block control.



Source: JR East

Figure 9.11-6 LCX Installation Example

(3) Interlocking Device

Interlocking device normally controls equipment such as track circuits and point machines, etc. and safely makes routes for movement of the trains. In HSR system, the Electronic Interlocking (hereinafter referred to as EI) shall be recommended due to sophisticated data transmission and reduction of a number of devices as well as enhancement of safety. At first, comparison between the EI used in Digital-ATC and that of ETCS Level-2 is shown below.

1) Comparison between the case of Digital-ATC and that of ETCS Level-2

In case of Digital-ATC

In Digital ATC, a type which integrates Digital-ATC with EI can be introduced. This integrated system can share logical processing unit, power supply unit, and so on. The EI with Integrated Digital-ATC will be with SIL 4 with redundancy devices. Figure 9.11-7 shows overview of signalling configuration with the EI function integrated with ATP function of Digital-ATC in stations.

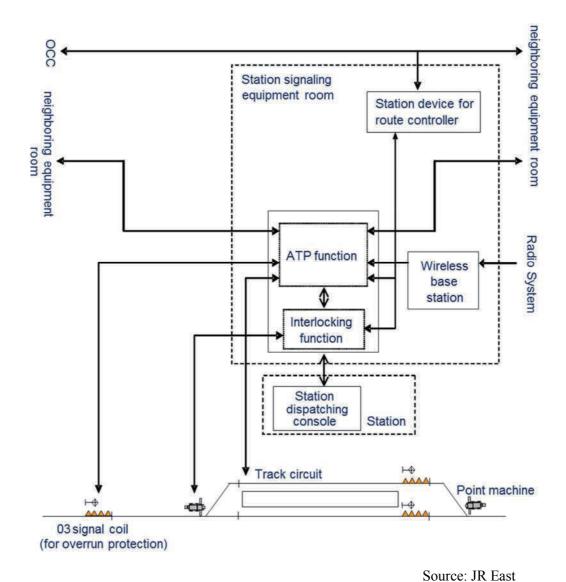
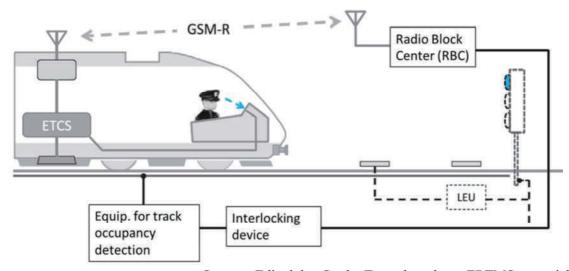


Figure 9.11-7 Overview of Signalling Configuration at Stations

Site equipment like track circuit and electric point machines shall directly be controlled by IC unit mounted in interlocking system using surge protective devices. And the system shall automatically make train routes based on train diagram and route data stored in a station controller for route controller. Daily train diagram and route data are periodically transmitted before the operation day from operation control system in OCC via telecommunication network.

In case of ETCS Level-2

On the other hand, ETCS Level-2 has an EI which is different from ATP system. The EI reports the status of objects controlling the routes of the train to the Radio Block Centre (hereinafter referred to as RBC) which in turn generates the correct MA for the different trains in the section. The interface between the EI and RBC has not been commonly specified resulting in adoption of project specific solutions. (Figure 9.11-8)



Source: Edited by Study Team based on ERTMS material

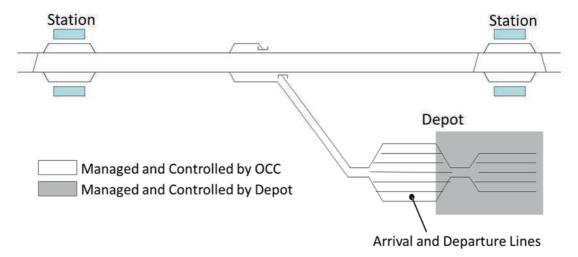
Figure 9.11-8 Interface between Interlocking and RBC on ETCS Level-2

2) Conclusion

On the Mumbai-Ahmadabad HSR corridor, it should be recommended EI of a type which integrates Digital-ATC with EI. The EI integrated with Digital-ATC has been used on Shinkansen HSR, which has lesser equipment and is more reliable, has SIL 4 Safety Integrity Level and has been successfully working for 9 years. The same is recommended for the Mumbai-Ahmedabad HSR.

3) Shunting control and management in depot

Area that OCC supervises high speed trains should be up to arrival and departure lines in depot. In depot, dedicated interlocking system should be installed and signal controllers of depot sets route control for shunting. (Figure 9.11-9)



Source: Edited by Study Team based on JR East material

Figure 9.11-9 Shunting Control and Management in Depot

(4) Track Vacancy Detection system

1) AFTC for the HSR

The use of audio frequencies permits the physical limits of an individual track circuit to be defined by tuned electric short-circuits between the rails rather than by insulation in the rails. AFTC system basically consists of following modules:

- Transmitter
- Receiver
- Tuned Unit (TU)
- Power Supply Unit (PSU)
- Surge arrester-Protections against lightning
- Leads/Connections and fastening to rails

2) AFTC should be on the Mumbai-Ahmedabad HSR corridor

In HSR systems in the world, AFTC is normally used. AFTC is the most proven and safest train detection device for HSR in the world. AFTC is also suitable for HSR system due to easily making non-insulated track circuit and having strong tolerance for power traction system. In the Mumbai-Ahmedabad HSR with the maximum speed of 320km/h, track circuit is strongly recommended as a device for track vacancy detection, not axle counter device. That is why track circuits fail-safe device and can be used to easily detect rail breakage in long distance section.

3) Recommended Track Vacancy Detection system

AFTC

The AFTC used in Digital-ATC recommended as ATP system shall be recommended for the Mumbai-Ahmedabad HSR. Example of frequencies for the AFTC applied in main line of the HSR is shown in Table 9.11-5. The frequency of the AFTC is decided in consideration of harmonics using 50Hz in the HSR, and adjacent track circuits use different carrier frequencies. The signal level adjustment function of the AFTC device automatically changes the boarder of occupancy track or vacant. Moreover, capacitors are installed between rails to improve transmission loss. So it is basically unnecessary for maintenance staffs to adjust the level of the AFTC. In stations, the AFTC with insulated rail will be used to make a boundary between track circuits clear.

Table 9.11-5 Frequency of Track Circuit Device Applied in the HSR Main Line

Item		Frequency	Remarks
Track circuit	Southbound	1,000-1,500 band	Used for train detection on section of
in stations			track circuit with insulated joints (in
(Hz)	Northbound	1,500-2,000 band	stations)
			The same signal as ATC signal
Track circuit	Southbound	1,500-2,000 band	Head for train detection on
between			Used for train detection on
stations	Northbound	2,000-2,500 band	non-insulated track circuit (between
(Hz)			stations)

Source: Study Team

Carrier wave of the track circuit device uses MSK (Minimum-Shift Keying) modulation as well as ATC signal. Standard track circuit length will be approx.1km to 1.2km. AFTC functions without any problems in section with the leakage conductance about 1.0 S/km. And, the use in submarine tunnel section with much leakage conductance (Max. 3.0 S/km is supposed) is proved as shown in Figure 9.11-10. The HSR shall install capacitors between rails every some intervals and shall not make grounding with rail to stably work. AFTC will mainly be used in main line. In depot, another track circuit will be used except for AFTC area.



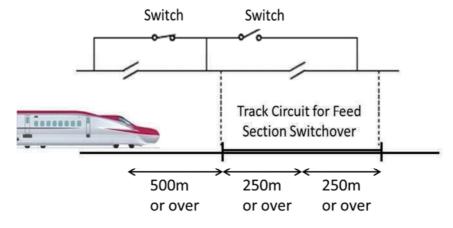
Source: JR East Figure 9.11-10 AFTC to Work in Much Leakage Conductance Section

> 03 signal coil for overrun protection

03 signal coil is a kind of track circuit which composed of cable installing along rails and the length is 50m. These circuit will be in front of next block section boundary because the device will transmit to the train with less than 5km/h of the speed that on-board tachometer generator may recognize error and prevent passing over dangerous boundary.

Track circuit for section with changeover switch

To make it possible for trains to accelerate on feeding section at substations and sectioning post, the HSR will have section with changeover switch. Dedicated track circuits will be installed due to trigger for switches. Figure 9.11-11 shows track circuit for section with changeover switch.



Source: Study Team

Figure 9.11-11 Track Circuit for Section with Changeover Switch

(5) Electric Point Machine

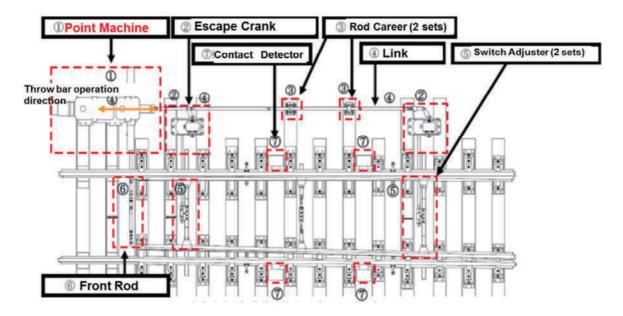
Although various point machines are used in railways, electric point machines are mainly used in HSR sections in the world. The Mumbai-Ahmedabad HSR shall have proven electric point machines for a long time due to highly important equipment in operation with maximum 320km/h, especially in main line. The point machine shall be high power and reliable, that is, to provide connected rail with strong force, to endure strong vibration and have robust lock function.

1) Recommended electric point machine

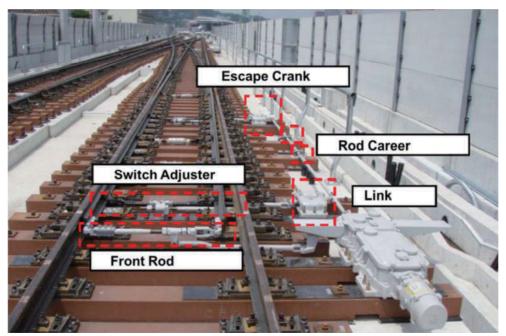
a) Overview

Electric point machine introduced in the Mumbai- Ahmedabad HSR shall be HSR-proven electric point machine compatible with interlocking device. Point machine recommended in the Mumbai-Ahmedabad HSR is stated below.

Switches to control motor in electric point machine shall be installed in equipment room due to preventing dangerous wrong switching by accident of grounding fault, vibration and lightning, etc. At standard turnout in main line, 2 point machines shall be used. Figure 9.11-12 and Figure 9.11-13 shows how to install point machines at tongue rail part and swing nose part in main line of the HSR, respectively. The length of control of point machine for tongue rail part is about 10m. The length of control of point machine for nose part is about 4.5m.

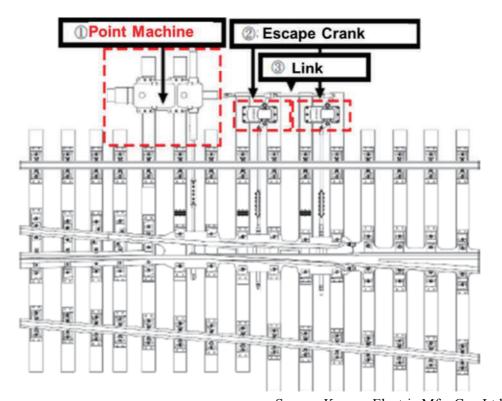


Source: Kyosan Electric Mfg. Co., Ltd



Source: Kyosan Electric Mfg. Co., Ltd

Figure 9.11-12 Electric Point Machine at Tongue Rail Part in Main Line



Source: Kyosan Electric Mfg. Co., Ltd



Source: Kyosan Electric Mfg. Co., Ltd

Figure 9.11-13 Electric Point Machine at Swing Nose Part in Main Line

As for electric point machines in depot, a type used in conventional line shall be accepted because train speed is slow.

b) System specification of the point machine used in main line

Table 9.11-6 shows specification example of the electric point machine recommended in main line for the Mumbai-Ahmedabad HSR. And, Table 9.11-7 shows a number of the electric point machines in main line.

Table 9.11-6 Basic Specification of the Electric Point Machine Recommended in Main Line

	Tolerance	for vibration	Stroke	e (mm)	Max. Load	Switching
Motor	Frequency (Hz)	Acceleration (m/s ²)	Moving Rod	Lock Rod	(kN)	Time (sec)
AC Single Phase	500-1000	About 190	200	85-190	About 10	less than 10sec

Source: Study Team

Table 9.11-7 A number of the Electric Point Machines in Main Line

Table 6:11 7 7 Trainber of the Electric Fount Machines in Main Eine				
Turnout	Limited speed for reverse side	Number of motors at tongue rail part	Number of motors at swing nose part	Remarks
1:18 (length: 71m)	80 km/h	1	1	Standard turnout

Source: Study Team

c) System configuration of the point machine used in main line

i) Motor

A capacitor activated type induction motor, symmetric two phases 6-pole single phase, with a sealed ball bearing

ii) Gear

A three-stage deceleration mechanism consisting of one pair of bevel gear, and two pairs of spur gear: To reduce abrasion loss of the bearing part, a final switching gear has a cylindrical roller bearing, and the other gears have sealed ball bearings.

iii) Friction clutch

After completion of switching, to prevent impact to the mechanism during rotation and stop of the motor, an hydraulic oil sealing, non-adjustable torque type friction clutch is installed between the large bevel gear at the first-stage and the small spur gear at the second stage, and absorbs the inertia and protects the motor in case of over-load or partway interference.

iv) Switch and lock movement

It is driven by the switching rod roller. A lock piece is driven when the switching roller is moving on the escape surface of the switching rod, and locks the lock rod and the switching rod. Traveling of the lock piece is 50 mm, and mutual interval with the lock rod notch is 1.5 mm.

v) Circuit controller

It is an insertion type three-position controller with mutual interlocking of the lock piece. The circuit controller lever is moved by 10 mm in the left and the right by the crank attached at the bottom frame, and releases a motor contact point and closes a display contact point after the electric point machine completes switching and locking. When switching operation is going on (in other words, unlocking), it closes the motor contact point and a display circuit shorting contact point, and opens the display contact point.

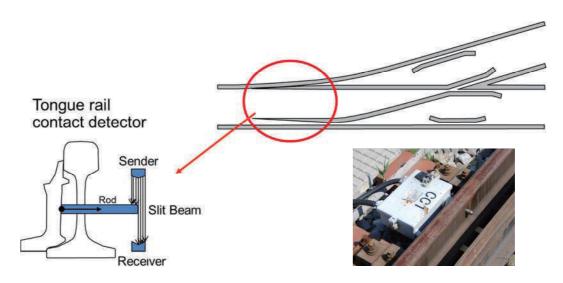
vi) Measuring terminal board

Terminals for measuring display circuit voltage and motor circuit voltage are prepared.

vii) Manual device

When an operator opens a small lid at the motor side on the external box top and fits the safety switch lever to the handle insertion hole, the motor circuit is blocked off and the operator can manually switch with an attached manual handle. In this case, when the operator completes manual switching and locking, a white arrow pointing the switching direction is displayed in the small lid window at the switching rod side on the external box top. When switching operation is going on and the lock is released, the circuit control driving crank interlocks and the white arrow is not displayed.

Furthermore, to prevent serious accident like derailment, the HSR shall have "tongue rail contact detector" to check whether tongue rail and basic rail closely contacts. The device shall be checked by optical sensor which is no problem to function in rainfall and dust. (Figure 9.11-14) The information will be sent to station EI.



Source: Kyosan Electric Mfg. Co., Ltd

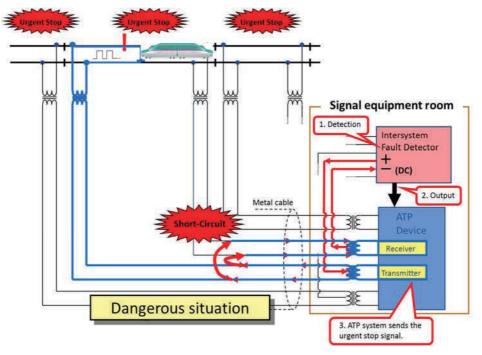
Figure 9.11-14 Installation of Tongue Rail Contact Detector

(6) Systems to realize "Fail-safe" operation

The Mumbai-Ahmedabad HSR corridor shall have various systems and functions to realize "Fail-safe" operation based on Shinkansen experience. The some systems has been introduced in shown below.

1) System to detect intersystem fault

This system has a function to transmit emergency stop signal in case of occurring intersystem fault in the same signal cable. The procedure shows in Figure 9.11-15.

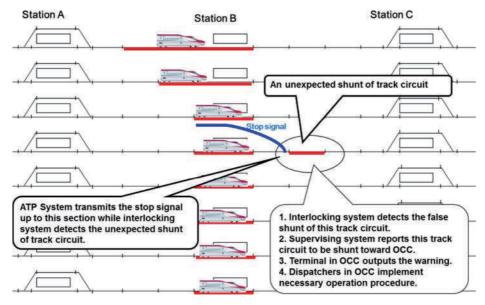


Source: JR East

Figure 9.11-15 The System to Detect Intersystem Fault

2) Function of Interlocking device to prevent collision between high speed trains

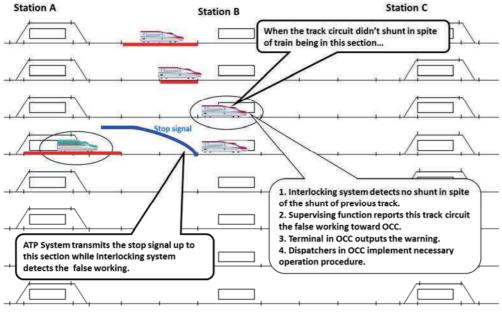
Interlocking device always monitors movement of trains in block order. However, if an unexpected circuit shunt occurred, ATP system would transmit stop signal while interlocking detects unexpected shunt as shown in Figure 9.11-16.



Source: JR East

Figure 9.11-16 Function to Prevent Collision in Case of Unexpected Circuit Shunt

Similarly, in case track circuit doesn't shunt in spite of train being in a section, ATP system transmits the stop signal up to the section while interlocking detects the false working as shown in Figure 9.11-17.

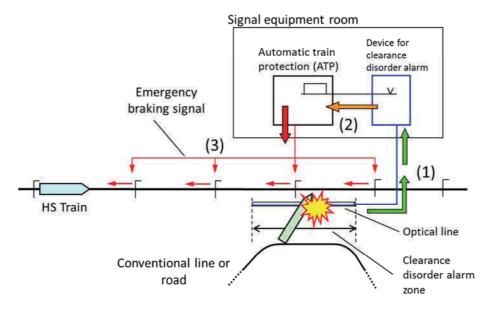


Source: JR East

Figure 9.11-17 Function to Prevent Collision in Case of No Occurrence of Circuit Shunt

3) System to prevent collision with conventional trains or cars

This system would stop related high speed trains if conventional trains parallel with HSR or cars running on nearby roads derailed. Optical cable is laid on fences and walls at the boundaries between HSR and conventional lines or roads. If conventional trains or cars overturn over the boundaries, the trains or the cars is supposed to make these cables cut off. Therefore the system realizes an emergency situation and sends the signal for emergency stop automatically. (Figure 9.11-18)



Source: JR East

Figure 9.11-18 System to Prevent Collision with Conventional Trains or Cars

(7) Power Supply of signalling

Power for signalling will be supplied from each station and intermediate equipment room. Power from overhead equipment will also be used as an auxiliary power. Regular power will be redundant loop configuration. On power receiving, insulated transformers will be installed in each receiving power point. Power supply devices consist of power distribution boards, insulation transformers with box housing, Uninterruptible Power Supply (UPS), rectifiers and batteries.

(8) Cable for signalling

Signal equipment installed in signal equipment rooms will connect with wayside equipment via cables along the HSR line. Cables are basically laid in the duct which will be installed by civil construction work. In tunnel sections, cables are installed at wall of tunnels.

(9) Monitoring for signalling

Almost of signal equipment shall be monitored at OCC and maintenance centers installed in each station, etc. for finding equipment breakdown and preventing failure in advance, using Facility-SCADA. Dispatchers in OCC will check and supervise these data so that they can precisely instruct maintenance staffs to repair failure equipment and control train operations.

9.11.2 Telecommunications

Almost of telecommunications can utilize the same system as that of conventional line. However, digital train radio system and backbone network should be considered for safe and reliable operation of HSR.

(1) Digital Train Radio System

1) Digital Train Radio System suitable for the HSR

The Mumbai-Ahmedabad HSR shall introduce train radio system with digital transmission as stated in Section 4.6.4.

Comparison between digital train radio systems used in world HSR systems is shown in Table 9.11-8.

Table 9.11-8 Comparison between Digital Train Radio Systems

	Dedicated Type	GSM-R	TETRA	
Type of radio transmission	LCX	Space radio	Space radio	
Modulation type	π/4 DQPSK	GMSK	π/4 DQPSK	
Voice quality	High	Normal	Normal	
Data rate	691.2kbps (high)	270.8kbps (middle)	36kbps (low)	
Channel bandwidth	518kHz	200kHz	25kHz	
Typical cell size	Along a railway line	5 to 10km	10 to 25km	
Comparison of cost	1	11	11	
Special applications for HSR	 Command transmission Vehicle support Passenger info. Fall back system to Digital-ATC 	- Command transmission	- Command transmission	
Remarks	Combination with Space Radio in some area is possible	Installation of LCX is required in long tunnel and place where it is difficult for radio waves to penetrate.	Installation of LCX is required in long tunnel and place where it is difficult for radio waves to penetrate.	

Source: Study Team

Study team recommends the dedicated system using LCX which has high voice quality and data rate. This type will have applications like passenger information and command transmission as shown in figure 9.11-19, and this can also be used as fall-back system to Digital-ATC if Indian Railways want.

The system consists of central control device, control station device, base station device,

repeater, and LCX cables. There is a dedicated maintenance system which can monitor, control, measure each equipment from OCC and maintenance centers.

Voice communication between crews and OCC



Vehicle support system



Send information shown on driver cabin motor to control center to advice driver in case of vehicle trouble

Command transmission system



Shows operation change information on driver cab monitor

Passenger Information service



News and train information is shown on LED display for customers

Source: JR East

Figure 9.11-19 Applications of the Dedicated Train Radio System using LCX

The system function, basic specification and configuration are shown below. Details of GSM-R and TETRA are excluded from this report because Indian Railways had already introduced their systems.

2) System function of the dedicated Digital Train Radio System

There are two major functions of the dedicated type, a voice system and a data system.

- a) Voice function
- i) Telephone function for traffic control

Telephone system for communication between a train dispatcher and drivers

ii) Telephone function for passenger services

Telephone system for passenger services between a dispatcher and train conductors

iii) Communication line for service and public

Telephone system for communication between train crews and industrial civil service organizations

iv) Operation broadcasting information

Broadcasting of train dispatchers to drivers

v) Conductor broadcasting information

Broadcasting of dispatchers for passenger services to conductors (dispatchers for conductors only)

b) Data transmission function

i) Traffic control notice

Data of dispatchers for crews from train dispatchers are transmitted and displayed on the on-board monitor.

ii) Traffic control

MA is transmitted via LCX cable as fall-back system of Digital-ATC, if necessary.

iii) Passenger information

Data of train delays, transfer to conventional lines and other information for passengers on-board from dispatchers for passenger services are transmitted and displayed on the on-board LED indicator.

iv) Monitoring train radio equipment

Troubles and operation state of the on-board radio equipment are transmitted to dispatchers in OCC.

v) Vehicle technology support

Data of train operation state, vehicle equipment state, and other related information which the vehicle monitor monitors are transmitted to train dispatchers in OCC.

3) System specification of the dedicated Digital Train Radio System

The dedicated train radio system uses the Time Division Multiple Access (TDMA) system for their digital train radio communication and generates multiple channels with their unique sound CODEC called "RL-CELP," which is a suitable voice coding system for the train radio communication in HSR.

Table 9.11-9 shows basic specifications of train radio system used in the Mumbai-Ahmedabad HSR.

Table 9.11-9 Specifications of Train Radio System Used in the Mumbai-Ahmedabad HSR

Basic		(Base station transmission)
specification	A	Time Division Multiplexing system
	Access system	(Mobile station transmission)
		Time Division Multiple Access system
	Modulation	(Base station transmission) $\pi/4$ DQPSK
	Modulation	(Mobile station transmission) $\pi/4$ DQPSK
	Eraguanav	(Base station transmission) 900 MHz band, 1-wave
	Frequency	(Mobile station transmission) 900 MHz band, 1-wave
	Transmission	(Base station transmission) 2 W
output		(Mobile station transmission) 4 W
Quality	Service area	Available for 99.99% or more in all sections
	Bit error rate	1×10^{-4} or lower
	Voice	Voice coding system RL-CELP (Very high-clear voice)
	VOICE	Transmission speed 5.6 kbps
	Data	Data rate Approx. 700kbps

Source: Study Team

4) System configuration of the dedicated Digital Train Radio System

The overall radio zone is divided into each base station, which is the minimum unit for the train radio, for the radio line control. When dispatchers call a train crew member from OCC, they specify a train number, or specify an area where the relevant train exists and calls it by voice. The area specified by the director who uses the voice call system is called "call zone" (of which minimum unit is a radio zone). Since the area is defined in consideration of the operation system of directors, the call zone for the telephone system for traffic control has a different size from that of the call zone for the telephone system for dispatcher for passenger services.

a) Central apparatus

- i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station
- ii) Connection of the control operation desk and other equipment with the train radio system
- iii) Monitoring terminals are set up at the OCC and they can supervise on-board equipment installed in high speed trains in real time.

b) Control station device

- i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station
- ii) Voice line and data line control for the communication line for service and public between the control station and the mobile station
- iii) Tracking control of voice line
- iv) Connection of telephone system

When a call is continuing even when a train enters into the neighbor zone, the control station device tracks that call so that the communication is maintained in the neighbor zone. For that purpose, it is necessary to reserve a common channel in surrounding zones in advance and to disable that channel in other trains.

c) Base station device

- i) Transmission and reception of electric waves with the mobile station devices
- ii) Conversion between radio signals and signals for wire communication

d) Relay device

i) Amplifier to compensate LCX transmission loss

e) LCX

- i) Propagation and radiation of electric waves sent from the base station
- ii) Reception and propagation of electric waves sent from the mobile station
- iii) Transmission of the relay device power

f) Mobile station device (on-board)

- i) Voice line and data line control for the telephone systems for control and traffic control notices between the central apparatus and the mobile station
- ii) Voice line and data line control for the communication line for service and public between the control station and the mobile station

iii) Connection of the operating panel and other on-board equipment with the train radio system

As shown in Figure 9.11-20, LCX cables shall be installed at both sides of the HSR line.

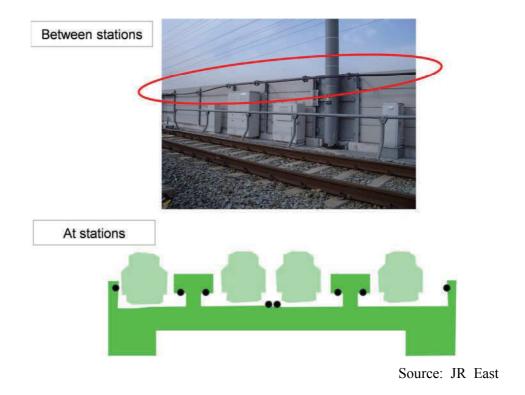


Figure 9.11-20 LCX Layout along HSR Line

(2) Backbone network using OFC

1) OFC system

An OFC system to give end to end communication connection between distant places and to provide connectivity through every site locations along the section will be provided. The size of the OFC will fully meet with the applications need of the HSR line and commercial exploitation of the Telecommunication Network by the HSR.

2) Synchronous Digital Hierarchy (SDH) network

This network is SDH network by Fiber Optic Transmission (FOT) with Optical Fiber Cable (OFC), which consists of STM-16 (2.4Gbps) as main communication network and STM-4 (600Mbps) as local communication network. Network using OFC has a feature that data can be transmitted with low loss so that there are no repeaters between SDH equipment. IP network shall not have important data like transmission of train control signal because the network requires high reliability.

Main communication network provides a high reliable multiple single paths in 4-fiber MS-SPR (Multiplex Section Shared Protection Ring) topology with STM-16 covering signal equipment rooms in stations and depots and OCC. The 4-fiber MS-SPR topology can be used by 100% for protection channel or for extra traffic and support ring switch and span switch. Local

communication system provides voice and data signal paths in 2-fiber MS-SPR topology with STM-4 covering Substations (SS), Sectioning Post (SP) and Sub-Sectioning Post (SSP), etc. In the 2-fiber MS-SPR topology, 50% of the band can be used for protection channel or for extra traffic and only ring switch is supported.

A Network Management System (NMS) shall be installed at OCC. And the network shall be synchronized by the information based on the National Telecommunication Reference Clock (NTRC). This reference clock shall also be installed at OCC.

3) Gigabit Ethernet network

To support comparatively unimportant facilities for the HSR operation like CCTV, ticketing system maintenance management system and Wi-Fi network, etc., a Gigabit Ethernet network shall be used. This network shall use the same OFC as the SDH network. The network is supposed to be 10 Gigabit Ethernet network.

(3) Public Address (PA) system

PA system shall be provided to broadcast voice messages to passengers and staffs in each station. It includes a network of amplifier and speakers linked to the station. The system shall also be used for urgent broadcast in emergency and connect Passenger Information System (PIS) to inform passengers of information on train approaching and operation situation automatically.

(4) Closed Circuit Television (CCTV) system

CCTV system shall be provided for real-time and visual supervision through the color displays, selecting specific location or all the public area in stations as well as in OCC, tunnels, substations and depots. These can mainly be monitored at station master's room and station cabin and at the OCC. CCTV system will consist of transmission equipment, remote camera, controller, monitor and video recorder. CCTV camera signals from selected area will be recorded by video recording device. And, CCTV monitor will be provided for displaying real-time pictures of each camera and recording playback.

(5) Passenger Information System (PIS)

PIS shall inform passengers of the state on the train operations such as timetable, departure and arrival of each train. And information for safety, train delay and emergencies shall be also displayed. OCC shall be able to control, monitor and communicate to any stations through PIS. And, operation control system installed in OCC shall also automatically control PIS.

(6) Telephone system

Telephone system will consist of dispatch telephone, PABX (Private Automatic Branch Exchange) and wayside telephone.

1) Dispatch telephone system

Dispatchers at OCC and staffs at each station, depot, workshop, maintenance depot, substation, signal & telecommunication equipment room, etc. will make communications with dispatch telephone. This telephone will be used for the purpose of conveying situation of train operation, electric power and signalling & telecommunications. Dispatchers at OCC shall have the highest

priority to communicate to any stations, etc. via the dispatch telephone.

In the dispatch telephone, an integrated communication console will be provided at OCC. The console enables dispatchers to communicate with station staffs, depot staffs and maintenance staffs by dedicated communication line. And, concentration equipment will also be used to concentrate and control local telephone lines. Two type of concentration equipment will be provided. Master Concentration Equipment (MCE) will be installed at OCC to interface with Communication Console and Remote Concentration Equipment (RCE) will be installed at stations, depots and substations, etc. to interface with Multiple Function Dispatcher Telephone.

2) PABX telephone system

This system will consist of digital PABX and telephones installed at OCC, stations, depots and maintenance depots, etc. Each telephone will have dialing function to connect branch exchange system. The PABX can interface with public telephone line and dispatch telephone system.

3) Wayside telephone system

Wayside telephone sets will be installed every approx. 500m of interval in underground and tunnel section. And, in open section such as embankment and viaduct, they will be installed every approx. 3,000m. These telephones will be used mostly for maintenance work and also for emergency.

4) Voice Recording System (VRS)

A centralized digital Voice Recording System (VRS) shall be provided at the designated place to record all telephone conversations of all dispatchers at OCC and at stations.

(7) Clock system

This system is used to supply reference standard time to locations where time will be displayed, read and recorded. The system will consist of a master clock and slave clocks installed at OCC, stations, depots and maintenance depots. The main master clock will be located at OCC and acquires clock correction signal from GPS. The accuracy shall be within 1.0 second time error per week. Each local master clock shall be synchronized with main master clock at OCC using backbone network and provide other subsystems with standard clock signal. All the slave clocks shall be interconnected with related local master clock.

(8) Facility-SCADA (F-SCADA)

F-SCADA (Supervisory Control and Data Acquisition) can realize that dispatchers in OCC confirm and monitor condition of equipment and data on measurers for disaster information, so they can precisely instruct train crews and maintenance staffs and control train operations to prevent failures. F-SCADA continuously monitors equipment status in OCC. In case of equipment failure, the information is transmitted to OCC in real time and displayed on the monitor with buzzing sound. In addition, F-SCADA terminals are installed at each maintenance office and equipment failure information can be obtained there at the same time as OCC.

In the F-SCADA introduced in the Mumbai-Ahmedabad HSR corridor, the following items shall directly be monitored by OCC dispatchers:

Stations equipment

Elevator, Escalator, Ticketing terminal, Lighting, Shutter, Pump, Fire alarm, Ventilation, Air Conditioning and Engine Generator, etc.

Signalling and Telecommunications

ATP system, Interlocking device, AFTC, Electric Point Machine, Radio system, LCX, OFC, PA, CCTV, Clock system, PABX, Fire alarm, PIS, Cable, Power Supply, etc.

Power distribution system

Power distribution board

- Disaster information

Wind, Rainfall, Water level in big river, Rail temperature, Earthquake and o utside temperature

In addition to the above-mentioned system, the HSR shall have measurers for rainfall, water level, wind speed, rail temperature and earthquake.

(9) Maintenance Management Information System

Maintenance Management Information System to record maintenance for rolling stock, track, power supply and signalling & telecommunications is described at the latter chapter in this report.

(10) Power Supply of telecommunications

Power supply for telecommunications needs to have reliability and high quality due to handling electronic device. Power for telecommunications will be supplied from each station and intermediate equipment room. Power supply devices consist of power distribution boards, insulation transformers with box housing, Uninterruptible Power Supply (UPS), rectifiers and batteries.

(11) Cable for telecommunications

Cables for telecommunications are basically desirable to use non-halogen flame retardant cable except OFC.

9.11.3 Cost Comparison of S&T Systems

(1) Cost comparison based on the differences in system combination

Table 9.11-10 shows cost comparison between combination of Digital-ATC System and the dedicated Train Radio System using LCX and that of ETCS Level-2 and GSM-R in the Mumbai-Ahmadabad HSR. The study team considered that the proposed system which consists of Digital-ATC and Train Radio System using LCX has the almost same cost as the system including ETCS Level-2 with GSM-R.

Table 9.11-10 Cost Comparison Based on the Differences in System Combination

System combination	Digital-ATC + Train Radio System using LCX	ETCS Level-2 + GSM-R
S&T cost	INR 24,595 million	INR 25,628 million

Source: Study Team

(2) Cost comparison between the joint F/S and the Pre-F/S

Table 9.11-11 shows cost comparison between the proposed system in the joint F/S and that of the Pre-F/S implemented in 2009.

Table 9.11-11 Cost Comparison between the F/S and the Pre-F/S

Report	F/S (2014)	Pre-F/S (2009 -> 2014)
S&T cost	INR 24,595 million	INR 37,197 million (*)

^{*}The present escalated cost based on estimation cost in 2009 (Inflation rate of 57.75% using IMF)

Source: Study Team

About contents proposed in the Pre-F/S,

- -Cost of OCC-related system is included in S&T category.
- -Many signal routes and cross sections are needed for bi-direction operation.
- -The HSR has equipment for interoperability and replacement of existing system.

The above factors may cause occurrence of the cost difference shown in Table 9.11 -11.

9.12 Operation Management System

9.12.1 Roles and Requirements of Operational Control Center

As one of element which support to "Safety and Sustainable Train Operation in high-speed rail", it is needless to say, Operational Control Center (OCC) is significant. Following matters are roles and requirements for OCC.

Role:

- Management of Train Operation
- Supervising

Track Facilities (Permanent Way, Power Supply, Signaling, communication, etc.) Weather Condition (strong wind, heavy rainfall, earthquakes, etc.)

Requirement:

- Real time Information Tracing of Train and Facilities
- Trouble Shooting in case of accident (Operation Arrangement, Train-Set Distribution, Driving Crew assignment, etc.)
- Notification for Station, Crew, Maintenance Depot and Passengers

To satisfy these requirements, OCC has also changed with technological progress and transition of transport year by year.

9.12.2 Historical Progress of Train Operation Controlling System

The first step of a Train Operation method is the leading by stations. Transport officers, who substitute the mission of train operation only for stationmaster, were placed in each station. They decided to the operation schedule, arrival and departure of the train, at the adjacent station each other. Also there were traffic dispatchers, however, dispatchers had no real time information about traffic situation, such that train location, delay time and so on, in this method. All information depends on station. So they had to confirm with each station staff and recorded the actual operation. Therefore, this method is not suitable for high density and high speed train operation.

The second step is the Centralized Traffics Controlling system (CTC). It was developed for single track and local lines in United States of America (USA) in 1927 to provide efficient train operation. Dispatchers controlled the all train passing route from central controlling center, instead of Transport officers at station. The device was composed of relay logic circuit.

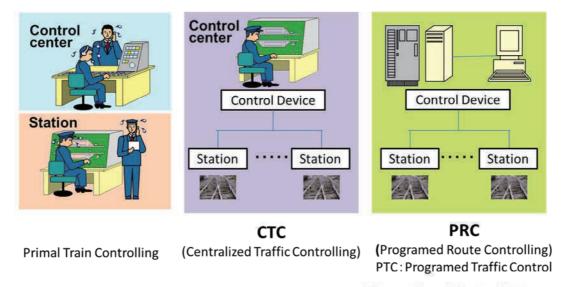
When Japanese National Railways (JNR) revealed the Tokaido Sinkansen line in 1964, CTC was applied to the High Speed Railway and trunk line. It was the first success in the world. JNR regarded that centralized operation management was essential in high-speed rail in particular. Because High speed Train operation needs "unified high speed decision-making". This system was composed of solid-state transistor devices. At this period, traffic dispatchers were controlling the train passing route by manual.

And then the train Operation Controlling System has developed, which is able to control the train route automatically by computer. This is the Programed Route Controlling (PRC). But

when the traffic incident occurred, it was necessary to change the train schedule. So that the man and machine interface device, which were able to change the train schedule, were added. In general, this is the Operational Control System

In 1972, when the Sanyo Shinkansen, which was extended from the Tokaido Shinkansen to west, was started on services, in this opportunity JNR adapted the PRC, named COMTRAC(Computer aided Traffic Controlling system). This system was automatically controlling the train route by computer with the inputted scheduling data beforehand.

In this way, Operation Controlling System has been developed and applied for not only high speed railway but also the city railway. It has been one of the symbols of the modern railway operation.



Operational Control Systems

Source: Study Team

Figure 9.12-1 Progress of Train Operation Methods

9.12.3 Example of Operation Controlling System

(1) Japanese Shinkansen

1) COMTRAC and SIRIUS

As mentioned above, COMTRAC has been developed for Tokaido and Sanyo Sinkansen. It is composed of three Sub-systems, as follows.

- a) EDP (Electronic Data Processing Computer) system
 - -Drawing a train diagram on the computer and Submitting diagram concerning section
- b) PRC (Programmed Route Control) system
 - -Controlling the train passing route and diagram arrangement in case of accident
- c) MAP (Man-Machine Advanced Processor) system
 - -Displaying the traffic information to mimic display by human and machine interface

SIRIUS (Super Intelligent Resource and Innovated Utility for Shinkansen Management) is the new system for Kyuushu Sinkansen and almost same performance for COMTRAC. Due to SIRIUS and COMTRAC are connected on line and real-time, it is possible to provide the direct through train operation between Sanyo Shinkansen and Kyushu Shinkansen.

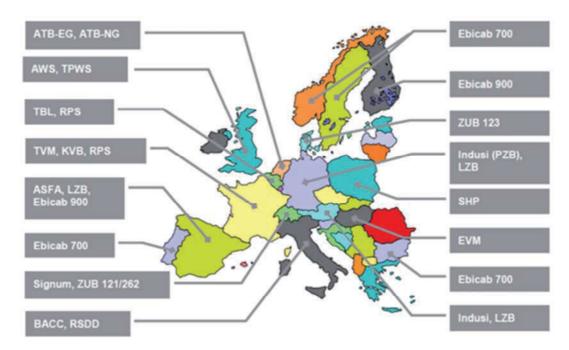
2) COSMOS (Computerized Safety, Maintenance and Operation Systems of Shinkansen)

The East Japan Railway Company (JR East) developed new two types of Operation Controlling System by using of the autonomous decentralized system in the late of 1990s. One is COSMOS for Japanese High Speed Rail, Tohoku and Joetsu Shinkansen and another is ATOS (Autonomous decentralized Transport Operation control System) for existing commuter lines in greater Tokyo area..

COSMOS is consisted in 7 data linked sub-systems which are Transport Planning, Operation Control, Rolling stocks Control, Maintenance Work Control, Station Yard Control, Centralized Monitoring and Power SCADA. It is comprehensive train operation Controlling System.

(2) Current European OCC

There are many kinds of Automatic Train Protection system (ATP) in European countries. This situation is one of the obstructions for the cross border train operations between some countries. European Union (EU) initiated the development of unified ATP and OCC systems since 1990s. Unified ATP is European Train Controlling System (ETCS) and OCC is European Railway Traffic Management System (ERTMS). ERTMS is composed of ETCS and GSM-R (Global System for Mobile communications - Railway)

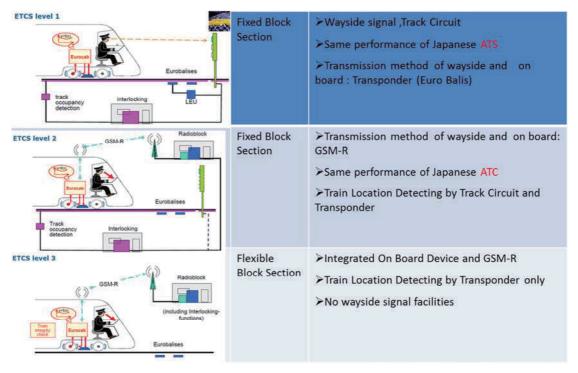


Source: http://www.ertms2012.eu/fileadmin/Content/Downloads/2011/pdf/InfoOnERTMS.pdf

Figure 9.12-2 ATP Methods in Europe

ETSC is categorized into 3 levels as below, and "Level 1 and 2" adapt fixed block section method and "Level 3" is flexible type. But German signaling system LZB

(Linienzugbeeinflussung), it has already realized flexible type block section. And also Equipment replacement will be still future.



Source: Study Team

Figure 9.12-3 ETCS and its Categorized

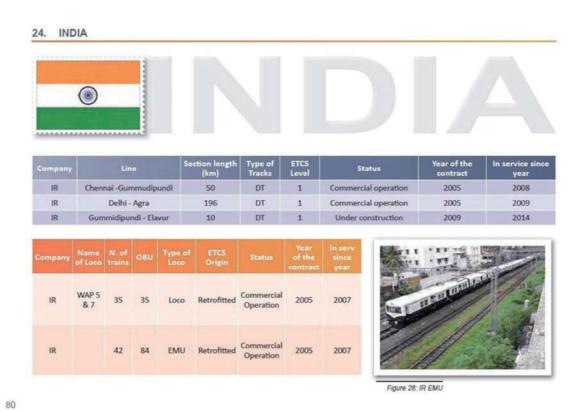
(3) Actual Statas in Asia

1) China

China High Speed Rail adopted CTCS which was based on ETCS Technology. As well known, the regrettable collision accident, which was caused of signal trouble and unappropriated human procedure, occurred in 2011. Although the operational control system was not a direct cause of the accident, all railway engineer should be lesson and learning from this accident that the system integration is important, not only system technology but also human handling and operation.

2) India

According to UIC report, already there are two installations of ETCS lines and one of which is under construction in India. On service line are existing lines and installed ETCS/LVEL1.



Source: ATLAS ERTMS 2012, UIC

Figure 9.12-4 Current Situation of ETCS in India

(4) Concern about ETCS / ERTMS introduction

Exactly ETCS/ERTMS project is important for not only European railway operators also manufactures and government sectors. Now ERTMS Level 2 is on service for the High Speed Rail in Italy and Spain. This function is limited for only train operation and other function, for example the passenger information function, is not complete yet.

This project is delay for some reasons as follows,

1-Basic system is designed for huge traffic volume countries, for example France, Germany, so that there are many extra functions. It may be too huge system for small traffic volume countries.

Usually, it is dearly difficult to accommodate downsizing from huge system. Because it is needed to confirm of program module functions again and added cost. System Providers would be preferred to recover the initial investment cost. Therefore, the customers would like to put up with the extra function and cost.

- 2-GSM-R is one of the important components for ETCS. GSM is popularized in many countries, however, there are many Special functions each countries. So it is difficult to specify unique.
- 3- There is not yet the man-machine interface in common for the transportation management system of the OCC, there is on board system only. "Europtirail" which is supporting system, can display the position and delay information of the train and including some static function, but there is no Diagram arrangement function.

Exactly European system, ERTMS, is the great system of unprecedented concept, because final target may be covered whole Europe and adapt the train controlling by wireless radio at Level 3 for furfure. However this system is so huge system that there are several technical and political

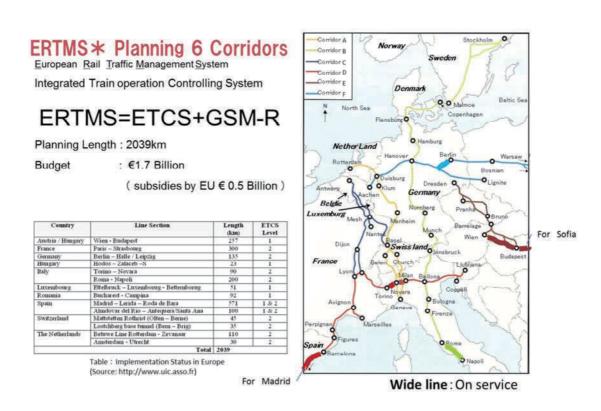
barriers. For example technical specifications are revised many times and they have to issue more than 20 European languages. And due to long project term, Basic technique progress so hurry day by day that it is difficult to catch up. ERTMS has adapted GSM-R for the high speed and large capacity communication method, but up-date communication method is LTE (Long Term Evolution).

First of beginning, the purpose of this system is available for the interoperability in European Railways, however, there are three places carrying it only. Some countries have doubts about the effect of the introduction and complain the delay of the construction progress.

And more ERTMS has been developed for the dedicated route controlling function only so that passenger information service function is not yet practical using. This function will be contributed for the punctual train operation, mentioned in detail 9.9.5(3).

Therefore study team recommend that Operational Control System, which is confirmed the compatibilities with Digital ATC, is suitable to compare the ETS/ERTMS, including China High Speed rail system, for any experiences and closed section of the high speed rail operation.

Finally adapting Digital ATC, which have already inspected and confirmed for all function with proposed system in detail, as a signal system, is advantage for shortening the installation term and to contribute the price down. Study team strongly expresses that High Speed Rail operation should be adapted due to actual result and proven safety system, which is based on the COSMOS and COMTRAC technology, sufficiently.



Source: http://www.uic.asso.fr

Figure 9.12-5 ERTMS Situations in Europe

9.12.4 Modern and Robustness system configuration

(1) Robustness network

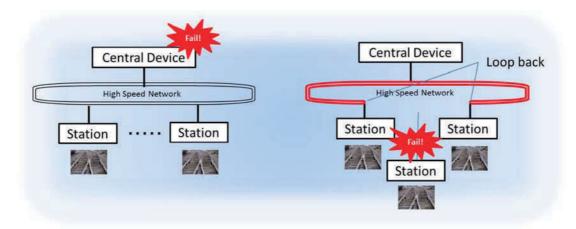
At the first of beginning, CTC and PRC were tree type system, which were composed of central computer and station devices. After then system composition have been progressed accompany with the progress of information technologies.

In recent technology, the autonomous and decentralized system, which consisted of central computer and station computers connected high speed and large capacity network cable, is current. The feature of this system is sharing the same diagram between central computer and station ones.

The advantage of this method is follows,

- 1- If central computer is failed but no problem each station system, it is possible to continue the train operation.
- 2- If some station system is failed, it is possible to continue the train operation by network loopback function.

And more, it is possible to set up station by station. So that construction and installation work is simple and easily.



Source: study team

Figure 9.12-6 Advantage of Autonomous and Decentralized System

(2) Without Train Information Display (TID)

Traffic information display or MIMIC Display is a one of the symbol of OCC. Recently, as shown in the photo on the left below; there is also OCC that is without such a panel.



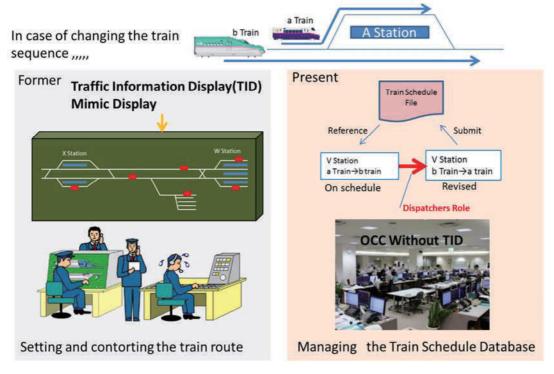
Source: Study Team

Figure 9.12-7 Comparison of Deferent Type OCC

This display which shows the traffic information, such that track layout, train location, delay time and so on, was the symbol of the train controlling center. However, COSMOS and ATOS system expelled it from the controlling center. That is why these systems have changed dispatchers' role.

In case of changing the train sequence at some station, dispatchers in the former CTC decided and setting the train route by switches. But dispatchers in new system, COSMOS and ATOS, arrange the train schedule diagram database without contradiction.

Therefore, COSMOS and ATOS bring epoch-making milestone for the Operation Controlling...



Source: Study Team

Figure 9.12-8 Change of the Dispatchers' Roles

9.12.5 Controlling Center Management

Controlling Center staff should be together same floor and room without bulkhead to share the information, because an immediate determination is essential in the case of incidents.

(1) Staff Responsibilities in OCC

1) Managing staff

In work shifts of 24 hours until 9:00 the next day from 9:00 in the morning, they are representative manager of this OCC.

2) Traffic Dispatchers

They are in charge of train operation and arrange the train diagram in case of traffic obstacle. Also they inform to concerning section such that station, depots, driving crews.

3) Operation Dispatchers

They are supporting Traffic Dispatchers to distribute train sets or assign driving crews. In charge of Passenger Service is information providing and customer service.

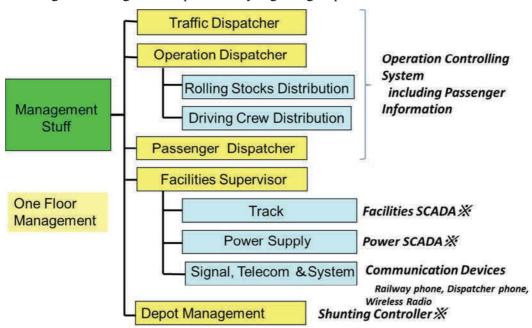
4) Facilities Supervisor

They are supervising track facilities, such that Permanent Way, Power Supply, Signaling, communication. Facilities-SCADA and Power-SCADA are proposed by Signaling and Electricity Expert. When monitor of SCADA inform alarm or warning, they immediately confirm the detail situation and request to Traffic Dispatchers.

5) Depot Management Staff

They are controlling the shunting in depot and prepare the in/out train for main track.

Shunting Controlling Panel is provided by Signaling Expert.

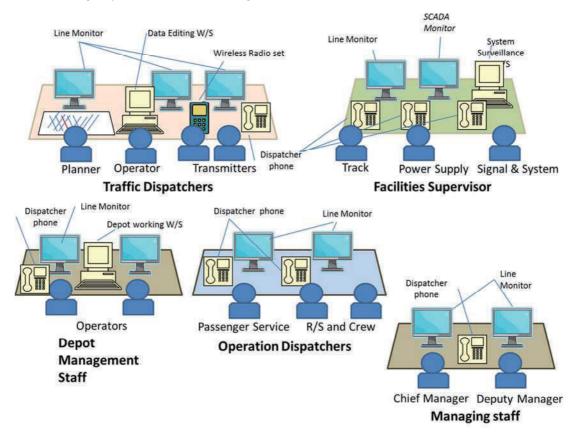


System or devise with * :consider and prepare by each section

Source: Study team

Figure 9.12-9 Organization Chart in the Controlling Center and Devices

Their working Layout is shown below figure.



Source: Study team

Figure 9.12-10 Center Layout

(2) Comparison with the current Indian Railway

The proposed the role-sharing and organization chart of OCC is confirmed almost as same as OCC of current Indian Railways through the field Surveillance by study team. Study Team visited at Delhi District Railway Management Office on 10th September, 2014.

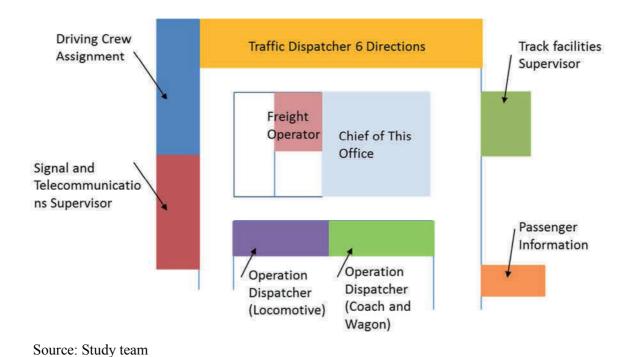


Figure 9.12-11 Indian Rail OCC

(3) Importance of the Passenger Information

One of the features of the proposed system is relation between the management system and passenger information. As usual, Passenger information System is one of the communication devices. But in this proposed system, passenger information system is linked with Operation Management system to be following the diagram arrangements. In other words, it is a function to automatically change the information display at stations, when the train sequence has changed.

Therefore concepts of this proposal are minimum function and reasonable cost. Proposal system is simple configuration for the train operation but remarkable function is including the passenger information function. This function seems to be very easy but it is very difficult and nerves, because it provides information for customers.

This function contributes to the punctual train operation. By displayed information, customers can get the train of theirs exactly. At the Tokyo terminal of JR East High Speed Rail, there are two platforms and 4 tracks, and provide more than 300 trains daily and minimum head way is 4 minutes. On the concourse, each platform and track train information, destination, departure time, reserved and non-reserved cars, and so on, are display for customers. Information of 3 trains is displayed at every track so information of 12 trains is displayed always. When one train left the station, the display immediately revise the train information.

Customers confirm their train and car's number by themselves and wait for train at the platform. Like this train leave station on time without customers' confusion.



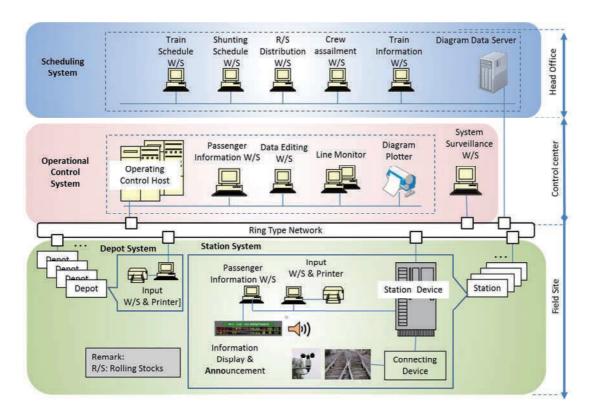
Source: Study team

Figure 9.12-12 Shinkansen Platform at Tokyo Station

9.12.6 Proposed Train Operation Controlling System

(1) Configuration

System should be introduced Autonomous decentralized system which consist of central system and local system, such that stations and each depot, with connected by high speed and large capacity communication cable.



Source: Study team

Figure 9.12-13 System Configuration

2) Central System

As follows, it should be consisted of 2 sub system and the System Surveillance.

a) Scheduling System

This system consists of some work stations (W/S), concerning the train schedule, passenger information etc., and file server with the redundant structure.

b) Operational Control System

This system consist of the dual host computer, it is hot standing by, some w/s which can be to change the timetable adjustment and line monitors which can display the whole line situations, detail station situations, each train diagram.

c) System Surveillance

This monitor is supervising and showing each system components situation,

If some components are failed, suddenly systems monitor alarm and show the message on the display.

Local system

a) Station

This is consisting of communication device and signaling-interlocking devise which is connected with wayside devices and passenger information device. The system receives the train diagram daily and when train schedule has changed by traffic dispatchers, it is available to change the train route and passenger information.

b) Rolling stocks and Driving Crew depot

This is w/s which receives distribution or assignment scheduled from the central server and reply information to central system.

(2)Function

a) Making the Train Operation Scheduling

There are 2 schedule modes, one is Present diagram and another is revise diagram for future, and prepares the basic and temporally train operation schedule. Operation schedule are reserved 180 days maximum in scheduling server.

Scheduling Section of Traffic Department draw the basic train diagram. It is impossible to train operation only basic diagram, so that Scheduling Section adds the shunting diagram at the Rolling stock depot to basic diagram. Also this section inputs Passengers' information which is displayed on information boards or automatic announcements at station.

Operational planners also inputs the Train set distribution and crew assignment. Each operating plans are submit to the Rolling stocks depot or crew office, Depot and office assign for resources and reply to Operation planners.

b) Transfer Train Diagram from scheduling system to operation system and each field Every day, diagram transfer from scheduling system to Operation Control System. And then Operation Control System generate the "Operation Diagram" and also send to concerning system, such that station, depots. Operation Control System keeps 4 day diagram which are yesterday, today, tomorrow and the day after tomorrow. In other words, the train schedules of up to 3 days are managed in the Operation Control System and more future diagram are managed in the scheduling system.

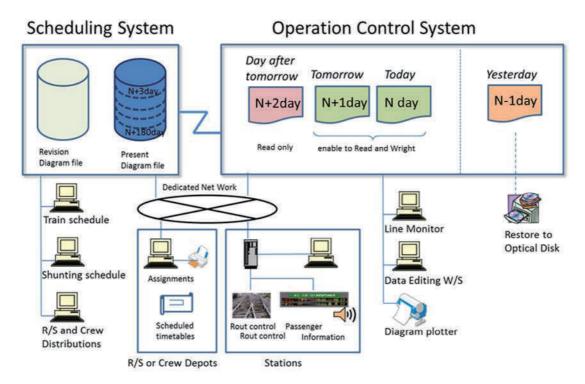
The actual result diagram of the previous day is stored in storage media.

c) In case of Train Operation Obstacle

Line Monitor displays the location and delay time of each train and weather situation, rain fall wind speed and so on, on the line. In case of train operation obstacle, Traffic dispatchers arrange the train diagram from Data Editing W/S. Changed schedules are submitted to the host computer and the computer check the contradiction. If there are some contradictions, reply to despatchers by alarm or caution messages. Changed schedule data without contradiction is transmitted to station system and station system is setting the train route by updated schedule.

d) Prevention for Natural Hazard

Track conditions are supervising by Facilities-SCADA. When some incident occurs, Terminal monitor of Facilities-SCADA, which is set on OCC, informs alert or warning to Track Facilities Supervisors. Track Facilities Supervisors inform and request to traffic dispatchers, then traffic dispatchers set the temporally limited speed section from Data Editing W/S.



Source: Study team

Figure 9.12-14 Date Flow

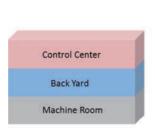
9.12.7 OCC Building

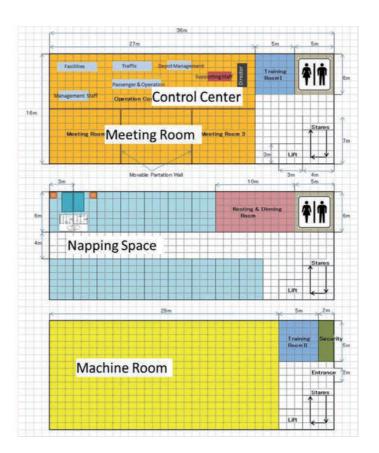
OCC building is assumed to be three-floors; ground floor is machine room, middle floor is back yard including Napping and catering space, top floor is OCC, such as the following.

Half of the OCC is a meeting room. In case of accident, this is used for "Accident Response Office". And also for the machine replacement, new generation system will built up on this space. In the same way, not only the current system to the Machine room, so as to secure a space for the system replacement.

As candidate sites of OCC, it is assumed the same area of Sabarumati Depot and Work shop. In this case, that the shunting operator and the operation panel of maintenance Depot should be placed in the OCC, because the communication between OCC and Depots is significant in case of accident.

For alternative idea, OCC Building builds nearby Head Quarters Building. The advantage of this is that it is easy to get the supporting from the Head Quarters and to be suitable for an information transfer related agencies, the Ministry of Railways, the police, to the public relations and so on.





Source: Study team

Figure 9.12-15 Layout of OCC Building

9.12.8 Backup Function of OCC

This is a question from Indian side at the subsystem Work shop which was held on 8th September. Study team propose that it is no necessary such redundancy equipment, due to follows reasons,

- 1) High speed OCC should be unified organization.
- 2)Due to 3days Diagram is submitted from Host computer to field computer reason, it is possible to operate the train at least during 3 days, (If disturbing of train operation more than 4days, it might has occurred so serious incident.)
- 3) Due to exclusive rule reason, it is difficult to build up the hot standing by system. Redundancy system must be built up cold standing by.

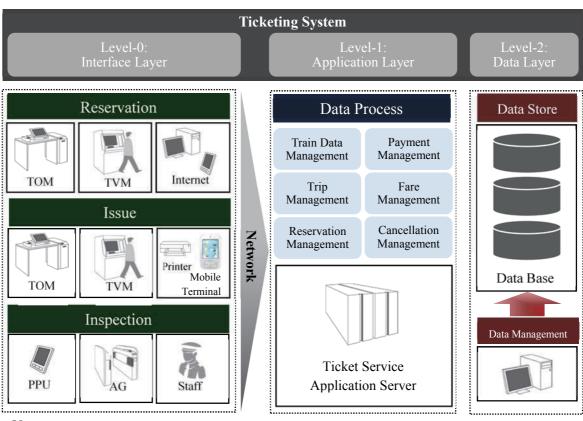
However, Delhi Metro has already equipped BCC (Backup Controlling Center) which is using training equipment as usual. But in case of problem of OCC, this equipment suddenly start up for actual system to copy the train diagram and arrange the train location. When considering the basic or detail design, study team suggest as future subject the necessary of backup control center.

9.13 Ticketing System

9.13.1 Ticketing System Structure

Tickets are most often used for receiving fares in exchange for railway transportation services provided for users. Tickets, on which the information on the service contents and the fare is shown, are given users who have paid fares for getting services. This process is ticket issuing. To get reserved seats, passengers need to reserve them. In this case, ticket issuing follows reservation. The railway business operator can confirm by checking the ticket that the user has a legitimate right to transportation services. This checking process is ticket inspection.

The ticketing system is a computerized system for effectively managing the processes of reservation, ticket issuing and inspection with a view to improving convenience for users. This system is generally built up from three layers as shown in Figure 9.13-1: the interface, application and data layers.



Note: Source: Compiled by Study Team TOM: Ticket Office Machine

TVM: Ticket Vending Machine PPU: Portable Processing Unit

AG: Automatic Gate

Figure 9.13-1 Ticketing System Structure

(1) Interface Layer

This layer provides an interface between users and the application layer. The TOM/TVM/PPU and the online system are offered as an interface for facilitating reservation, ticket issuing and inspection for both users and station clerks. Convenience, operability and functionality are important for the interface layer because it constitutes a direct contact with users.

(2) Application Layer

The application layer handles requests from the interface layer and delivers the results. In general, the application layer that implements a processing program is linked with the interface layer via the network. Upon request, the ticketing system properly conducts transactions, including reservation management, cancellation management, route/fare management, train data management, and payment management. Real-timeliness, responsiveness and throughput are important for the application layer because requests from users are handled simultaneously.

(3) Data Layer

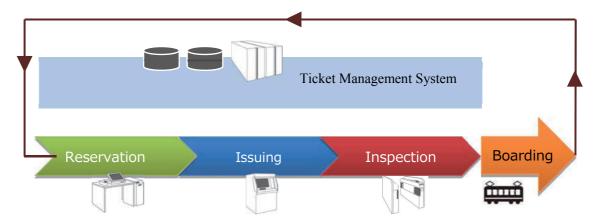
This layer manages data used on the application layer. As necessary, the application server extracts data from the data layer, renews and stores it. Data confidentiality and integrity are important for the data layer, so data is encrypted and disks are multiplexed.

9.13.2 Processes Handled by the Ticketing System

The ticketing system handles reservation, ticket issuing and inspection processes, as shown in Figure 9.13-2. The reservation process is a process in which passengers book tickets in a prescribed way: for example, by using TOM/TVMs or the online system. In the ticket issuing process, booked tickets are issued through TOM/TVMs according to the reservation number. When a reservation is made through a TOM/TVM at the station, reservation and ticket issuing are processed in a sequence.

In the ticket inspection process, passengers' tickets are checked to confirm their validity. Inspection is conducted at the time of both entering and exiting the concourse, or on board.

The data used throughout the ticketing system is stored in the database connected to the application server. When any of the processes is done, a relevant channel on the interface layer inquires the application server, and then receives transaction results as an answer from the server. Multiple requests are sent concurrently from station machines and the online system, so the application server needs to effectively respond to them and ensure that no improper transactions occur, including dual issuing.



Source: Compiled by Study Team

Figure 9.13-2 Ticketing System Cycle

9.13.3 Ticketing Systems for High Speed Railways in Other Countries

The ticketing system is different in structure according to the operation/management system, equipment specifications, and services offered. Therefore, research was carried out concerning ticketing systems for high speed railways in other countries. Table 9.13-1 shows its findings. Here, they are discussed from the following three points: (1) ticket medium, (2) reservation and ticket issuing, and (3) ticket inspection.

(1) Ticket Medium

Tickets used in the surveyed countries are classified into four medium: paper tickets, magnetic tickets, IC cards and e-tickets. Conventional paper and/or magnetic tickets are used in all the countries surveyed, while e-tickets are also used for almost all the railways because they are very convenient for reservation and ticket issuing.

(2) Reservation and Ticket Issuing

There are two reservation methods found. One is going to ticket windows or TVMs at stations for reservation. The other is using the online system on the Internet. The online reservation system has already been introduced for almost all the high speed railways, and many passengers book tickets in advance via the Internet. Such tickets can be received at the station, or gotten by mail. If they are e-tickets, they can also be printed at home. Moreover, services that make it possible to download and display ticket information on mobile terminals, such as smartphones, are spreading. Internet reservation and e-tickets are popular among users due to their convenience. High speed railways are expected to be used more often by business people who try to use their time effectively than existing railways. Such business people tend to use the online system for reservation, rather than waiting in line at ticket windows, so a need for internet reservation is probably greater for high speed railways than for existing railways. The wider use of such mobile terminals as smartphones, which enable reservation even outside offices, is expected to further accelerate this tendency.

(3) Ticket Inspection

Inspection methods are different according to ticket medium. In the case of a magnetic ticket or IC card, its validity is checked by a reader equipped at the automatic gate. The validity of an e-ticket is confirmed by reading information printed or displayed on the mobile terminal.

Some railway operators separate the concourse for the high speed railway from other concourses, and conduct inspection at the entrance to the HSR concourse to allow only valid ticket holders to board the train. Other operators do not conduct inspection before boarding but on board. The latter method is often used in Europe, as is shown in the table. This is because many railway companies do not separate HSR lines and platforms from ones for the existing railway. On-board inspection is conducted regardless of whether inspection at the entrance to the concourse is conducted or not, because it is necessary to check passengers who do not use the seat and train designated on the ticket. On-board inspection has been done by the conductor according to the printed chart of reserved seats, but now the use of PPUs on which the reserved seat information is downloaded from the application server is gradually becoming common to make sure that the passenger's ticket is consistent with the given information.

Table 9.13-1 Ticketing Systems for High Speed Railways in Other Countries

_	ltem	Eurostar (France, UK, Belgium)	Pendolino (UK)	Javelin (UK)	Train à Grande Vitesse InterCity Express (France)	InterCity Express (Germany)	Sapsan (Russia)	Acela Express (USA)	Korea Train eXpress (Korea)	Taiwan High Speed Rail (Taiwan)	China Railway Express (China)	Shinkansen (Japan)
Ticket	Ticket Medium	Paper Magnetic ticket e-ticket	Paper Ticket e-ticket Mobile Device	Magnetic ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Paper Ticket e-ticket	Magnetic ticket(Card) e-ticket	Magnetic ticket(Paper)	Magnetic ticket(Paper) e-ticket (Card, Mobile Device)
	Reservation	Ticket window TVM hternet reservation	Ticket windows TVM Internet reservation,	Ticket windows TVM Internet reservation,	Ticket windows TVM Internet reservation,	Ticket windows TVM Internet reservation,	Ticket windows Internet reservation	Ticket windows TVM Internet reservation Phone On board	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation	Ticket windows TVM Internet reservation
Reservation	Payment	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Cash Credit/Debit Card Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Cash Cash Credit/Debit Card Credit/Debit Card Credit/Debit Card Credit/Debit Card Credit/Debit Card	Cash Credit/Debit Card (Cash Credit/Debit Card	Cash Credit/Debit Card	Cash Credit/Debit Card
	Seat	Reserved and All for reserved seat non-reserved seats	Reserved and thon-reserved seats	All for non- reserved seats	All for reserved seat, non-reserved seat during busy season	Reserved and non-reserved seats	Reserved and the non-reserved the seats	All form non- reserved seats but issued ticket Reserved and r number is fixed to reserved seats the number of seats	ion-	Reserved and non- reserved seats	All seats for reservation	Reserved and non- reserved seats
Ticket	Inspection at entrance to concourse	Inspection by Automatic Gate	No inspection	Inspection by Automatic Gate	No inspection	No inspection	No inspection	No inspection	No inspection	Inspection by Automatic Gate	Inspection by Automatic Gate	Inspection by Automatic Gate
Inspection	On board Inspection	nspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor	Inspection by Conductor Inspection by Conductor Inspection in some lines.	Inspection by Conductor No inspection in some lines.
F	Track	Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines	Exclusive line for Exclusive line for HSR and existing HSR and existing lines	Exclusive line for HSR and existing lines	Exclusive line for HSR and existing lines lines		Existing lines	Exclusive line for HSR	Exclusive line for HSR	Exclusive line for HSR and existing lines	Exclusive lines for HSR but partially using existing lines.
Separa existing	Separation from existing railways	Separated	Open to existing concourse and platform	Separated	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Open to existing concourse and platform	Separated	Separated	Separated

Source: Compiled by Study Team

9.13.4 Ticketing System for High Speed Railway in India

(1) Existing Ticketing System

Indian Railways issues 21 million ordinary tickets and 1.5 to 2.2 million reserved-seat tickets per day. CONCERT (Country-wide Network of Computerized Enhanced Reservation and Ticketing) is used for issuing reserved-seat tickets*¹). Here this existing reservation system is discussed with reference to the above-mentioned layer model in order to consider a desired system for the high speed railway in India. Figure 9.13-3 shows only the layer structure for convenience of reference.

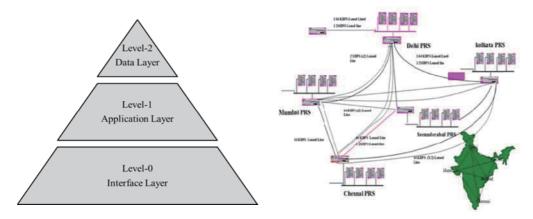


Figure 9.13-3 Ticketing System Structure

Figure 9.13-3 Indian Railways' Reservation System*²⁾

Source: Compiled by Study Team

- *1) https://www.services.irctc.co.in/beta images/sms booking/sms ussd.pdf
- *2) CONCERT: Journals of Engineering, Computer and Applied Sciences, vol. 2 No. 6,

CONCERT was developed and is managed by CRIS (Center for Railway Information Systems: an organization under Ministry of Railways). CONCERT, one of the world's largest reservation systems, has five data centers across the country, as seen in Figure 9.13-4, for ticket issuing and reservation for any train line.

CONCERT is the core of the reservation system and works on Level 1 and Level 2 of Figure 9.13-3. Level 0 of the figure has a structure as shown in Figure 9.13-5, which provides various ways of booking and buying tickets not only at the station but at agents including post offices, on the Internet, and by mobile phones.

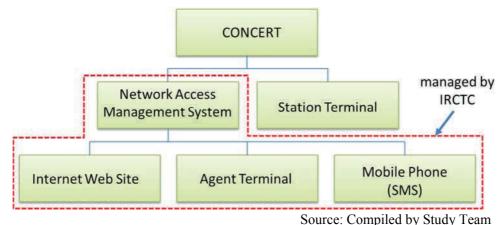


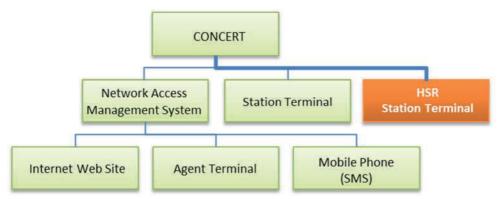
Figure 9.13-4 Structure of Existing Ticket Booking and Issuing System

Passengers can buy ordinary paper tickets at the ticket window, or e-tickets via the Internet. E-tickets can be printed and displayed on mobile terminals. The SMS for buying tickets without Internet connection is also available beginning on June 28, 2013. Passengers, if they have no tools for accessing the Internet, can book tickets at stations, 2,000 agents with terminals nationwide, 270 post offices, 70,000 agents linked to the reservation website of IRCTC (Indian Railway Catering and Tourism Corporation), and via mobile phones. This existing ticketing system, which provides various ways for using services, is very convenient.

(2) Ticketing System Structure for High Speed Railway

The HSR must provide as convenient services as the existing railways. In order to realize it, HSR should utilize the existing system—rather than creating a new system. When the existing system is used, reservation and ticket issuing will become possible not only at HSR stations but at existing stations and agents, and via the Internet and mobile phones. Moreover, tickets of both HSR and existing railways can be bought at one site. Connection to the existing railway is planned at four of the twelve HSR stations. The integrated ticketing system enables to issue connection tickets all together, which would improve convenience for users.

The development of the HSR ticketing system by utilizing the existing system is considered as basically possible if an HSR terminal system is connected to CONCERT and HSR reservation-related data, including operating schedules, seating charts and fares, is added to CONCERT.

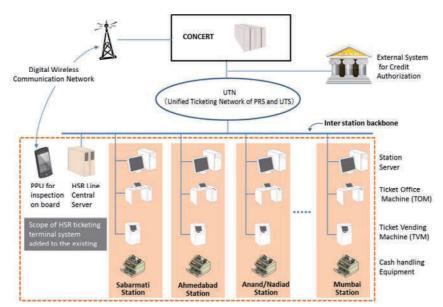


Source: Compiled by Study Team

Figure 9.13-5 Relationship of Entire Ticketing System and HSR System

According to CRIS that manages CONCERT, technical specifications, including API (Application Programming Interface), for devices connected to CONCERT have been available, and their use will make connection to CONCERT possible, as indicated in Figure 9.13-6.

In considering the HSR ticketing system connected to CONCERT, its scope of work to be considered is focused on the terminal system. Figure 9.13-7 shows a terminal system structure to be considered. The dotted part in the figure represents the terminal system. As mentioned below, it includes the PPU used for on-board inspection by the conductor.



Source: Compiled by Study Team

Figure 9.13-6 HSR Terminal System Structure

(3) System Components

1) Tickets

When the existing ticketing system with CONCERT as its core is applied, the same ticket format with that for the existing railways, as shown in Table 9.13-2, can be used for the HSR. The ticket format is common between both HSR and existing railways, therefore the connection ticket can be used throughout both railway routes. It is very convenient for users.

Table 9.13-2 Types of Tickets

Tie	cket	Issue of Ticket	Method of Payment	Image of Ticket
		Ticket window at Station	Cash	100 M 10
700	aper cket	Agent	Cash, Credit/Debit card	221-45000 10 mm of the common
		TVM at Station	Prepaid smart card	SAMPLE OF STATE OF ST
E-	ticket	Website		
	i-ticket	Website Ticket delivery to customer	Credit/Debit card Withdrawal from bank account	
	SMS ticket	SMS to mobile phone	Net-money	PAR4355527800 TRAIN12645.D 0.118-06145.L.H-S NZM.Deo10036, DVS2-49, Fare-405.SD11/2419-6 OHOS Catering comp no.1800-1115/21

Source: Compiled by Study Team

Ticket Issuing

i) Ticket Issuing System: The existing ticketing system being used, HSR tickets can be issued not only at HSR stations, but also at existing railway stations and travel agents, on the

website, and via mobile phones, as shown in Table 9.13-3. The table also indicates the number of mobile phone users. Given the fact that PCs can also be used for Internet reservation, the use of the existing issuing system is obviously more beneficial than the development of a new exclusive system.

Table 9.13-3 Number of Sites to Issue Existing Railway Tickets

Site of Ticket Issue	No. of Site	
Sales Agent	2,000 agents	
Post Office	270 offices	
Internet Sales Agent	70,000 agents	
3G-mobile phone user	34 million users	*/
Other mobile phone	870 million users	*)

^{*)} http://wirelesswire.jp/Inside Out/201309271245.html

Source: Compiled by Study Team

ii) Issuing Equipment at HSR Stations: The issuing system installed at HSR stations is supposed to be primarily composed of machines as listed in Table 9.13-4. These machines will be connected to CONCERT, so technical specifications for connection, data processing, ticket issuing, etc. must comply with the technical specifications drawn up by CRIS, the developer and manager of CONCERT.

Table 9.13-4 Issuing Equipment Installed at Station

Equipment	Function
Ticket office machine (TOM)	Reservation and issue of ticket by operation of station staff.
Ticket vending machine(TVM)	Reservation and issue of ticket by operation of customer.
Station server	Management of station equipment (TOM,TVM), and processing of data from/to the station equipment.
Cash handling equipment	Counting bank note and coins

Source: Compiled by Study Team

TOMs for the existing railways are installed at ticket windows, as seen in Figure 9.13-8, and CRT displays and dot impact printers are installed as output equipment. As for areas that have no relation to the specifications and requirements for connecting to CONCERT, latest, superior technology should be adopted to reduce electricity consumption, improve performance, and save costs.

For example, though cash payment is common at ticket windows, there seem to be greater needs for payment by credit/debit card among HSR users. To use the TVM currently introduced on a trial basis (Figure 9.13-10), a customer must buy a prepaid smart card in advance. It is also necessary, for improving users' convenience, to make it possible to use the TVM in cash and with the credit/debit card.





Figure 9.13-8 Ticket Issuing Window

Figure 9.13-7 Equipment at Window



Figure 9.13-8 TVM used for the Existing Railways

3) Ticket Inspection:

There are two ways: i) inspection at the entrance to the concourse and ii) inspection on board.

Inspection at the entrance to the concourse: It is estimated that the high speed railway will be used mainly by customers who have chosen aircraft instead of railways before then. And such users are supposed to demand safety and quality services equivalent or exceeding those of air travel. To meet this demand, the HSR must ensure that only HSR ticket holders are allowed to get on board. For this purpose, it is required to separate the HSR concourse from the free concourse and check both security, which is inevitable for HSR as same as for aviation, and tickets at the inspection gate, as seen in Figure 9.13-11. It is difficult to prevent passengers with no HSR tickets from entering HSR platforms unless free access to the concourse is permissible. The train will have ten vehicles when services start in 2023, and the number of vehicles is to be increased to 16 in 2043. In addition, the number of trains running each way during peak hours will also increase from three, four, six to eight per hour. So, though checking tickets before the train door is plausible, this method that requires assigning an enough number of staff members at each station is likely to impose a heavy burden on management.

ii) Inspection on Board: All HSR seats are supposed to need reservation. Passing through the ticket gate means that the reserved seat is secured for the relevant customer. However, as the number of trains running per hour increases as mentioned above, trains arrive at the station one after another at shorter intervals. In such conditions, passengers may get on a train before them without waiting for the designated train to come, and try to find empty seats. Though two or more types of seats, including business class and standard class seats, are planned to be provided, there may be some passengers who take a seat in other class than that designated for them. In order to prevent improper riding, it might be possible to close the platform until the train arrives to allow only holders of reserved-seat tickets for the train to enter. However, when train intervals are short, many passengers must wait outside the concourse. Terminal and other stations used by a large number of people can be so crowded unless they have enough space, which may undermine convenience and safety for users. Moreover, such a method cannot help find passengers who take a seat in other class than that designated for them, or who do not take the right seat reserved for their own. Given these factors, on-board inspection is required.

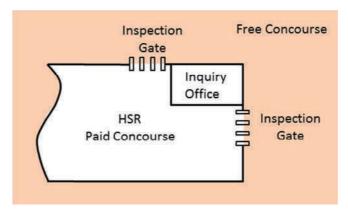


Figure 9.13-9 Inspection at the Entrance to the HSR Concourse

iii) Comparison of inspection methods: Table 9.13-5 shows the summary of what was discussed above. Entrance inspection and on-board inspection are complementary each other, so it is probably desirable to adopt both methods.

Function of Inspection	Entrance Inspection	On-board Inspection	Entrance and On- board Inspection
Admission of boarding by HSR ticket	Possible	N/A	Possible
Instruction to take designated train	N/A	Possible	Possible
Instruction to take designated class of seat	N/A	Possible	Possible
Instruction to take designated seat	N/A	Possible	Possible

Table 9.13-5 Comparison of Inspection Methods

iv) Inspection Equipment

a) Ticket gate: HSR tickets will be issued by use of the existing ticketing system. Their

format is the same as that for the existing railways, so HSR tickets are not adaptable to automatic inspection. If the bar code or the 2D QR code is attached to the ticket, it is possible to scan it for automatic ticket inspection. However, the dot impact printer currently used at ticket windows does not have a high resolution enough to print the bar code and the 2D QR code. Even if the ticket is received on the SMS, the low-resolution mobile phone cannot display the code accurately, so it cannot respond to automatic inspection.

Given these conditions, automatic inspection should be considered along with the future renewal of the existing system. Inspection by station clerks is desirable for the meantime.

b) Portable conductor terminal (PPU): Seat reservation is locked when the prescribed time before the departure time of the train is over (Reservation for existing railway seats is possible until thirty minutes before the departure time). Then CONCERT outputs a reserved-seat chart to be used by the conductor for on-board inspection (Figure 9.13-12). The conductor checks tickets against this chart in which passengers' names, reservation numbers, seat locations, etc. are described. The conductor charges an additional fare to the passenger who does not have a proper ticket. What is seen in Figure 9.13-13 is a ticket book for on-board issuing.

The status of seat reservation changes as reservation data is input from other stations after the train leaves the starting station. The HSR train will run about 500 km from the starting station to the terminal in approximately three hours by ordinary service. There will be twelve stations on the route. This means that the train runs between two stations in an average of 16 minutes, including the stoppage time at the station. Therefore, passengers will change in a short time, so the changing information on reservation needs to be delivered to the conductor in the train on a real-time basis. That's why the introduction of PPUs is necessary. The use of the PPU always connected to the ticketing system by digital wireless communication network would make it possible to renew the reserved-seat information before the train reaches the next station. It will also be possible to assign the function of on-board issuing to the PPU. According to CRIS, some existing railways have begun to introduce PPUs, and an infrastructure for the host system has been built. Therefore, the adoption of PPUs for the HSR is also deemed to be possible.



Figure 9.13-11 Reserved-seat Chart for On-board Inspection



Figure 9.13-11 Ticket Book for On-board Issuing

(4) Proposal on the Ticketing System Structure

Based on the above examination, the following proposal on the ticketing system for HSR is submitted from the viewpoint of realizing a system with high investment efficiency and due consideration of cost reduction while placing the highest importance on the safety and convenience of users.

1) System Structure

A ticketing system for HSR is constructed as part of the CONCERT-centered ticketing system. This is because utilization of CONCERT, which is highly functional and time-proven, should be supposed to realize a convenient ticketing system of a lower investment cost than constructing another one for HSRs independently.

2) Ticket

Tickets in the same format applied to the tickets for the existing railways will be used from the two viewpoints of the convenience of connection to the existing railways and the convenience of purchasing. The common format will offer a possibility of purchasing tickets in various existing methods, such as from agent and by mobile phone, and make it possible to issue tickets available for connection as a package. Consequently, users can make connections seamlessly from the existing railway to the HSR and vice versa without bothering to purchase a ticket at every connection station.

Ticket Issuing

Taking the above concepts into consideration, a system that can utilize all the existing systems including stations of the HSRs, stations of the existing railways, agents, the Internet and reservation by mobile phone, will be adopted.

4) Ticket Inspection

Paid concourse will constructed separately and ticket inspection gate and security check gate will be constructed at the entrance to ensure high security and service quality desired by users of the HSR. In addition, on-board ticket inspection will be conducted to correct the usage of undesignated train, seat class, and seat. Station staffs will inspect tickets in the initial stage, and in future stage the automation like automatic ticket inspection will be considered from the viewpoint of establishing a comprehensive ticketing system because manual inspection will cause congestion at the gate. However, PPUs will be introduced to reduce the burden of conductors in on-board ticket inspection and the dissatisfaction of users in ticket inspection.

5) Flexibility to the Fare System

There is a probability to introduce a system that sets the fare higher in the busy season for better profitability and offers discount fare in the off season to improve seat availability. The ticketing system should be constructed to cope with various fare systems. Generally, fares are calculated and processed by the Application Layer (Level-1) and Data Layer (Level-2) of the ticketing system. Therefore, in the case that a system is constructed on the basis of the CONCERT system, the requirements can presumably be satisfied by adapting the software of CONCERT to the fare system.

6) Concept of Equipment Specifications

Based on the above mentioned approach, the equipment necessary for ticketing of HSR consists of ticket office machine (TOM), automatic ticketing machines (TVM), Station Servers that manage these pieces of equipment and process necessary data, Line Central Server that collects data from all stations on the HSR line, and PPUs used by conductors for on-board ticket inspection. These pieces of equipment should adopt the technological specifications to make them connect to CONCERT, while other specifications with state of the art functions will be incorporated in the design stage taking the requirements into consideration.

Equipment for Education and Training

Equipment for the education and training of staffs will be installed. The equipment will have the same station equipment and PPU used in the practical business. At least two pieces each of station equipment will be prepared to allow education and training for such practical operations as handling ticket issued at other stations. A server with restricted functions of Line Central

Server for education, training and emulating CONCERT will be installed to give staffs satisfactory training opportunities without the anxiety of affecting the system that actually operating.

(5) Technological Requirements for the Ticketing Equipment

The following are the results of examination on the equipment to be installed anew for ticketing of the HSR.

1) Technological specifications

TOM, TVM, and PPU are connected to CONCERT for operation. Therefore, they have to be compatible with the technological specifications necessary for the connection to CONCERT.

2) Requirements of the Station Equipment

(i) TOM (Ticket Office Machine)

- a) The function to handle booking of reserved tickets of the HSR and the existing railways, issuance of various types of tickets such as booked reserved tickets, and refund via the online connection to CONCERT.
- b) The online system function that can manage sales, data of money received and paid, and operation history.
- c) Such functions as the cash box management and ID management that manage the work shift of station staffs.
- d) The access control function that allows only certified staffs to get access.
- e) The function to print tickets. It should have enough resolution to print bar codes and enough resistance to fading for the future.
- f) The function to issue receipts.
- g) The function to accept credit cards and debit cards besides cash.
- h) The function to display information for users.
- i) The voice guidance function for blind users.
- j) The function that provides sings and voice guidance in more than two languages including English and Hindi.
- k) The UPS function that copes with temporary power shutdown.

(ii) TVM (Ticket Vending Machine):

- a) The function to handle booking of reserved tickets of the HSR and those of the existing railways, issuance of various types of tickets such as booked reserved tickets via the online connection to CONCERT.
- b) The online system function that can manage sales, data of money received and paid, and operation history.
- c) The function that allows users to input information necessary for ticket issuing on the operation panel.
- d) The print function to print tickets. It should have enough resolution to print bar codes and enough resistance to fading for the future.
- e) The function to issue receipts.
- f) The function to accept payment by banknote.
- g) The function to accept credit cards and debit cards besides cash.

- h) The function to accept payment by non-contact prepaid card (Optional).
- i) The function that allows blind users to purchase a ticket using braille keys and the voice guidance function.
- j) The function that provides sings and voice guidance in more than two languages including English and Hindi.
- k) The UPS function that copes with temporary power shutdown.
- The access control function that allows only certified staffs to get access for repair and maintenance.

(iii) Station Server

- a) The function that tallies ticket issuing data (sales, OD information) coming from ticketing equipment at stations.
- b) The function to produce various kinds of reports.
- c) The function that monitors the condition of the station ticketing equipment.
- d) The function to trades data with Line Central Server and CONCERT.
- e) The function that backups data through redundancy.
- f) The access control function that allows only certified staffs to get access.

(iv) Cash counting machine:

- a) The function to count banknotes.
- b) The function to bundle banknotes.

3) Requirements for the Center Equipment

(i) Line Central Server

- a) The function that tallies ticket issuing data (sales, OD information) coming from ticketing equipment at all the stations of HSR.
- b) The function to produce various kinds of reports.
- c) The function that manages the registered machine organization of the ticket equipment at every station.
- d) The remote control function that monitors and maintains the condition of all ticketing equipment

(ii) Equipment for education

- a) TOM, TVM, Station Server, PPU: They should the same function as the equipment that is really been operated.
- b) Emulator: It should focus only on the functions necessary for education and training and allows the emulation of Line Central Server and CONCERT.

4) Requirements for Other Equipment

- (i) Portable Processing Unit (PPU)
 - a) The function that downloads information on booking of reserved seats and ticket issuing via the digital wireless communication network to the CONCERT system.
 - b) The function to display the seat reservation situation in accordance with train organization.
 - c) The function to input, record, and display the result of on-board ticket inspection.
 - d) The function to transmit ticket issuing data to CONCERT.

- e) The function that allows ticket issuing on board via the connection to CONCERT.
- (6) Examination of the Number of Ticketing Equipment
- 1) Preconditions for examining the number of ticketing equipment
- (i) Calculation is based on the number of passengers of each station and the number of traveling trains examined by the study team.
- (ii) The peak rate was calculated using the number of traveling trains at the peak time and that of all day on the condition that all seats are reserved seats: 10%
- (iii) Using the information on reserved tickets obtained from the related department of India, the ratio of tickets issued at station vs. ticket issued by the network, and the ratio of tickets issued at TOM and by TVM of all tickets issues at stations are set as shown in Table 9.13-6.

Year 2023 2053 Station Station Ticket Network Network Purchasing TOM TOM TVM TVM Ratio (%) 40 70 30 60 30 50 50 70

Table 9.13-6 Ratio of Ticket Issuing Method

Source: Compiled by Study Team

- (iv) Based on the information from the related department of India and results of the field survey, the time to purchase a ticket at TOM or by automatic ticketing machine is set: 1 minute/person
- (v) The waiting time in queuing line is set with consideration of the target set by the Delhi Metro Service: 5 minutes at most.
- (vi) The minimum number of units is set both for TOM and TVM with consideration of backup in failure: 2 units at least.

2) The number of units to be set a station

Table 9.13-7 shows the number of TOMs and TVMs to be installed at a station. Because users of the Internet will presumably increase more than anticipated, it is advisable to set the number of units to process passengers for a period of 10 years after the inauguration at this moment and set it in accordance with the dynamics of passengers. However, station space that takes the number of passengers in 2053 into consideration is required.

Table 9.13-7 Estimated Number of TOMs and TVMs at Each Station

Station	Initial (Y20	23-Y2033)	Future	(Y2053)
Station	TOM	TVM	ТОМ	TVM
Sabarmati	2	2	2	2
Ahmedabad	10	4	14	14
Anand/Nadiad	3	2	3	3
Vaodara	3	2	4	4
Bharuch	2	2	2	2
Surat	3	2	4	4
Bilimora	2	2	2	2
Vapi	2	2	2	2
Boisar	2	2	2	2
Virar	2	2	2	2
Thane	2	2	3	3
Mumbai	14	6	20	20
Total	47	30	60	60

Source: Compiled by Study Team

3) The number of units to be installed in the center

(i) Line Central Server: 1 unit

(ii) Equipment for education and training:

a) Emulator: 1 unitb) TOM: 2 unitsc) TVM: 2 unitsd) PPU: 2 units

4) Other equipment:

• PPU: 100 units

The calculation was made on the condition that the number of conductors on board is two (10-vehicle train) and three (16-vehicle train), and the number of trains was considered for the calculation.

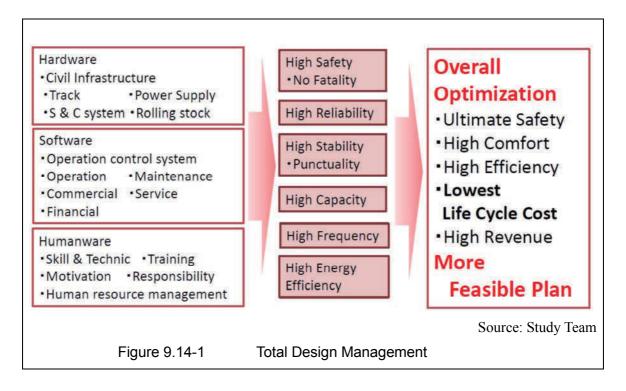
9.14 Comparison between Recommended Systems and Alternatives

9.14.1 System Integration and Total Design Management

(1) Total Design Management

HSR is an integrated system composed of not only hardware systems, such as infrastructure, rolling stock, power supply, signaling and communications, but also software & humanware, such as skills, technics, motivation, responsibility, and so on. Though hardware sub-systems are usually designed and provided by each supplier, hardware, software and humanware affect one another. Therefore system integration is the key to the success of HSR.

Generally, a railway operation company needs to be responsible for all results and issues generated from railway operation. Therefore it needs to manage all concerned suppliers and work with them to develop system best suited for its needs. It is extremely important to pursue total design management aiming at overall optimization, rather than partial optimization from the planning stage of HSR. Figure 9.14-1 shows the concept of Total Design Management.



Examples of total optimization aspect are total safety system, total efficient system, lowest Life Cycle Cost (LCC) and so on. Safety is the top priority of HSR. Reduction of construction cost is of course important, however regarding a huge and long-life project like HSR, it is more important to evaluate by not just construction cost but by total safety, efficiency or LCC. That is because, even if selection of higher quality system might lead higher construction cost, it could realize higher safety level, stability, efficiency, comfort, and increase passenger revenue, decrease operation and maintenance cost. Higher safety level, higher stability, higher comfort; such as high-grade accommodation and service; could capture more customer satisfaction and confidence, resulting higher revenue. Higher efficiency can contributes to low cost operation, resulting reduction of operation cost and higher competitiveness. As the result it could pay higher construction cost and contribute to higher profit and more feasible plan. System integration aiming at overall optimization is exactly what Japanese Shinkansen system has realized, and Shinkansen system has been improving through adopting state of the art technologies from the view point of them.

(2) Shinkansen's way

The Shinkansen system is based on the concept of eliminating collisions by using grade-separated dedicated track and an advanced train protection system known as ATC. In addition, unauthorized persons are prohibited from entering the track right-of-way by law. These key factors together with high-reliable protection systems against natural disasters have enabled Shinkansen to continue its record of "zero" passenger fatalities since the start of revenue service over 50 years ago.

The introduction of EMU, a lightweight wide-body rolling stock, has provided large passenger capacity and is robust in the event of a failure. With the EMU's light axel load and air-tight body structure, it also contributes to compact infrastructure, lesser-loads, smaller cross sectional tunnel and so on, resulting reduction of infrastructure cost.

Moreover EMU is also capable fast acceleration and deceleration. In conjunction with this, these following, such as 1) Unification of train operation, 2) Centralized operation control system, and 3) Separation of operation & maintenance has ensured high-density stable operation. Therefore the most operation efficiency is realized. Besides them, excellent operation and maintenance system, technic & skills realized lowest life cycle cost.

Recently after the success of Shinkansen, dedicated-line, EMU or other excellent features Shinkansen proved, have been adopted in many countries, but Shinkansen still has great advantages owing to its greater experience and accumulation of knowhow.

9.14.2 Comparison from the View Point of Cost and Technical Aspect

(1) Civil infrastructure

As a result of comparing the HSR structure of Japan, France, China and other countries, study team recommends the dimensions of civil and track and structures for Mumbai-Ahmedabad HSR project as table 9.14-1. Compared to alternatives of the standard of France or China, recommended dimensions are cost effective. For example, 80m² of tunnel cross section is 30% cost effective than 100m² cross section tunnel in France or China. Ballastless track costs high at the capital cost, but LCC of ballastless track would be lower than ballasted track in 10 years in Japanese Shinkansen case.

(2) E & M system selection

As mentioned above, HSR is an integrated system therefore it means little to compare each sub-system on one's own separately. Moreover such a sub-system is more or less customized according to its requirement, and generally its price, which is affected by its current sales policy, is not disclosed. Therefore in this section, comparison between recommended systems and alternatives will be roughly described regarding only main sub-systems, Power supply, Signaling & communication, and rolling stock, just for information.

Recommended systems and those alternatives are compared in the table 9.14-2. It is not necessarily the case that the recommendations are lower than the alternatives in construction cost aspect. However the alternatives have insufficient performance or ability for high safety, stability, and high density H.S train operation expected in this project, or inferior to recommendations in aspect of system integration and overall optimization.

Table 9.14-1 Comparison of Civil & Track Structures

Re	Recommendation	Alternative	Alternative's	Technical Aspect
			Procurement Cost	
•	Maximum Axle Load (design)	Japan: 16-17t	Japan: Low-Same	17t is enough for passenger dedicated line.
	17(t)	France: 17t	France: Same	
		China: 20t	China: High	
•	Distance between Track Center	Japan: 4.2-4.3m	Japan: Low-Same	Distance between Track Centers affects land acquisition and structure
	4.5 m	France: 4.2-4.8m	France: Low-High	volume.
		China: 5.0 m	China: High	
•	Formation Width	Japan: 10.9-11.7m	France (14.0m)	Formation width affects land acquisition and structure volume.
	11.5 m	France: 13.6-14.2m	: $High (+3.6\%)$	
		China: 13.4-13.8 m	(viaduct)	
•	Cross Section of Double-Track	Japan: 62.8-63.5 m ²	France, China (100m²)	The tunnel cross section affects the cost.
	Tunnel 80 m ²	France: $71-100 \text{m}^2$: High (+ 30%)	
		China: 90-100 m ²		
•	Track Structure	Ballasted	Low in Initial Cost	Ballasted track will cost higher in 10 years* in view of LCC
	Ballastless		High in LCC	* Case of Shinkansen in Japan

Source JICA Study Team

Table 9.14-2 Comparison of Sub-Systems, Recommendation and Alternatives

Reco	Recommendation	Alternative	Alternative's	Technical Aspect	
			Procurement Cost	Procurement Cost (Disadvantages of Alternative)	ternative)
Powe	Power Supply system				
•	Single Phase AC 2X25 kV	None	ı		
•	Transformer/ Scott connection	V-connection	Almost same	 Higher unbalance rate 	rate
•	OHC/ Compound Catenary	Simple Catenary	Low	• Inadequate for High speed & High	Inadequate for High speed & High density
		Y-Catenary(SC with Stich wire)	Almost same	More difficult for maintenance	maintenance
•	Section System/ Change over switch	Neutral Section	Low	 Unsuitable for em 	Unsuitable for emergency stop system at
				earthquake	
				 Operation speed d 	Operation speed decreases at neutral section
Sign	Signaling & Communication System				
•	Signaling/ Digital-ATC	ETCS-Level2	Almost same	 GSM-R's frequen 	GSM-R's frequency band is insufficient
				 Inferior in reliability 	ty
				 Track circuit syste 	Track circuit system is most reliable
•	Train Radio System/ LCX	GSM-R/TETRA	Low	 Data rate is less and in advanced Information 	Data rate is less and insufficient to highly advanced Information
Rolli	Rolling stock				
•	EMU	Loco	Cost per Train-set is	 Inferior in Passeng 	Inferior in Passenger Capacity or other functions
			almost same,	such as traction pe	such as traction performance, energy efficiency
•	Wide Body	Standard	however	 Inferior in Passeng 	Inferior in Passenger Capacity, resulting higher
			Total Procurement	cost	
•	Non-Articulated	Articulated	cost is High	 Inferior in Passeng 	Inferior in Passenger Capacity, resulting Higher
				cost	

Source JICA Study Team

9.15 Summary of Workshop for HSR Subsystem

For the purpose of deeply understanding for Indian Participant and reflecting for the *Interim Report 2*, JICA study team held the work shop concerning sub-system, which are Rolling stock, power-supply, Signalling and Telecommunication, OCC, etc., as follows.

9.15.1 Date, Time, Place and Number of Participants

- -Date and Time: 8th September, 2014 11:00AM-17:30PM
- -Place: CSOI Conference Room, Vinay Marg, New Delhi
- -Total Number of Participants: MOR, RDSO and JICA officer 29 people

9.15.2 Program

- (1) Introduction and Main Characteristic of HSR and Operation Plan
- (2) Rolling stock plan
- (3) Maintenance Equipment for Rolling stoke
- (4) Power Supply System
- (5) Signalling and Telecommunication
- (6) Working of Operation Control Center

9.15.3 Output and Effect of Workshop

- -Workshop started and closed on time schedule. At first Japanese Experts explained their presentation for each specialized field, after then Indian participants gave some questions.
- -Questions, which included detail and technical matters, were very helpful and show the height of the interest of the Indian side. Each proposal of the Japanese side were almost accepted positive and favorably. We were able to succeed the Workshop with plenty of Indian side cooperation.-These results will be summarized and reflected in the Interim Report 2 until this November.



Figure 9.15-1 Presentation by Japanese Expert



Figure 9.15-2 Closing Remark by Mr. Mathur, Evaluator on staudy Team