Final Preliminary Project Report

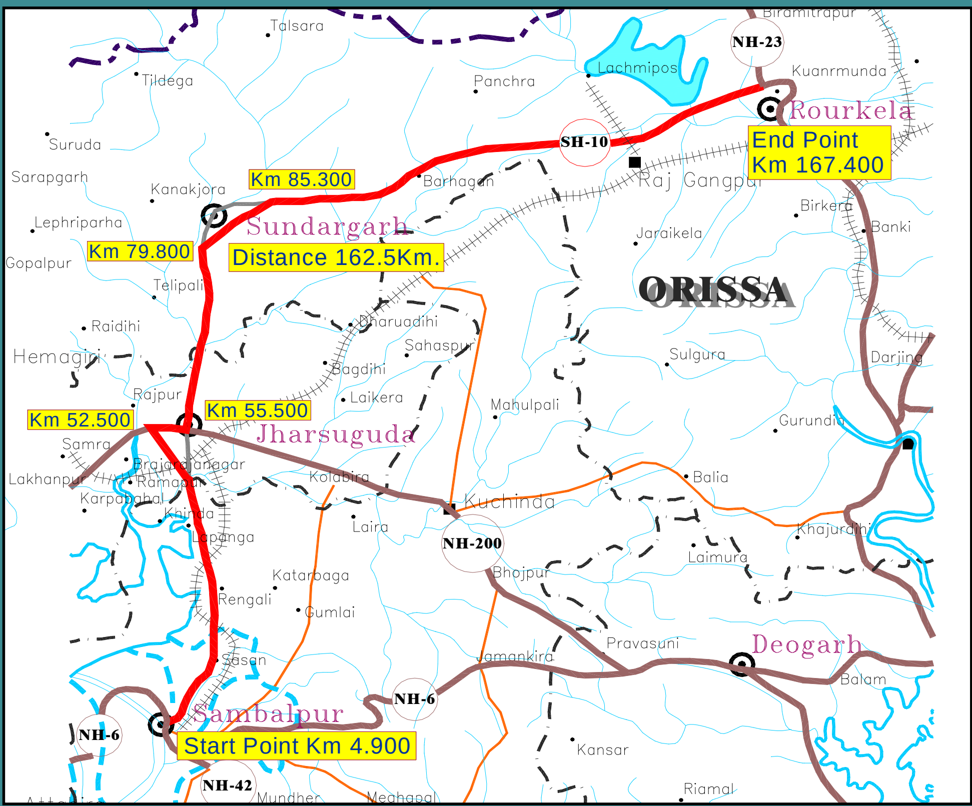
Part 1: Sambalpur-Rourkela Road (SH-10)

VOLUME II: DESIGN REPORT

Submitted By

PRICEWATERHOUSECOOPERS   LEA

Joint Venture



For Project:

"PPP Techno-Economic Feasibility Study and Transaction Advisor for Selected State Roads in the State of Orissa"

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: DESIGN STANDARDS

1.1 INTRODUCTION

Design standards form the basis of the design for various elements of a particular project. Formulation of design standards is required in order to avoid any inconsistency in design from one section to the other and provide a desirable level of service and safety.

The standards for the project presented in the sections that follow have been formulated primarily based on IRC publications, MORT&H Circulars and guidelines, the recently published Manual of Specifications and Standards for Four-Laning of Highways through Public-Private Partnership by the Indian Roads Congress, as well as current international best practices such as AASHTO and TRL standards and procedures.

1.2 CAPACITY STANDARDS

The main reference for determination of standard capacities for roads in India is the Indian Road Congress code (IRC: 64 – 1990). The capacity standards and design service volumes for various configurations of roads for peak hour traffic in the range of 8-10% and design service level corresponding to LoS “B” is summarized in Table 1-1.

Table 1-1: Design Service volume (PCU / Day) for 8-10 % peak hour share

Configuration	Plain Terrain		Rolling Terrain		Hilly Terrain	
	Curvature (degree per km)		Curvature (degree per km)		Curvature (degree per km)	
	0-50	>50	0-100	>100	0-200	>200
Single Lane	2000	1900	1800	1700	1600	1400
Intermediate Lane	6000	5800	5700	5600	5200	4500
Two Lane	15000	12500	11000	10000	7000	5000
Two Lane with 1.5m Paved Shoulder	17250	14375	12650	11500	8050	5750
4 Lane	35000	29000	25500	23000	16000	11500
4 Lane with 1.5m Paved Shoulder	40000	33500	29500	26500	18500	13000

1.3 HIGHWAY AND ROAD APPURTENANCES

1.3.1 Geometric Design Standards

Geometric Design Standards have been largely extracted from IRC: 73 – 1980 and The Hill Road Manual (IRC: SP: 48 – 1998). Since IRC standards do not specify standards for median widths, raised or sunk median, shyness strips etc., these have been recommended as per MOST circulars.

The design speed shall be 100/ 80 kmph in plain and rolling terrain for road passing through rural sections and 40/ 50 kmph for road passing through settlements and industrial areas. The design speed would be 40/ 50 kmph in hilly terrain. However, since the project corridor of Sambalpur - Rourkela passes predominantly through plain terrain, the provisions/ standards related to hilly terrain are not applicable. These have been given for the purpose of reference only.

The normal width of medians will be 4.5m in rural areas while in urban sections it has been reduced to 1.5m depending upon availability of ROW.

AS per IRC guidelines the value of superelevation provided in horizontal curves to counter the effect of centrifugal force will be calculated using the following formula:

$$e = \frac{V^2}{225R}$$

e = Superelevation;
v = Design Speed in kmph; and
R = Radius of Curve in m.

The value of superelevation thus obtained will be limited to the following values:

- In plain and rolling terrain: 7 percent; and
- In hilly terrain: 10 percent.

The length of transition curve is larger of the two values arrived at on the basis of the following criteria:

i) Rate of change of centrifugal acceleration; and
ii) Rate of change of superelevation.

The transition length, in meters, thus obtained is given in Table 1-2 below.

Table 1-2: Length of Transition Curves (M)

Plain and Rolling Terrain				
Curve Radius (m)	Design Speed in Kmph			
	100	80	65	50
45				
60				NA
90				75
100			NA	70
150			80	45
170			70	40
200		NA	60	35
240		90	50	30
300	NA	75	40	25
360	130	60	35	20
400	115	55	30	20
500	95	45	25	NR
600	80	35	20	
700	70	35	20	
800	60	30	NR	
900	55	30		
1000	50	30		
1200	40	NR		
1500	35			
1800	30			
2000	NR			

Mountainous and Steep Terrain					
Curve Radius (m)	Design Speed in Kmph				
	50	40	30	25	20
14				NA	30
20				35	20
25			NA	25	20
30			30	25	15
40		NA	25	20	15
50		40	20	15	15
55		40	20	15	15
70	NA	30	15	15	15
80	55	25	15	15	NR
90	45	25	15	15	
100	45	20	15	15	
125	35	15	15	NR	
150	30	15	15		
170	25	15	NR		
200	20	15			
250	15	15			
300	15	NR			
400	15				
500	NR				

The desirable distance between grade changes is 150m in plain terrain and 75m in hilly terrain.

The gradients to be adopted for different terrains are given in Table 1-3.

Table 1-3: Gradients for Roads

Terrain	Gradient in percentage		
	Ruling	Limiting	Exceptional
Plain or Rolling Terrain	3.3	5	6.7
Hilly Terrain upto 3000m above MSL	6	7	8

The exceptional gradients will be for short lengths not exceeding 100m in length and should be separated by 100m length of gentler or limiting gradient.

The minimum length of vertical curve along with the maximum grade change not requiring vertical curve is given in Table 1-4.

Table 1-4: Minimum Length of Vertical Curve

Design Speed in Kmph	Max. grade change not requiring vertical curve in percent	Minimum length of vertical curve in meters
Upto 35	1.5	15
40	1.2	20
50	1	30
65	0.8	40
80	0.6	50
100	0.5	60

1.3.2 Design Criteria for Hair-Pin Bends

The design standards to be adopted for hair-pin bends are given in Table 1-5. This has been extracted from the Hill Road Manual (IRC: SP: 48 – 1998).

Table 1-5: Design Criteria for Hair-Pin Bends

Design Speed	20 Kmph
Minimum Carriageway Width	11.5 m for two lanes
Minimum Radius of Inner Curve	14.0 m
Minimum Length of Transition Curve	15.0 m
Maximum Gradient	2.50%
Minimum Gradient	0.50%
Superelevation	10%
Roadway Flaring	Concentric w.r.t. Center Line
Distance between two Hair Pin Bends	60m
Type of Full Roadway Width	Surfaced

1.3.3 At-Grade Intersections

Design standards for at-grade intersections will be in accordance with IRC: SP: 41 – 1994, ‘Guidelines for the Design of At-grade Intersections in Rural and Urban Areas’ and the MOST Type Designs for Intersections on National Highways. For design of elements not covered in the aforesaid publications, AASHTO’s Green Book on Geometric Design will be followed. The minimum and maximum radii for left turning lane, rate of taper and other details to be provided are given in Table 1-6.

1.3.4 Grade-Separated Intersections

IRC: 92 – 1985, giving guidelines for the design of interchanges, IRC: 62-1976 giving guidelines for control of access on highways and AASHTO's publication 'A Policy on Geometric Design of Highways and Streets' will be followed for design of grade-separated intersection.

1.3.5 Surface Drainage

An effective drainage system shall be planned for the drainage of roadway including medians, toll plazas, wayside amenities such as rest areas, truck parking areas and bus stops. The following types of drains will be provided for surface drainage of roadway and ROW.

- Longitudinal lined/ unlined drains near the toe with outlets at cross-drainage structures in rural sections. The drain size and shape will be adequately designed to take design run off, and prevent soil erosion;
- Longitudinal covered drains beneath the footpath beside service road or slip road, whichever is applicable;
- Median drains in superelevated sections; and
- Combination of longitudinal drains and chute drains in high embankment stretches of height 3m and above.

1.3.6 Bus Bays

The lay out for bus bays will be in accordance with Manual of Specifications and Standards on Four-Laning of Highways through Public Private Partnership by the Indian Roads Congress. Minor modifications will be made in the layout plan to take care of ROW constraints, if any.

1.3.7 Truck Laybys

The truck laybys will be designed as per the guidelines of MOST Technical Circular No. RW/34032/5/88 – DOII dated 22.8.88. Minor modifications will be made to suit site requirements. The minimum length of truck layby will be fixed at 100m. A rate of taper of 1:5 will be maintained in the layby.

1.3.8 Toll Plazas

The Manual of Specifications and Standards on Four-Laning of Highways through Public Private Partnership by the Indian Roads Congress shall be followed for the planning and design of toll plazas. An open system of toll collection shall be followed on the Project Corridor. The number of service lanes shall be as per the above guidelines. There shall be a separate lane for traffic not required to pay fees. A minimum gradient of 0.05% shall be followed at the approaches and toll plaza area for drainage requirement. The vertical clearance shall be kept at 5.5m in normal lanes and 8.5m for lanes meant for oversized vehicles.

1.3.9 Wayside Amenities

All building works, water storage systems, sanitary sewer and sewage disposal system, electrical systems shall be as per relevant sections and clauses of NBC. All steel works shall conform to Section 6, Part VI of the NBC and Section 1900 of MoSRT&H specifications.

1.3.10 Traffic Aid posts, Medical Aid Posts and Vehicle Rescue Posts

Traffic Aid Posts, Medical Posts and Vehicle Rescue Posts will be provided at toll plaza locations.

1.3.11 Safety Barriers, Pedestrian Guard Rails and Pedestrian Facilities

The safety barriers will be provided at outer edges of roadways wherever the embankment height is more than 3m in plain terrain, at valley sides in hilly terrain and at major bridge approaches. Pedestrian facilities will be adequately provided in urban sections and at major intersections.

1.3.12 Slope Protection

Embankments less than 3m in height will be turfed; those greater than 3m height will be protected with stone pitching. Slope protection in cut sections of hilly terrain will be provided as per standards given in the Hill Road Manual (IRC: SP: 48 – 1998).

1.3.13 Traffic Control Devices

Road markings and road signs are provided as per relevant IRC codes and MORT&H specifications. Lane markings and object markings will be in accordance with Clause – 803 of MORT&H specifications, 2001. Road markings will be in accordance with IRC: 35 – 1997 and the median kerb and kerb separator painting shall be in accordance with Clause 803.3 of MORT&H specifications. The road signs shall be in accordance with IRC: 67 – 1977, Code 600 of Addendum to Ministry's technical circular, directives on NH and centrally-sponsored bridge projects, 1996 and IRC: SP: 31. Traffic signboards are to be painted as per IRC: 67 – 1977 and the text in sign boards are to be as per IRC: 30 – 1968.

1.3.14 Access Control

Access control would be in accordance with the provisions of IRC: 62 – 1976 and the Manual of Specifications and Standards on Four-Laning of Highways through Public Private Partnership by the Indian Roads Congress. On highways with a divided cross-section, median openings should generally be limited to intersections with public roads, and should not be permitted for individual business needs.

While the preceding sections discuss details of proposed standards for different constituents, these along with additional pertinent standards for carriageway configuration four-lane divided carriageway are précised in Table 1-6.

Table 1-6: Design Standards for Highway and Road Appurtenances

S. No.	Item	Design Standard proposed to be followed	Proposed Standards for Adoption
1	**Design Speed, kmph** **i) in plains** **ii) in rolling terrain** **iii) in mountainous terrain** **iv) in steep terrain**	 80-100 65-80 40-50 30-40	 -same-
2	**RoW, m (desirable)**	27-45m	-same-
3	**Carriageway**		
i)	Width per lane for widening	3.5 m	-same-
ii)	Cross-slope/ Camber		
	a) Flexible pavement having bituminous concrete surfacing	2.5%	-same-
	b) Cement Concrete pavement	2.0%	-same-
4	**Paved Shoulder (on Outer Side)**		
i)	Width (rural sections)	1.5 m	-same-
i)	Width (urban sections)	-----	1.5/2.5m
iii)	Cross-slope/ Camber (bituminous surface)	2.5%	-----
5	**Hard Shoulder (on Outer Side)**		
i)	Width	2.0 m	-same-
ii)	Cross-slope/ Camber	3.5%	-same-
6	**Edge Strip**		
i)	Rural section - on median side	….	0.250m
ii)	Urban section - on median side	….	0.250m
7	**Stopping Sight Distance**		
i)	Desirable	360m	-same-
ii)	Minimum	180m	-same-
8	**Horizontal Curvature**		
i)	Minimum Radii, m (desirable)	60 to 360 depends on terrain conditions	-same-
ii)	Minimum Radii, m (Absolute)	30 to 230 depends on terrain conditions	-same-
iii)	Desirable requiring no superelevation	1800	-same-
iv)	Minimum requiring 7% superelevation	360	-same-
v)	Absolute minimum requiring 7% superelevation	230	-same-
9	**Vertical Alignment**		
i)	Minimum distance between PVI	…..	For Existing Carriageway, a minimum distance of 80m and for new carriageway a minimum distance of 150m
ii)	Minimum length of vertical curve	IRC: 73	-same-
iii)	Maximum grade change not requiring vertical curve	IRC: 73	-same-
10	**Gradient, %**		
i)	Maximum	3.3	-same-
ii)	Minimum		
	a) In cut and kerbed sections	0.5-1.0%	-same-
	b) On unkerbed sections on embankment	Near level grades	0.05%
11	**Superelevation,%**		
i)	Minimum	2.5% (Camber)	-same-

S. No.	Item	Design Standard proposed to be followed	Proposed Standards for Adoption
ii)	Maximum	7	-same-
12	**Width of Side Walk (in urban stretches), m**	1.5	-same-
13	**Median Width, m**		
i)	Rural sections	5	-same-
ii)	Urban/other sections	1.2m-1.5m	2m
iii)	Cross-slope/ Camber (5m wide)	----	4%
14	**Width of side walk (in urban stretches)**	1.5m	-same-
15	**Intersections**	IRC: SP: 41 and IRC: 92	-same-
i)	Length of storage lane (including taper) for right turning	…..	80m
ii)	Minimum length of acceleration lane	…..	120m
iii)	Minimum length of deceleration lane	…..	90m
iv)	Maximum radius for left turn	…..	30m
v)	Minimum radius for right turn	…..	15m
vi)	Width of turning lane (inner radius of 30 m)	…..	5.5m
vii)	Rate of taper (min)	…..	1 in 15
16	**Bus Bay**		
i)	Min. length of bus bay, m	15	30
17	**Truck Lay-bye**		
i)	Min length of lay-bye	….	100m
ii)	Min parking length for each vehicle	….	15m
iii)	Min parking width for each vehicle	….	2.75m
iv)	Min. width of raised separator between layby and carriageway	….	3m, can be reduced depending on the availability of ROW
v)	Rate of taper (min)	….	1 in 5
18	**Toll Plaza**		
i)	Width of lane at toll plaza	3.2m	-same-
ii)	Width of lane for oversized vehicles	4.1m	-same-
iii)	Width of islands	1.8m	-same-
iv)	Rate of taper (min)	1 in 10	-same-
v)	Longitudinal slope at the central portion	…..	minimum 0.05%
vi)	Longitudinal slope at approaches	…..	minimum 0.05%
vii)	Vertical clearance of canopy over standard lane	..…	5.5m
viii)	Vertical clearance of canopy over oversized vehicle lane	…..	8.5m
19	**Traffic Control and Road Safety Devices**	IRC: 35, IRC: 67 and MOSRTH guidelines.	-same-
20	**Roadside Furniture**	IRC: 25, IRC: 8, IRC: 103, IRC: 35, MOSRTH guidelines	-same-
21	**Clearance for Utility Lines**		
	Horizontal		As per IRC 32-1969
i)	*Street lighting poles*		
	a) Roads with raised kerbs	…..	300mm min from edge of kerb
	b) Roads without raised kerbs	…..	1.5m min from edge of carriageway
ii)	*Overhead power and telecommunication lines*	…..	It shall be as per the cross section submitted for urban area
	Vertical		As per IRC 32-1969
i)	*Ordinary wires/lines carrying voltage upto and including*	…..	5.5m min.

S. No.	Item	Design Standard proposed to be followed	Proposed Standards for Adoption
	110 volts and telecommunication lines		
ii)	*Electric power lines carrying voltage upto and including 650 volts*	…..	6.0m min.
iii)	*Electric power lines carrying voltage exceeding 650 volts*	…..	6.5m min.

1.4 PAVEMENT DESIGN

The design of flexible pavement for main carriageway shall be in accordance with IRC: 37 – 2001 or any other international standard method/ guidelines for pavement design. Flexible pavement shall be designed for a minimum design period of 15 years or operation period whichever is more. Stage Construction shall be permissible subject to the requirements specified below.

Alternative strategies or combinations of initial design, strengthening and maintenance can be developed by the Concessionaire to provide the specified level of pavement performance over the operation period subject to satisfying the following minimum design requirements:

(a) The thickness of sub-base and base of pavement section are designed for a minimum design period of 15 years and the initial bituminous surfacing for a minimum design period of 10 years; and

(b) The pavement shall be strengthened by bituminous overlays as and when required to extend the pavement life to full operation period. The thickness of bituminous overlay shall be determined on the basis of IRC: 81 - 1997.

The thickness of bituminous overlay shall be determined on the basis of Benkelman Beam Deflection Technique and the design traffic as per the procedures outlined in IRC: 81 - 1997. The design period shall be the same as specified for new pavement sections. In case stage construction is adopted, the initial strengthening shall be done for a minimum design period of 8 years.

The thickness of bituminous overlay for pavement strengthening shall not be less than 50 mm. The subsequent strengthening shall be done at the end of initial design period or earlier, in case of any structural distress in the pavement or if the surface roughness exceeds certain threshold values.

Rigid Pavement shall be designed for a minimum design period of 30 years. Stage construction shall not be permitted in case of rigid pavement. Rigid pavement shall be designed as per IRC: 58 – 1988 or the Portland Cement Association (PCA) method and/ or any other internationally accepted standard method/guidelines based on a flexural strength of 4.5 Mpa. Contraction joints with dowel bars and longitudinal joints with tie bars shall be provided.

The Pavement Quality Concrete (PQC) shall rest over Dry Lean Concrete (DLC) sub-base of 150mm thickness. The DLC will be M10 concrete (7days' strength) as prescribed in IRC: SP: 49

– 1988. A properly designed drainage layer of Granular Sub-Base (GSB) of 150-200mm thickness shall be provided.

Pavement composition for bus bays shall be the same as main carriageway in order to maintain the continuity and uniformity of the pavement layers. However, the pavement composition suggested at truck layby locations may be provided at bus bay locations. Interlocking Concrete Block pavement shall be designed at truck laybys as per IRC: SP: 63 - 2004.

1.5 DESIGN STANDARDS FOR STRUCTURES

This section gives the detailed design standards considered for new construction as well as repair and rehabilitation work of structures.

1.5.1 Codes of Practices

Design standards and the loading to be considered are generally based on the requirements laid down in the latest versions of IRC/ IS codes of practices and standard specifications, and guidelines issued by MoSRT&H. Additional technical references have been used wherever the provisions of IRC/ IS codes are found inadequate. The following IRC/ IS codes are proposed to be used in the design of structures:

- **IRC: 5 - 1998:** Standard Specifications & Code of Practice for Road Bridges, Section I - General Features of Design (Seventh Revision)
- **IRC: 6 - 2000:** Standard Specifications & Code of Practice for Road Bridges, Section II - Loads and Stresses (Third Revision)
- **IRC: 21 - 2000:** Standard Specifications & Code of Practice for Road Bridges, Section III - Cement Concrete (Plain and Reinforced) (Second Revision)
- **IRC: 78 - 2000:** Standard Specifications & code of Practice for Road Bridges, Section VII-Foundations & Substructure (First Revision)
- **IRC: 40 - 2002:** Standard Specifications & Code of Practice for Road Bridges, Section IV- (Brick Stone and Cement Concrete Block Masonry)
- **IRC: 83 (Part II) - 1987:** Standard Specifications & Code of Practice for Road Bridges, Section IX - Bearings, Part II: Electrometric Bearings.
- **IRC: 89 - 1997:** Guidelines for Design & Construction of River Training and Control Works for Road Bridges (First Revision)
- **IRC: SP 13 - 2004**: Guidelines for Design of Small Bridges & Culverts.
- **IRC: SP 40 - 1993**: Guidelines on Techniques for Strengthening and Rehabilitation of Bridges

For items not covered in the above specifications, provisions of the following standards will be followed in the given order of priority:

- Provisions of IS codes of practices; followed by
- Relevant provisions of BS codes of practices; followed by
- Sound engineering practice, international best practices, technical literatures/ papers and provisions of relevant codes of other nations.

1.5.2 Design Standards

The general standards for design of structures shall be as presented in Table 1-7 below:

Table 1-7: General Design Standards for Structures

S. No.	Item	Standard
1	Geometry	Highway alignment and cross-section will be followed. Crash Barrier shall be kept outside the roadway width.
2	Widening	
	a. Extent of Widening	Widening will be decided by Centre-Line (CL) of proposed road, cross-section of road and width of existing structure.
	b. Material for Widening	In case of widening, all components of new structure shall be of RCC or PSC.
3	Connection between existing and widened portion	a. In case of one-side widening there shall be a gap with proper joint between the existing substructure and new widened substructure; the slab-type superstructure will be cast monolithic. b. In case of both-side widening, the substructure and foundation will be extended monolithic on either side.
4	Reconstruction of Existing Bridge or New Construction: Major/ Minor Bridge & Culvert	a. Reconstruction will be as per the findings and recommendations of the Condition Survey report. Based on detailed hydrological study the recommendations for hydrologically inadequate structure will be reviewed.
		b. Bridges up to 8m span will be of RCC box type.
		c. Bridges above 8m and up to 15m span will be of RCC slab on RCC pier/ abutments.
		d. Bridges above 15m and up to 25m span will be of RCC T-girder and RCC deck slab on RCC pier/ abutments.
		e. Bridges above 25m and below 35m span will be of PSCC T-girder and RCC deck slab on RCC pier/ abutments.
		f. Bridges of span 35m and above will be of PSC box girder on RCC pier/ abutments.
		g. All new culverts will of RCC box type
		h. (a) All existing culverts in good condition will be widened with same type. (b) All existing pipe culverts less than 0.9m dia. will be replaced with 1.2m dia pipe.
5	Flyover structures	a. Foundation- Pile foundation of concrete grade M-35 in accordance with IRC: 78 - 2000
		b. Pier – RCC circular column type with RCC pier cap Abutments – RCC wall type
		c. Superstructure - PSC Box girder of concrete grade M-45
		d. Approach - Embankment with RE wall.
6	Underpass	a. RCC box structure to be provided.
7	Vertical Clearance at Flyovers/ Grade-Separators	Minimum headroom of 5.5m from the highest point of formation level of underlying cross-road to soffit of deck slab as per IRC: 5 - 1998
8	Cross-Slope	a. For culvert and structure with single span less than 4.0 m, same cross-slope as that of the road will be followed.
		b. Fill over culvert will be as per pavement design.
		c. Profile corrective course will be as per pavement composition.
		d. For new structure deck slab will follow a cross-slope of max 2.5 %
9	Wearing Course	Wearing course will be 56 mm thick as per MoSRTH Specifications.
10	Approach Slab	a. Provided in Flyovers, Major Bridges, Minor Bridges and Underpasses (For Minor Bridge, single span should be more than 4.0 m). For Underpass, approach slab can be avoided if earth cushion is more than 200mm.
		b. No approach slab for Culvert. IRC:SP: 13 - 2004
11	Bed Protection	All culverts and box type minor bridges will have proper bed protection, as per IRC: 89 - 1997.
12	Retaining Walls	a. Embankment toe wall will be of PCC M-15.
		b. Other cases- RCC retaining wall.
13	Ventilation Vent	For new underpasses, suitable ventilation will be provided.
14	Crash Barrier	RCC M-40 around 0.9 m ht for all structures. (as per IRC: 5 – 1998)

1.5.3 Material Properties

1.5.3.1 Concrete

Following material properties are proposed to be used for various RCC components of bridge structures:

Coefficient of Thermal expansion:	$11.7 \times 10^{-6}/^{o}C$ as per IRC: 6 - 2000
Poisson's Ratio:	0.2
Modulus of Elasticity:	As per Table 9 of IRC: 21 - 2000 for RCC members and as per Clause 10.2 of IRC: 18 – 2000 for PSC members.
Creep & Shrinkage:	As per relevant IRC codes for (Coefficient & time effects)
Concrete Grade:	Refer: Durability Consideration in Design

1.5.3.2 Reinforcement

The reinforcement will conform to the following specifications:

- Mild Steel and Medium steel bars conforming to IS: 432 (Part1) - 1966 (Grade Designation S 240); or
- Cold-twisted bars conforming to IS: 1786 – 1979 (Grade Designation S 500); and

The characteristic strength and elastic modulus of steel will be taken from Table 2 of IRC: 21 - 2000

A) Pre-Stressing Steel System

All ducts and anchorages will be suitable for 19T13 stress relieved low relaxation strands conforming to IS: 14268 – 95. The properties of the strands will be as follows:

a)	Nominal Diameter	:	12.7mm
b)	Nominal Steel area	:	$98.7mm^2$ per strand
c)	Ultimate Load	:	183.71 KN per strands
d)	Modulus of Elasticity	:	1.95×10^5 Mpa
e)	Friction Coefficient	:	0.25/radian
f)	Wobble Coefficient	:	0.0046/m
g)	Anchorage Slip	:	6mm average
h)	Loss of force due to relaxation	:	2.5% at 0.7 UTS after 1000 hrs.

B) Structural Steel

Structural steel will conform to IS: 226 with yield stress of 23.6 Kg/cm^2.

1.5.3.3 Bearings

Depending upon the type of structure, span length of each superstructure, skew angle either Pot fixed/ Pot-cum-PTFE sliding bearings or elastomeric bearing will be suggested.

1.5.3.4 Expansion Joints

Three type of expansion joints are suggested for bridge structures, as follows:

- Strip Seal type of expansion joint is proposed for PSC box girder, PSC T-girders and RCC T-girder type superstructures; and
- Asphaltic plug type expansion joint is proposed for RCC T Girder and RCC solid Slab type superstructure.

1.5.4 Loads and Load Combinations

1.5.4.1 Dead Loads

Following unit weights has been considered for dead load computations in the design:

- Reinforced Concrete: 2.4 t/m^3
- Pre-stressed Concrete: 2.5 t/m3
- Plain Concrete: 2.2 t/m^3
- Structural Steel: 7.85 t/m^3
- Wearing Coat: 2.2 t/m^3

1.5.4.2 Superimposed Dead Loads

A) Wearing Coat

25mm thick mastic asphalt over 40mm thick asphaltic concrete layers has been considered for the wearing coat. The load considered for wearing coat is 200 Kg/m^2 of carriageway (considering future overlays as well).

B) Crash Barrier

Concrete crash barriers shall be 450 mm wide and shall be provided adjacent to the carriageway on either side. Loading may be considered as 1.6 t/sq m for both edges.

C) Raised Footway Kerb

A 0.75m wide raised footway kerb has been provided on one side of the carriageway.

1.5.4.3 Carriageway Live Loads

Bridges have been designed for the worst effect of the following carriageway live loads:

- One/ Two lanes of IRC Class A loading; and
- One lane of IRC Class 70R loading (Wheeled/ Tracked).

1.5.4.4 Pedestrian Live Loads for Minor Bridge

The pedestrian live load has been taken as per Clause 209 of IRC: 6 – 1966 where required. The basic intensity of live load has been considered as 400 Kg/m^2.

1.5.4.5 Longitudinal forces due to Bearing Friction

The coefficient of friction for the sliding bearings has been taken to be 5%. When considering the effects of differential friction on bearings on either side of the fixed piers, the friction on one side of the bearing has been taken as 5% while on the other side it is taken as 2.5%.

1.5.4.6 Horizontal Forces due to Water Currents

The water current forces have been taken as per Clause 213 of IRC: 6 – 1966.

1.5.4.7 Seismic Loading

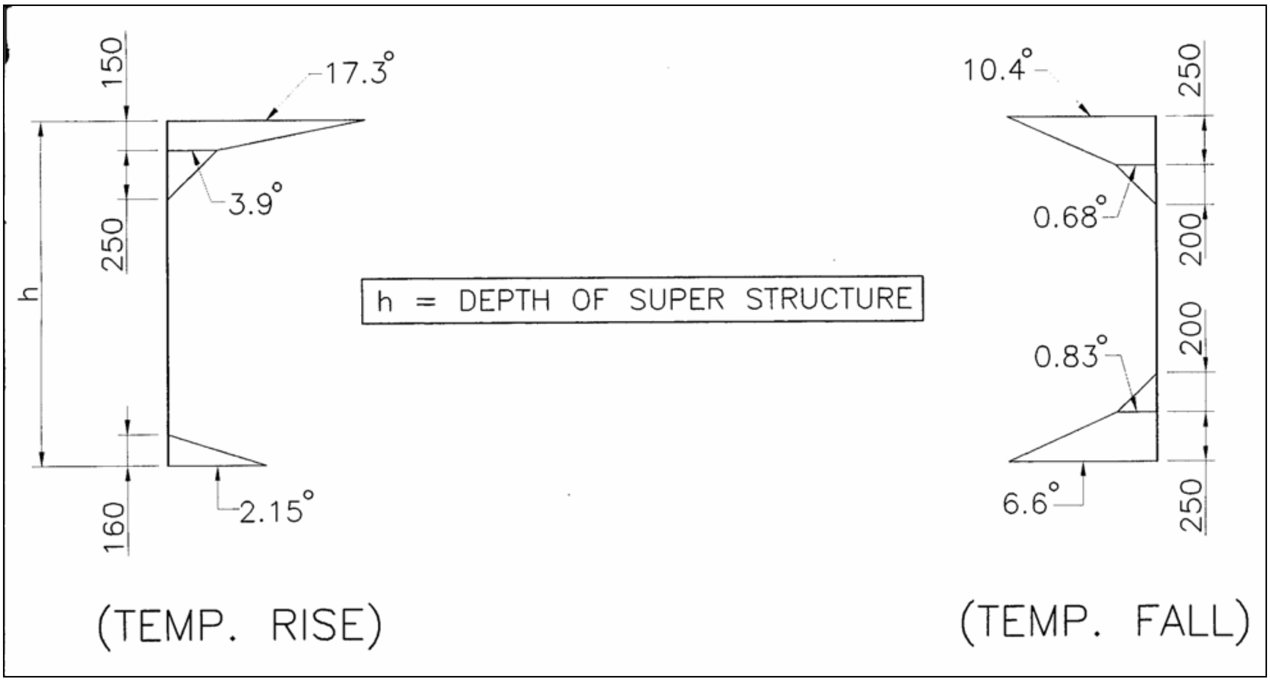
The bridges are located in Seismic Zone - II as per the relevant IRC code. Hence, seismic forces will be considered only for those bridges having span greater than 15m or overall length of the bridge is more than 60m.

1.5.4.8 Wind Loading

As per IRC: 6 – 1966, the project corridor falls under “double intensity” zone based on which the wind intensity to be taken is double the values given in Clause 212.3 of IRC: 6 – 1966. However, considering the frequent occurrences of cyclones in Orissa, which have often created havoc in the state, it is considered prudent to take a higher wind velocity for the structural design. A wind velocity of 260 Km/hr has been considered for the design of structures.

1.5.4.9 Temperature Loading

- The bridge superstructure/ components i.e. bearings and expansion joints have been designed for a temperature variation of +/- 17^{o}C, considering the severe climatic conditions;
- The superstructure has also been designed for effect of distribution of temperature across the deck depth as given in Sketch - A enclosed, suitably modified for the surfacing thickness provided as per Table 1 enclosed. These are based on the stipulations of BD 37/ 88.



- Temperature effect has been considered as follows :
    - Effects of non-linear profile of temperature are combined with 50% live load. The value of modulus of elasticity for concrete, "E_c" is taken as "E_i/2"; and
    - Effects of global rise and fall of temperature is combined with 100% live load and value of modulus of elasticity for concrete, "E_c" is taken as equal to "E_i".

1.5.4.10 Load Combination

All members are designed to sustain safely the most critical combination of various loads and forces that can co-exist. Various load combinations as relevant with increase in permissible stresses considered in the design are as per Clause 202 of IRC: 6 – 1966 and Clause 706 of IRC: 78 – 2000.

1.5.5 Exposure Condition

The project corridor is located in interior part of Orissa and the condition of exposure is considered as "Normal" for the purpose of structural design.

1.5.6 Cover to Reinforcement

Following concrete covers are proposed to be used for various structural components:

- Foundation : 75mm
- Sub-structure : 75mm
- Super-structure : 50 mm

1.5.7 Durability Considerations in Design

In view of the severity of the environment, which subjects the bridge to additional loads, considerations have been given for reducing the need for general and long term maintenance and to achieve a durable structure.

The following items have been identified as requiring special attention in this regard:

- Concrete Grade to be used shall be as follows :

	Major Bridges	*Minor Bridges*	*Culverts*
PSC Structure	M40	-	-
RCC Structure	M35	M35/M30	M25
PCC Structure	M30	M25	M20

- The design and detailing of various components are such that ease of access for inspection and maintenance operation is addressed for all aspects; and
- Easy access to bearings at pier locations will be provided from well cap level.

1.5.8 Design of Culverts

Following are the major design standards/ strategies for new construction of culverts:

- IRC Standard Box culverts have been provided where box culverts are recommended; and
- IRC: SP: 13 – 1973 has been followed for new construction of pipe culvert.

1.5.9 Sample Structural Design of bridges

On the basis of finalized span arrangement for the bridges, the design standards as given in this Chapter and the topographical and geotechnical information, the design for various components has been carried out. The design methodology, philosophy and sample design calculations for different structural components is presented separately in Volume IIA of this report. The detailed design calculations of different structural elements are supported by Detailed Structural drawings given in Volume III of this report.

The various structural components covered in Volume IIA of this report are as follows:

- Design of Super-structure:
  - Design of PSC Box Super-structure;
  - Design of PSC T-Girder Super-structure;
  - Design of RCC T-Girder Super-structure; and
  - Design of RCC Solid Slab Type Super-structure.
- Design of Sub-structure and Foundation:
  - Design of Pier and Pier Cap;
  - Design of Wall-type Pier; and
  - Design of RCC Well Foundation.
- Design of RCC Box Type Minor Bridge:
- Design of Elastomeric Bearing and

- Design of RCC Retaining Wall Cantilever type.

1.6 GEOTECHNICAL

The geotechnical engineering of the project includes carrying out a comprehensive exploration program at selected locations of the project corridor. The subsoil data obtained during exploration have been used for analyzing the stability of existing and proposed structures and roadway embankments.

The geotechnical design, in general, conforms to the applicable IRC and/ or IS codes of practice. In addition, some international design manuals and popular technical books have been referenced. The design has been based on the serviceability loads criterion with a safety factor adopted on the ultimate design value. The geotechnical recommendations include the adequacy of foundations of the existing structures, allowable bearing capacity for the foundations in the widening areas and new structures, ground improvement, if any, for increasing the shear strength of foundation soils & limiting post-construction settlements of structures and roadway pavements, compaction control of fill used in the embankments & foundation/utility trenches and erosion control of embankment side slopes. The proposed design methodology is itemized in the Table 1-8 below:

Table 1-8: Proposed Design Methodology of Geotechnical Aspects

Sl. No.	Item	Standards
1.	Sub-soil Investigation	The field and laboratory tests shall be conducted for structure locations in compliance with Contract Agreement. The procedure for testing shall be in accordance with relevant BIS codes.
2.	Seismic Zone	Zone and Peak ground acceleration (PGA) shall be decided based on IS: 1893 (Part 1): 2002. However, cross reference shall be made for Peak ground acceleration (PGA) on report of National Geophysical Research Institute (NGRI), Hyderabad, under The Global Seismic Hazard Assessment Program (GSHAP).
3.	Embankment	
	i) *Fill Material*	
	a) Embankment material properties (c, □, □)	Property shall be determined based on laboratory test data on approved fill material. Fill material in the vicinity of embankment stretches will be considered for construction. Guidelines from MORT&H, IRC: 36-1970, IRC: 58 – 2001 shall be followed.
	b) Pavement material properties (c, □, □)	Based on grain size and index properties, strength parameters will be estimated.
	ii) *Embankment Stretches*	
	Approach Embankment	Generally following stretches considered based on the height of the embankment i) 75 - 100m on either side of Pile supported structure ii) 25 - 50m on either side of open/ well foundation supported structure
	b) Running Embankment	Other than approach embankment
	iii) Embankment Geometry	
	a) Design Road Top Width	Depending upon proposed highway c/s either a) Width of widened part or, b) Total proposed road width
	b) Design Height	Average of heights measured from ground level to finished road level along the c/s and then maximum of all those average heights along the stretch based on proposed highway c/s and l/s.
	iv) *Traffic Load*	Generally 1.50 t/m^2 depending upon traffic volume

Sl. No.	Item	Standards
	v) *Ground Water Table*	For analysis, generally the ground water will be assumed at ground level. However, GWT shall be confirmed from Geotechnical Investigation Report as well as from existing well in the vicinity with judgment of seasonal variation
	vi) *Sub-soil Profile and Properties*	Based on Geotechnical Investigation Report and engineering judgment and interpretation.
	vii) *Stability Analysis*	Following standards and criteria will be adopted / used: MORT&H approved HED software package / "XSTABL" (version 5) software package (developed by Interactive Software Designs, Inc, USA) for static analysis. For seismic analysis, "XSTABL" (version 5) software package (developed by Interactive Software Designs, Inc, USA) Simplified Bishop's method as per IRC 75 Undrained unconsolidated condition analysis Slope, toe and deep seated base failure analysis Min F.O.S – 1.25 (for short term), 1.5 (for long term) & 1.00 (for seismic) Slope – Generally 1(v): 2(H) wherever ROW is available
	viii) *Settlement Analysis*	Following standards and criteria will be adopted/ used: a) MORT&H approved HED software package b) One dimensional consolidation settlement for cohesive and partly cohesive deposition as per IRC: 75 Permissible Total Settlement Limits as per IRC: 75: 400 – 600mm for Running Embankment, 100-125mm for open/ well foundation and 30 to 45mm for pile foundation.
	ix) *Bearing Capacity Analysis*	For bearing capacity, the method recommended by IRC: 75, Pilot, Silvestri and Meyerhof will be followed.
	x) *Sand Drainage Blanket*	Based on sub-soil type, position of ground water table and embankment fill material, the requirement, if any, will be decided.
	xi) *Slope protection*	For ≥3m high embankment, stone pitching/ geomeshes/ geonets/ geogrids/ jute or coir Geotextile, if any, as per detailed site condition. For <3m high embankment, natural plantation/ artificial vegetative turfing.
	xii) *Ground Treatment*	Based on analysis, suitable ground improvement technique, if any, shall be proposed.
	xiii) *Instrumentation*	Based on suggested ground improvement method, suitable instrumentation, if required, will be provided.
	xiv) *Mechanically Stabilized Walls*	Following criteria shall be adopted: Geogrid / metallic reinforcement Discrete concrete panel and segmental block Design for static condition – BS 8006 Design for seismic condition – French Standard NF 94-220, FHWA publication No. 43 Material and construction – MORT&H Specification
	xv) Ground treatment for pond, water logged and marshy areas	Treatment will be indicated on the basis of extent, depth of water, location, land use in the neighborhood.
4	Foundation	
	i) *Open Foundation*	
	a) Foundation shape	Based on site condition and structural requirement
	b) Foundation size	Based on sub-soil profile and properties, site condition, structural requirement etc.
	c) Foundation depth	Based on sub-soil profile and properties, structural requirement, ground water table, scour level etc as per IRC: 78, IS: 1904.
	d) Design procedure	a) Safe Bearing Capacity: For soil and completely disintegrated rock according to procedure given in IS: 6403(1981), IS: 1904(1986). For rock as per IS: 12070(1995), Standard Reference Books. F.O.S: Minimum 2.5 for soil, 6 or as recommended in above references for rock. b) For Total & Differential Settlement: According to IS: 8009(part-I)-1976,IS: 1904-1986, Schmertmann method, Standard Reference Books
	ii) Pile Foundation	
	a) Type of pile	Generally Bored cast in situ piles and Rock socketed piles

Sl. No.	Item	Standards
	b) Pile Shape	Generally circular.
	c) Pile Diameter	As per IRC: 78 – 2000.
	d) Design procedure	Following standards and criteria will be adopted/ used: a) Vertical Compression, Vertical tension and Lateral load capacity - as per IS: 2911(part-I/sec-II)-1979, IS: 14593-1998, IRC: 78- 2000, Standard Reference Books F.O.S - For soils: 2.5 – 3.0, For socketed piles: End bearing : 5.0 – 6.0, Skin friction= 10 Settlement – as per IS: 8009 (Part II), Standard Reference Books etc. Spacing – As per IS: 2911(part-I/sec-II)-1979, IRC: 78-2000. Negative drag - IRC: 78-2000, Standard Reference Books
	e) Depth of Pile	Based on sub-surface profile, structural load requirement, scour level etc. in accordance with above codal provisions. For socket length in rock, IS : 14593 and IRC: 78-2000 shall be followed.
	f) Pile load tests	As per provision of IRC: 78 – 2000 and MORT&H Specification. Pile Integrity test if number of piles is substantial. Initial pile load test preferably by cyclic method
	iii) *Well Foundation*	
	a) Well Shape	Generally circular.
	b) Well Diameter	Based on sub-soil profile, scour level, structural load etc.
	c) Design procedure	Following standards and criteria will be adopted/ used: a) Safe Bearing Capacity: For soil and completely disintegrated rock according to procedure given in IS: 6403(1981), IS: 1904(1986). For rock as per IS: 12070(1995), Standard Reference Books. F.O.S: Minimum 2.5 for soil, 6 or as recommended in above references for rock. b) For Total & Differential Settlement: According to IS: 8009(part-II)-1976,IS: 1904-1986, Schmertmann method, Standard Reference Book
5.	Minimum Compaction Requirement	
	i) Embankment a) For granular soils For c-ϕ soils	i) Minimum 75-80% Relative Density otherwise, 95% of MDD as per MORT&H specification ii) Minimum 95% of MDD as per MORT&H specifications
	ii) Subgrade	Minimum 97% of MDD as per MORT&H specifications

1.7 DRAINAGE

The road drainage system has been planned as per IRC: SP: 42 – 1994 and IRC: SP: 50 – 1999. A camber of 2.5% shall be provided in the main carriageway, service road as well as in truck layby and bus bay locations. Longitudinal unlined drains shall be provided one metre away from toe of highway in rural sections with outlets towards cross drainage structures. Longitudinal lined trapezoidal drains are provided in between Main Carriageway (MCW) and Service Road (SR) to cater surface runoff from MCW and SR. Sumps connecting with 600 mm HP Pipe shall be provided wherever needed to continue the lined drain across the service road provided in between MCW and SR to ensure proper drainage. Median cuts or median drains have been provided in super elevated sections. Chute drains at a distance of 20m are provided in stretches having embankment height more than 3.0m. At the location of high embankment where RE wall has been provided, the water from MCW shall be carried out by 150 mm diameter PVC down take pipe provided at spacing of 20m c/c. Whenever there is less space in between toe of MCW/ SR and ROW a RCC rectangular lined drain with 0.6 width has been provided. The details of design standards followed in this regard are given as below.

CHAPTER 2: TOPOGRAPHICAL SURVEYS

2.1 INTRODUCTION

Topographical survey is the backbone of any project preparation engineering design. Accuracy of the information collected during this survey has direct bearing on almost all the design activities involved in project preparation. The beginning of topographical surveys is made with the collection of preliminary information on latitude and longitude of the project area as well as the approximate reduced level above the Mean Sea Level (MSL) from Survey of India maps available in the region. For the purpose of detailed engineering design, topographical surveys were divided into the following activities:

- Setting up permanent bench marks and control stations to be used during construction;
- Establishment of horizontal control to have unique coordinate systems of Northing and Easting along the project corridor;
- Establishment of vertical control to have elevation coordinates linked to the nearest GTS stations along the project corridor;
- Collection of Digital Terrain Model (DTM) data containing the existing highway, rivers, streams and other topographical features to form the basis for the new designs; and
- Preparation of base plans containing all the natural and man-made features like buildings, fences, walls, utilities, trees, temples and other religious structures etc. that would govern the finalization of horizontal alignment.

2.1.1 Stages of Topographic Surveys

Topographic features were examined along the entire stretch of the corridor so as to explore the suitability of pavement widening. The options of eccentric widening, concentric widening and realignments were examined so that the most appropriate solutions are arrived at. The locations requiring bypasses and geometric improvements were surveyed and improvement proposals prepared. Horizontal/ vertical control points were established and detailed topographic surveys were carried out for evolving the Digital Terrain Model to study the various alternatives and for the preparation of horizontal and vertical alignments.

2.2 PERMANENT BENCH MARKS

Bench marks pillars at every 1000m along the route within the ROW have been constructed. These pillars have to be located at strategic locations so that they remain undisturbed. All these pillars have been furnished with X, Y and Z co-ordinates. The pillars are of size (150 x 150 x 450) mm. These are embedded in concrete, with 150 mm remaining above the ground. A steel rod has been fixed in the centre for punching the point; finally, these have been painted canary yellow. The Reduced Level (RL) has to be marked on the pillars with red paint after leveling surveys.

At every Tenth Km, comparatively larger pillars of (300 x 300 x 600) mm size have been constructed. These pillars also have the rod arrangement as in the case of the smaller pillars.

The horizontal face of pillars should be absolutely flat and truly vertical with respect to the ground. Reference marks with paint have been made on the pavement for these pillars. These co-ordinates have been presented in Appendix 2.1, Volume IIA of this report.

2.3 HORIZONTAL CONTROL

Horizontal control stations were established at every 10 km interval along the corridor. The control points were established through a 6 mm diameter bar fixed on (150 x 150 x 450) mm and (300 x 300 x 600) mm size concrete blocks embedded in concrete along the sides of shoulders. Traversing in loop has been completed prior to the detailed survey. Stations have been established 300 – 400 m apart during traversing. The minimum accuracy of this survey was kept at 1: 20,000. Traverse loops were processed and adjusted. The Horizontal Coordinate system used in Control Stations so established with closed loop traversing was used as a base line for the DTM Survey. The benchmark pillars established along the project corridor were also connected during the closed loop traversing. However, since elevation data obtained by Total Station is not accurate enough to be used, this data was discarded and elevations obtained by Auto Level survey (discussed in the subsequent section) were used. This data covers information about the locations, absolute horizontal coordinates and elevations. This data is also given in the highway design drawings in Volume III of this report.

2.4 VERTICAL CONTROL POINTS

A closed circuit leveling has been run along the entire route. During the course of leveling, all Bench Marks established at intervals of 1000 m above were connected. Apart from this, benchmarks have also been left on permanent structures available en-route. All traverse stations and pillars have also been connected. The benchmark at Sambalpur Railway Station with RL of 150.202 m above MSL has been used as the reference for leveling surveys. Closed loop leveling was carried out, with the closing error being within the permissible limits of 6 $\sqrt{K}$, where K is the loop length in km and the error is in mm. The permissible error was then distributed using length-weighted distribution to get the exact elevation of a particular benchmark. The elevation (Z) coordinates so established from closed loop leveling was then used in DTM survey for picking up the longitudinal section and cross-sections of the road. Apart from these newly-constructed reference pillars, benchmarks have also been left on permanent structures (bridges, slab culverts etc).

2.5 DTM SURVEYS

Using already established horizontal and vertical control points, accurate data in the digital format in terms of Northing (Y), Easting (X) and Elevation (Z) co-ordinates for cross-section of the existing road, apart from the center line and edges of the existing pavement, paved shoulder (if any) demarcation, shoulder drop, edge of formation, toe line and points on existing ditches have been taken perpendicular to the centre line at 100 m intervals in tangent sections and 25-50m intervals in curved sections using Total Station. Points on the natural surface have been taken 10m apart within the proposed ROW. Longitudinal spot levels on the existing carriageway were captured at three locations, namely at the centerline, and along the pavement edges at both ends, in order to assess the requirement of profile corrective course.

At minor junctions, the survey was extended to a minimum of 100 m on either side of the road centerline, while in major intersections and railway crossings the survey was extended to a minimum of 250 m on either side of the road centerline to allow for improvements including at-grade intersections to be designed. All natural and man-made features such as buildings, factory boundaries, irrigation channels, drainage structures, religious structures, trees and utilities (OFC cables, water pipe lines, electrical poles, telephone poles) etc., were picked up during the survey.

2.5.1 Quality Assurance

Every effort was made to minimize errors during the field survey. A system of checks was implemented to ensure the accuracy of all survey information to be gathered, particularly concerning the horizontal and vertical control points. As a part of quality assurance, primary and secondary responsibilities were established and instruments checked at regular intervals. DTM data collection was also based on the loop system with loop closures at every 250 m. A minimum precision of 1: 10000 was adopted in DTM data collection survey. Suitable corrections were applied to coordinates wherever the error was within the permissible limits and requisite adjustments were made. DTM survey was repeated wherever the required precision was not met.

2.5.2 Data Storage

A spatial co-ordinate system was followed for referencing all data points. Each data point was referenced by a system of x, y and z co-ordinates, the first two representing the horizontal locations and the third the elevation. The horizontal co-ordinates were referenced to the absolute grid system of Northing and Easting established by Closed Loop Traversing. The elevation datum used was the bench mark at Sambalpur Railway Station.

The survey information data format for DTM survey was as follows:

- Point number;
- Easting (x);
- Northing (y);
- Elevation (z); and
- Description.

All data was stored electronically, downloaded to a computer and then backed up on CD drives.

2.6 BASE MAPS

Base Maps showing the alignment of existing roads, ROW and pertinent topographic features such as buildings, factory boundaries, irrigation channels, drainage structures, religious structures, trees and utilities (OFC, water pipe lines, electrical poles, telephone poles) overhead tanks, open wells were prepared using the DTM data collected. Highway design software was then used to process the raw data and create co-ordinate files. Base plans were updated through walk-over surveys on the corridor. Wherever a feature was found not captured, survey was again done at that location to prepare final base plans.

2.7 RIVER BED PROFILES AND CROSS-SECTIONS

In accordance with IRC Special Publication No. 13 and IRC: 5 – 1998 recommendations for the hydraulic design of major bridges and culverts, bed stream cross-sections and longitudinal sections were taken depending upon the size of the catchment area. The number of cross-sections varied from 3 to 5 and the length of the longitudinal section varied from 300 m to 1000 m on the upstream and downstream sides of the existing cross-drainage structures.

CHAPTER 3: HYDROLOGICAL AND HYDRAULIC ASSESSMENT

3.1 INTRODUCTION

The project corridor of SH-10 from Sambalpur to Rourkela passes mainly through plain and rolling terrain having cultivated, forested, barren lands and a few urban settlements and industrial Complexes. Some part of the corridor lies in the influence area of Hirakud dam on river Mahanadi. All hydraulic structures in the area are under the jurisdiction of the Water Resources Department, Government of Orissa.

Natural streams intercept and cross the road at a few stretches, thus making the drainage system more effective, though requiring extensive bank protection works. From Sambalpur till Sundergarh the road has a north-south orientation and water coming from the surrounding areas flow from the right side of the project corridor (while traveling in the direction of increasing road chainage) and crosses over to the left side. From Sundergarh to Rourkela the corridor has an east – west orientation and drainage channels cross over from the left to the right of the road. Except at two locations, submergence of the road during heavy downpour is not reported.

3.2 DATA COLLECTION AND OBSERVATIONS

3.2.1 Data collection

The hydraulic condition of each structure was assessed thoroughly by visual observation and was supplemented with local inquiries. Visits to the local offices of PWD and Water Resources department were also made to collect the available hydrological data. Most of the cross-drainage (CD) structures are observed to be hydraulically adequate. There is no evidence of overtopping of project road sections along the corridor, which has been confirmed by local enquiry. Comprehensive hydraulic analyses of various CD structures and roadside drainage have been carried out based on detailed topographical survey.

There are 6 major and 39 minor bridges along the project road. Attempts were made to collect hydraulic details of rivers from the PWD/ Water Resources Department, Government of Orissa. Further information was collected through reconnaissance survey and topographical surveys to carry out the hydraulic parameters calculations.

3.2.2 Observations

3.2.2.1 Minor Bridges

There are thirty-nine minor bridges on various rivulets/ nallas crossing the road from the right side. It has been found that at some places of bridge locations there is substantial siltation and closing of opening on both sides. Proper dredging is required to clean the openings of all the bridges in order to pass the maximum flow without endangering the structures.

3.2.2.2 Major Bridges

There are 6 major bridges with structure nos. 42/2, 67/2,118/1,145/1,155/1 and 166/2 on various rivers crossing the road from the right side. The general condition of the bridges is good with minor damages and mostly sufficient waterway to render the bridges hydraulically adequate. Strengthening of bank protection works at Kherwali bridge site at structure no. 42/2 is required. It is recommended that 10-20 m bank protection works on the both sides of bridge be constructed.

3.3 DESIGN ASSUMPTIONS

3.3.1 Return Period and Rainfall

As per IRC: 5 – 1998 (Standard Specifications and Code of Practice for Road Bridges, Section – 1, General Features of Design), bridges are designed for a return period of not less than 50 years. A flood of this specified return period should pass easily through the structure, while an extraordinary and rare flood may pass without doing excessive damage to the structure or the road.

The 50-year, 24-hour rainfall for the zone under consideration varies from 300 to 360 mm. (Ref: “Flood Estimation Report for Mahanadi Basin, Sub-Zone – 3 (d)”, published by the CWC).

Topographic maps, obtained from the Survey of India, on a scale of 1: 50,000 and 1: 2, 50,000, have been utilized for the hydrological study of the corridor.

3.3.2 Cross-Sections and Longitudinal Sections at Bridges

For the calculation of discharge of the stream by the Area-Velocity method, topographical survey including leveling surveys were carried out across and along the water courses to determine the cross-section and longitudinal slope. A number of cross-sections have been taken at regular intervals on both upstream and downstream sides of the structure, including one at the proposed location of a new structure, in accordance with relevant IRC specifications.

The following assumptions have been made for peak discharge computations:

- For locations where water spreads over the banks, the cross-sections shall be extended up to the HFL, in order to calculate the effective cross-section of flow; and
- The longitudinal section to determine the bed slope shall be taken at approximately regular intervals following the channel course, and extending on both the upstream and the downstream sides of the structure. Caution shall be exercised by following the curved flow line for longitudinal gradient, rather than a straight line.

3.4 DESIGN CRITERIA FOR HYDROLOGY OF CROSS-DRAINAGE STRUCTURES

3.4.1 Assessment of Peak Discharge

The peak discharge and the HFL have been calculated by the following methods:

- Area-Velocity method;
- Rational method; and
- Synthetic Unit Hydrograph (SUH) method.

3.4.1.1 Area – Velocity Method (Manning's Formula)

$$Q = A \times V$$
$$= A \times [(1/n) \times (R)^{2/3} \times (S)^{1/2}]$$

Where, Q = the discharge in cumecs;

A = Area of the cross section in sq m;

V = Velocity in m/ sec;

R = Hydraulic mean depth in m = A / P;

P = Wetted perimeter of the stream in m;

S = Bed slope of the stream; and

n = Rugosity Co-efficient.

3.4.1.2 Rational Formula

This method is applicable for area of catchments less than 25 sq km. As per "Bridges and Flood Wing Report No. RBF-16" ("Flood Estimation Methods For Catchments Less Than 25 sq km in Area"), published by Research Design and Standards Organization (RDSO), Ministry of Railways, Government of India, in March 1990; the Rational Formula has been further improved upon as follows:

$$Q_T = 0.278\, C\ I\ A$$

Where, Q_T = Design flood discharge for design return period of T years, in cumecs;

C = Runoff Coefficient;

I = Rainfall intensity lasting for t_c hour duration in, mm/ hr;

t_c = Time of concentration (in hours); and

A = Area of catchment in sq km.

The Runoff Coefficient, *C*, depends on the nature of soil, soil cover and location of the catchment, and is given in the following Table 3-1.

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Table 3-1: Values of Runoff Coefficient

Description of Type of Catchment		Runoff Coefficient
1.	Sandy Soil/ Sandy Loam/ Arid Areas	C = 0.249 (R x F) 0.2
2.	Alluvium/ Silty Loam/ Coastal Areas	C = 0.332 (R x F) 0.2
3.	Red Soil/ Clayey Loam/ Grey or Brown Alluvium/ Cultivated Plains/ Tall Crops/ Wooded Areas	C = 0.415 (R x F) 0.2
4.	Black Cotton/ Clayey Soil/ Lightly Covered/ lightly Wooded/ Plain and Barren/ Sub-montane and Plateau	C = 0.456 (R x F) 0.2
5.	Hilly Soils/ Plateau and Barren	C = 0.498 (R x F) 0.2

Where R = 24-hour point rainfall for T years, in cm;

T = Design return period of rainfall in years; and

F = Areal Reduction Factor, depending upon the catchment area and duration of rainfall as given in the following Table 3-2

Table 3-2: Values of Areal Reduction Factor

Catchment Area (sq km)	Duration of Rainfall		
	< 30 min	30 to 60 min	60 to 100 min
< 2.5 sq km	0.72	0.81	0.88
>=2.5, <= 5.0 sq km	0.71	0.80	0.87
>5.0, <= 13.0 sq km	0.70	0.79	0.86
>13.0, <25.0 sq km	0.68	0.78	0.84

The time of concentration, t_c (in hours), shall be calculated by using Brasnsby Williams' formula (since in most of the places the catchment area is in an elongated form), which is given by:

$$t_c = 0.9 \left(\frac{L}{M^{0.1} \quad S^{0.2}} \right)$$

Where,

L = Length of longest stream in miles;

M = Catchment area in sq miles; and

S = Average grade from source to site in percent.

The following steps shall be followed to obtain rainfall intensity (I) of a return period of T years, lasting for t_c hours:

- Get the T-year, 24-hour rainfall ($R_{T(24)}$) from the report *"Flood Estimation Report For Mahanadi Basin, (Sub zone – 3 (d) "* for return period, T;
- Get the 1-hr and t_c-hr ratio from Fig. 4 of "*Bridges and Flood Wing Report No. RBF-16";*
- Calculate K = (t_c-hr ratio) / (1-hr ratio);
- Calculate T-year, 1-hr rainfall, i.e. $R_{T(1)} = R_{T(24)}$ x (1-hr ratio);
- Calculate T-year, t_c-hr rainfall, i.e. $R_{T(tc)}$ = K x $R_{T(1)}$; and
- Calculate rainfall intensity for a T year return period, lasting for t_c hours, i.e. I = $R_{T(tc)} / t_c$.

The catchment area, A, for major and minor bridge structures has been determined from the topographic sheets of 1: 50,000 or 1: 10, 00, 000.

3.4.1.3 Synthetic Unit Hydrograph Method

This method is based on the unit hydrograph principle, used when the catchment area is greater than 25 sq km. CWC has published Flood Estimation Reports for different zones in India. The project alignment from Sambalpur to Rourkela falls in Zone- 3(d). A detailed approach along with equations for unit hydrograph has been given in the report *"Flood Estimation Report for Mahanadi Basin (Sub Zone –3 (d)"*, published in January 1994. In this method the design flood discharge has been calculated as per guidelines given in the report.

Design discharge at the bridge sites has been taken as per above procedures and calculations were also carried out at upstream and downstream of the bridge at locations where cross-sections are available by area slope method. The maximum of the peak flood discharge by different above methods are considered provided it does not exceed the next highest discharge by more than 50%. If it does exceed so, it is then restricted to that limit (as per Article 6.2.1 of IRC: SP: 13 – 2004).

3.5 DESIGN CRITERIA FOR HYDRAULICS OF CROSS-DRAINAGE STRUCTURES

3.5.1 Hydraulic Analysis for Design HFL

In hydraulic analyses, the design HFL shall be calculated corresponding to the Design Discharge by Manning's Equation at the bridge site, as described above.

3.5.2 Afflux Calculation

When the waterway area of the opening of a bridge is less than the unobstructed natural waterway area of the stream, i.e. when bridge contracts the stream, afflux occurs. The afflux will be calculated using Molesworth's formula as given below: -

$$h = \left(\frac{V2}{17.88} + 0.01524 \right) \{ (A/a)2 - 1 \}$$

Where, h = Afflux in meters;

V = Average velocity of water in the river prior to construction in m/sec;

A = Unobstructed sectional area of the river at proposed site in sq m; and

a = Constricted area of the river at the bridge in sq m.

3.5.3 Scour Depth Calculation

To provide an adequate margin of safety for design of foundation, a further increase by 30% shall be made over the design discharge as per IRC: 78 – 2000, thus obtaining the final design discharge for the design of foundation.

By IRC: 5-1998 / IRC: 78-2000

As per IRC: 5 – 1998 or IRC: 78 – 2000, the mean depth of scour below the highest flood level, Dsm, will be given by the following equation:

$$D_{sm} = 1.34 \times (D_b^2 / K_{sf})^{1/3}$$

Where, D_b = Discharge in cumecs per meter width; and

Ksf = Silt Factor.

The value of 'D_b' shall be the total design discharge divided by the effective linear waterway between abutments.

For most bridges, the silt factor, K_{sf}, shall be calculated as per guidelines given in IRC: 78 – 2000 (Clause 703.2); alternatively, it will be assumed to be 1.5 in case of absence of soil distribution curve.

3.5.4 Maximum Depth of Scour for Design of Foundation

The maximum depth of scour below the Highest Flood Level (HFL) for the design of piers (dsmp) and abutments (dsma), having individual foundations without any floor protection, are as follows:

In the vicinity of pier: dsmp = 2 x D_{sm}

In the vicinity of abutment: dsma = 1.27 x D_{sm}

For the design of floor protection works for rafts or open foundations, the following values of maximum scour depth may be adopted:

In a straight reach: 1.27 x Dsm

In a bend: 1.50 x Dsm

For RCC Box type structures, proper scour protection will be given in the form of floor apron and flexible apron both on the upstream and downstream sides. No scour will be allowed to occur in the RCC Box type structures.

3.6 RESULTS OF HYDROLOGICAL AND HYDRAULIC STUDIES

The detailed hydrological calculations have been carried out for major and minor bridges. Along the corridor there are six major bridges. The catchment areas of these bridges are more than 25 sq km. Therefore, the Synthetic Unit Hydrograph (SUH) method was used for the hydrological analyses. CWC has published the Flood Estimation Report for different zones of India. The project alignment from Sambalpur to Rourkela falls in Zone 3(d). Design flood discharge has been calculated in accordance with the detailed approach and equations of unit hydrograph as given in the report *"Flood estimation Report for Mahanadi Basin (Sub Zone –3 (d) "*

Design discharge at the bridge sites has been taken as per above procedures and calculations were also carried out at upstream and downstream of the bridge at locations where cross-sections are available by Area-Velocity method.

The summary of these calculations has been presented in Table 3-3 and Table 3-4 for minor and major bridges respectively. It is observed that most of the bridges are hydraulically adequate. In addition to the above, it has also been found that at several bridge locations the opening on both sides has been partially choked due to vegetation growth, siltation, damaged bed protection and poor maintenance.

Table 3-3: Summary of Hydrological Study for Minor Bridges

MINOR BRIDGES

SNo	Bridge No	Existing Chainage	Existing Span Arrangement	Discharge Q(cumecs)			HFL			Velocity (m/s)			Lowest Bed Level (m)	Max Scour Level		Soffit Level	Vertical Clearance (available)	Vertical Clearance (required)	Adequacy	Appendix No
				At Bridge	u/s	d/s	At Bridge	u/s	d/s	At Bridge	u/s	d/s		Abutment(m)	Pier(m)					
1	6/1	5+460	1x7.50	8.353	8.625	8.616	151.843	151.943	151.743	1.328	1.346	1.250	150.943	149.964	-	152.718	0.875	0.6	adequate	3.1
2	8/1	7+015	1x7.70	12.479	12.346	12.260	151.940	152.040	151.840	1.130	1.150	1.110	151.045	149.787	-	152.565	0.625	0.6	adequate	3.2
3	11/1	10+653	1X17.1	128.964	129.696	128.929	155.625	155.775	155.475	2.616	2.465	2.528	152.554	149.682	-	156.879	1.254	0.9	adequate	3.3
4	12/1	11+518	4x7.1	(canal is passing under the bridge, ie., regulated flow hence it is adequate)													-	-	adequate	3.4
5	17/1	16+025	1X20	149.678	152.752	148.737	175.643	175.733	175.553	2.794	2.772	2.730	171.653	170.117	-	176.553	0.910	0.9	adequate	3.5
6	22/1	21+050	1x7.20	28.507	28.679	28.565	193.527	193.742	193.312	2.615	2.595	2.600	192.208	189.805	-	194.152	0.625	0.6	adequate	3.6
7	23/2	22+865	3x13.30	223.094	223.779	223.499	191.184	191.499	190.749	2.920	2.822	2.726	188.431	186.684	183.991	192.906	1.722	0.9	adequate	3.7
8	30/2	29+193	1x17.1+1x25.65+1x17.1	417.556	418.022	417.408	186.324	186.544	186.034	2.753	2.707	2.574	183.189	181.152	179.189*	188.164	1.830	1.2	adequate	3.8
9	33/1	32+100	1X15.4	217.502	217.907	217.980	186.523	186.613	186.433	2.882	2.911	2.841	181.423	177.738	-	187.998	1.475	0.9	adequate	3.9
10	35/2	34+650	1X10.4	54.912	58.920	49.758	187.540	187.715	187.365	2.428	2.840	2.734	185.733	182.736	-	188.480	0.940	0.9	adequate	3.10
11	38/3	37+970	1x6.2	9.718	9.456	10.009	195.599	195.749	195.449	1.721	1.721	1.656	194.499	193.583	-	196.474	0.875	0.6	adequate	3.11
12	43/2	42+553	1x6.9	36.766	36.627	36.575	191.265	191.365	191.165	2.006	1.991	1.927	188.325	186.765	-	192.300	1.035	0.9	adequate	3.12
13	52/1	51+020	3X13.30	171.335	179.119	171.811	212.355	212.934	211.674	2.761	2.983	2.830	210.210	208.560	206.378	213.455	0.950	0.9	adequate	3.13
14	58/1	57+350	1x14.20	74.046	74.468	73.851	202.036	202.311	201.761	2.721	2.678	2.722	199.686	197.420	-	202.986	0.950	0.9	adequate	3.14
15	60/1	59+260	1x21	111.941	113.051	111.574	204.128	204.373	203.883	2.764	2.705	2.705	201.578	199.585	-	205.078	0.950	0.9	adequate	3.15
16	62/5	61+600	1x21	139.296	139.659	138.481	205.400	205.510	205.290	2.275	2.304	2.261	201.420	200.144	-	206.320	0.920	0.9	adequate	3.16
17	66/3	65+550	1X13.8	139.734	141.678	135.804	208.064	208.844	207.859	2.847	2.972	2.795	204.164	200.990	-	209.339	1.275	0.9	adequate	3.17
18	75/1	74+224	1X8.30	19.541	20.093	19.657	231.853	232.003	231.764	1.782	1.828	1.769	230.347	229.222	-	233.022	1.169	0.6	adequate	3.18
19	80/1	79+000	1X19.35	300.172	302.869	297.516	228.950	229.125	228.655	2.518	2.533	2.475	222.529	219.821	-	230.604	1.654	1.2	adequate	3.19
20	80/2	79+433	1X11.70	136.334	136.060	136.020	231.848	232.008	231.848	2.425	2.687	2.600	229.075	224.834	-	233.523	1.675	0.9	adequate	3.20
21	86/4	85+625	1X21.45+1X14.3	350.694	349.673	350.259	223.750	223.985	223.592	2.729	2.808	2.762	220.524	219.724*	219.724*	225.100	1.350	1.2	adequate	3.21
22	91/1	90+327	1X7.5	24.252	23.920	24.458	98.272	98.385	98.102	1.979	2.008	1.970	96.495	94.606	-	98.972	0.700	0.6	adequate	3.22
23	91/3	90+628	1X7.5	37.067	41.665	37.424	101.358	101.853	100.863	2.609	2.932	2.995	100.023	96.493	-	102.358	1.000	0.9	adequate	3.23
24	98/2	97+700	1X11.70	46.919	48.597	45.519	268.500	268.585	268.415	1.767	1.595	1.672	265.854	264.699	-	269.500	1.000	0.9	adequate	3.24
25	101/2	100+800	2X13.9	241.187	241.509	240.339	246.188	246.271	246.051	2.697	2.259	2.288	242.831	241.983	239.566	247.088	0.900	0.9	adequate	3.25
26	103/1	102+000	1X13.9+1X20.85	218.885	219.000	218.809	254.375	254.423	254.283	2.556	2.567	2.634	249.512	249.410	246.557	255.412	1.037	0.9	adequate	3.26
27	106/2	105+647	1X10.5	12.175	13.283	12.158	271.383	271.583	271.183	1.063	0.941	1.109	270.324	269.649	-	272.183	0.800	0.6	adequate	3.27
28	109/1	108+788	1X22.5	47.793	53.794	47.604	269.691	269.001	270.381	2.346	2.960	2.932	268.578	267.291	-	270.791	1.100	0.9	adequate	3.28
29	119/2	118+414	1x8.00	58.664	62.205	57.931	249.818	249.848	249.455	1.493	1.481	1.348	245.725	243.567	-	250.718	0.900	0.9	adequate	3.29
30	120/2	119+725	1X19.35	121.649	122.611	120.888	245.295	245.535	245.055	1.882	1.851	1.714	242.370	240.287	-	246.195	0.900	0.9	adequate	3.30
31	122/3	121+942	3X11	329.410	330.768	329.209	248.554	248.582	248.432	2.610	2.601	2.195	244.092	242.592*	242.592*	249.804	1.250	1.2	adequate	3.31
32	135/1	134+417	3X11	323.726	323.264	322.067	226.243	226.491	225.891	2.713	2.468	2.607	222.206	221.006*	221.006*	227.493	1.250	1.2	adequate	3.32
33	136/1	135+334	1x8.00	20.099	19.152	20.230	228.278	228.368	228.188	1.343	1.279	1.529	226.796	225.221	-	228.900	0.622	0.6	adequate	3.33
34	139/1	138+460	1x8.00	23.968	27.015	21.065	224.295	224.345	224.245	1.162	1.309	1.514	221.945	220.840	-	224.995	0.700	0.6	adequate	3.34
35	142/2	141+862	1X19.35	86.985	86.659	87.609	218.450	218.510	218.390	1.064	1.028	1.050	214.947	214.283	-	219.450	1.000	0.9	adequate	3.35
36	144/4	143+820	1x7.2	17.041	17.436	17.580	207.565	207.765	207.365	1.513	1.458	1.498	205.665	204.552	-	208.265	0.700	0.6	adequate	3.36
37	145/2	144+682	1x7.2	71.268	73.064	69.355	210.231	210.906	209.556	2.656	2.697	2.527	207.276	203.276	-	211.131	0.900	0.9	adequate	3.37
38	154/2	153+676	1x7.2	50.348	50.206	50.761	196.223	195.948	196.043	2.053	1.795	1.985	193.175	192.580	-	196.668	0.900	0.9	adequate	3.38
39	159/2	158+171	1X16.8	179.181	179.751	177.856	188.370	188.455	188.285	2.441	2.556	2.634	185.589	181.151	-	189.270	0.900	0.9	adequate	3.39

NOTE: * indicates the scour depth level limited to rock level as per geotechnical data

Table 3-4: Summary of Hydrological Study for Major Bridges

MAJOR BRIDGES

SNo	Bridge No	Existing Chainage	Existing Span Arrangement	Discharge Q(cumecs)			HFL			Velocity (m/s)			Lowest Bed Level (m)	Max Scour Level		Soffit Level	Vertical Clearance (available)	Vertical Clearance (required)	Adequacy	Appendix No
				At Bridge	u/s	d/s	At Bridge	u/s	d/s	At Bridge	u/s	d/s		Abutment(m)	Pier(m)					
1	42/2	41+450	2x12.8 + 6x36.58	8281.241	8282.153	8281.968	194.414	194.650	193.600	4.432	4.176	3.996	183.275	178.213	168.901	196.080	1.666	1.500	adequate	3.40
2	67/2	66+850	2x26.85+3x47.2	3440.110	3454.473	3439.476	208.805	208.897	208.657	2.918	2.827	2.869	201.137	199.304	193.844	210.502	1.697	1.500	adequate	3.41
3	118/1	117+975	3x23.50	1324.536	1375.254	1324.026	242.822	242.831	242.711	2.967	2.636	3.073	234.790	232.668	226.832	244.194	1.372	1.200	adequate	3.42
4	145/1	144+250	4x15.15	671.233	674.355	671.219	207.356	206.900	207.147	2.623	2.274	2.325	200.103	200.038	195.786	208.946	1.590	1.200	adequate	3.43
5	155/1	154+100	2x16.2 + 5x17.00	1116.535	1123.008	1112.036	185.717	185.759	185.549	2.737	2.289	2.817	178.666	178.429	174.229	190.125	4.408	1.200	adequate	3.44
6	166/2	165+215	4x15.25	549.300	551.994	549.318	180.199	180.500	179.800	2.947	2.794	2.787	176.401	173.876	170.232	181.472	1.273	1.200	adequate	3.45

3.7 DRAINAGE

Presence of a good drainage system is essential. It is therefore necessary to perform a detailed survey of the existing drainage system, the adjoining terrain and its ambient slope, in order to make recommendations for a new drainage system or suggest modification to the existing drainage system. A detailed field survey for the existing drainage system has therefore been carried out.

Some basic principles that have been adopted in order to meet the relevant IRC standards are as follows:

- Surface runoff from the carriageway, paved shoulders, embankment slopes and the adjoining land must be effectively drained off without allowing it to percolate into the sub-grade;
- Drains must have sufficient capacity and adequate longitudinal slope to drain away the entire collected surface water to the nearest natural surface stream, river or nallah;
- No longitudinal side drains are proposed where the road runs over a canal bank. The rainwater will directly go to the canal in such cases; and
- No roadside drains are proposed where longitudinal water bodies are present parallel to the road.

In the project alignment, the following types of drains have been proposed:

1. Drain in between the main carriageway and service road;
2. Roadside drain in rural areas;
3. Median drains in super elevated sections;
4. Chute drains along high embankments;
5. Down-take drainage pipes at RE wall locations; and
6. Drains in approaches of CD structures.

The hydraulic adequacy of the drains has been checked as per IRC: SP – 42, “Guidelines on Road Drainage”.

3.7.1 Drain between Main Carriageway and Service Road

Open lined trapezoidal drains with 0.6m width and 1H: 2V side slopes have been provided between the Main Carriageway (MCW) and Service Road (SR) to cater to the runoff from the MCW and SR. Sumps connected through 600mm Hume Pipes have also been provided wherever needed to continue the lined drain across the service road to ensure proper continuity of drainage. These drains are proposed to be lined with 225 mm thick grouted stone pitching.

3.7.2 Roadside Drain in Rural Areas

In rural areas, open unlined trapezoidal drains with 0.6 m width and 2H: 1V side slope near ROW or having berm not less than 1.0 m have been provided on both sides of the road as per guidelines given in IRC: SP – 42.

3.7.3 Drain below the footpath in settlement

Lined drain has been provided below the footpath in the settlement as per IRC-50.

3.7.4 Median Drains in Super elevated Sections

Median at 10m c/c have been provided at the location of super-elevation to pass the surface runoff of one carriageway to the other carriageway. Wherever the edge of the outer carriageway on the horizontal curves is lower than that of the inner carriageway, lined 100mm thick PCC (M-15) median drains with 0.6m width have been provided.

3.7.5 Chute Drains at High Embankments

When the height of the embankment is more than 3.0m, the possibility of erosion of embankment slopes and shoulders increases. In such cases longitudinal kerbed drains at edge of roadway have been provided to channelise the flow, led down by lined chute drains. These chute drains ultimately discharge into roadside drains

3.7.6 Down-take Drainage Pipes At RE Wall Locations

At the location of high embankment where RE wall has been provided, the water from MCW shall be drained out by a 150mm diameter PVC down-take pipe provided at spacing of 20m c/c.

3.7.7 Drain in Approach of Bridges

At the approaches of the bridges, lined V-drains/ trapezoidal drains have been proposed to protect the embankment erosion. This shall be 225mm thick with grouted stone pitching.

3.8 ADDITIONAL CULVERTS

3.8.1 Additional Culverts for Field Channel

Subsequent to demand by the local people, additional culverts of 1.0 m dia HP (NP-4) for field channels have been provided along bypasses to allow for water to pass from one side to other side if the lands on both side of the road belong to the same owner.

3.8.2 Additional Culverts on Cross-Roads

Additional culverts of 1.0 m dia HP have been provided on cross-roads joining MCW (i.e. at intersections etc.), where a drain passes through. This size shall be increased to fulfill the road drainage requirement. If there are existing culverts on the cross-road, the size of the culvert shall be the maximum of the existing size of the culvert and 1.0m dia HP.

3.8.3 Additional Balancing Culverts on Main Carriageway

Additional balancing culverts on MCW have been provided if it is required for planning of adequate drainage system.

CHAPTER 4: GEOTECHNICAL ASSESSMENT

4.1 INTRODUCTION

Geotechnical investigations have been carried out at the project site to characterize and assess the sub-surface conditions at the locations of various proposed ROBs, major and minor bridges. The overall objectives of the exploration were to study and evaluate the stratigraphy of the said project corridor and to obtain geotechnical/ geological parameters of the sub-surface formations for design and construction of various foundations, embankments, mechanically stabilized earth walls etc.

The sub-soil exploration and testing have been carried out under the supervision of M/S Lea Associates South Asia Pvt. Ltd. (LASA) through M/S Design Bureau of Bhubaneswar who had previous experience of executing projects of similar magnitude and nature.

The field investigation program was carried out between April 2008 and May 2008 for Sambalpur – Rourkela stretch of SH 10.

4.2 FIELD AND LABORATORY INVESTIGATIONS

Geotechnical exploration consisted of field and laboratory testing programs. The field testing program consisted of soil borings/ rock drillings, performing in-situ tests, obtaining soil, rock and water samples and field observations of the sub-surface conditions and ground water table. The laboratory testing program comprised of testing samples (soil, rock, water) as collected from site to characterize the geotechnical/ geological properties. Around 30 boreholes were drilled at about 25 important sites of bridges and ROB locations along the project corridor of Sambalpur – Rourkela stretch of SH 10 with a length of around 163 km. The soil investigation works have been undertaken at abutment locations for almost all proposed new minor bridges, ROBs and at abutment and one pier location of major bridges. The location of boreholes for bridges and structures were decided and approved by the Client.

Geotechnical investigation program was developed at each structure location depending upon the span length, anticipated structural load, sensitivity of the structure, geological formation etc., so that the sub-surface profile and properties can generally be ascertained and established. Bore holes were drilled at a distance of 9m from the parapet of existing bridges. Table 4-1 summarizes the numbers and locations of the boreholes drilled for all the specific structures along the project corridor.

Table 4-1: Sub-Soil Investigation Plan

Sl. No	Structure No	Existing Span Arrangement for Structure (m)	Proposed Span Arrangement	No. of Boreholes: Abut-ment	No. of Boreholes: Pier	Depth Of Borehole	Location/ Position of Boreholes
Minor Bridges							
1	12/1	4 x 7.10	4 x 7.10	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
2	17/1	3 x 6.56	1 x 20	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
3	30/2	7 x 8.55	1 x 17.1 + 1 x 25.65 + 1 x 17.1	1	1	10	15.0 m from the Outside Parapet Edge of Existing Bridge on RHS for abutment and 25.0 m from the Outside Parapet Edge of Existing Bridge on RHS for Pier
4	33/1	2 x 7.7	1 x 15.4	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
5	38/3	1 x 6.20	1 x 6.20	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
6	50/4	22.1(Clear)	1 x 24.5	1	-	15	15.00 m from the Outside Parapet Edge of Existing Bridge on RHS
7	52/1	3 x 13.3	3 x 13.3	1	-	15	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
8	66/3	2 x 6.9	1 x 13.8	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
9	75/1	1 x 8.30	1 x 8.30	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
10	80/1	3 x 6.45	1 x 19.35	1	-	15	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
11	86/4	5 x 7.15	1 x 21.45 + 1 x 14.3	1	-	15	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
12	91/1	1 x 7.50	7.5 x 2.5	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
13	98/2	1 x 9.25	1 x 11.7	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
14	101/2	4 x 6.95	2 x 13.9	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
15	103/1	5 x 6.95	1 x 13.9 + 1 x 20.85	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
16	109/1	3 x 7.50	1 x 22.5	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
17	120/2	3 x 6.45	1 x 19.35	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
18	122/3	2 x 11.20 + 1 x 11.00	3 x 11	1	-	15	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS
19	135/1	3 x 11.00	3 x 11	1	-	15	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
20	142/1	3 x 6.45	1 x 19.35	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on RHS
21	159/2	2 x 8.4	1 x 16.8	1	-	10	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS

Sl. No	Structure No	Existing Span Arrangement for Structure (m)	Proposed Span Arrangement	No. of Boreholes		Depth Of Borehole	Location/ Position of Boreholes
				Abut-ment	Pier		
Major Bridge							
1	67/2	2 x 26.85 + 3 x 47.2	2 x 26.85 + 3 x 47.2	1	1	35	On C/L of Old abandoned bridge at Abutment and Pier
2	118/1	3 x 23.50	3 x 23.5	1	1	35	3m on RHS from the outside parapet edge of the old abandoned bridge at Abutment and pier location.
3	145/1	4 x 15.5	2 x 30.3	1	1	15	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS at abutment and pier locations
4	158/1	2 x 16.2 + 5 x 17.00	1 x 33.2 + 1 x 51 + 1 x 33.2	1	1	35	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS at abutment and pier locations
5	166/2	4 x 15.25	2 x 30.5	1	1	15	9.00 m from the Outside Parapet Edge of Existing Bridge on LHS at abutment and pier locations
ROB							
1	143	1 x 20	1 x 20	1	-	10	2m away from Railway boundary line at 15m from C/L of Road on LHS

4.2.1 Methodology of Investigation

4.2.1.1 Field Investigation

The boreholes were progressed using a Calyx Rotary drilling machine for overburden soil. Where caving of the borehole occurred, 150 mm diameter casing was used to keep the borehole stable. Where hard strata/ very severely weathered rock strata was encountered, borehole was advanced by chiseling. The chisel was attached to heavy sinker bars to progress the borehole. Percussion drilling or T.C. bit or diamond rotary drilling has been adopted for soft and weathered rock, using NX size double tube core barrel. The work has been generally in accordance with IS: 1892 – 1979. The soil samples, in general, have been obtained at every 1.5m or suitable intervals, or whenever there was a significant change in strata. The soil samples consisted of Split-Spoons (disturbed) and Shelby tubes (undisturbed).

The in-situ tests in the soil borings consisted of Standard Penetration Tests (SPTs). The undisturbed Shelby tube samples were taken alternately with the split-spoons or in the cohesive or partly cohesive soils only. All recovered rock core pieces obtained from drilling were stored in standard core boxes and preserved for future references. For each run, core recovery and rock quality designation were noted and each core were numbered from top downward with good quality enamel paint. In addition to the soil samples, ground water samples were also obtained from various borings.

Field observations included visual classification of soil types, and measurement of ground water table. All field investigation works were performed in accordance with the following current applicable IS codes as given in Table 4-2.

Table 4-2: BIS Codes Used in Field Exploration Works

Field Investigation Activity	IS Code Referred
Soil Classification	IS: 1498 – 1970
Soil Boring	IS: 1892 – 1979
Rock Drilling	IS: 4464 – 1967, IS: 5313 – 1980, IS: 4078
Sampling	IS: 2132 – 1986, IS: 8763 – 1978, IS: 9640 - 1980
In-situ testing	IS: 2131 – 1981
Ground water table measurement in borehole	IS: 6935 – 1973

4.2.1.2 Laboratory Testing

The laboratory testing program consisted of testing the soil index and strength properties, as well as the consolidation characteristics. In addition, chemical tests were performed on soil and ground water samples.

The index tests were performed to determine the soil moisture content, unit weight, specific gravity, gradation characteristics (gravel, sand and fines content – the silt and clay fractions) and consistency limits. The strength tests were performed to determine the shear parameters (cohesion, friction angle) of soil; and the consolidation tests were performed to find out the consolidation properties (pre-consolidation pressure, initial void ratio, compression and recompression index, coefficient of volume compressibility and vertical consolidation).

The index tests were performed on disturbed split-spoon soil samples or undisturbed samples, except the natural moisture content and dry density tests, which were performed only on the undisturbed soil samples.

The strength tests consisted of the direct shear box and the triaxial Unconsolidated Undrained (UU) test. The consolidation characteristics tests were preformed on a one-dimensional consolidometer. The strength and consolidation tests were performed on undisturbed soil samples.

The index and strength tests were performed on both cohesive and cohesion less soil samples. The consolidation tests were performed on predominantly cohesive soil samples. The chemical tests consisted of pH, chloride and sulphate content tests.

Unconfined compression, point load index, water absorption, porosity and unit weight tests were conducted on rock wherever cores were recovered. If RQD obtained was nil to poor, point load index test was carried out; otherwise unconfined compression tests were conducted on selected rock cores.

The tests were performed according to the Indian Standards (IS) codes of practice for testing of soil, rock and groundwater samples. The various IS codes of testing used in the program are listed in the following Table 4-3.

Table 4-3: BIS Codes Followed in Laboratory Tests

Laboratory Test	Number of IS Code
Natural Moisture Content	IS: 2720 (Part-II)-1973
Specific Gravity	IS: 2720 (Part-III)-1980
Particle Size Analysis	IS: 2720 (Part-IV)-1985
Liquid and Plastic Limits	IS: 2720 (Part-V)-1985
Unconfined Compression	IS: 2720 (Part-X)-1991
Unconsolidated Undrained (UU) Triaxial Shear	IS: 2720 (Part-XI)-1993
Consolidated Undrained (CU) and Consolidated Drained (CD) Triaxial Shear	IS: 2720 (Part-XII)-1981
Direct Shear	IS: 2720 (Part-XIII)-1986
One-Dimensional Consolidation	IS: 2720 (Part-XV)-1986
Modified Proctor Compaction	IS: 2720 (Part-VIII)-1983
Free Swell Index	IS: 2720 (Part-XL)-1977
Swelling Pressure	IS: 2720 (Part-41)-1977
Permeability	IS: 2720 (Part-17)-1986
Point load index of Rock	IS: 8764 - 1978
Unconfined Compression	IS: 9143 - 1979
Water Absorption and Porosity	IS: 1124 and 1122
Unit Weight	-
pH (Soil)	IS: 2720 (Part-XXVI)-1973
Sulphate Content (Soil)	IS: 2720 (Part-XXVII)-1977
Chloride Content (Soil)	-
Chemical Analysis (Water)	IS: 3025 – 1964

4.3 GENERAL GEOLOGY OF PROJECT AREA

The project corridor falls mainly in the Singhbhum – Keonjhar – Bonai - Gangpur iron ore belt of the Peninsular Shield. The iron ore series of Singhbhum and the adjoining Keonjhar are associated with Archaean rocks. This area contains a sequence of Archaean sediments. It essentially consists of a series of iron-bearing sediments – phyllites, tuffs, lavas, quartzites and limestones – designated as the iron-ore series resting uncomformably on an older metamorphic series. The age of the iron-ore series is regarded as the Upper Dharwar. The ores occur as massive beds and lenses of ferric oxides, soft powdery haematite, and as banded or ribboned haematite – quartzite or jasper – from which the free ore is liberated by leaching out of the inter-laminated silica. There is a considerable amount of igneous volcanic action in this area, witnessed by the masses of Singhbhum and Bonai granite, by masses of ultra basic intrusive and by lava-flows and tuffs. The basic intrusives have given origin to the chromite, asbestos and steatite of Singhbhum.

In Gangpur area (now called Sundargarh district), lying towards the west of Singhbhum, the Archaean rocks have been folded in the form of geanticlines or an anticlinoria. The axial zone of this anticlinoria is made up of the oldest gonditic rocks, which are overlain by quartzites, phyllites, mica – schist and marbles. The gondites of Gangpur series contain workable deposits of manganese ore. The calcitic and dolomitic marbles are used as flux and in the manufacture of lime. The rocks of Gangpur series have been traversed by Chota Nagpur granite and some silts of basic composition. Gangpur series and iron ore series of Singhbhum – Gangpur area are equivalent to Dharwarian rocks of South India.

4.4 GROUND WATER TABLE

The ground water table as measured in the boreholes is summarized in Table 4-4. Majority of the rivers in this stretch are not perennial but flashy in nature. Fluctuations may occur in measured water levels due to seasonal variation in rainfall and surface evaporation rates as well as flow of water in the drain.

4.5 SEISMICITY

The occurrence of earthquakes generally depends on the geotectonic conditions of the region. Seismicity is associated with zones of weaknesses, such as shear zones, fractures, faults, thrust-blocks and so on.

Sambalpur – Rourkela area marks the contact between iron ores sediments (Banded Haematite Quartzite) towards Keonjhar and gonditic rocks comprising of manganese ore towards Gangpur.

As per the latest seismic hazard map, the project site is located in Seismic Zone III, where the maximum intensity expected would be around MSK VII. The zone factor of this area as per IS: 1893 (Part 1) – 2002, depending on the perceived maximum seismic risk characterised by Maximum Considered Earthquake (MCE), is 0.16. The design horizontal seismic co-efficient of this zone is about 0.08g to 0.10g (Ref. IS: 1893 (Part 1) – 2002).

4.6 SITE-SPECIFIC SUB-SURFACE CONDITIONS

The site-specific sub-surface conditions at the project site have been characterized using the field and laboratory-testing data obtained during exploration. Generally, the sub-soil comprises of following four different strata, as follows:

- Stratum I: Moorum with Clay/ Clay;
- Stratum II: Sand;
- Stratum III: Soft Rock/ Disintegrated Rock / Highly Weathered Rock; and
- Stratum IV: Rock.

The top stratum of moorum with clay and clay layer is underlain by a sandy stratum. This is followed by highly weathered rock/ soft rock/ disintegrated rock whose core recovery varies from nil to 20%. In this case, rock material is either completely converted to soil or more than half of the rock material is decomposed and/ or disintegrated to soil. Rock fabric is, in general, discernible i.e. the original rock mass structure is still found to be largely intact. SPT value is refusal in this stratum. Sound rock, which lies beneath the highly weathered rock, has a core recovery of more than 20%. The core recovery and RQD obtained ranges from 21 – 85% and nil to 40% respectively. Table 4-4 summarizes the stratifications for majority of the important structures.

Based on soil classification/ rock weathering, consistency/ compactness /soundness, compressibility / plasticity, etc., soil / rock profiles for all-important structures were considered to evaluate and assess the behaviour of soil/ rock strata. For locations with one boring per site, the sub-soil conditions were derived from boring data itself. Wherever the boreholes were not available at a particular structure location, adjoining borehole data were used for analysis. The soil/ rock profiles for ROBs, major and minor bridges indicating soil/ rock type with respect to depth (RL), "N" value, position of ground water table, core recovery and RQD for rock are presented in Table 4-4 below. The bore logs, which include field observations and laboratory test results of various structures, are detailed in **Appendix 4.1**, Volume IIA of this report.

Table 4-4: Summary of Anticipated Sub-Soil Conditions for Major, Minor Bridges and ROBs

Type of Structure	Proposed Structure No	Borehole No.	Sub-Surface Conditions: Approximate Depths/ Range of Depths of Bottom of Soil Strata (m)					Ground Water (m)
			Existing Ground/ Bed Level (M)	Overburden Soil (Moorum with Clay/Clay) – Layer I	Overburden Soil (Sand) – Layer II	(Soft rock/ Disintegrated rock /Highly Weathered Rock– Layer III	(Rock)– Layer IV	
A) PROPOSED MINOR BRIDGES								
Minor Bridge	12/1	A2	151.735	0-1.95	-	1.95-4.50	4.50-5.70	151.235
Minor Bridge	17/1	ABT-2	173.001	0-2.80		2.80-3.00	3.00-8.00	171.741
Minor Bridge	30/2	ABT-1	184.821	0-4.00	-	-	4.00-10.0	183.021
Minor Bridge		P-6	183.221	-	0-4.00	4.00-10.00	-	181.521
Minor Bridge	33/1	ABT-1	186.773	-	0-4.50	4.50-10.00	-	185.573
Minor Bridge	38/3	A-1	196.482	0-3.50	-	3.50-10.00	-	194.882
Minor Bridge	52/1	A2	207.500	0-10.95	10.95-15.00	-	-	206.100
Minor Bridge	66/3	A1	205.620	-	0-2.70	2.70-10.00	-	205.02
Minor Bridge	75/1	A2	231.103	-	0-10.00	-	-	229.283
Minor Bridge	80/1	A1	231.241	-	-	0-7.60	-	230.741
Minor Bridge	86/4	A2	225.400	-	0-0.80	0.80-3.80	-	224.000
Minor Bridge	91/1	A2	236.120	0-0.50	0.50-10.00	-	-	234.920
Minor Bridge	98/2	A1	263.457	0-6.00	6.00-10.00	-	-	261.807
Minor Bridge	101/2	A1	243.102	0-3.50	3.50-7.50	7.50-10.00	-	242.602
Minor Bridge	103/1	A1	253.123	-	-	0-1.60	1.60-4.60	252.923
Minor Bridge	109/1	A2	275.179	-	0-6.30	-	6.30-9.30	273.919
Minor Bridge	120/2	A-1	240.791	-	0-1.50	1.50-2.00	2.00-6.00	239.891
Minor Bridge	122/3	ABT-1	246.873	-	0-2.00	2.00-3.40	3.40-6.40	245.873

Type of Structure	**Proposed Structure No**	**Borehole No.**	**Sub-Surface Conditions – Approximate Depths/ Range of Depths of Bottom of Soil Strata (m): Existing Ground/ Bed Level (M)**	**Overburden Soil (Moorum with Clay/Clay) – Layer I**	**Overburden Soil (Sand) – Layer II**	**(Soft rock/ Disintegrated rock /Highly Weathered Rock– Layer III**	**(Rock)– Layer IV**	**Ground Water (m)**
Minor Bridge	135/1	ABT-2	222.641	-	0-1.20	-	1.20-4.20	222.041
Minor Bridge	142/1	ABT-2	220.201	0-8.10	-	-	8.10-10.10	219.201
B) PROPOSED MAJOR BRIDGES								
Major Bridge	67/2	A1	208.720	0-2.00	2.00-9.00	9-19.00	-	207.720
		P4	208.400	-		0-6.50	-	207.900
Major Bridge	118/1	ABT-1	241.304	-	0-5.10	-	5.10-8.10	240.304
		P-2	240.110	-	0-1.00	-	1.00-4.00	239.910
Major Bridge	145/1	ABT-1	202.971	-	0-1.50	1.50-2.30	2.30-5.30	202.471
		P-3	201.690	-	0-2.00	2.00-3.00	3.00-6.00	201.490
Major Bridge	155/1	ABT-1	180.231	-	0-3.00	3.00-4.10	4.10-7.10	179.231
		P-5	179.200	-	0-2.00	2.00-3.20	3.20-6.20	178.400
C) PROPOSED ROBs								
ROB	50/4	A1	180.320	0-7.50	-	7.50-15.00	-	178.720
ROB	143	-	213.687	0-6.00	6.00-8.00	8.00-10.00	-	212.687

NOTE:

1. Bottom of strata was not encountered within the depth of boring drilled at this structure location.

2. NE – Not encountered

3. Seasonal variation is expected in case of GWT

4.7 ASSESSMENT OF ENGINEERING PROPERTIES OF SOIL AND ROCK

The engineering properties e.g. gradation, consistency limits, bulk density, natural moisture content of cohesive or cohesion less soil as obtained from laboratory test on disturbed/ undisturbed samples were generally adopted for analysis purpose. The shear parameters determined from laboratory for loose to medium dense cohesionless soil have also been used in design considerations. For cohesionless soil, angle of internal friction was estimated in accordance with IS: 6403 – 1981.

The completely to highly weathered rock has been treated as granular mass and based on SPT values, its shear parameters have been assigned. Generally, continuous refusals have been observed in this weathered rock. In case of severely to moderately weathered rock where cores were recovered, the rock was classified based on geomechanics of jointed rock mass in terms of Rock Mass Rating (after Bieniawski 1989) as per IS: 13365 (Part I), 1998). The Rock Mass Rating (RMR) was determined on the basis of strength of intact rock material, drill core quality (RQD), spacing of discontinuities, condition of discontinuities, ground water and adjustment for discontinuity orientations. A typical calculation for RMR in highly weathered and moderately to partly weathered rock is presented in Table 4-5 below:

Table 4-5: Typical Rock Mass Rating (RMR) For Rock

Rock Parameters	Rating in Highly Weathered Rock		Rating in Moderately to Partly Weathered Rock	
	Basis of Rating	Rating	Basis of Rating	Rating
Strength of Intact Rock Material	Compressive strength between 10 – 25 Mpa	2	Compressive strength between 25 – 50 Mpa	4
Rock Quality Designation (RQD)	Very Poor RQD i.e. RQD < 25%	3	Poor RQD i.e. RQD ranges between 25% - 50%	8
Spacing of Discontinuities	Very close spacing i.e. Spacing < 0.06m	5	Close spacing i.e. Spacing between 0.06m – 0.2m	8
Condition of Discontinuities	Slickensided wall rock surface or 1 – 5 mm thick gauge or 1 – 5mm wide opening, continuous discontinuity	10	Slightly rough and moderately to highly weathered wall rock surface, separation < 1mm	20
Ground Water Condition	Dripping condition	4	Wet condition	7
Adjustment for Joint Orientation	Strike and Dip orientation of joints for Raft foundation is “Fair”	-7	Strike and Dip orientation of joints for Raft foundation is “Fair”	-7

Based on the laboratory test results, the ranges of properties of each soil/ rock stratum encountered at different locations are presented below in Table 4-6.

Table 4-6: Range of Engineering Properties of Sub-Soil/ Rock

Structure	Description of Soil/Rock	For Soil								For Rock			
		SPT (N)	PI (%)	γ_b (gm/cc)	NMC (%)	C (t/m^2)	φ (degree)	P_c (t/m^2)	C_c	Core Recovery / RQD (%)	Unit Weight (gm/ cc)	Point Load Strength Index (Kg/cm^2)	Unconfined Compressive Strength (Kg/ cm^2)
Minor Bridge 12/1	Moorum with clay (Layer I)	11	10	-	-	-	-	-		-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	85/21		279	215.8
Minor Bridge 17/1	Moorum with clay(Layer I)	58	11	-	-	-	-	-		-	-	-	-
	Soft rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	-	46-80/12	-	212.2
Minor Bridge 30/2	Clay (Layer I)	11	12	-	-	5	-	-	-	-	-	-	-
	Sand(Layer II)	10-14											
	Rock (Layer IV)									16-25	-	2.74	-
Minor Bridge 33/1	Sand (Layer II)	16-18	-	-	-	-	29	-	-	-	-	-	-
	Soft Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
Minor Bridge 38/3	Clay (Layer I)	10	10	-	-	6	-	-	-	-	-	-	-
	Soft Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-

Structure	Description of Soil/Rock	For Soil								For Rock			
		SPT (N)	PI (%)	γ_b (gm/cc)	NMC (%)	C (t/m^2)	φ (degree)	P_c (t/m^2)	C_c	Core Recovery / RQD (%)	Unit Weight (gm/ cc)	Point Load Strength Index (Kg/cm^2)	Unconfined Compressive Strength (Kg/ cm^2)
Minor Bridge 52/1	Clay/Moorum with Clay (Layer I)	10-90	9-12	-	-	6	-	-	-	-	-	-	-
	Sand (Layer II)	94	-	-	-	-	30	-	-	-	-	-	-
Minor Bridge 66/3	Sand (Layer II)	-	-	-	-	-	30	-	-	-	-	-	-
	Fragmented rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
Minor Bridge 75/1	Sand (Layer II)	4-68	-	-	-	-	29-31	-	-	-	-	-	-
Minor Bridge 80/1	Disintegrated rock/ Weathered Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	2.79	-
Minor Bridge 86/4	Sand (Layer II)												
	Highly weathered Rock (Layer III)	-	-	-	-	-	-	-	-	30-52/ 10-15	-	2.81	212.9
Minor Bridge 91/1	Moorum with Clay (Layer I)	-	-	-	-	-	-	-	-	-	-	-	-
	Sand (Layer II)	30-100	-	-	-	-	30	-	-	-	-	-	-
Minor Bridge 98/2	Clay/moorum with clay (Layer I)	4-30	21	-	-	6	-	-	-	-	-	-	-
	Fine Sand (Layer II)	30-48	-	-	-	-	-	-	-	31	-	-	-
Minor Bridge 101/2	Clay (Layer I)	6	8-9	-	-	1	22	-	-	-	-	-	-
	Sand (Layer II)	22-30	-	-	-	-	32	-	-	-	-	-	-
	Disintegrated Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
Minor Bridge 103/1	Disintegrated Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	32-55/22-24	-	-	216.1
Minor Bridge 109/1	Sand (Layer II)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	26-35	-	-	219.5
Minor Bridge 120/2	Sand (Layer II)	-	-	-	-	-	28	-	-	-	-	-	-
	Disintegrated Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	28-51/10-12	-	-	212.8
Minor Bridge 122/3	Sand (Layer II)	-	-	-	--	-	30	-	-	-	-	-	-
	Disintegrated Rock(Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	34-47/10-26	-	-	212.4
Minor Bridge 135/1	Sand (Layer II)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	47-60	-	-	212.9

Structure	Description of Soil/Rock	For Soil								For Rock			
		SPT (N)	PI (%)	γ_b (gm/cc)	NMC (%)	C (t/m^2)	φ (degree)	P_c (t/m^2)	C_c	Core Recovery / RQD (%)	Unit Weight (gm/ cc)	Point Load Strength Index (Kg/cm^2)	Unconfined Compressive Strength (Kg/ cm^2)
Minor Bridge 142/1	Clay/moorum with clay (Layer I)	5-18	10 - 14	-	-	6	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	37-40/10	-	-	216.4
Minor Bridge 143	Clay (Layer I)	5-26	10	-	-	6.2	-	-	-	-	-	-	-
	Disintegrated Rock (Layer III)	-	-	-	-	-	-	-	-	-	--	-	-
Major Bridge67/2	Clay (Layer I)	10	-	-	-	-	-	-	-	-	-	-	-
	Sand (Layer II)	50-80	-	-	-	-	-	-	-	-	-	-	-
	Disintegrated Rock/ Highly weathered Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	2.81	-
Major Bridge118/1	Sand (Layer II)	8-21	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	29-55/10-28	-	-	2107
Major Bridge145/1	Sand (Layer II)	15	-	-	-	-	30	-	-	-	-	-	-
	Disintegrated rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	29-52/11-42	-	-	216.8
Major Bridge 155/1	Sand (Layer II)	6	-	-	-	-	29	-	-	-	-	-	-
	Disintegrated rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-
	Rock (Layer IV)	-	-	-	-	-	-	-	-	27-60/10-25	-	-	216.00
ROB 50/4	Moorum with Clay (Layer I)	15-25	8-11	-	-	6	-	-	-	-	-	-	-
	Soft rock (Layer IV)	-	-	-	-	-	-	-	-	-	-	-	-
ROB 143	Clay (Layer I)	5-26	10	-	-	6.2	-	-	-	-	-	-	-
	Sand (Layer II)	-	-	-	-	-	-	-	-	-	-	-	-
	Disintegrated Rock (Layer III)	-	-	-	-	-	-	-	-	-	-	-	-

Note:

1) N : Standard Penetration Test; γ_b : Bulk density; NMC : Natural Moisture Content; C : Cohesion; ϕ : Angle of internal friction; C_c : Compression index; Pc : Preconsolidation pressure

The bore logs including soil properties as evaluated from laboratory tests are presented in Appendix 4.1, Volume IIA of this report.

4.8 ENGINEERING ANALYSIS AND DESIGN

4.8.1 Design of Embankments

A. Introduction

A perusal of the engineering characteristics of the foundation soils presented in section "Site-Specific Sub-Soil Conditions" indicates that the project stretch in general consists of CL/ MI or SP-GP and underlain by highly to moderately weathered rock. As such, while running embankments can be designed using routine engineering methods, the design of high embankments forming approaches to various major bridges, minor bridges, ROBs, would require detailed analysis in respect of their slope stability and settlement aspects. The bearing capacity aspect of the foundation soils did not appear to be critical in view of the good quality foundation soils encountered. Accordingly, the following paragraphs focus on the evaluation of slope stability and settlement aspects for the high approaches.

B. Slope Stability Analysis

Stability analyses have been carried out to check the global stability (slope, toe and base) of the embankment for assessing the adequacy of the slopes at locations of approach embankments to various structures. The analyses of stability of the high embankments were performed using Bishop's Modified Method for establishing the minimum Factor Of Safety (FOS) against rotational failure along the potential slip circles. The geometry (top and bottom width, slope, height) of the embankment was depicted from highway cross-sections generated for each approach location. Height of the approach was considered from ground level to finished road level inclusive of the existing embankment height. Analysis was carried out for the maximum height of the particular approach embankment. The embankment is considered to be built up with approved fill material, in the vicinity of embankment stretches, having required properties as per the guidelines of MORT&H, and IRC: 36 – 1970, as well as IRC: 58 – 2001. The embankment is considered to be built up with "Borrow Soil" (Sand/ Silty Sand /Clayey Sand etc.) The following parameters are used in stability analysis of embankments:

1. Embankment Fill:

(a) Type: Cohesionless Soil (Sand / Silty Sand/ Clayey Sand etc.); and

(b) C = 0.1 kg/cm^2, ϕ = 27^o and γ = 1.90 gm/cc.

2. Embankment Geometry:

(a) Top width: 26.00/ 26.5 m; and

(b) Height: Maximum height from ground level to FRL as per highway c/s drawing for both the approaches.

3. Foundation Soil Properties: Sub-soil corresponds to individual structure location.

4. Traffic Surcharge: 1.5 t/ m^2.

The computer software "XSTABL" (version 5.00) software package (developed by Interactive Software Designs, Inc, USA) was used for stability analysis under static condition. A minimum FOS of 1.25 was used to design the safe height of the embankment in rotational stability. Slope stability for earthquake condition was analyzed using the same "XSTABL" (Version 5) software package as mentioned before. The FOS against static condition is presented in Table 4-7 for various high approach embankments. For simulating the worst condition during its service life, the effect of side cover and intermediate layer has not been considered for road embankment.

Sample calculation of Slope Stability Analysis of Embankment is given in **Appendix 4.1**, Volume IIA of this report.

Table 4-7: Summary of Slope Stability Analysis

Sl. No.	Chainage (KM)/ Structure No	Type of Structure	Embankment Geometry			Factor of Safety
			Maximum Design Height (m)	Top Width (m)	Side Slope	Static
1	11+075	Underpass	4.00	26	1V: 2.0H	1.77
2	12/1	Minor Bridge	3.00	26	1V: 2.0H	1.80
3	27+425	ROB	11.00	26	Vertical	1.25
4	28+825	Minor Bridge	5.00	26	1V: 2.0H	2.00
5	39+100	Under Pass	9.00	26	Vertical	1.25

Note:

1. Borrow area, which is in the vicinity of the structure, was considered for analysis
2. Shear parameters were obtained from laboratory testing of borrow samples. For cohesive material unconsolidated undrained and for cohesion less soil consolidated drained triaxial tests/ direct shear tests were conducted.

The above table indicates that the proposed slopes of high approach embankments and R.E. wall-supported embankments are safe and stable under static condition with a FOS of more than 1.25.

C. Settlement Analysis

The consolidation settlements of compressible clay deposits under the action of embankment loads are estimated using Terzaghi's one-dimensional consolidation theory. The immediate settlement of foundation soil is considered to be over during the construction stage and hence is not significant. Various design parameters of sub-soil required for the analysis are based on the boreholes applicable to each structure. The computer software 'HED' [Version 1.0, Reference: Ministry of Surface Transport, Roads Wing (1992)] for the computation of settlements based on Terzaghi's theory of consolidation, is included in the above mentioned publication "Computer Aided Design System for High Embankment Problem" and the same is used to analyse the problem. Due to the presence of highly weathered rock at shallow depths, the post-construction consolidation settlements are well within the permissible limits as specified in Clause 4.6 of IRC: 75 – 1979.

4.9 FOUNDATION DESIGN

The geotechnical design of foundations considered the bearing capacity and deformation aspects of the foundation soil. The anticipated foundation loads included vertical and horizontal loads. The selection of the type of foundation was based on the following major aspects:

- Availability of suitable bearing strata under anticipated vertical loads;
- Whether settlements of foundation soils under anticipated vertical loads are within permissible limits;
- Availability of adequate uplift capacity under anticipated loads;
- Anticipated discharge and flow of the channel and corresponding scour level;
- Position of ground water table, liquefaction and swelling potential etc.; and
- Foundation type in the existing structure at the vicinity.

Shallow and deep foundations were adopted in the design for various structures based on above considerations

4.9.1 Shallow (i.e. Open) Foundations

Shallow foundations were considered where the foundation load requirement was met at shallow depth (foundation depth/ width (d/ B) ratio of <=1), and/ or to suit with the hydraulic requirement. The depth of foundation was decided based on scour level, competent founding strata, liquefaction potential etc. The minimum embedment criterion as specified in Clause 705.2.1 of IRC: 78 – 2000 for open foundation in soil/ rock is followed in the design.

a) Bearing Capacity

Bearing capacity for shallow foundations in soil has been analysed in accordance with IS: 6403 – 1981, which is based on the modified Terzaghi's classical approach. The weighted average of shear parameters for various strata up to a significant influence zone of 2.0 B (B = width of the foundation) below the foundation level is used in the analysis. Considering the fluctuation of ground water, it is assumed that water table will be at foundation level or at HFL and accordingly the water table correction is applied. An FOS of 2.5 is selected based on Clause 706.3.1.1.1 of IRC: 78 – 2000 to estimate the net safe bearing capacity from ultimate net bearing capacity.

Standard Penetration Test (SPT) results are also used to determine the safe bearing capacity of shallow foundation in accordance with IS: 6403 – 1981 for non-cohesive soil, hard clay and completely disintegrated weathered rock. While using this approach, the N-value was corrected, wherever applicable, below the footing base to at least 1.5B below the base to account for the effects of energy ratio, adopted boring procedure, dilation for submerged silty fine sands/ fine sands as well as that due to the overburden pressure (Reference: IS: 2131-1981, "Foundation Analysis and Design" by J.E. Bowles).

Bearing capacity for shallow foundation in rock has been estimated based on the guidelines of IS: 12070 in addition to the codal provisions as given in IRC: 78 – 2000.

The safe bearing capacities as determined from analytical approach and from field test results are compared with presumptive pressures for the said foundation soil (Reference: “Foundation Analysis and Design” by J.E. Bowles, US Naval Facility Command, NAVFAC, Design Manual DM 7.02 -1986).

b) Settlement

The magnitude of settlement, when foundation loads are applied, depends upon the compressibility of the underlying strata and rigidity of the substructure. In cohesive deposition, the post-construction settlement is caused by dissipation of pore pressures and hence is time dependent so that consolidation settlement is computed for such soils using Terzaghi’s one-dimensional consolidation theory. The immediate settlements in clays are estimated using the elastic theory considering the effect of a rigid stratum underlying the foundation soils (Reference: “Foundation Analysis and Design” by J.E. Bowles). The immediate settlements in cohesionless soil are estimated using elastic theory as mentioned above, the Schmertmann Method and using SPT value as per IS: 8009 (Part 1). For completely weathered rock, which is treated as granular mass, only elastic/ immediate settlement is considered and is determined based on the approach as has been adopted for cohesionless soil.

The bore logs and profiles developed on the basis of sub-soil investigations conducted along the project corridor indicate that a major portion of the soils within the significant influence zone of the foundations i.e. 2.00 B below the base of the foundation is represented by silty sand/ sand underlain by highly weathered rock wherein immediate settlement will govern. The immediate settlement of foundation soil is considered to be over during the construction stage and hence the settlement of open foundation seems to be of little concern.

The allowable bearing capacity for each structures and type of soil are so determined that the settlement caused due to net soil pressure on the base does not exceed the permissible limit as given in IS: 1904 – 1978 for isolated and raft foundations (B > 6.0m).

Sample calculations of bearing capacity for shallow (i.e. open) foundation in Soil and Rock are given in **Appendix 4.1,** Volume IIA of this report.

4.9.2 Pile Foundation

The total vertical load-carrying capacity of pile foundation is a combination of skin friction along the surface and end bearing at the pile tip. The design of the vertical load-carrying capacity was carried out following IRC: 78 – 2000 and IS: 2911(Part 1). The uplift capacity of pile was also calculated based on IRC: 78 – 2000 and IS: 2911(Part 1). The lateral capacity was calculated based on IS: 2911(Part1/ Section 2) and IRC guidelines.

For the design of pile foundations socketed into rocks, IS: 2911 (Part-1), IS: 14593 and IRC: 78 – 2000 have been followed. The axial compressive capacity for bored pile socketed into rock has been computed based on static analysis using core recovery, RQD value and unconfined compressive strength of rock as interpreted from the site stratigraphy and laboratory test results. The axial compressive capacity for cast-in-situ bored pile was estimated also using the Cole and Stroud approach given in IS: 14593 based on rock class, Rock Mass Rating (RMR) and core strength.

Sample calculations of load carrying capacity for pile foundation in soil and rock are given in **Appendix 4.1**, Volume IIA of this report.

The recommended allowable load bearing capacities for shallow foundations and the recommended vertical axial compressive capacity for bored pile for various structures including foundation details are summarized below in Table 4-8.

Table 4-8: Summary of Shallow (i.e. Open) Foundations, and Pile Foundations

Structure	Foundation Location	Foundation Dimension (m)	Foundation Type	Approx. Ground Level/ Lowest Bed Level (m)	Founding RL (m)	Approx. Depth of Foundation below Ground Level/ Lowest Bed Level (m)	Classification of Bearing Stratum	Safe Bearing Capacity (T/ m^2)	Pile Cut-off Level (m)	Pile Tip Level (m)	Vertical Pile Capacity Socketed into Rock (T)	End Bearing Stratum
Minor Bridges												
Minor Bridge 12/1	A1	4 x 8.6	Open	151.735	147.235	4.50	Soft Rock	30	Not Applicable			
	A2	4 x 8.6	Open	151.735	147.235	4.50	Soft Rock	30	Not Applicable			
Minor Bridge 17/1	A1	4 x 8.6	Open	173.001	169.501	3.5	Rock	30	Not Applicable			
	A2	4 x 8.6	Open	173.001	169.501	3.5	Rock	30	Not Applicable			
Minor Bridge 30/2	A1	4 x 8.6	Open	184.821	180.321	4.5	Soft Rock	28	Not Applicable			
	P1	4 x 8.6	Open	184.821	180.321	4.5	Soft Rock	28	Not Applicable			
	P2	4 x 8.6	Open	184.821	180.321	4.5	Soft Rock	28	Not Applicable			
	A2	4 x 8.6	Open	184.821	180.321	4.5	Soft Rock	28	Not Applicable			
Minor Bridge 33/1	A1	4 x 8.6	Open	186.773	182.273	4.5	Soft Rock	30	Not Applicable			
	A2	4 x 8.6	Open	186.773	182.273	4.5	Soft Rock	30	Not Applicable			
Minor Bridge 38/3	A1	4 x 8.6	Open	196.482	191.982	4.5	Soft Rock	30.	Not Applicable			
	A2	4 x 8.6	Open	196.482	191.982	4.5	Soft Rock	30	Not Applicable			
Minor Bridge 50/4	A1	4 x 8.6	Open	180.320	175.820	4.5	Moorum with clay	25	Not Applicable			
	A2	4 x 8.6	Open	180.320	175.820	4.5	Moorum with clay	25	Not Applicable			
Minor Bridge	A1	4 x 8.6	Open	207.500	203.00	4.5	Moorum with clay	25	Not Applicable			

Structure	Foundation Location	Foundation Dimension (m)	Foundation Type	Approx. Ground Level/ Lowest Bed Level (m)	Founding RL (m)	Approx. Depth of Foundation below Ground Level/ Lowest Bed Level (m)	Classification of Bearing Stratum	Safe Bearing Capacity (T/ m^2)	Pile Cut-off Level (m)	Pile Tip Level (m)	Vertical Pile Capacity Socketed into Rock (T)	End Bearing Stratum
52/1	P1	4 x 8.6	Open	207.500	203.00	4.5	Moorum with clay	25	Not Applicable			
	P2	4 x 8.6	Open	207.500	203.00	4.5	Moorum with clay	25	Not Applicable			
	A2	4 x 8.6	Open	207.500	203.00	4.5	Moorum with clay	25	Not Applicable			
Minor Bridge 66/3	A1	4 x 8.6	Open	205.692	201.192	4.5	Fragmented Rock	30	Not Applicable			
	A2	4 x 8.6	Open	205.692	201.192	4.5	Fragmented Rock	30	Not Applicable			
Minor Bridge 75/1	A1	4 x 8.6	Open	231.103	226.603	4.5	Medium Dense Sand	20	Not Applicable			
	A2	4 x 8.6	Open	231.103	226.603	4.5	Medium Dense Sand	20	Not Applicable			
Minor Bridge 80/1	A1	4 x 8.6	Open	231.241	227.241	4	Disintegrated rock	30	Not Applicable			
	A2	4 x 8.6	Open	231.241	227.241	4	Disintegrated rock	30	Not Applicable			
Minor Bridge 86/4	A1	4 x 8.6	Open	225.400	222.900	2	Rock	30	Not Applicable			
	P1	4 x 8.6	Open	225.400	222.900	2	Rock	30	Not Applicable			
	A2	4 x 8.6	Open	225.400	222.900	2	Rock	30	Not Applicable			
Minor Bridge 91/1	A1	4 x 8.6	Open	236.120	231.620	4.5	Dense Sand	18	Not Applicable			
	A2	4 x 8.6	Open	236.120	231.620	4.5	Dense Sand	18	Not Applicable			
Minor Bridge 98/2	A1	4 x 8.6	Open	263.457	258.957	4.50	Moorum with clay	20	Not Applicable			
	A2	4 x 8.6	Open	263.457	258.957	4.50	Moorum with clay	20	Not Applicable			
Minor Bridge 101/2	A1	4 x 8.6	Open	243.102	238.602	4.50	Medium Dense Sand	20	Not Applicable			
	P1	4 x 8.6	Open	243.102	238.602	4.50	Medium Dense Sand	20	Not Applicable			
	A2	4 x 8.6	Open	243.102	238.602	4.50	Medium Dense Sand	20	Not Applicable			
Minor Bridge 103/1	A1	4 x 8.6	Open	253.123	250.123	3.00	Rock	30	Not Applicable			
	P1	4 x 8.6	Open	253.123	250.123	3.00	Rock	30	Not Applicable			
	A2	4 x 8.6	Open	253.123	250.123	3.00	Rock	30	Not Applicable			
Minor Bridge 109/1	A1	5 x 8.6	Open	275.179	270.679	4.5	Medium Dense Sand	20	Not Applicable			
	P1	5 x 8.6	Open	275.179	270.679	4.5	Medium Dense Sand	20	Not Applicable			

Structure	Foundation Location	Foundation Dimension (m)	Foundation Type	Approx. Ground Level/ Lowest Bed Level (m)	Founding RL (m)	Approx. Depth of Foundation below Ground Level/ Lowest Bed Level (m)	Classification of Bearing Stratum	Safe Bearing Capacity (T/ m^2)	Pile Cut-off Level (m)	Pile Tip Level (m)	Vertical Pile Capacity Socketed into Rock (T)	End Bearing Stratum
	A2	5 x 8.6	Open	275.179	270.679	4.5	Medium Dense Sand	20	Not Applicable			
Minor Bridge 120/2	A1	4 x 8.6	Open	240.791	237.791	3.00	Disintegrated Rock	25	Not Applicable			
	A2	4 x 8.6	Open	240.791	237.791	3.00	Disintegrated Rock	25	Not Applicable			
Minor Bridge 122/3	A1	4 x 8.6	Open	246.873	243.873	3.00	Disintegrated Rock	25	Not Applicable			
	P1	4 x 8.6	Open	246.873	243.873	3.00	Disintegrated Rock	25	Not Applicable			
	P2	4 x 8.6	Open	246.873	243.873	3.00	Disintegrated Rock	25	Not Applicable			
	A2	4 x 8.6	Open	246.873	243.873	3.00	Disintegrated Rock	25	Not Applicable			
Minor Bridge 135/1	A1	4 x 8.6	Open	222.641	220.141	2.5	Rock	35	Not Applicable			
	P1	4 x 8.6	Open	222.641	220.141	2.5	Rock	35	Not Applicable			
	P2	4 x 8.6	Open	222.641	220.141	2.5	Rock	35	Not Applicable			
	A2	4 x 8.6	Open	222.641	220.141	2.5	Rock	35	Not Applicable			
Minor Bridge 142/1	A1	4 x 8.6	Open	220.201	215.701	4.5	Moorum with clay	24	Not Applicable			
	A2	4 x 8.6	Open	220.201	215.701	4.5	Moorum with clay	24	Not Applicable			
Major Bridges												
Major Bridge 67/2	A1	Not Applicable							206.420	189.420	350	Fragmented Rock
	P1	Not Applicable							206.420	189.420	350	Fragmented Rock
	P2	Not Applicable							206.420	189.420	350	Fragmented Rock
	P3	Not Applicable							206.420	189.420	350	Fragmented Rock
	P4	Not Applicable							206.420	189.420	350	Fragmented Rock
	A2	Not Applicable							206.420	189.420	350	Fragmented Rock
Major Bridge 118/1	A1	4 x 8.6	Open	241.304	235.604	5.7	Rock	35	Not Applicable			
	P1	4 x 8.6	Open	241.304	235.604	5.7	Rock	35	Not Applicable			
	P2	4 x 8.6	Open	240.110	237.610	2.5	Rock	35	Not Applicable			
	A2	4 x 8.6	Open	240.110	237.610	2.5	Rock	35	Not Applicable			
Major Bridge 145/1	A1	4 x 8.6	Open	201.690	197.670	4.00	Rock	35	Not Applicable			
	P1	4 x 8.6	Open	201.690	197.670	4.00	Rock	35	Not Applicable			

Structure	Foundation Location	Foundation Dimension (m)	Foundation Type	Approx. Ground Level/ Lowest Bed Level (m)	Founding RL (m)	Approx. Depth of Foundation below Ground Level/ Lowest Bed Level (m)	Classification of Bearing Stratum	Safe Bearing Capacity (T/ m^2)	Pile Cut-off Level (m)	Pile Tip Level (m)	Vertical Pile Capacity Socketed into Rock (T)	End Bearing Stratum
	A2	4 x 8.6	Open	201.690	197.670	4.00	Rock	35	Not Applicable			
Major Bridge 155/1	A1	Not Applicable							180.231	173.231	350	Rock
	P1	Not Applicable							180.231	173.231	350	Rock
	P2	Not Applicable							180.231	173.231	350	Rock
	A2	Not Applicable							180.231	173.231	350	Rock
ROB												
ROB 50/4	A1	4 x 8.6	Open	180.320	175.820	4.50	Soft Rock	25	Not Applicable			
	A2	4 x 8.6	Open	180.320	175.820	4.50	Soft Rock	25	Not Applicable			
ROB 143	A1	4 x 8.6	Open	213.687	209.187	4.50	Stiff Clay	20	Not Applicable			
	A2	4 x 8.6	Open	213.687	209.187	4.50	Stiff Clay	20	Not Applicable			

Note:

1. *Complete floor protection is assumed and hence scour effect is not considered.*
2. *Minimum foundation embedment of 0.60 m and 1.50 m shall be ensured in hard and weathered rock respectively.*
3. *Wherever there will have a discrepancy in foundation RL, depth of foundation from GL / LBL along with foundation stratum shall have precedence over RL as per site condition.*
4. *Fill material consists of Silty Clayey Sand / Silty Sandy Clay / Sandy Gravel with or without kankars, gravels, fragmented rock pieces etc.*

From the above table it can be seen that, in general, open foundations are proposed to be placed on soil/ completely to highly weathered rock. It is proposed to carry out Plate Load Test (PLT) at alternate pier locations in each carriageway for ROBs, major and minor bridges prior to actual construction of foundation to confirm the designed allowable bearing capacity of weathered rock.

Note:

1) *PCC thickness is proposed to be of minimum 200 mm of M 20 grade*
2) *Any loose pockets/ voids at founding level shall be removed, compacted and filled with lean concrete of M 20 grade*
3.) *It is assumed that floor protection of bed has been provided all through*

CHAPTER 5: PAVEMENT INVESTIGATIONS AND DESIGN

5.1 PAVEMENT EVALUATION AND DESIGN

5.1.1 General

Pavement design forms an integral part of the engineering study for a highway project. Pavement performance under prevailing and projected traffic and environmental conditions is considered to be crucial as it has a direct bearing on the economic returns from the project development. The present section of the report deals with the design methodology adopted for pavement design and also evaluates the present condition of the existing pavement crust.

5.1.2 Pavement Design Methodology

Pavement design has two components; design of strengthening overlay for existing pavement and design of new crust for the additional two lanes. The type of pavement to be adopted for the additional two lanes shall also be decided based on the life cycle cost analysis as a part of the pavement design methodology. Accordingly, the following methodology has been adopted:

Step 1: Various pavement investigations have been carried out on the project corridor to assess the adequacy of the existing pavement crust. These investigations include:

- Visual Pavement Condition Surveys;
- Pavement Roughness Surveys;
- BBD Measurements;
- Pavement Composition Surveys;
- DCP Investigations;
- Sub-Grade Investigations; and
- Investigations for Quarries and Borrow Areas.

Details of these investigations have been presented below. Based on these investigations, locations for rehabilitation and reconstruction of existing pavement have been identified.

Step 2: Axle Load Surveys have been conducted on the corridor and VDF for different categories of vehicles established. Design traffic loading for pavement design has been estimated from VDF and projected traffic figures. Axle load spectrum for rigid pavement design has also been established.

Step 3: Detailed material investigations have been conducted in the project influence area and availability of construction material has been determined. Details of material investigations have been presented in Chapter 5 of this report.

Step 4: For the purpose of designing the overlay, the project corridor has been divided into homogeneous sections based on Benkelman Beam Deflection (BBD) measurements using the Cumulative Difference Approach (AASHTO, Guide for Design of Pavement Structures, 1993, USA). Design thickness of overlay has been estimated using IRC: 81 - 1997 for the estimated traffic level (in MSAs) and characteristic deflection (in mm) of the homogeneous sections. Estimated equivalent Bituminous Macadam (BM) thickness is then converted to equivalent thickness of Asphaltic Concrete (AC) and Dense Bituminous Macadam (DBM) using conversion factors given in IRC: 81 - 1997.

Step 5: Homogeneous sections for pavement design have been established based on the homogeneous traffic sections as mentioned in Chapter 4 of this report and the design traffic loadings for each is identified. Design of flexible pavement for additional two lanes has been carried out in accordance with guidelines contained in IRC: 37 - 2001.

Step 6: Design of rigid pavement has been carried out in accordance with the PCA method.

Step 7: Life Cycle Cost analysis has been carried out to select the pavement type (Flexible or Rigid) for the additional two lanes.

5.1.3 Pavement Condition Surveys

Pavement condition surveys have already been elaborated in Chapter 3 of this report. A summary of the pavement condition is presented in the form of a bar chart in Figure 5-1. Individual distresses are plotted along the length for each Km length of the corridor. It can be observed from the figure that the total distress comprising cracking, raveling and patching is more in Km 25, 26, 27, 36, 37, 122, 123, 125 and 126. Bleeding has been observed in Km 135 and Km 142, and in sections between Km 147 and Km 152.

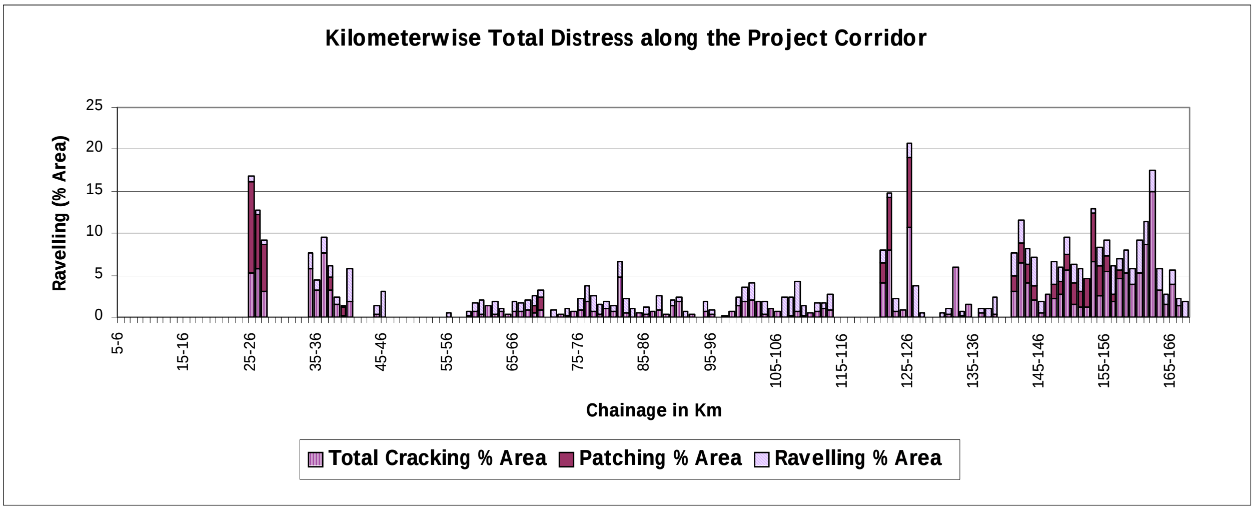


Figure 5-1: Kilometer-Wise Pavement Condition along the Project Corridor

5.1.4 Pavement Roughness Survey

Pavement roughness surveys have been conducted using ROMDAS (Road Measurement and Data Acquisition System). Roughness is represented in units of International Roughness Index (IRI) in terms of m/ km. Roughness surveys have been conducted in the last week of December 2007.

The ROMDAS vehicle has been calibrated at pre-selected sites and speeds, and trend lines have been established for each set of data from the regression analysis and the calibration coefficients have been estimated. Details of calibration are presented in Appendix 5.1 in Volume IIA of this report.

One run of ROMDAS vehicle has been undertaken on each direction along the project corridor. The raw counts of bumps have been measured in each run. These raw counts along with regression coefficients developed during calibration were fed into the ROMDAS software to get the average IRI of each kilometer. Average of both runs has been considered as the representative roughness on the corridor.

The roughness values in terms of IRI are presented in Appendix 5.2, Volume IIA of this report. Average IRI values along the corridor were grouped into four categories as tabulated below.

Table 5-1: Roughness Values along the Corridor

Roughness (IRI) Range	Length (Km)
2 - 3 IRI (Good)	0.000
3 - 4 IRI (Fair)	147.50
4 - 5 IRI (Poor)	10.000
5 - 6 IRI (Bad)	5.000
Total Length	162.50

Bar diagram showing the Kilometer-wise roughness along the corridor has been presented in Figure 5-2.

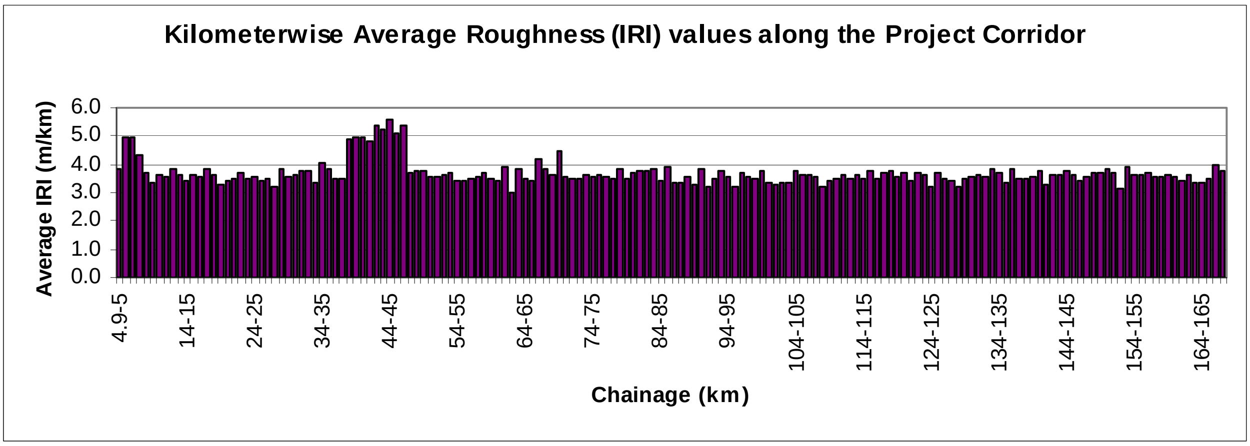


Figure 5-2: Kilometer-Wise Average Roughness (IRI) values along the Project Corridor

It can be seen from the above results that the project corridor has a poor pavement riding quality in section between Km 38 and Km 47, and has fair pavement riding quality in almost all the remaining sections. The poor riding quality observed is between the Bhushan Steel Plant and the start point of the existing Jharsuguda bypass.

5.1.5 Benkelman Beam Deflection (BBD) Survey

Pavement BBD survey has been carried out in the month of December 2007 on the project corridor using a Benkelman Beam in accordance with the testing approach given in IRC: 81 – 1997. Deflection measurements were made at an offset distance of about 0.90m from the edge of the pavement and at 100m intervals in a staggered manner on the adjacent lanes of project road, giving a total of 11 points in a kilometer length. At each point, 4 sets of measurements were taken, namely at D_{-200}, D_0, D_{2700} and D_{9000} at regular intervals along the outer wheel path.

Pavement temperature and sub-grade moisture data has also been collected during the course of survey for applying temperature and seasonal corrections. The BBD data collected in the field has been presented in Appendix 5.3 in Volume IIA of this report.

5.1.5.1 Temperature Correction

Pavement temperatures at the time of BBD measurements varied between 25^0 C and 45^0 C. Since the bituminous wearing course of the pavement is in a satisfactory condition and the thickness is more than 75mm on the average, appropriate temperature corrections were made based on the recommendations in IRC: 81 – 1997.

5.1.5.2 Correction for Seasonal Variation

Characteristics of the existing sub-grade were collected from test pit surveys and material investigations. Most of the sub-grade samples collected from the test pits indicate that the soil type is sandy in nature except one location where the soil type was found to be clayey type. Rainfall characteristics of the project area indicate that the rainfall on the project corridor comes under high rainfall category (annual rainfall > 1300 mm) as per IRC: 81 – 1997. The correction for the seasonal variation has been done in accordance with provisions of IRC: 81 – 1997 by using respective charts for rainfall and soil type.

5.1.5.3 Characteristic Deflection

For the set of deflection readings on a per Km-length, the average and standard deviation have been calculated and the characteristic deflection for that Km-length has been taken as the mean plus 2 standard deviations. This data is presented in Appendix 5.3 in Volume IIA of this report. Analysis of BBD data for overlay design has been explained in greater detail in subsequent sections of this report.

5.1.6 Pavement Composition Survey

The composition of the existing pavement crust has been noted from test pit surveys. Test pits have been taken at intervals of about 10 km in a staggered manner for both lanes of the existing carriageway. In addition to these, wherever the pavement condition was found to be poor; an additional pit has been made. In all twenty (20) test pits have been sampled in the entire length, along the junction of main carriageway and paved shoulder.

Results of the test pit survey indicate a varying thickness of pavement layers for the main carriageway as well as paved shoulders. Total thickness of the pavement for main carriageway varies between 410 – 800 mm. In general, the thickness of bituminous layer varies between 120 - 250 mm, and that of WMM between 200 - 250 mm. Pavement is mainly composed of a black-topped layer, WMM base layer over a granular sub-base and compacted sub-grade. In almost all locations, the granular sub-base material was found to be naturally occurring moorum.

It was noticed that the paved shoulders were laid at a different point in time (i.e. later) as compared to the main carriageway. This has resulted in a continuous horizontal joint between the paved shoulder and the carriageway on both sides. The overall thickness of paved shoulders varies from 300 - 600 mm. In general the thickness of bituminous layer over the base course varies from 30 - 50 mm; further, the bituminous layer of the paved shoulders appears to be surface dressing material. The pavement composition data collected is presented in Appendix 5.4 in Volume IIA of this report. The observed variation in thickness of different pavement layers has been shown graphically in Figure 5-3 below.

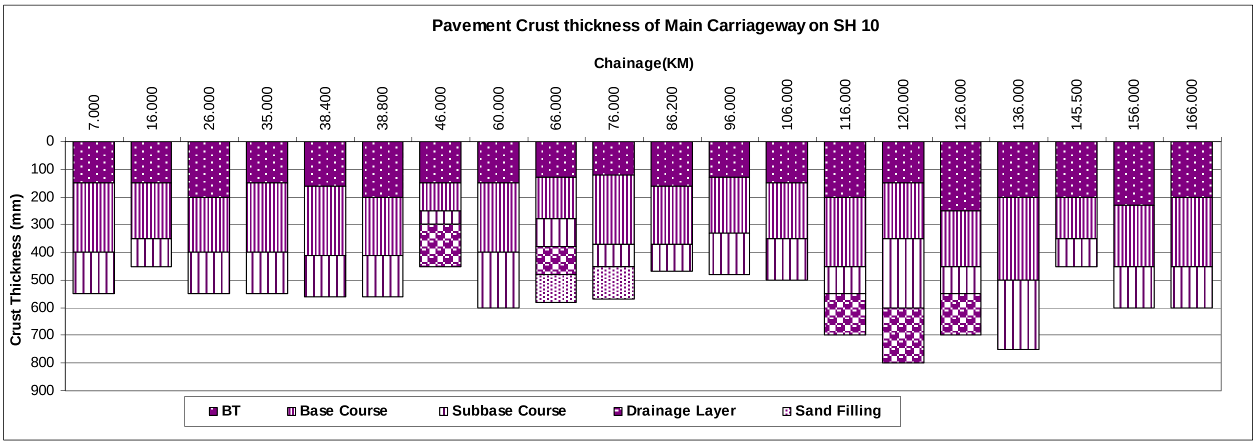


Figure 5-3: Pavement Composition (Main Carriageway)

Apart from the composition, field density measurements were made on the existing sub-grade and representative samples of sub-grade material were collected for laboratory testing of engineering properties. Results of sub-grade investigations have been presented in Chapter 5 of this report.

5.1.7 DCP Surveys and Analyses

TRRL Dynamic Cone Penetration (DCP) tests were conducted on the exposed sub-grade in the test pits to estimate the CBR strength of the sub-grade at the field density and field moisture conditions at the time of testing.

Tests were carried in accordance with the TRRL Overseas Road Note No. 8 and the estimated CBR of the sub-grade layers calculated from the TRRL equation (Log_{10} (CBR) = 2.48 – 1.057 log_{10} (mm/blow). The thickness of the various layers of the sub-grade material was estimated from changes in the slope of the plot of penetration versus number of blows. Table 5-2 presents the field CBR obtained from DCP tests. Analysis of DCP test data is presented in Appendix 5.5 in Volume-IIA of this report.

Table 5-2: Summary of DCP Test Results

Sl. No.	Location	Direction UP/DN	Test Pit No.	Depth (mm)	CBR Values (%)
1	Km166.000	DN	RS/TP/01	0 - 150	84.32
				150 - 484	57.81
2	Km156.000	UP	RS/TP/02	0 - 132	21.86
				132 - 240	75.52
				240- 611	31.26
3	Km 45.500	DN	RS/TP/03	0 - 450	35.82
				450- 644	16.76
4	Km 136.000	UP	RS/TP/04	0 - 400	60.02
				400- 540	86.40
5	Km 126.000	DN	RS/TP/05	0 - 394	21.18
				394- 620	9.66
6	Km 116.000	UP	RS/TP/06	0 - 425	26.03
				425- 730	73.11
7	Km 106.000	DN	RS/TP/07	0 - 300	44.69
				300- 730	26.59
8	Km 96.000	UP	RS/TP/08	0 - 80	132.43
				80- 725	15.40
9	Km 86.200	DN	RS/TP/09	0 - 450	62.98
				450- 585	58.40
10	Km 76.000	UP	RS/TP/10	0 - 400	26.03
				400- 570	73.11
11	Km 66.000	DN	RS/TP/11	0 - 260	63.72
				260- 520	35.14
				520- 730	8.36
12	Km 60.000	UP	RS/TP/12	0 - 679	20.21
13	Km 46.000	UP	RS/TP/13	0 - 300	50.02
				300- 660	32.53
14	Km 25.000	DN	RS/TP/14	0 - 145	40.23
				145- 230	144.52
				230 - 530	18.34
15	Km 26.000	UP	RS/TP/15	0 - 205	72.00
				300- 230	183.32
				230- 520	26.73
16	Km 16.600	DN	RS/TP/16	0 - 300	93.06
				300- 600	42.78

Sl. No.	Location	Direction UP/DN	Test Pit No.	Depth (mm)	CBR Values (%)
17	Km 7.000	UP	RS/TP/17	0 - 390	56.90
				390- 625	26.79
				625- 700	53.88
18	Km 120.000	DN	RS/TP/18	0 - 480	11.13
				480- 725	6.90
19	Km 38.800	UP	RS/TP/19	0 - 100	46.32
				100 - 130	268.46
20	Km 38.400	DN	RS/TP/20	0 - 200	147.22

5.1.8 Observations on Pavement Condition

The foregoing discussions on various surveys reveal that the project pavement is in good condition and does not require any reconstruction, either to partial or full depth. Merely strengthening overlays would be sufficient to cater for future design traffic loading, apart from minor pre-overlay treatments at a few locations. As discussed in the highway improvement options, the widening considered for the project corridor is mostly eccentric. In doing so, the prevailing bi-directional camber needs to be corrected a uni-directional camber as per design requirement. Hence, a Profile Corrective Course (PCC)/ Camber Corrective Course would be needed before placing the overlay material.

5.2 PAVEMENT DESIGN

Pavement design would basically involve arriving at input parameters required. The following sections elaborate the design considerations made in the pavement design.

5.2.1 Design Period

Pavement design life is the period for which the initial design of pavement crust layers shall be designed. Design life should not be used to refer to the terminal stage of crust beyond which crust becomes unusable. A design life of 15 years (from year 2012 to year 2026) for flexible pavement and 30 (from year 2012 to year 2041) years for rigid pavement has been considered for the design purpose.

5.2.2 Vehicle Damage Factors

VDF factors for commercial vehicles have been established from axle load surveys that were conducted at three locations, between Sambalpur and Jharsuguda at Km 22/ 000, between Jharsuguda and Sundargarh at Km 79/ 400 and between Sundargarh and Rourkela at Km 160/ 800. Direction-wise VDF for each mode of commercial traffic has been estimated. The results of axle load surveys have been presented in Table 5-3 below. The raw data and analysis of axle load survey data have been presented as Appendix 5.6 in Volume IIA of this report.

Table 5-3: Estimated and Adopted Vehicle Damage Factors

Vehicle Type	Location 1 (at Km 22.0)			Location 2 (at Km 79.4)			Location 3 (at Km 160.9)		
	Sambalpur –Rourkela Direction	Rourkela-Sambalpur Direction	Adopted VDF	Sambalpur –Rourkela Direction	Rourkela-Sambalpur Direction	Adopted VDF	Sambalpur –Rourkela Direction	Rourkela-Sambalpur Direction	Adopted VDF
Standard Bus	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
2-Axle trucks	2.15	2.60	2.60	1.08	4.18	4.18	2.80	2.88	2.88
3-Axle trucks	3.07	3.80	3.80	3.90	5.17	5.17	2.45	3.07	3.07
M-axle Trucks	2.30	8.88	8.88	3.46	8.97	8.97	1.67	3.14	3.14
Tempo/LCV	0.27	0.41	0.41	0.28	0.58	0.58	0.27	0.54	0.54

It can be noticed from the above table that Vehicle Damage Factors (VDF) obtained for all modes in the Rourkela – Sambalpur direction are higher when compared with the Sambalpur – Rourkela direction, except for buses. It is to be noted here that the AADT in either direction does not vary much. Since the VDF values in the Rourkela – Sambalpur direction are higher compared to the Sambalpur – Rourkela direction, hence the same has been adopted for pavement design purpose in order to maintain a constant pavement thickness across the carriageway.

5.2.3 Design Traffic Considerations

The base year and projected traffic for the design period for each category of vehicle have been extracted from Chapter 4 of this report. The entire corridor has been divided into four homogeneous traffic sections for the purpose of pavement design. Design traffic loading (MSA) has been estimated using the estimated traffic data, VDF as estimated above and the appropriate lane distribution factors as suggested in IRC: 37 - 2001.

For calculation of Design Traffic Loading, the following assumptions have been made:

- PPR preparation, tendering process and award of work will be completed by mid-2009;
- 36 months' construction period has been considered, from mid-2009 to end-2011; and
- Four-laning construction works will be completed and the facility would be opened to traffic in the year 2012.

The details of MSA calculations are presented in Appendix 5.7 in Volume IIA of this report. However the summary of the estimated design traffic loading for each section has been given in Table 5-4 below.

Table 5-4: Design Traffic Loading in Million Standard Axles (MSAs)

Year	Sambalpur-Rourkela Direction			
	Section 1: Sambalpur to Jharsuguda Km 4.9 to Km 55.5	Section 2: Jharsuguda to Sundergarh Km 55.5 to Km 79.8	Section 3: Sundergarh to Rajgangpur Km 79.8 to Km 145.5	Section 4: Rajgangpur to Ved Vyas Chowk Km 145.5 to Km 167.4
5th year (2016)	13	13	10	13
10th year (2021)	33	34	26	35
15th year (2026)	60	61	50	66
20th year (2031)	96	99	83	109

It can be noted from the above table that the design loading for a period of 15 year varies from 50 MSA to 66 MSA, and for a period of 20 years varies from 83 to 109 MSA.

Clause 5.4.1 of “Manual of Specifications & Standards for Four-Laning of State Highways through Public Private Partnership”, issued by the Planning Commission, Government of India specifies that the flexible pavement shall be designed for minimum period of 15 years or operation period whichever is more. And it also specifies that stage construction shall be permissible provided that the thickness of sub-base and base of pavement section is designed for a minimum period of 15 years and the initial bituminous surfacing for a minimum design period of 10 years. And it also mentions that the pavement shall be strengthened by bituminous overlay, as and when required, to extend the pavement life to full operation period. The thickness of overlay shall be determined on the basis of IRC: 81 - 1997.

This will improve financial viability of the project since subsequent overlay costs shall be incurred when the project revenues would have started flowing in, thereby improving the overall cash flow of the project. Accordingly, the thicknesses of base and sub-base have been designed for the full design life, while the surface and binder courses have been designed for a traffic loading of 35 MSA corresponding to a design period of 10 years. This would involve providing an overlay to cover the balance traffic loading after the pavement has carried 35 MSA traffic.

As cited in the earlier section, the axle load data as obtained from the axle load surveys has been compiled to represent the axle load distribution on the project corridor. The same has been used in conjunction with the projected traffic data to compute the numbers of single and tandem axles of various weights expected during the design period (30 years) as required for the design of rigid pavement.

5.2.4 Sub-Grade Strength

Sub-grade strength of soil to be considered in the pavement design has been derived from the material investigations. The results of borrow soil investigations identified along the corridor have been presented in greater details in Chapter 5 of this report. As discussed in this chapter, a design CBR value of 10% has been considered for the purpose of pavement design.

5.3 STRENGTHENING OF EXISTING PAVEMENT

The strengthening requirements (overlay designs) for the existing pavement (except reconstruction stretches) have been estimated from the deflection measurements taken on the project corridor using IRC: 81 - 1997 for a traffic loading of 35 MSA.

It is not practical to provide different overlay thicknesses for each kilometer. Adjacent lengths have been combined together for this purpose. Considering the proposed bypass locations and the narrow variation in the obtained deflection values of the demarcated homogeneous sections, the number of such sections has been rationalized and brought down to nine. *(The characteristic* *deflection for each homogeneous section is calculated as the mean deflection for that section, plus 2 standard deviations)*.

Using the characteristic deflection and projected traffic, the overlay thickness derived in mm of Bituminous Macadam (BM) as per IRC: 81 - 1997 has been tabulated in **Table 5-5** below. This thickness is converted to BC and DBM by taking the conversion equivalency suggested in IRC: 81 - 1997.

Table 5-5: Overlay Thickness for Existing Carriageway

Homogeneous	Chainage		Length	Deflections			Required BM Thickness (mm) for 35 MSA	Equivalent (BC+DBM) thickness (mm)	Recommended	
	From	To		Average	Std. Deviation	Char. Deflections (mm)			BC (mm)	DBM (mm)
1	4.90	22.60	17.70	0.41	0.13	0.67	<50	<50	50	-
2	22.60	24.30	1.70	Rengali Realignment/Bypass						
3	24.30	37.60	13.30	0.51	0.18	0.87	60	<50	50	-
4	37.60	52.50	14.90	0.41	0.16	0.74	47	<50	50	-
5	52.50	63.40	10.90	Jharsuguda Realignment/Bypass						
6	63.40	113.00	49.60	0.47	0.20	0.87	60	<50	50	-
7	113.00	130.20	17.20	0.34	0.15	0.64	<50	<50	50	-
8	130.20	131.40	1.20	Kutra Realignment/Bypass						
9	131.40	167.40	36.00	0.35	0.15	0.66	<50	<50	50	-

5.4 DESIGN OF PAVEMENT FOR NEW CARRIAGEWAY (FLEXIBLE PAVEMENT)

5.4.1 Review of Design Methods for New Construction and Reconstruction

The AASHTO and IRC methods of pavement design have been first reviewed before recommending the pavement composition. However, in the perspective of such a review, it is important to note that no method in practice can be considered better than the other with each having its inherent limitations, given the nature of materials used for construction and their complex interaction.

AASHTO, Guide for Design of Pavement Structures, 1993, USA

The basic approach is based on empirical expressions obtained from the AASHO road tests. This approach considers the ‘Present Serviceability Index’ (or PSI, the performance variable), ‘reliability’ (probability that the pavement system will perform its intended function over the design life and under the conditions encountered during the operation period), resilient modulus of sub-grade besides the constituent materials, drainage and climatic conditions.

This method gives the total required pavement composition in terms of the parameter ‘Structural Number’ (SN) and a procedure to arrive at the individual pavement layer thicknesses in relation to the strength characteristics of the pavement layers, defined as layer coefficients.

The Structural Number (SN) is represented by the sum of the products of the layer coefficient, the thickness expressed in inches and the drainage coefficient of each layer in the pavement structure. An acceptable fall in the 'serviceability' is considered as a main design criterion in this method. The end of design life is considered in the form of a terminal PSI, which usually corresponds to a minimum acceptable riding quality. The pavement composition obtained by this method is elaborated in subsequent sections of this chapter.

IRC: 37 – 2001, "Guidelines for the Design of Flexible Pavements", 2001, INDIA

The pavement designs given in this guide are based on the results of pavement research work done in India and experience gained over the years on the performance of the designs given therein. Flexible pavement has been modelled as a three-layer structure with stresses and strains at critical locations computed using the linear elastic model FPAVE developed under the Ministry of Road Transport & Highways Research Scheme, R – 56.

The pavement designs are given for sub-grade CBR values ranging from 2 per cent to 10 percent and design traffic ranging from 1 MSA to 150 MSA for an average annual pavement temperature of 35^0 C. The pavement compositions given in the design catalogue are relevant to Indian conditions, materials and specifications. Where changes to layer thickness and specification are considered desirable from practical considerations, the guidelines recommend modifications using an analytical approach.

5.4.2 Pavement Composition by AASHTO Method

Input Data

Roadbed modulus	:	15,000 psi (corresponding to 10% CBR)
Traffic on Design Lane	:	35 MSA (for the initial stage of multi stage design)
Design Serviceability Loss, ∆PSI	:	2.0
Reliability Level	:	90%
Overall Standard Deviation, S_o	:	0.49

Layer Coefficients

Layer coefficients in the AASHTO method are attributes of relative strength of the materials used in the pavement layers and the values reported there are the regression coefficients for the AASHO Road Test data. These are not constant and vary with material properties, environmental conditions (temperature and moisture) and the stress state. It is improper to adopt the AASHTO Road Test value of 0.42 for asphaltic layers for Indian roads since pavement temperatures here are very high. Accordingly, these values have been for different asphaltic layers based on the MOST studies (Research Scheme R-56) as given below:

(a) AC: 0.33

(b) DBM: 0.30

The layer coefficient values for the non-bituminous WMM and GSB layers are taken as 0.14 and 0.11 respectively, which are the AASHTO values. The drainage coefficient 'm' has been taken as

1.0 representing good drainage conditions for the new carriageway. The adopted values for design are given below.

Pavement Layer	Resilient Modulus	Layer Coefficient
AC		0.33
DBM		0.30
WMM	30000 psi	0.14
GSB	15000 psi	0.11
Drainage Coefficient, m		1.0

Using this data and applying the layered analysis as suggested by AASHTO, the pavement composition comes to the following:

Layer	Thickness in mm)
AC	50
DBM	250
BM	-
WMM	180
Total	**480**

From structural point of view no requirement of GSB layer has been indicated in this design because of the high sub-grade strength (M_R = 15000 psi, same as that assumed for the GSB in the AASHTO method). However, a 100mm thick granular layer is suggested below the WMM layer to serve as a drainage layer.

5.4.3 Pavement Composition by the IRC Method

For the same traffic and sub-grade characteristics, the pavement composition derived using the IRC: 37 - 2001 is as follows:

Layer	Thickness in mm
AC	40
DBM	95
BM	-
WMM	250
GSB	200
Total	**585**

5.4.4 Comparison of Pavement Compositions by the AASHTO and IRC Methods

Although the AASHO Road Test had established good correlations between pavement structures and traffic data elements, its experimental nature has the following limitations:

- The experiments tested specific pavement materials and roadbed soils that were not inclusive of all materials used in practice;
- The test site experienced particular environmental conditions not representative of conditions in all regions of the world;
- An accelerated two-year test period was extrapolated to longer design periods (15-30 years); and
- Vehicles with similar axle loads and configurations were employed, as opposed to mixed traffic.

Essentially, therefore, although the AASHTO design guide extrapolated the results of the AASHO Road Test to numerous flexible pavement sections with varying environmental conditions and layer characteristics, realistically they are most applicable to the conditions under which they were developed.

Flexible pavement composition derived by this method would require more thickness of bituminous layers and less thickness of granular layers. Thus, the AASHTO design method is less economical; the same has been found for the present case too.

As cited in the previous section, when the AASHTO and IRC method are compared, the asphalt layer thickness by the AASHTO method comes out higher than by the IRC method, but the granular layers are correspondingly thinner. In the AASHTO method, satisfactory performance is derived mainly from the strength and stiffness of asphalt layers rather than the structural capacity of the granular layers. However, experience in tropical countries show that asphalt mixes are prone to rutting during high summer pavement temperatures. An understanding of the asphalt mix behaviour suggests that under slow-moving loads (like heavily loaded trucks) and at high pavement temperatures, stability of asphalt mix is primarily contributed by frictional resistance of the aggregate mass contained in it. The shear strength of asphalt, which is highly influenced by temperature, reduces with increase in temperatures, and therefore contributes very little to the stability at high ambient temperatures.

The failures that observed in some of the roads elsewhere in India during the early life of the pavement by heavy rutting in the asphalt layers confirms such behaviour. It is from this point of view that it is recommended to adopt the IRC composition in lieu of that designed by AASHTO, which results in thicker asphalt layers in lieu of granular layers. Furthermore, the IRC designs are expected to reflect the field conditions more appropriately as compared to AASHTO designs.

5.4.5 Recommended Flexible Pavement Composition

The pavement composition obtained by the IRC method is recommended with slight modification to suit the adjacent overlay requirement.

The actual requirement of BC layer is 40mm but since the overlay requirement is 50mm, hence the suggested thickness of BC layer is recommended as 50mm as against 40mm and accordingly the required DBM thickness of 95 mm has been brought down to 85 mm. The finally recommended design thicknesses, including overlay designs, are given below:

Table 5-6: Recommended Layer Thicknesses for New and Old Pavement

Pavement Composition	New C/ W	Old C/ W
BC	50	50
DBM	85	
WMM	250	
GSB	200	
Sub-grade (10% CBR)	500	

It is to be noted here that the strengthening overlay on the existing carriageway would be laid only after laying the profile corrective course as per the design requirement and cost considerations.

5.4.6 Periodic Maintenance Requirements

Even though the design traffic loading on the project corridor for a 15-year period is more than 50 MSA, the overlay on the existing carriageway and the pavement for the new lanes have been designed for a traffic loading of 35 MSA for all sections. It is to be noted here that the granular layers for new two lanes have been designed up to 150MSA but the surfacing and binder course have been designed for 35 MSA Traffic. Hence it is required to examine the functional and structural adequacy of the in-service pavement at close intervals to ensure satisfactory performance. It is suggested that pavement roughness and BBD measurements should be undertaken periodically, and whenever the roughness value exceeds an IRI of 4.0, a roughness corrective course shall be laid and whenever the characteristic BBD deflection exceeds a value of 1.0 mm, requisite strengthening overlay shall be laid for 5-year design traffic. It is recommended to provide an overlay of 50mm bituminous concrete in the 5th year and 10th year from the date of completion of construction of new two lanes as a periodic maintenance, in case the above conditions do not warrant an overlay in 5 years.

5.4.7 Shoulder Composition

Wherever paved shoulder suggested, the same has been designed as an integral part of the pavement for the main carriageway. Therefore the total pavement thickness in the paved shoulder adjacent to the new two lanes would be the same as in the main carriageway. The pavement composition for the paved shoulder adjacent to the existing carriageway would be the same as that for the new 2 – lane pavement. It is, however, highlighted that the final recommended option for this project does not recommend paved shoulders, but hard shoulders.

The hard shoulder shall be covered with a 150mm thick layer of granular material conforming to the requirements specified for GSB materials. The total thickness of granular sub-base should be extended to the full width of embankment i.e. up to the side slopes or the ditches.

The hard shoulders above the granular sub-base/ drainage layer and below the top 150mm thick layer of granular material may be constructed with selected borrow material having the same soaked CBR value as that of the sub-grade soil.

5.4.8 Pavement Design for Slip Road/ Service Road

The proposed flyovers/ vehicular underpasses on the project corridor are at the junction with important roads. Pavement thickness for the slip roads at these locations shall be same as that of main carriageway.

The pavement design for service roads at other than these locations has been done considering a design sub-grade CBR of 10% for a traffic loading of 2 MSA in accordance with IRC: 37 -2001. As per these guidelines, for the design traffic and sub-grade CBR, the recommended wearing course is 20 mm Premix Carpet over a binder course of 50 mm BM. A 225 mm WMM layer and 150 mm GSB layer are also recommended over the selected sub-grade fill material.

Keeping in view the intensity of traffic on the service roads, a 25mm SDBC layer has been suggested in place of 20mm Premix Carpet material in view of the former's obvious superior performance qualities. Table 5-7 presents the pavement composition for service roads along the project corridor.

Table 5-7: Pavement Composition for Service Road

Layer	Layer Thickness in mm
SDBC	25
BM	50
WMM	225
GSB	150
Total	**450**

5.4.9 Pavement Design for Cross-Road

Pavement thickness for the improvement of cross-roads at all the major intersections shall be the same as that of the main carriageway up to ROW limits on both sides. The pavement composition at minor intersections shall be the same as that of the service road. Table 5-8 below presents the pavement composition at minor intersections.

Table 5-8: Pavement Composition at Minor Intersections

Layer	Layer Thickness in mm
SDBC	25
BM	50
WMM	225
GSB	150
Total	**450**

5.4.10 Pavement Design for Bus Bays

Since bus bays are an extension of the paved shoulder at isolated locations and the axle loads of buses are low, it is felt prudent to recommend the same pavement composition as that of the adjacent main carriageway in bus bays in order to maintain the continuity and uniformity of the pavement layers. However the pavement composition suggested at truck layby locations may be provided at bus bay locations.

5.4.11 Pavement Design for Truck Laybys/ Rest Areas

Interlocking Concrete Block pavement has been proposed at truck laybys and rest area locations in view of its suitability and merits over the other pavements for these locations. The interlocking concrete block pavement for these locations has been designed as per IRC: SP: 63 - 2004. Table 5-9 below presents the recommended pavement thickness at truck laybys/ rest areas.

Table 5-9: Pavement Composition at Truck Laybys/ Rest Areas

Layer	Layer Thickness in mm
Concrete Blocks	100
Sand Bed	40
WMM	250
GSB	200
Total	**590**

5.4.12 Pavement Design for Toll Plaza

It is proposed to convert SH-10 into a toll road; consequently, toll plazas will be erected. It is recommended to design the rigid pavement at toll plaza location. It is assumed that out of the 4 gates suggested for each direction in Toll plaza, two gates would be utilized by the truck traffic including LCVs. It is suggested to provide the same rigid pavement composition as that of mainline rigid pavement design, which has been designed for the purpose of life cycle cost analysis. The rigid pavement design details are given in subsequent sections.

5.5 RIGID PAVEMENT DESIGN

Before recommending the rigid pavement composition at toll plaza locations, as obtained from the PCA method, it is felt prudent to review the other internationally accepted rigid pavement design methods including their merits and demerits. The following sections describe these comparisons.

The AASHTO method for rigid pavement design makes a number of assumptions and does not take into account the actual axle load spectrum as captured by the Axle Load surveys, whereas the IRC method does not take into account one of the most important mode of distress, i.e. erosion of material from below the pavement, which is mainly caused by tandem and multi-axle vehicles. On the other hand, the Portland Cement Association (PCA) Method takes into account the actual axle load spectrum as captured from Axle Load surveys, and also addresses the erosion of material beneath and beside the pavement slab.

Hence, the Portland Cement Association (PCA) method is adopted for designing the rigid pavement in view of its merits over the other methods.

In view of the heavy axle loads plying on the corridor, it is suggested to use 150 mm dry lean concrete sub-base and GSB layer of 150mm thick below the Dry Lean Concrete (DLC) layer to serve as a stable working platform on which to operate the construction equipment as well as a drainage layer. Accordingly, the Pavement Quality Concrete (PQC) thickness has been calculated by the PCA method in this report.

Rigid Pavement Design - PCA Method

The PCA method has been adopted for the design of rigid pavement. The effective modulus of sub-grade reaction has been estimated from the sub-grade CBR and the thickness of DLC course. The design is carried out by assuming slab thickness and checking for fatigue life and erosion damage due to the repetitions of axle loads of different magnitudes.

The following input parameters have been considered for the purpose of rigid pavement design at toll plaza locations by the PCA method.

Design Period

Design thickness of rigid pavement is predominantly influenced by the magnitude and proportion of heavy axles plying on the highway and is relatively economical to design for longer lives, that is, in the range of 30 to 40 years. Since the facility once built would continue to serve beyond the normal pavement design period of 15 years and since strengthening overlays on a rigid pavement are difficult to execute, a 30 year design period has been considered for the purpose of rigid pavement design at the toll plaza location.

Flexural Strength of Concrete

The Modulus of Rupture, MR, of the Pavement Quality Concrete (PQC) is taken as 4.5 Mpa or 650 PSI for M-40 grade concrete.

Sub-Grade and Sub-Base Support

Since plenty of borrow material with 10% soaked CBR at 97% of MDD is available, as in the flexible pavement design for main carriageway, the soaked CBR value has been assumed as 10%. The sub-grade support for the concrete slab would be represented by the effective modulus of sub-grade reaction offered by the combined influence of the sub-grade and sub-base layer.

Design Traffic

Mode-wise and year-wise traffic figures have been extracted from Chapter 4 of Volume-I of this report. As cited above, it is assumed that of the four lanes suggested for each direction in the toll plaza, two lanes would be utilized by truck traffic including LCVs. The rigid pavement thickness required for these two lanes to cater for truck traffic would suffice for the other lanes too.

Axle Load Distribution

The axle load data as obtained in the axle load surveys for different directions has been compiled to represent the axle load distribution on the project corridor and the same has been used in conjunction with the projected traffic data to compute the numbers of single and tandem axles of various weights expected during the design period.

All the single-wheel single-axles have been omitted from the analysis since the stresses and deflections caused by the corresponding axle load groups are small enough to withstand unlimited applications.

Load Safety Factors

A Load Safety Factor (LSF) of 1.2 has been considered in order to provide a greater allowance for the possibility of unpredicted heavy truckloads and volumes and higher level of pavement serviceability.

Joints and Shoulders

Contraction joints with dowel bars are provided. Analysis was carried out assuming monolithic shoulders.

Results

Results of rigid pavement design have been presented in Appendix 5.8, Volume IIA of this report. However the summary of the results is given in the Table 5-10 below:

Table 5-10: Proposed Rigid Pavement Composition

Layer Type	Layer Thickness (mm)
PQC (With Modulus of Rupture of 4.5 Mpa at 28 days)	270
DLC (With characteristic 7 day compressive strength of 10 Mpa)	150
Granular Sub-base (With 30% soaked CBR)	150
Subgrade (With 10% soaked CBR)	500

5.6 LIFE CYCLE COST ANALYSIS

The objective here is to identify the most economical option for pavement type to be considered for pavement design. In this regard, following options were considered:

- Flexible pavement; and
- Rigid pavement.

The option selected is based on the principle of maximizing the net present value of net benefits, estimated by adopting life cycle cost analysis method. Hence, the procedure involves estimating the benefits, costs and net overall benefits.

5.6.1 Methodology

The life cycle cost analysis has been carried out using the HDM-4 Model. This study has been done only for the additional new 2-lane construction, as the existing pavement is proposed to be strengthened by flexible overlays.

The life cycle cost of the project is estimated considering only the costs that vary due to the pavement type. In other words, costs of all works have not been considered to account for the total construction costs. While estimating the economic costs of the project in the with- and without-project scenarios, routine maintenance and periodical maintenance costs have been included in the analysis.

5.6.2 Results of the Study

Based on the above considerations, estimated NPV values at a 12% interest rate for the life cycle of the project is as given in the Table 5-11 below:

Table 5-11: Results of Life Cycle Cost Analysis

Pavement Type	NPV/ Cost (30 Yrs)	EIRR
Flexible	3.40	34.5
Rigid	3.35	32.6

From the above table it can be noted here that the EIRR and NPV/ Cost for Flexible Pavement is marginally higher than rigid pavement. Hence it is recommended to adopt flexible pavement type for new carriageway.

CHAPTER 6: HIGHWAY IMPROVEMENT OPTIONS AND DESIGN

6.1 INTRODUCTION

Improvement proposals for highway development basically consist of two major components, *functional* and *structural*. While the functional components address geometric improvement and visible dimensions of the roadway, the structural components deal with design aspects for pavement, CD structures, bridges and embankments i.e. the ability of the highway to adequately carry and support the vehicle/ wheel loads over the design period.

Improvement proposals apropos functional components manifested in appropriate horizontal and vertical alignments, sight distance availability, lateral and vertical clearances, intersection treatment etc aim at improved design speed, road safety and also cover facilities such as proper intersection treatments, truck laybys, bus bays, wayside amenities, toll plazas etc. Improvement proposals apropos structural components on the other hand calls for detailed evaluation of widening options, concentric or eccentric widening of the existing road as dictated by site situations like available ROW, existing utilities, terrain, etc., and also existing structural conditions, both for pavement and CD structures.

As evident from the above, the first step towards formulating Improvement Options is to collect information on the project road primarily from engineering surveys and secondarily from various agencies concerned. Towards this end detailed information on past and present traffic, availability of land, condition of CD structures, potential sources of construction material, environmentally sensitive areas and social hot spots has been collected. Also collected are information pertaining to existing settlements, present configuration of intersections, importance of discrete cross roads, utility lines, locations of bus stops, truck parking etc.

Subsequent to a close observation of all these parameters, frequent site-visits have been undertaken to formulate improvement options that suit requirements of the project. The following subsections outline an appreciation of the different parameters against each constituent and thereby leading to improvement-options development.

6.2 RURAL CROSS-SECTION

While intermittently settlements are there, the project corridor predominantly traverses through rural areas. It bypasses settlement areas such as Rengali, Jharsuguda and Kutra and also traverses through the settlements of Karamdihi, Bargaon, and Beldihi.

The ROW along the project road varies from 13m to 90m with an average ROW of 36m. However, in some rural stretches industries and agricultural lands are also there abutting the project road. The rural sections in plain/ rolling terrain along the project road do not pose any major concern except for acquiring additional land to make a total land width of 45m as ROW which would call for acquisition of some structures along the corridor.

With these factors, the choices available for widening in rural areas are, i) Concentric widening and ii) Eccentric widening. The decision of eccentric widening on either side of the existing road is dependent on the side which merits preference and the distance of the existing centerline from the ROW boundaries. The factors influencing this decision are:

- Availability of land;
- Geometric improvement;
- Utility Lines;
- Terrain – Plain, Rolling or Hilly;
- Ribbon developments and settlements; and
- Environmental and Social concerns.

However, it is preferred to widen the corridor eccentrically wherever site conditions permit to utilize the existing formation completely and to avoid two longitudinal joints on either side. Also, this would ensure uninterrupted traffic movement during construction. Concentric widening in rural areas is mostly avoided, except at locations where scattered developments and concerns posed by environment and social issues exist on either side of the corridor. It is proposed to provide pedestrian underpasses at locations where major pedestrian movement is observed in order to avoid pedestrians entering the main carriageway.

Accordingly, the following typical cross-sections have been developed for the project corridor in rural areas:

- Eccentric Widening on left hand side;
- Eccentric widening on right hand side; and
- Concentric widening.

6.3 CROSS-SECTION IN BYPASSES

The option of widening the existing road in some settlements is restrained by the non-availability of sufficient land and also major concerns posed by environment and social issues. Hence it is felt prudent to recommend bypasses along these settlements in the project corridor. The three settlements for which bypasses are proposed are Rengali, Jharsuguda and Kutra. The alignment options, merits and demerits of each such option have already been discussed in great detail in a separate chapter of the Feasibility Report submitted earlier for this project. Typical cross-sections for the proposed bypasses are given in subsequent paragraphs of this chapter.

6.4 CROSS-SECTION IN APPROACHES OF UNDERPASSES

While vehicular underpasses and flyovers are provided wherever major roads are crossing/ entering the project corridor, and major industries are located in the proximity of the project corridor, pedestrian underpasses are provided at locations with heavy pedestrian movement.

These are provided to ensure free movement of traffic along the main carriageway. Slip roads of 5.5m width are provided on both sides of vehicular underpasses to give connectivity to the main carriageway. The locations for vehicular underpasses are Shyam Dry industries, Bhushan Steel Plant, cross-road leading to Sundergarh town on existing Sundergarh bypass and Karamdihi.

RESTRICTED ROW CROSS-SECTIONS

It has been discussed in the earlier sections that concentric widening has been proposed in the rural and urban sections where scattered developments and concerns posed by environment and social issues exist on either side of the corridor. The Transaction Advisors in consultation with the Client i.e. OWD have proposed reduction in the proposed ROW to minimise the social impacts. Typical cross-sections for restricted ROW are given in the subsequent paragraphs of this chapter.

6.5 CROSS-SECTIONAL ELEMENTS

Cross-sectional elements are based on the design standards and specifications set out in the earlier chapters. The lane width shall be 3.5m, paved shoulder width shall be 1.5/ 2.5m in urban areas, hard shoulder width 2.0m, median width 4.5/ 1.5m in rural and urban areas with shyness strip of 0.25m width on both sides of the median.

6.6 TYPICAL CROSS-SECTIONS

Based on the foregoing considerations typical cross-sections proposed to be adopted for various situations are listed below:[1]

- Figure 6-1: Typical Cross-Section for Right Hand Side Widening in Rural Area(Type ER);
- Figure 6-2: Typical Cross-Section for Left Hand Side Widening in Rural Area (Type EL);
- Figure 6-3: Typical Cross-Section for Concentric Widening (Type CONC);
- Figure 6-4: Typical Cross-Section for Concentric Widening at Major Urban Area (Type CONC-1);
- Figure 6-5: Typical Cross-Section for Concentric Widening with 1.5m Sidewalk on both sides and 1.5m median (Type CONC-2);
- Figure 6-6: Typical Cross-Section for New Construction (Type New/ Bypass);
- Figure 6-7: Typical Cross-Section at Underpass Location (Type UP);
- Figure 6-8: Typical Cross-Section for Widening of Existing Section at ROB (Type ROB_E);
- Figure 6-9: Typical Cross-Section at New ROB location (Type ROB);
- Figure 6-10: Typical Cross-Section for Unidirectional Flyover Approach with Slip Road at 145.500 Design Chainage (Type Unidirectional Flyover);
- Figure 6-11: Typical Cross-Section for Unidirectional Flyover Approach with Slip Road at 79.800 Design Chainage (Type Unidirectional Flyover);
- Figure 6-12: Typical Cross-Sections for High Embankment at Bridge Approaches (Type-BR);
- Figure 6-13: Typical Cross-Section for High Embankment at New Bridge Approaches (Type BR_N);

[1] The cross-sections detailed herein have references to side of widening viz. Left Hand Side (LHS) or Right Hand Side (RHS). The sides herein refer to that along existing increasing kilometer i.e. from Km (5.000) to Km (167.000)

- Figure 6-14: Typical Urban Cross-Section for Restricted ROW (Type CONC-2R);
- Figure 6-15: Typical Rural Cross-Section for Restricted ROW (Type CONC-R); and
- Figure 6-16: Typical Cross-Section for Concentric Widening at Major Urban Area for Restricted ROW (Type CONC-1R).

The drawings for all these cross-sections have been included in Volume III of this report. Some of the cross-sections are presented below for ready reference.

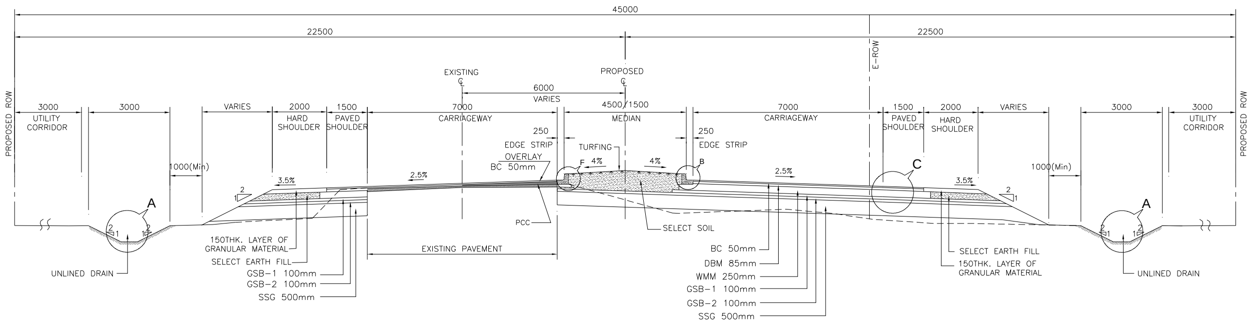


FIG 1. TYPICAL CROSS SECTION FOR RIGHT HAND SIDE WIDENING IN RURAL AREA
(TYPE : ER)

Figure 6-1: Typical Cross-Section for Right Hand Side Widening in Rural Area(Type ER)

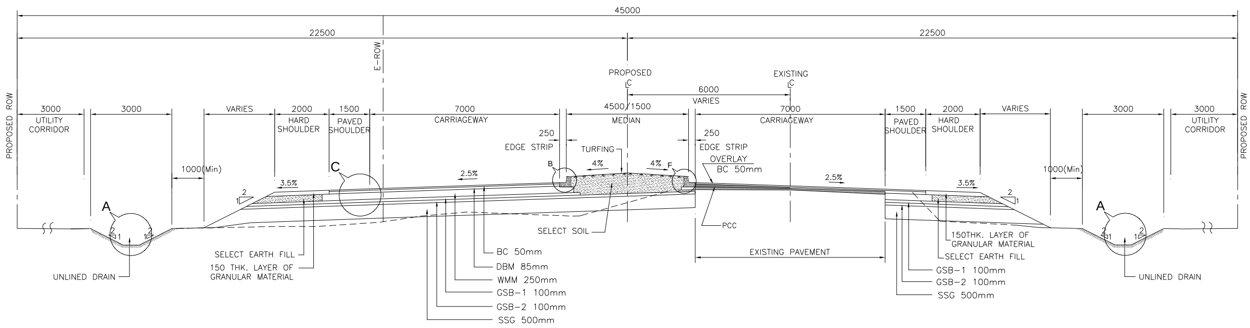


FIG 2. TYPICAL CROSS SECTION FOR LEFT HAND SIDE WIDENING IN RURAL AREA
(TYPE : EL)

Figure 6-2: Typical Cross-Section for Left Hand Side Widening in Rural Area (Type EL)

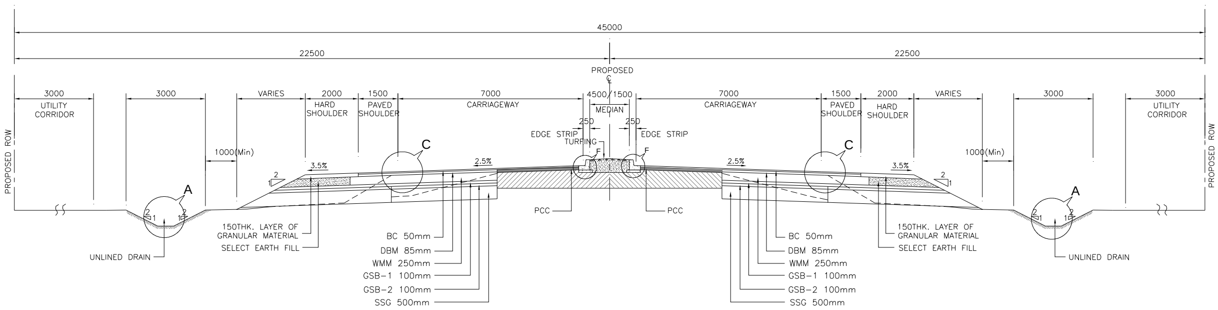


FIG 3. TYPICAL CROSS SECTION FOR CONCENTRIC WIDENING
(TYPE: CONC)

Figure 6-3: Typical Cross-Section for Concentric Widening (Type CONC)

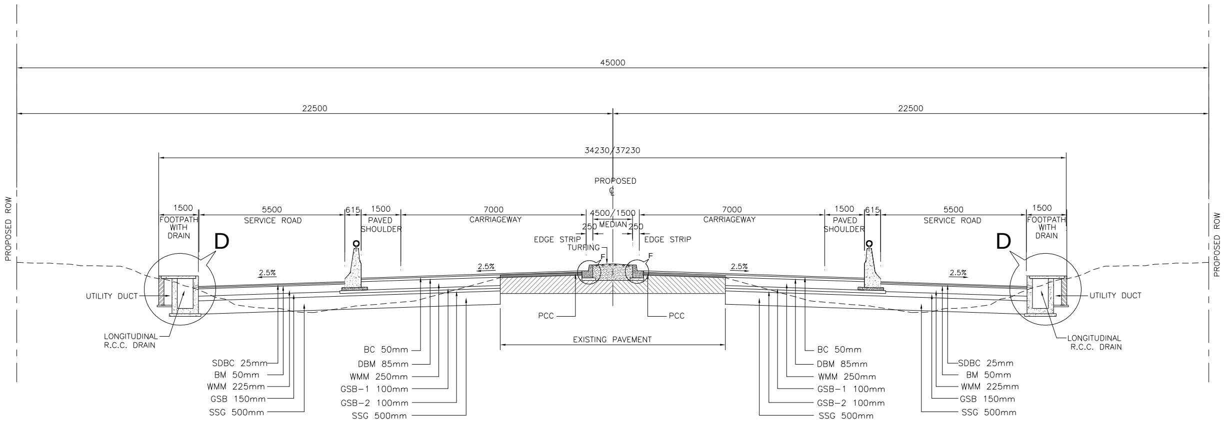


FIG 4. TYPICAL CROSS SECTION FOR CONCENTRIC WIDENING AT MAJOR URBAN AREA
(TYPE: CONC-1)

Figure 6-4: Typical Cross-Section for Concentric Widening at Major Urban Area (Type CONC-1)

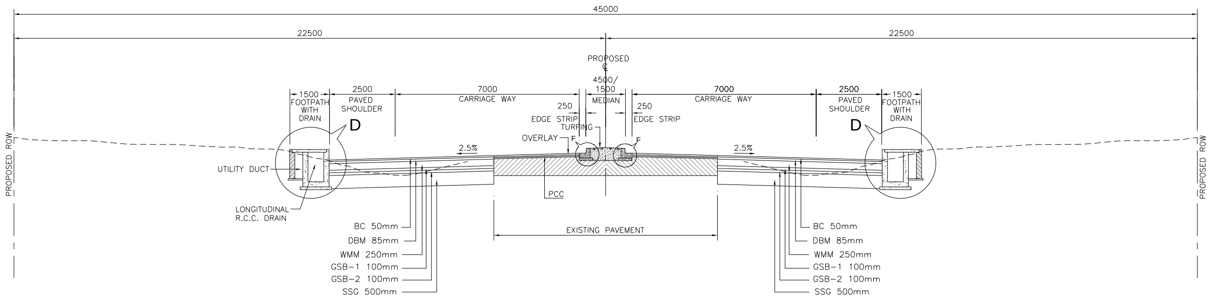


FIG 5. TYPICAL CROSS SECTION FOR CONCENTRIC WIDENING WITH 1.5m SIDE WALK ON BOTH SIDES & 1.5m MEDIAN
(TYPE : CONC - 2)

Figure 6-5: Typical Cross-Section for Concentric Widening with 1.5m Sidewalk on both sides and 1.5m median (Type CONC-2)

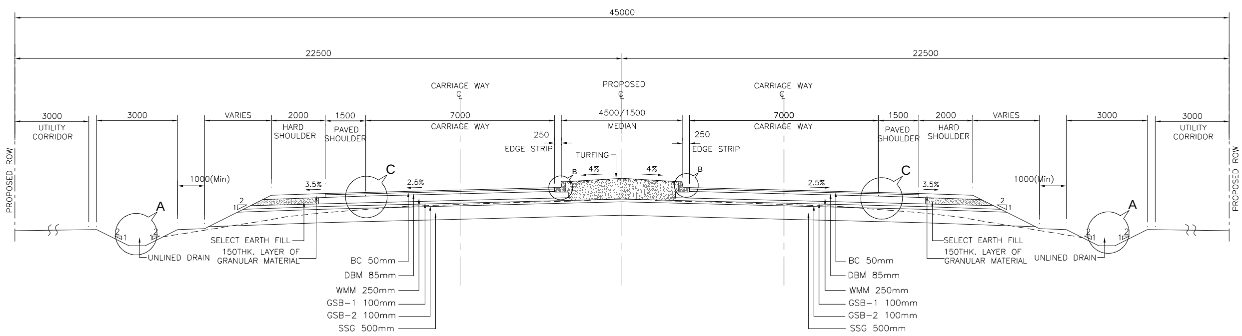


FIG 6 TYPICAL CROSS SECTION FOR NEW CONSTRUCTION
(TYPE : NEW/BYP)

Figure 6-6: Typical Cross-Section for New Construction (Type New/ Bypass)

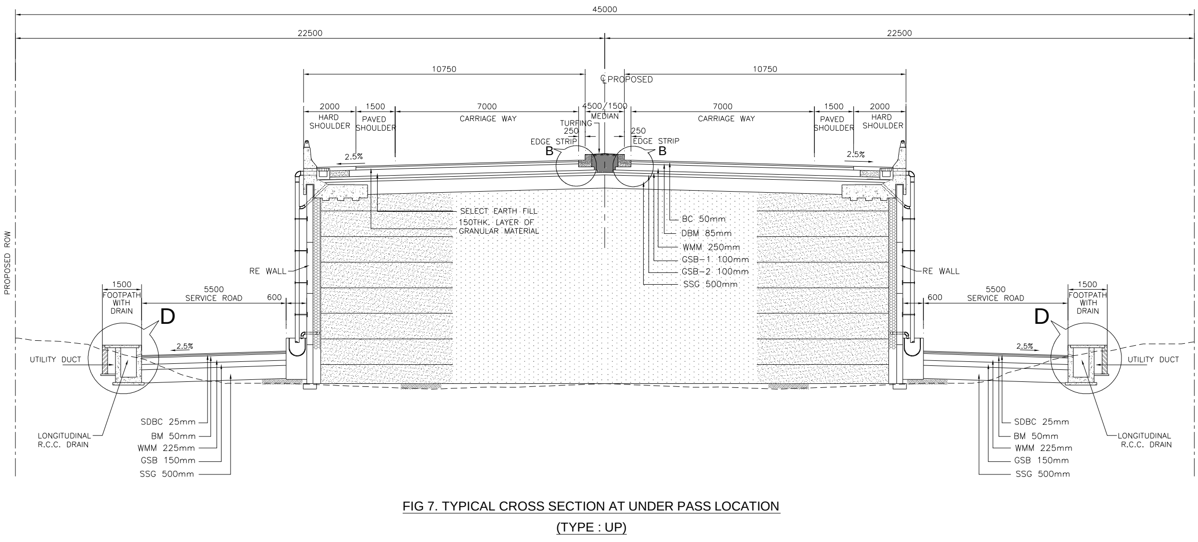


Figure 6-7: Typical Cross-Section at Underpass Location (Type UP)

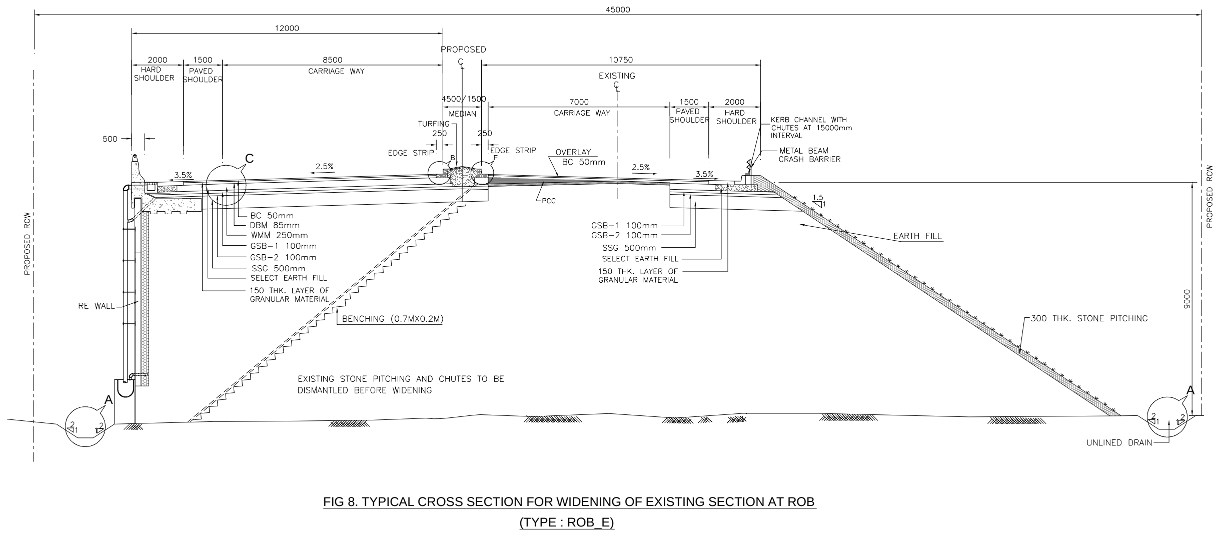


Figure 6-8: Typical Cross-Section for Widening of Existing Section at ROB (Type ROB_E)

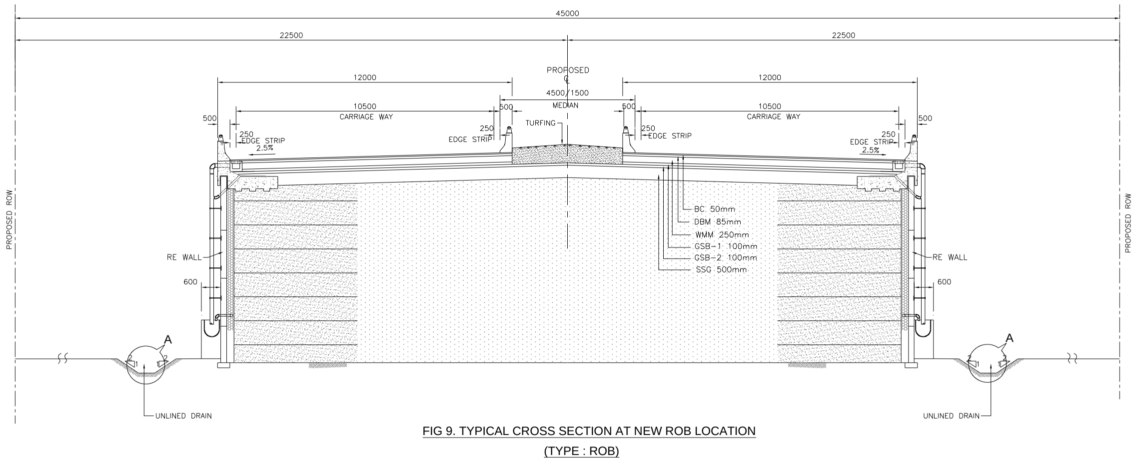


Figure 6-9: Typical Cross-Section at New ROB location (Type ROB)

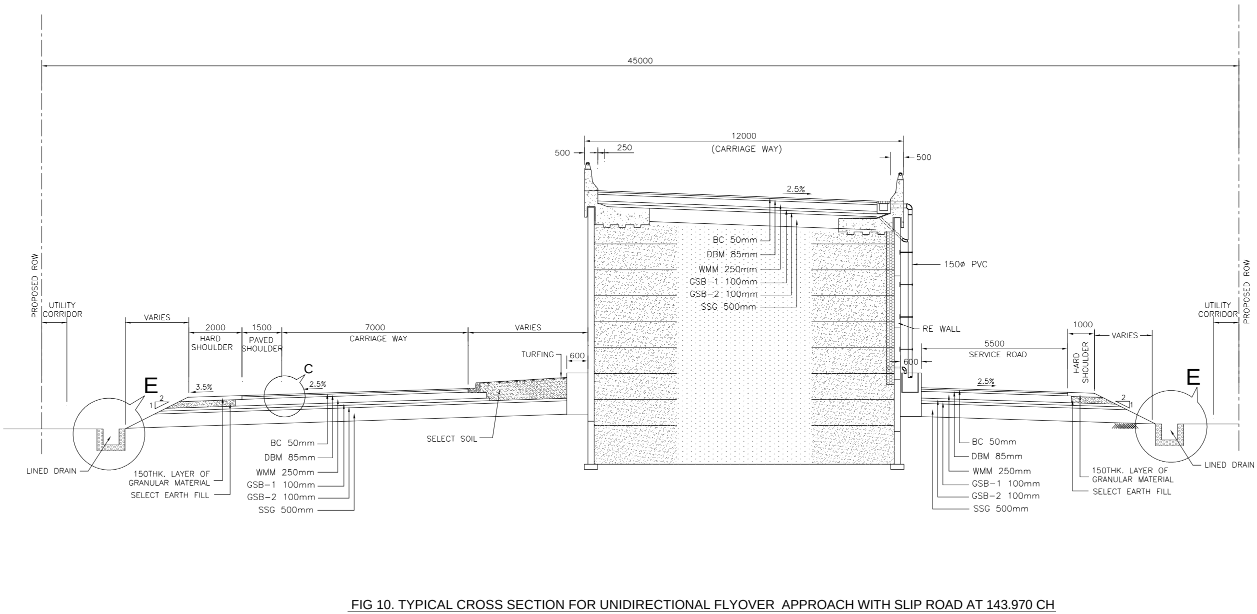


Figure 6-10: Typical Cross-Section for Unidirectional Flyover Approach with Slip Road at 145.500 Design Chainage (Type Unidirectional Flyover)

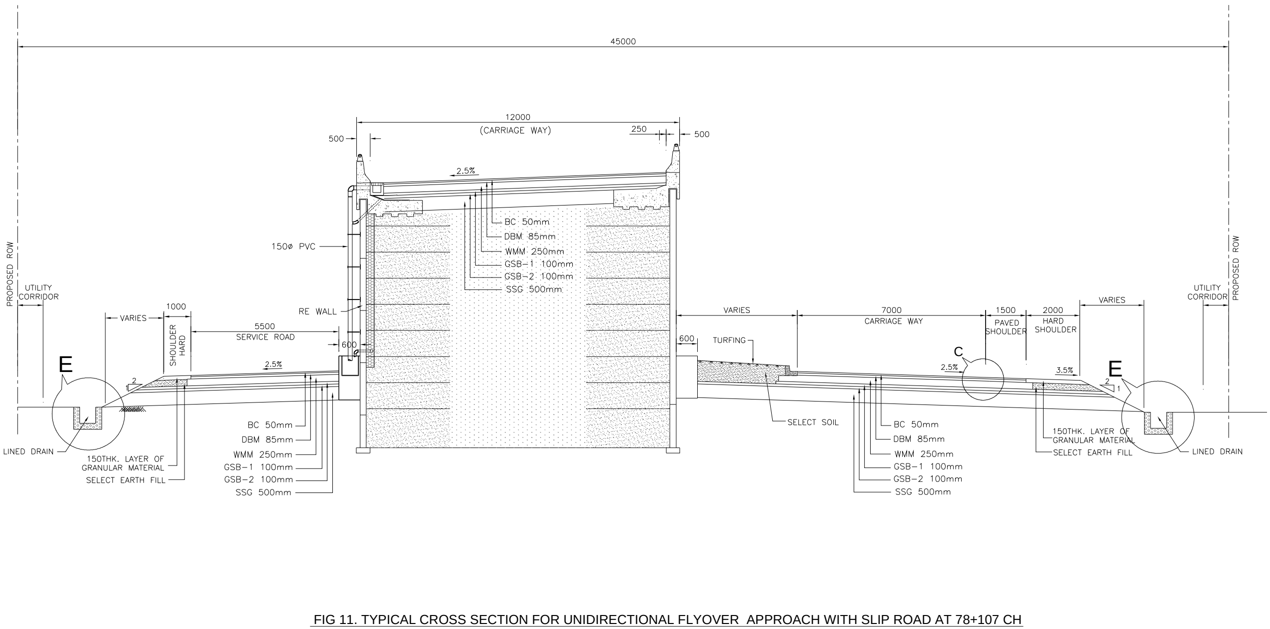


Figure 6-11: Typical Cross-Section for Unidirectional Flyover Approach with Slip Road at 79.800 Design Chainage (Type Unidirectional Flyover)

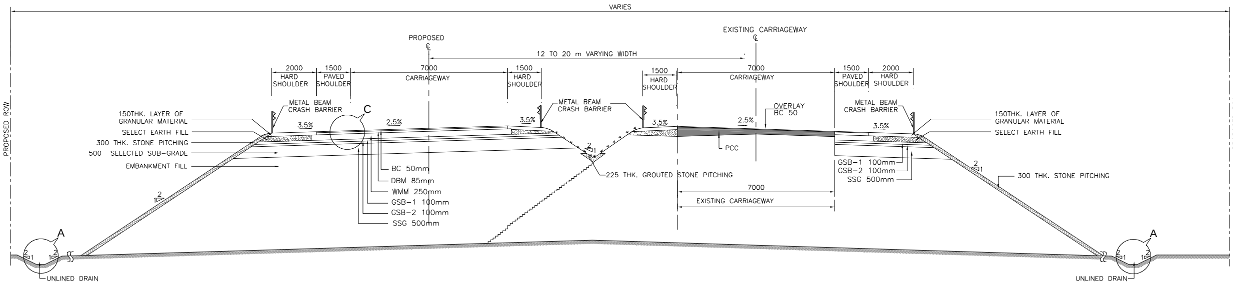


FIG 12. TYPICAL CROSS SECTION FOR HIGH EMBANKMENT AT BRIDGE APPROACHES
(TYPE - BR)

Figure 6-12: Typical Cross-Sections for High Embankment at Bridge Approaches (Type-BR)

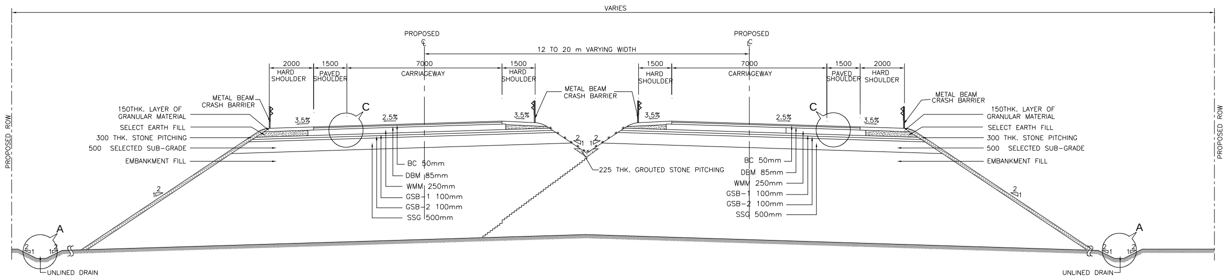


FIG 13. TYPICAL CROSS SECTION FOR HIGH EMBANKMENT AT NEW BRIDGE APPROACHES
(TYPE - BR _N)

Figure 6-13: Typical Cross-Section for High Embankment at New Bridge Approaches (Type BR_N)

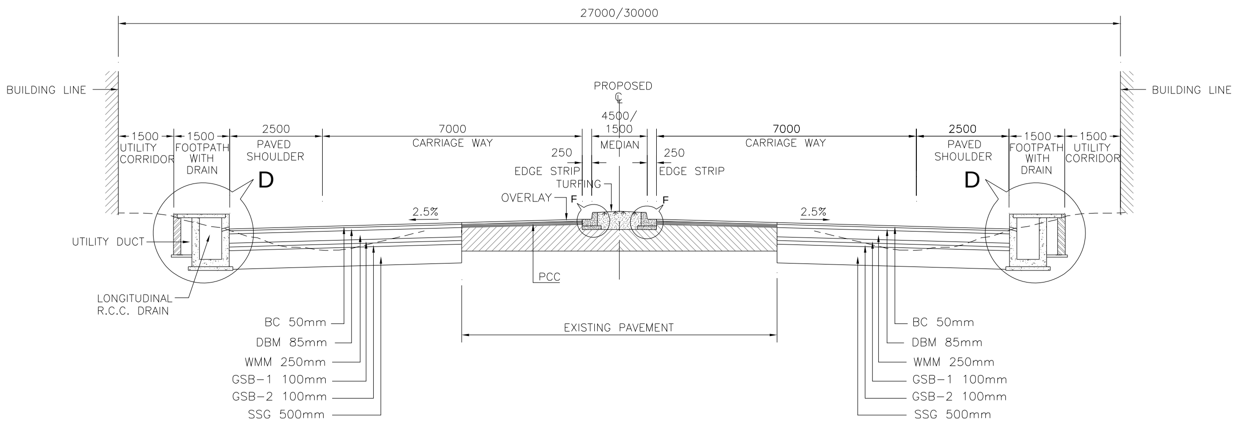


FIG 14. TYPICAL URBAN CROSS SECTION FOR RESTRICTED ROW
(TYPE : CONC-2R)

Figure 6-14: Typical Urban Cross-Section for Restricted ROW (Type CONC-2R)

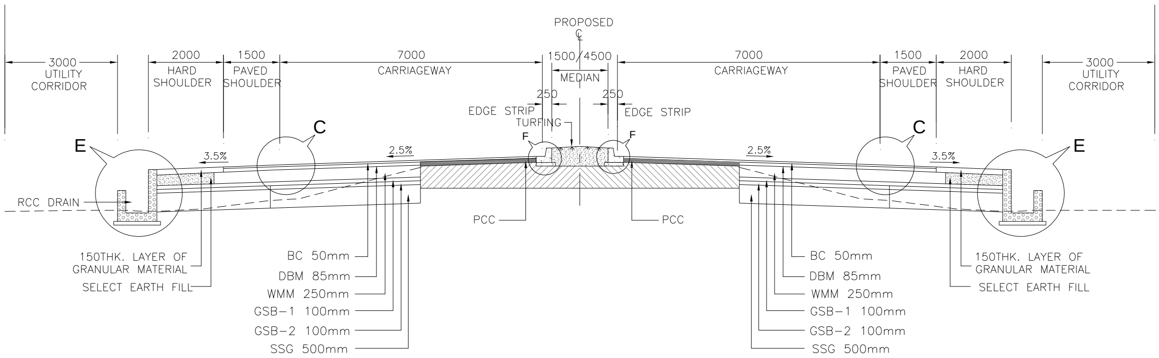


FIG 15. TYPICAL RURAL CROSS SECTION FOR RESTRICTED ROW
(TYPE : CONC-R)

Figure 6-15: Typical Rural Cross-Section for Restricted ROW (Type CONC-R)

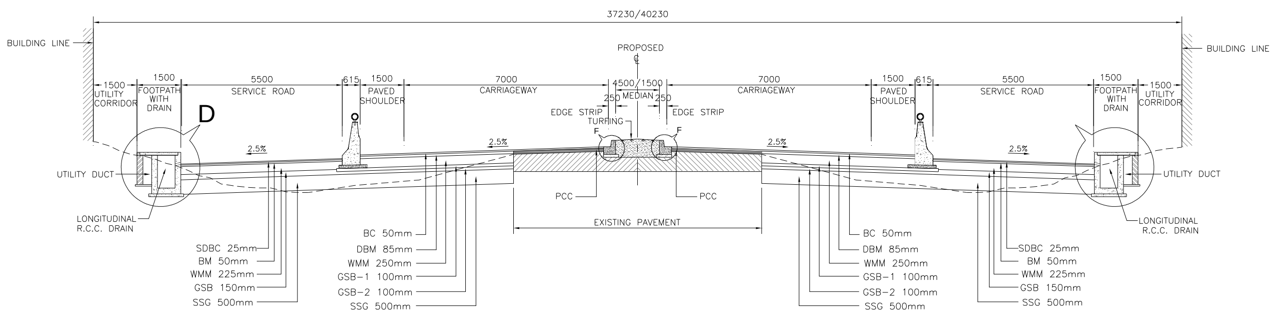


FIG 16. TYPICAL CROSS SECTION FOR CONCENTRIC WIDENING AT MAJOR URBAN AREA FOR RESTRICTED ROW
(TYPE: CONC-1R)

Figure 6-16: Typical Cross-Section for Concentric Widening at Major Urban Area for Restricted ROW (Type CONC-1R)

6.7 BYPASS CANDIDATES

There are some settlements with ribbon developments along the project road, namely, Rengali, and Jharsuguda. These settlements, as mentioned above, require realignments because of continuous and thick ribbon developments with proper buildings very close to the existing carriageway, poor geometry and non-availability of ROW. It would not be possible to accommodate a four-lane cross-section through these settlements within the available ROW. Acquisition of land through these settlements shall be difficult due to social implications thereof. Initial appreciation of these settlements revealed that there is enough space to take realignments minimizing the social concern and acquisition of land. Essential features of these realignments are given in the Table 6-1 below.

Table 6-1: Details of Bypass Candidates

S. No	Existing Chainage		Design Chainage		Length of Existing Road Bypassed	Length (km) as per Proposed Chainage	Side of Existing Road	Settlement Name
	From	To	From	To				
1	22550	26600	22550	27275	4.050	4.725	Right	Rengali
2	52539	63375	52200	61665	10.836	9.465	Left/Right	Jharsuguda

6.8 WIDENING SCHEME

A detailed evaluation of the information collected and options described in the preceding subsections has enabled formulation of widening scheme that best suits the different stretches of the project road. The following Table 6-2 gives the details of the cross-section type and widening scheme along the project corridor.

Table 6-2: Cross-Section Type and Widening Scheme along the Project Corridor

S. No.	From	To	Length (km)	Type	Remarks
1	4944.547	5550	0.605	CONC-2R	
2	5550	5750	0.200	NEW/BYP	
3	5750	6935	1.185	CONC-2R	
4	6935	8930	1.995	CONC-R	
5	8930	9900	0.970	ER	
6	9900	10703	0.803	EL	
7	10703	11308	0.605	EL	Restricted RoW - Urban
8	11308	13050	1.742	ER	
9	13050	14800	1.750	EL	
10	14800	15000	0.200	CONC-R	
11	15000	16725	1.725	EL	
12	16725	17325	0.600	Toll plaza	
13	17325	17450	0.125	EL	
14	17450	17700	0.250	ER	
15	17700	19125	1.425	NEW/BYP	Location of First Railway Level Crossing, Railways are constructing rail track at lower level
16	19125	20600	1.475	CONC-2R	
17	20600	20925	0.325	NEW/BYP	
18	20925	22550	1.625	CONC-2R	
19	22550	27168	4.618	NEW/BYP	
20	27168	27327.754	0.160	EL	**Chainage Equation 27327.754 = 26328.398**
21	26328.398	26850	0.522	EL	
22	26850	27875	1.025	ROB	ROB with both sides service roads from 27537 to 27966
23	27875	28600	0.725	ER	
24	28600	29300	0.700	NEW/BYP	
25	29300	32200	2.900	ER	
26	32200	33800	1.600	EL	
27	33800	34300	0.500	CONC-2R	
28	34300	35300	1.000	ER	
29	35300	35500	0.200	NEW/BYP	
30	35500	37250	1.750	ER	
31	37250	37675	0.425	EL	
32	37675	38675	1.000	EL	U/P c/s with SR at Bhushan
33	38675	39550	0.875	UP	U/P c/s with SR at Bhushan
34	39550	40050	0.500	EL	U/P c/s with SR at Bhushan
35	40050	40575	0.525	EL	
36	40575	41850	1.275	BR	Overlay on RHS bridge approach
37	41850	44500	2.650	EL	
38	44500	44675	0.175	CONC-R	
39	44675	46550	1.875	CONC-2R	

S. No.	From	To	Length (km)	Type	Remarks
40	46550	49475	2.925	EL	
41	49475	49565	0.090	RoB_E	Existing RoB
42	49565	50050	0.485	EL	
43	50050	51725	1.675	ER	
44	51725	52200	0.475	CONC-R	
45	52200	53400	1.200	NEW/BYP	
46	53400	54500	1.100	ROB	
47	54500	61665	7.165	NEW/BYP	
48	61665	61830	0.165	CONC-R	
49	61830	62125	0.295	CONC-2R	
50	62125	62520	0.395	CONC-2R	Split carriageway, overlay on both
51	62520	62680	0.160	CONC-2R	
52	62680	62950	0.270	ER	
53	62950	63350	0.400	UP	
54	63350	64400	1.050	ER	
55	64400	65650	1.250	BR	Overlay on RHS bridge approach
56	65650	71050	5.400	ER	
57	71050	71450	0.400	UP	
58	71450	71700	0.250	ER	
59	71700	72100	0.4	Toll plaza	
60	72100	72625	0.525	ER	
61	72625	73200	0.575	EL	
62	73200	73700	0.500	UP	
63	73700	73881	0.181	ER	
64	73881	74056	0.175	CONC-R	
65	74056	76756	2.700	CONC-2R	
66	76756	77400	0.644	ER	
67	77400	78493	1.093	Uni directional flyover	
68	78493	79880	1.387	ER	
69	79880	80480	0.600	ER	
70	80480	81100	0.620	ER	
71	81100	81755	0.655	CONC	
72	81755	82430	0.675	UP	
73	82430	84200	1.770	EL	
74	84200	84345	0.145	CONC	
75	84345	85345	1.000	CONC-1	
76	85345	89350	4.005	EL	
77	89350	89550	0.200	CONC-1	
78	89550	90300	0.750	UP	
79	90300	90533	0.233	CONC-1	
80	90533	91675	1.142	ER	
81	91675	91800	0.125	NEW/BYP	
82	91800	92325	0.525	ER	
83	92325	92400	0.075	NEW/BYP	
84	92400	94750	2.350	EL	
85	94750	95200	0.450	UP	No service roads for Elephant Underpass
86	95200	96400	1.200	EL	
87	96400	97750	1.350	ER	

S. No.	From	To	Length (km)	Type	Remarks
88	97750	98200	0.450	UP	
89	98200	100450	2.250	ER	
90	100450	102800	2.350	EL	
91	102800	103500	0.700	UP	
92	103500	103700	0.200	CONC	
93	103700	105934	2.234	EL	
94	105934	106284	0.350	UP	
95	106284	107100	0.816	NEW/BYP	Animal Underpass
96	107100	109609	2.509	ER	
97	109609	110200	0.591	UP	
98	110200	110330	0.130	ER	
99	110330	110456	0.126	CONC-R	
100	110456	112256	1.800	CONC-2R	
101	112256	112400	0.144	CONC	
102	112400	112800	0.400	UP	
103	112800	112906	0.106	CONC	
104	112906	113256	0.350	CONC-2R	
105	113256	114950	1.694	ER	
106	114950	116000	1.050	BR	
107	116000	119000	3.000	ER	
108	119000	122881	3.881	EL	
109	122881	123406	0.525	CONC-R	
110	123406	123550	0.144	CONC	
111	123550	128600	5.050	EL	
112	128600	129700	1.100	CONC-2R	
113	129700	129786.616	0.087	ER	
114	129811.871	135350	5.538	ER	**Chainage Equation 129786.616 = 129811.871**
115	135350	135709	0.359	CONC	
116	135709	136075	0.366	UP	
117	136075	140000	3.925	ER	
118	140000	142930	2.930	EL	
119	142930	143306	0.376	CONC-2R	
120	143306	143466	0.160	CONC	
121	143466	144606	1.140	Uni directional flyover	
122	144606	147456	2.850	CONC-R	
123	147456	147775	0.319	ER	
124	147775	148025	0.250	NEW/BYP	
125	148025	149781	1.756	ER	
126	149781	150381	0.600	Toll plaza	
127	150381	151609	1.228	ER	
128	151609	152100	0.491	UP	
129	152100	152200	0.100	ER	
130	152200	152712	0.512	BR	
131	152712	154011	1.299	CONC-2R	
132	154011	154236	0.225	CONC-R	
133	154236	155250	1.014	EL	
134	155250	156500	1.250	ER	
135	156500	156900	0.400	EL	

S. No.	From	To	Length (km)	Type	Remarks
136	156900	157363	0.463	UP	
137	157363	157586	0.223	EL	
138	157586	157661	0.075	CONC-R	
139	157661	159111	1.450	CONC-2R	
140	159111	161150.516	2.040	EL	**Chainage Equation 161150.516 = 0.000**
141	0	250	0.250	EL	
142	250	1125	0.875	CONC-2R	
143	1125	1405.669	0.281	CONC-1R	**Chainage Equation 1405.669 = 162557.293**
144	162557.293	163200	0.643	CONC-1R	Conc
145	163200	163411	0.211	CONC-1R	Right Overlay
146	163411	164151	0.740	EL	
147	164151	165708.589	1.558	CONC-1R	

6.9 HORIZONTAL ALIGNMENT DESIGN

Design of the horizontal alignment has been carried out using highway design software as per the widening scheme finalized at the feasibility stage. Extensive field checks to verify the feasibility of the proposed alignment have been carried out and suitable modifications to the alignment have been done wherever considered essential to safeguard sensitive elements.

Base plan of the existing highway corridor showing all natural and manmade features has been prepared using the topographical survey data. All the features within a band width of 45m have been captured with a unique "description code" during the survey along with the details of existing carriageway centerline, edge of pavement, edge of shoulder, toe line of the embankment etc. This data has been downloaded into the highway design software to prepare the base plans. The following activities elucidate the preparation of base plans in more detail:

- Format survey data to suit the requirements of highway design software environment;
- Download the data into software;
- Define main corridor features by joining the points of centerline, edge of pavement, embankment toe line;
- Join the points with same description codes for all physical features like rivers, buildings, religious structures, shops, telephone poles, electric poles, cross roads etc within the above specified limits;
- Establish break lines for features such as edge of the road, shoulder, nallahs, top and bottom of ditches, etc;
- Insert the details of existing cross drainage structures such as bridge number, span arrangement etc.;
- Cross check the so prepared base plans by "walkover" surveys; and
- Update and finalise the base plans with additional survey data, if necessary.

Geometric design of the project corridor has been conceptualized for a design speed of 100/ 80 kmph in plain and rolling terrain for road passing through rural sections and 40/ 50 kmph for road passing through settlements and industrial areas as per the design standards formulated for the project. The project corridor in general has poor geometrics not conforming to the relevant IRC standards for a design speed of 100 kmph. The details of some locations with major poor geometric characteristics are given in the following Table 6-3.

Table 6-3: Locations of Poor Road Geometry

S. No	Location (Km)	Remarks	Improvements	Design Speed
1	13-14	Sharp Curve on LHS	Changeover in widening scheme from right to left has been achieved at this curve.	80 kmph
2	18-19	Railway Level Crossing, Sharp Curves on both sides of it	Realignment	80-100 kmph
3	23-24	Sharp Curve	Bypassed	80 kmph
4	27-28	Railway Level Crossing, Sharp Curves on both sides of it	ROB proposed, Speed reduced to avoid impacting industries	40-50 kmph
5	42-43	Sharp Curve on Bridge Approach	Split carriageway	80 kmph
6	62-63	Sharp Curve, Talpatia Village	Bypassed	80-100 kmph
7	66-67	Sharp Curve on Bridge Approach	Split carriageway	80 kmph
8	73-74	Poor Geometry, Minor Village Ribbon Developments	Pedestrian Underpass	100 kmph
9	96-98	Poor Geometry, Forest Area	Changeover in widening scheme from left to right has been achieved at curve location.	100 kmph
14	108-109	Sharp Curves on Minor Bridge Approaches	Curve improvement	80 kmph
15	135-136	Sharp Curve on LHS,	Curves designed for 100 kmph.	100 kmph
16	157-160	Deficient Curves, Reverse Curves, Poor Geometry on Bridge Approaches, and Engineering College and minor ribbon development	Geometric design considering ribbon development	50-100 kmph

The horizontal alignment and curve station report and proposed centerline coordinates has been given in **Appendix 6.1** and **Appendix 6.2**, Volume IIA of this report.

Realignment

Alignment of the existing two-lane carriageway has been improved at the locations of poor geometry as indicated in the table above. Realignment was necessitated for achieving requisite design speed along project corridor and attaining design compatibility with improvement options such as flyovers, ROBs and RUBs. Further, efforts have been made to have a change over of the side of widening at curves, wherever possible. In case of tangent sections, change over is suggested with very flat curves. Some cross-roads have been realigned at the junction with the main carriageway to reduce the skew angle of the crossing.

6.10 JUNCTION DESIGN

At-grade intersections, unless properly designed, can be accident-prone and can reduce the overall capacity of the road. The basic requirements for the design of intersections are not only to cater to safe movements for drivers, but also to provide them complete traffic-related information by way of signs, pavement markings and traffic signals. Simplicity and uniformity should be the guiding principles for intersection design. Based upon these principles the at-grade intersections have been categorized as:

1) Minor;
2) Channelised with or without acceleration and deceleration lanes;
3) Staggered;
4) Rotaries;
5) Signalized intersections; and
6) Grade separated flyovers/ interchanges.

There are a number of intersections along the project corridor with various categories of roads. At the start of the project corridor is a rotary intersection on the existing NH-6 bypass at Sambalpur at Km 4/ 900, with Km 0/ 000 being inside Sambalpur town. At the end of the project corridor there is a channelised intersection with NH-23 at the Ved Vyas Chowk on the outskirts of Rourkela town at Km 167/ 400. The project corridor crosses NH-200 at the start of Jharsuguda bypass. It has been discussed and decided that, with the exception of the intersection of NH-200 with the project corridor, the intersections with NH at the start and end of the project corridor would not be part of the intersection improvements. Apart from this, there are intersections of primary importance with SH, MDR etc. The balance intersections are of lower significance, and are with village roads and earthen roads leading to fields.

Some of the intersections are getting bypassed and some are getting added due to bypasses being proposed. The total number of intersections is divided into five categories of varying importance and developments as given in following Table 6-4.

Table 6-4: Proposed Intersection Improvements

S. No	Type	Proposed Improvement
1	Type-I: Intersections of prime Importance	At-grade/Grade separated intersection with Acceleration /Deceleration lane /service road and median opening
2	Type-2:Intersections of secondary importance	At- Grade channelised intersections with median opening. No Acc/Dec lanes
3	Type-3: Intersections of tertiary importance	At-grade with only central divider on the cross road. Median opening is optional
4	Type-4: Minor intersections: with black top roads	Only fillet
5	Type-5: Minor intersections with earthen and access roads	Only fillet and access provision

A) Primary Intersection

These are intersections with category of roads like NH, SH and MDR, with black-topped surface. The typical designs developed for these intersections are designated as Type-I, Type-II and Type-III. Details of these intersections are given in the following Table 6-5.

Table 6-5: Intersections of Primary Importance

Sl. No.	Chainage	Category of Road	Side w.r.t Increasing Chainage	Proposed Type
1	12/358	VR (channelised intersection)	Right	II
2	22/685	Proposed Rengali Bypass start	Left	II
3	27/029	Proposed Rengali Bypass end	Left	II
4	46/354	VR (Existing Jharsuguda bypass start)	Right	II
5	52/200	NH 200, Proposed Jharsuguda Bypass start	Both	II
6	60/600	SH 10 crossing with proposed Jharsuguda bypass	Both	II
7	61/475	Proposed Jharsuguda Bypass end	Both	II

Sl. No.	Chainage	Category of Road	Side w.r.t Increasing Chainage	Proposed Type
8	76/630	MDR 31	Right	II
9	78/100	VR (Existing Sundargarh bypass start)	Left	Unidirectional Flyover
10	81/475	VR	Both	Rotary
11	83/795	VR (Existing Sundargarh bypass end)	Left	II
12	140/643	VR (Existing Rajgangpur bypass start)	Right	II
13	144/002	VR (Existing Rajgangpur bypass end)	Right	Unidirectional Flyover

Junctions have been designed at the start and end of bypasses. Considering existing intersection, traffic requirements and improvement proposals, unidirectional flyovers of 3-lane configuration have been proposed from Design Chainage 77/400 to 78/493 and from Design Chainage 143/466 to 144/606.

Rotary Intersection at Design Chainage 81+475

It has been learnt, based on interactions with OWD, that a new bus terminal has been proposed on the right hand side of the existing road, between existing Km 83 and Km 84. Further, as discussed and decided, a rotary intersection has been proposed at the existing four-arm intersection at the existing Km 83/ 150, which is equivalent to Design Chainage 81+475.

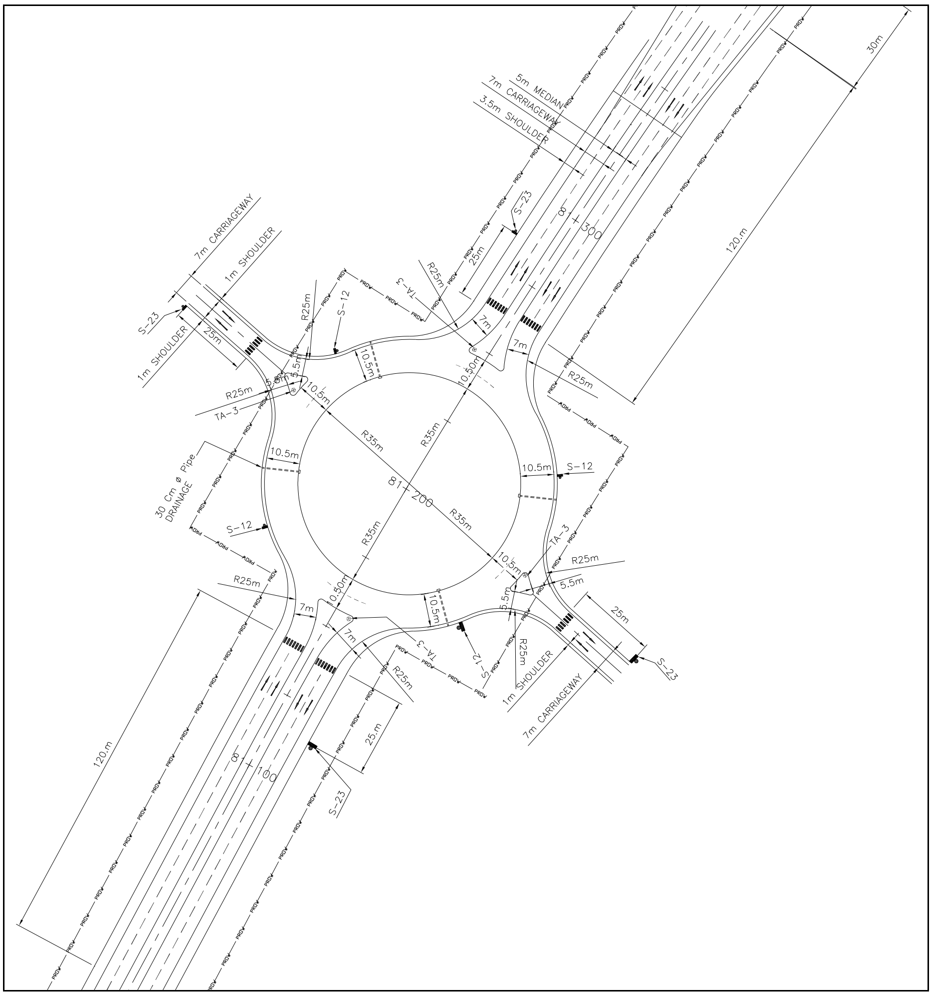


Figure 6-17: Rotary Intersection at Chainage 81+475

B) Secondary Intersection

These are the intersections with category of roads like ODR, VR and have black-topped, brick-soled, gravel, moorum or earthen surface. Two typical designs (Type-IV and Type-V) have been developed for these intersections. Details of intersections with secondary importance are presented in the Table 6-6 below.

Table 6-6: Intersections of Secondary Importance

Sl. No.	Design Chainage	Category of Road	Side w.r.t increasing Chainage	Type
1	5/022	VR	Left	V
2	5/144	VR	Left	V
3	5/318	VR	Left	V
4	5/462	VR	Left	V
5	5/582	VR	Left	V
6	5/664	VR	Left	V
7	5/972	VR	Left	V
8	6/208	VR	Right	V
9	6/361	VR	Right	V
10	6/628	VR	Left	V
11	7/133	VR	Left	III
12	7/999	VR	Right	V
13	8/092	VR	Left	V
14	10/356	VR	Left	IV
15	10/469	VR	Left	IV
16	11/046	VR	Left	V
17	11/078	VR	Left	V
18	11/675	VR	Right	IV
19	12/25	VR	Left	V
20	12/869	VR	Left	V
21	13/623	ODR	Left	IV
22	13/639	VR	Right	V
23	15/071	VR	Left	V
24	15/548	VR	Right	V
25	15/787	VR	Left	V
26	15/934	VR	Left	V
27	16/017	VR	Right	V
28	16/022	VR	Left	V
29	16/055	VR	Right	V
30	18/158	VR	Left	IV
31	18/88	VR	Left	V
32	19/536	VR	Right	V
33	19/55	VR	Left	V
34	21/244	VR	Right	V
35	21/537	VR	Right	V
36	21/699	VR	Right	V
37	24/296	VR	Right	V
38	24/298	VR	Left	V
39	25/163	VR	Right	V
40	25/175	VR	Left	V
41	25/865	VR	Left	V
42	25/874	VR	Right	IV
43	26/928	VR	Left	V
44	26/929	VR	Right	IV
45	28/351	VR	Right	V
46	28/529	VR	Right	IV
47	29/594	VR	Left	V
48	30/967	VR	Left	V
49	30/978	VR	Right	V

Sl. No.	Design Chainage	Category of Road	Side w.r.t increasing Chainage	Type
50	32/098	VR	Right	V
51	32/543	VR	Left	V
52	33/145	VR	Left	V
53	33/704	VR	Left	V
54	34/065	VR	Right	V
55	34/072	VR	Left	V
56	34/657	VR	Right	V
57	35/431	VR	Left	III
58	36/562	VR	Right	V
59	36/576	VR	Left	V
60	37/253	VR	Right	V
61	37/9	VR	Left	V
62	38/8	VR	Left	V
63	39/37	VR	Left	V
64	40/74	VR	Right	V
65	42/196	VR	Left	V
66	42/63	VR	Left	V
67	42/767	VR	Right	V
68	43/231	VR	Right	V
69	43/806	VR	Left	V
70	44/343	VR	Right	V
71	44/596	VR	Left	V
72	45/301	VR	Left	V
73	46/068	VR	Left	IV
74	46/456	VR	Left	V
75	47/514	VR	Left	IV
76	47/519	VR	Right	V
77	48/677	VR	Right	IV
78	48/697	VR	Left	IV
79	49/84	VR	Left	V
80	49/847	VR	Right	IV
81	50/364	VR	Left	IV
82	50/366	VR	Right	IV
83	51/404	VR	Left	IV
84	51/41	VR	Right	IV
85	51/658	VR	Right	IV
86	51/683	VR	Left	IV
87	53/31	VR	Left	V
88	53/315	VR	Right	V
89	54/641	VR	Left	V
90	54/643	VR	Right	V
91	55/092	VR	Right	IV
92	55/114	VR	Left	IV
93	56/367	VR	Left	V
94	56/369	VR	Right	V
95	57/103	VR	Left	V
96	57/132	VR	Right	V
97	58/627	VR	Right	V
98	58/636	VR	Left	V
99	59/019	VR	Left	V
100	59/023	VR	Right	V
101	61/312	VR	Left	V
102	61/932	VR	Left	V
103	61/942	VR	Right	V
104	62/754	VR	Right	V
105	63/152	VR	Left	V
106	63/152	VR	Right	IV
107	63/274	VR	Right	V
108	64/412	VR	Right	V
109	64/826	VR	Right	V

Sl. No.	Design Chainage	Category of Road	Side w.r.t increasing Chainage	Type
110	65/711	VR	Left	V
111	66/521	VR	Left	V
112	66/654	VR	Left	IV
113	66/831	VR	Right	IV
114	66/856	VR	Left	IV
115	69/22	VR	Left	III
116	69/468	VR	Left	V
117	69/676	VR	Right	V
118	70/552	VR	Left	V
119	70/739	VR	Left	V
120	71/249	VR	Left	IV
121	71/341	VR	Left	V
122	71/627	VR	Right	V
123	74/097	VR	Right	V
124	74/962	VR	Left	IV
125	75/023	VR	Right	V
126	75/44	VR	Left	V
127	75/657	VR	Right	V
128	76/332	VR	Left	IV
129	76/434	VR	Right	V
130	77/55	VR	Right	IV
131	79/66	VR	Right	V
132	79/662	VR	Left	V
133	80/82	VR	Right	V
134	82/087	VR	Left	IV
135	82/106	VR	Right	IV
136	83/422	VR	Left	V
137	83/429	VR	Right	V
138	84/784	VR	Left	IV
139	85/32	VR	Left	IV
140	86/86	VR	Left	V
141	88/251	VR	Left	V
142	89/188	VR	Right	V
143	89/577	VR	Left	IV
144	89/613	VR	Right	V
145	90/525	VR	Right	V
146	92/708	VR	Left	V
147	93/032	VR	Left	IV
148	94/206	VR	Left	V
149	96/305	VR	Left	V
150	96/68	VR	Right	V
151	97/084	VR	Left	V
152	97/467	VR	Left	IV
153	98/117	VR	Right	V
154	98/759	VR	Left	V
155	99/607	VR	Left	IV
156	100/443	VR	Right	IV
157	101/375	VR	Left	V
158	102/38	VR	Right	V
159	103/379	VR	Right	IV
160	103/534	VR	Left	V
161	105/12	VR	Left	V
162	105/46	VR	Right	V
163	105/859	VR	Left	V
164	105/943	VR	Left	IV
165	106/176	VR	Left	IV
166	106/191	VR	Right	IV
167	107/523	VR	Right	V
168	107/532	VR	Left	V
169	107/851	VR	Right	III

Sl. No.	Design Chainage	Category of Road	Side w.r.t increasing Chainage	Type
170	109/229	VR	Left	V
171	109/854	VR	Right	V
172	109/975	VR	Right	IV
173	110/315	VR	Right	IV
174	110/479	VR	Left	IV
175	110/746	VR	Right	V
176	110/758	VR	Left	IV
177	111/267	VR	Right	III
178	111/28	VR	Left	III
179	112/546	VR	Right	V
180	113/026	VR	Right	IV
181	113/153	VR	Left	V
182	113/153	VR	Right	V
183	114/208	VR	Right	V
184	115/49	VR	Right	V
185	116/495	VR	Left	III
186	116/499	VR	Right	III
187	117/364	VR	Right	V
188	118/641	VR	Left	IV
189	118/815	VR	Right	IV
190	118/816	VR	Left	IV
191	118/984	VR	Left	V
192	119/724	VR	Right	V
193	120/148	VR	Left	IV
194	121/077	VR	Right	V
195	121/366	VR	Right	V
196	121/579	VR	Left	V
197	121/989	VR	Left	IV
198	122/797	VR	Left	V
199	122/926	VR	Left	IV
200	122/94	VR	Right	IV
201	124/243	VR	Right	IV
202	124/266	VR	Left	IV
203	125/388	VR	Left	IV
204	130/413	VR	Right	V
205	130/974	VR	Left	V
206	131/593	VR	Right	V
207	131/895	MDR28	Left	IV
208	133/063	VR	Right	V
209	133/452	VR	Right	IV
210	133/933	VR	Left	V
211	133/933	VR	Right	V
212	135/856	VR	Left	V
213	135/857	VR	Right	V
214	136/437	VR	Left	V
215	137/762	VR	Left	V
216	138/005	VR	Right	V
217	138/041	VR	Left	V
218	139/556	VR	Left	V
219	139/604	VR	Left	IV
220	140/367	VR	Right	V
221	141/568	VR	Right	V
222	141/57	VR	Left	V
223	142/894	VR	Right	V
224	143/677	VR	Right	IV
225	143/686	VR	Left	V
226	144/408	VR	Left	IV
227	144/482	VR	Right	IV
228	145/566	VR	Left	IV
229	146/157	VR	Right	V

Sl. No.	Design Chainage	Category of Road	Side w.r.t increasing Chainage	Type
230	146/161	VR	Left	V
231	147/804	VR	Left	V
232	149/314	VR	Right	V
233	149/363	VR	Left	V
234	149/607	VR	Right	V
235	151/037	VR	Right	IV
236	151/207	VR	Right	V
237	151/485	VR	Left	IV
238	151/67	VR	Left	IV
239	152/766	VR	Right	IV
240	153/221	VR	Right	IV
241	153/662	VR	Left	IV
242	153/995	VR	Left	V
243	155/222	VR	Left	IV
244	157/305	VR	Right	V
245	157/367	VR	Left	IV
246	158/148	VR	Right	IV
247	159/566	VR	Right	V
248	159/567	VR	Left	V
249	160/09	VR	Left	V
250	161/284	VR	Left	IV
251	162/995	VR	Right	IV
252	164/593	VR	Right	IV
253	164/631	VR	Right	IV
254	165/281	VR	Right	V
255	165/351	VR	Left	V

6.11 SERVICE ROADS

Major settlements along the project corridor have already been proposed to be bypassed. Apart from these major settlements, substantial local and industrial traffic has been observed in locations viz. Shyam Dry Industries, Bhushan, Karamdihi, Beldihi etc. Therein, in order to segregate through traffic from local traffic and to provide safe passage to slow-moving non-motorized vehicles, provision of service roads has been considered. Apart from this, slip roads have also been proposed at locations of unidirectional flyovers, vehicular and pedestrian underpasses. The details of service/ slip roads are given in the following Table 6-7.

Table 6-7: Details of Service/ Slip Roads

Sl. No.	Design Chainage		Total Length (km)	Width	Side
	From	To			
1	27/538	27/962	0.424	5.5	Left
2	27/538	27/962	0.424	5.5	Right
3	37/681	40/047	2.366	5.5	Left
4	37/681	40/047	2.366	5.5	Right
5	62/990	63/310	0.320	5.5	Left
6	62/990	63/310	0.320	5.5	Right
7	71/088	71/408	0.320	5.5	Left
8	71/088	71/408	0.320	5.5	Right
9	73/320	73/640	0.320	5.5	Left
10	73/320	73/640	0.320	5.5	Right
11	77/723	78/493	0.770	5.5	Left
12	81/755	82/430	0.675	5.5	Left
13	81/755	82/430	0.675	5.5	Right

Sl. No.	Design Chainage		Total Length (km)	Width	Side
14	84/345	85/345	1.000	5.5	Left
15	84/345	85/345	1.000	5.5	Right
16	89/349	90/533	1.184	5.5	Left
17	89/349	90/533	1.184	5.5	Right
18	97/784	98/134	0.350	5.5	Left
19	97/784	98/134	0.350	5.5	Right
20	102/909	103/259	0.350	5.5	Left
21	102/909	103/259	0.350	5.5	Right
22	105/934	106/284	0.350	5.5	Left
23	105/934	106/284	0.350	5.5	Right
24	109/609	109/980	0.371	5.5	Left
25	109/609	109/980	0.371	5.5	Right
26	112/409	112/759	0.350	5.5	Left
27	112/409	112/759	0.350	5.5	Right
28	135/709	136/059	0.350	5.5	Left
29	135/709	136/059	0.350	5.5	Right
30	143/482	144/407	0.925	5.5	Right
31	151/609	151/959	0.350	5.5	Left
32	151/609	151/959	0.350	5.5	Right
33	157/013	157/363	0.350	5.5	Left
34	157/013	157/363	0.350	5.5	Right
35	162/212	163/387	1.175	5.5	Left
36	162/212	163/387	1.175	5.5	Right
37	164/153	165/709	1.556	5.5	Left
38	164/153	165/709	1.556	5.5	Right

6.12 VEHICULAR/ PEDESTRIAN/ANIMAL/ELEPHANT UNDERPASS

There are educational institutions in the form of schools along the project corridor. It is proposed to provide pedestrian underpasses at such locations. While vehicular underpasses are provided wherever industries are in the vicinity, and major roads are crossing/ entering the project corridor, pedestrian underpasses are provided at locations having heavy pedestrian movement. These are provided to ensure free movement of traffic on main carriageway. A total of 16 (sixteen) box culverts have been provided as pedestrian and vehicular underpasses. Animal and Elephant Underpass has also been provided for the cross movement of animals, reptiles and elephants. The details of underpasses are given in the following Tables.

Table 6-8: Details of Proposed Vehicular Underpasses along the Corridor

S. No.	Structure No. (Bridge/ Culvert)	Proposed Chainage	Existing Span Arrangement (No. x Width x Depth)	Proposed Span Arrangement (No. x Width x Depth)	Proposal for Improvement	Required Width for Four-Laning
1	VUP01	27+446	-	1x15x5.5	New Const	28.00
2	VUP02	39+090	-	1x15x5.5	New Const	38.00
3	VUP 03	82+081	-	1x15x5.5	New Const	27.00
4	VUP 04	90+031	-	1x15x5.5	New Const	27.00

Table 6-9: Details of Proposed Pedestrian Underpasses along the Corridor

S. No.	Structure No. (Bridge/ Culvert)	Proposed Chainage	Existing Span Arrangement (No. x Width x Depth)	Proposed Span Arrangement (No. x Width x Depth)	Proposal for Improvement	Required Width for Four-Laning
1	PUP 01	11+075	-	1x5x3	New Const	27.20
2	PUP 02	63+156	-	1x5x3	New Const	27.00
3	PUP 03	71+281	-	1x5x3	New Const	26.00
4	PUP 04	73+481	-	1x5x3	New Const	27.00
5	PUP 05	97+931	-	1x5x3	New Const	27.00
6	PUP 06	103+081	-	1x5x3	New Const	27.00
7	PUP 07	106+184	-	1x5x3	New Const	27.00
8	PUP 08	109+806	-	1x5x3	New Const	27.00
9	PUP 09	112+581	-	1x5x3	New Const	24.00
10	PUP 10	135+881	-	1x5x3	New Const	27.00
11	PUP 11	151+781	-	1x5x3	New Const	27.00
12	PUP 12	157+186	-	1x5x3	New Const	27.00

Table 6-10: Details of Proposed Elephant & Reptile Underpasses along the Corridor

S. No.	Structure No. (Bridge/ Culvert)	Proposed Chainage	Existing Span Arrangement (No. x Width x Depth)	Proposed Span Arrangement (No. x Width x Depth)	Proposal for Improvement	Required Width for Four-Laning
1	RUP01	26+000	-	1x3x3	New Const	27.00
2	RUP02	46+970	-	1x3x3	New Const	27.00
3	RUP03	57+150	-	1x3x3	New Const	27.00
4	RUP04	60+750	-	1 x 1.2(HPC)	New Const	27.00
5	EUP	93+646	-	1x10x6	New Const	27.00
6	RUP05	107+172	-	1x3x3	New Const	27.00

6.13 BUS STOPS

There are existing bus stops along the project corridor. Generally, these stops are associated with a settlement area or an intersection with a cross-road. It is proposed to provide bus bays in both directions at some locations. At locations of service/ slip roads, buses would stop on the slip road. The details of proposed bus bays along the project corridor are given in the following Table 6-11.

Table 6-11: List of Bus Bays along SH-10

S.No.	Chainage	Side	Type
1	8/265	LHS	Bus bay
2	8/440	RHS	Bus bay
3	9/675	LHS	Bus bay
4	9/850	RHS	Bus bay
5	12/491	RHS	Bus bay
6	12/750	LHS	Bus bay
7	46/225	LHS	Bus bay
8	46/638	RHS	Bus bay
9	66/649	RHS	Bus bay

S.No.	Chainage	Side	Type
10	67/024	LHS	Bus bay
11	76/219	LHS	Bus bay
12	77/024	RHS	Bus bay
13	93/199	LHS	Bus bay
14	93/374	RHS	Bus bay
15	121/819	RHS	Bus bay
16	122/159	LHS	Bus bay
17	124/374	RHS	Bus bay
18	124/639	LHS	Bus bay

S.No.	Chainage	Side	Type
19	131/419	RHS	Bus bay
20	132/084	LHS	Bus bay
21	136/599	LHS	Bus bay
22	136/774	RHS	Bus bay

S.No.	Chainage	Side	Type
23	153/523	LHS	Bus bay
24	153698	RHS	Bus bay
25	158828	LHS	Bus bay
26	159003	RHS	Bus bay

6.14 TRUCK LAYBY

Truck parking has been observed at locations of industries, petrol pumps, dhabas etc along the project corridor. Truck Laybys shall be provided at the following proposed design chainages:

i) Km 13+500 (Left and Right);

ii) Km 69+900 (Left and Right);

iii) Km 96+875 (Left and Right); and

iv) Km 128+025 (Left and Right).

Apart from the above, service roads proposed at the location of Shyam Dry industries and Bhushan Steel Plant would also facilitate parking of trucks, thereby reducing congestion on the main carriageway.

6.15 TOLL PLAZA

The proposed design chainage of Toll Plazas is Km 17+025, Km 80+181 and Km 150+075. Toll Plaza would be provided in accordance with Manual of Specifications and Standards for Four-Laning of Highways through Public-Private Partnership by the Indian Roads Congress. A total of minimum 6x2 = 12 lanes have been provided, of which one lane on each side is for oversized vehicles, vehicles not required to pay toll and spare lane for maintenance purposes. The toll plaza would have a semi-automatic system of toll collection comprising equipments for registering of vehicle classification, ticket issuing, data processing and power supply. If at any time, the queue of vehicles becomes so large that the waiting time of the user exceeds three minutes, the number of toll lanes shall be increased so that the maximum waiting time is brought down to less than three minutes. Within a period of 3 years from COD at least two booths for either side traffic shall be upgraded to automatic toll collection with the help of smart card/ censor.

The Toll Plaza complex would consist of the following facilities:

i) Office Complex with toilet, bathroom and rest room;

ii) Traffic Aid Post;

iii) Medical Aid Post;

iv) Vehicle Rescue Post;

v) Telecom Rescue Post; and

vi) Traffic Census Post.

6.16 MEDIAN OPENINGS

Tentative location of median openings is given in the following Table 6-12. The actual locations and size of median opening and additional median openings, if any, shall be finalized in consultation with IE/ OWD at the time of execution.

Table 6-12: Location of Median Openings

S.No.	Chainage
1	7/125
2	12/350
3	22/685
4	27/029
5	28/350
6	35/425
7	40/425
8	46/350
9	52/200
10	55/100
11	60/575
12	64/125
13	69/225
14	72/325
15	76/625
16	81/475 (Rotary)

S.No.	Chainage
17	83/800
18	88/775
19	94/200
20	99/375
21	104/375
22	107/850
23	111/275
24	116/500
25	121/075
26	125/850
27	132/675
28	137/125
29	140/650
30	154/600
31	159/575
32	163/800

CHAPTER 7: PRELIMINARY DESIGN OF STRUCTURES

7.1 INTRODUCTION

This Chapter presents the detailed information of existing structural condition, assessment of structures, proposals for improvement of structures, rehabilitation scheme of existing structures and Design standards for the design of various structural elements. The standards and specifications conform broadly to the relevant codal provisions and the requirement of the project.

7.2 INVENTORY SURVEY OF EXISTING STRUCTURES

A detailed condition survey along with visual inspection of the existing structures has been carried out by the concerned key professionals to assess and ascertain the existing condition/ characteristics of the bridges and other CD structures. Inventory of bridges has been prepared based on the condition survey, which consists of recording relevant technical data for each bridge, such as name, location, length, type of material, carriageway width, type of structure etc.

There are in all 375 existing structures along the Project Corridor. Of these, 06 are major bridges, 39 are minor bridges, 02 RoB and the remaining 328 are culverts. Out of the total 328 culverts, 222 are slab culverts, 98 are pipe culverts and 8 are box culverts. The summary of existing structures is presented in Figure 7-1 in the form of a pie chart.

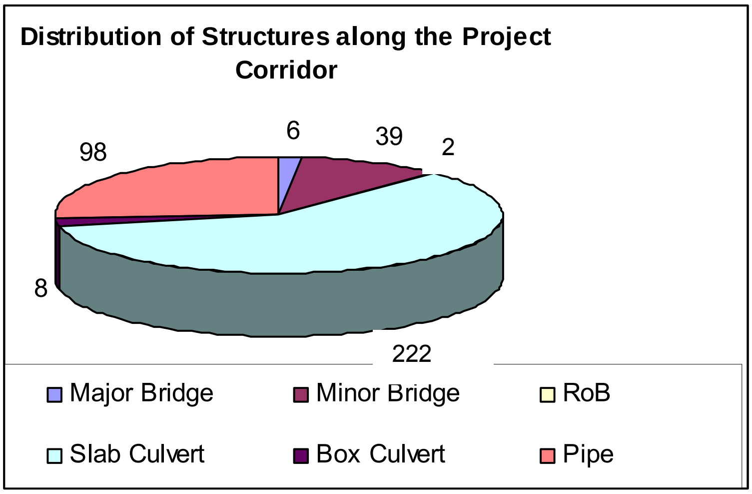


Figure 7-1: Summary of Existing Structures

Following tables gives the type of superstructure used in existing major, minor bridges and ROBs. It also gives the idea about the number of structures of different spans and diameters. Range of spans on existing Minor and Major Bridges is also given.

Table 7-1: Summary of Major Bridges

Sr. No.	Superstructure Type	Span Range	Numbers
1	Bow String R.C.C Girder	36.08 m	01
2	RCC Box girder	23.5 m	01
3	RCC T-girder	15.15 m to 17.0 m	03
4	P.S.C T-girder combined with PSC Box Girder	26.85 m and 47.2 m	01
	Total no of Major Bridges		**06**

Table 7-2: Summary of Minor Bridges

S. No.	Superstructure Type	Span Range	Numbers
1	RCC Box	7.5m to 8.0m	03
2	RCC Solid Slab with Cantilever	5.25m to 8.3m	12
3	RCC Solid Slab	3.75m to 9.25m	17
4	RCC T-girder with RCC deck slab	7.7m to 13.3m	05
5	Combination of RCC Solid Slab and Stone masonry Arch	6.56m	01
6	Steel Plate girder with RCC deck slab	8.55m	01
	Total no of Minor Bridges		**39**

Table 7-3: Summary of ROB

S. No.	Structure Type	Span Range	Numbers
1	PCC T-girder and RCC deck slab	22.7m	01
2	RCC Single Cell Box type	1 x 13.0m	01
Total no of ROB			**02**

Table 7-4: Summary of Slab and Box Culverts

S. No.	Structure Type	Span Range (L) in meters	Numbers
1	Slab Culvert	0 <L ≤ 2	141
2	Slab Culvert	2 <L ≤ 3	59
3	Slab Culvert	3 <L ≤ 4	08
4	Slab Culvert	4 <L ≤ 5	09
5	Slab Culvert	5 <L < 6	05
4	Box Culvert	0 <L ≤ 3	02
5	Box Culvert	3 <L < 6	06
	Total no Slab and Box Culverts		**230**

Table 7-5: Summary of Pipe Culverts

S. No.	Structure Type	Diameters in meters	Numbers
1	Pipe Culvert	0.600	28
2	Pipe Culvert	0.750	0
3	Pipe Culvert	0.900	31
4	Pipe Culvert	1.000	10
5	Pipe Culvert	1.200	29
Total no Pipe Culverts		**-**	**98**

Table 7-6: Deck Width of existing Major and Minor Bridges

S. No.	Structure Type	Carriageway width varies from
1	Major Bridge	7.00m to 7.50m
2	Minor Bridge	10.45m to 11.3m

Detail inventory survey of all existing structures is given in **Appendix 7.1 and 7.2,** Volume IIA of this report.

7.3 STRUCTURAL STATUS ON VISUAL INSPECTION

Inventory and condition survey report have been prepared with the objective to verify the form of construction, the dimensions of the structure, the nature and condition of the structural components, etc. to assess necessary information on which decision would be made for carrying repairs, strengthening, widening, replacement of the structural part or rebuilding of the bridge and culverts. Inspection covered not only the condition of individual components but also the condition of the structure as an entity, especially noting signs of distress, if any, and its cause to ascertain long-term remedial measures to provide assurance that the bridge is structurally safe and fit for its designed use.

Inspection was not confined to only scanning of existing , but also included the range of anticipated problems. During and following the inspection, it was aimed to determine the cause to prevent the repetition and spread of the deterioration.

7.3.1 Checklist for Visual Inspection

The reasons for deterioration are either physical or chemical process, which cause visible signs of damage. Therefore, during inspection, the following signs of deterioration were particularly noted at locations indicated below:

Locations	Deterioration
All over	• General condition of the structure and pre-stressed components in particular • Condition of concrete/masonry • Cracks • Honeycombing • Corrosion signs • Scaling of concrete • Spalling of concrete • Efflorescence • Condition of construction joints
Top and bottom of deck slab	• Cracks • De-lamination • Blocking of drainage • Worn out wearing coat • Seepage • Corrosion signs • Leaching • Scaling • Damage due to accident or any other causes
Steel girders	• Pitting • Painting condition • Loose rivet • Loss of Camber • Deformation • Cracks and bends in flanges/webs
Support point of bearings	• Whether the seating of girder over bearing is uniform • Condition of anchor bolts, if any • Spalling/crushing/cracking around bearing support
Webs of girders	• Cracks • Corrosion signs
Junction of slab and girder	• Separation
Drainage spouts	• Whether provided • Clogging • Physical condition • Adequacy of projection of spout on the underside
Joints in precast construction	• Separation • Physical appearance
Expansion joints	• Check whether the expansion joint is free to expand and contract • Hardening/cracking of bitumen filler • Condition of sliding plates – check for corrosion, damage of welds, etc.

Locations	Deterioration
	• Debris in joints • Alignment checking • Distortion
Elastomeric Bearing:	• Whether the bearing is free to move/rotate in different directions as envisaged in design • Whether the bearings are fully and evenly seated • Whether all the bearings are at same level • Physical condition • Cleanliness • Flattening of bearings • Splitting/tearing • Bulging • Oxidation • Non uniform thickness other than that which may be the result of normal rotation • Displacement (longitudinal or lateral) from original position • Whether correct operation of the bearings is prevented or impaired by structural members built into abutment or pier.
Piers, Abutments, Retaining Walls and Wing Walls	• Tilting and rotation, in any direction • Rocking • Cracking, splitting and spalling • Erosion beneath water level • Weathering and material deterioration, including lack of pointing for masonry • Growth of vegetation • Lack of effective drainage • Internal scour, and leaching of fill • Settlement of fill
Waterway	• Width of Waterway • Observed Scour Depth • Crossing Angle • Evidence of Submergence, if any • Flow Direction • Any obstruction to the free flow • Vertical clearance
Parapet/ Railing, Wearing coat, Drainage spout, Utility lines, Floor protection, Approach slab and Embankment slope protection • Whether provided • Physical condition • Material type	

7.3.2 General Condition Survey of Existing Structures

The detailed visual inspection survey reveals that the conditions of all major and minor bridges are generally good. General distress of major and minor structures is damaged railing and expansion joints, choked drainage spouts, damaged cantilever portion of deck slab etc. Conditions of the major structures are discussed separately in following paragraphs.

In general, the over all condition of the existing bridge superstructures and substructures is good. Foundations could not be inspected. Only in the case of Minor Bridge no 30/2, structural distresses/damages were observed in both substructure and superstructure, which are beyond repairable. All other bridges require only minor repair.

Based on visual inspection the following types of distress in the structural components were observed:

a) Concrete elements (RCC or PSC)

- Honeycombing
- Spalling
- Corroded Reinforcement
- Exposed Reinforcement
- Visible Cracks

- Leaching
- Scaling etc.

b) Masonry elements

- Cracks
- Drainage of spandrel filling
- Vegetation growth
- Leaching

Detailed structural conditions for six Major Bridges with Structure Nos. 42/2, 67/2, 118/1, 145/1, 155/1 and 166/2 on rivers are described below:

Major Bridge at Km 41/650: The Major Bridge Structure No.42/2 is across Kherwall River. It is having in all 9 spans; of which two end spans are having RCC deck slab on 3 nos. RCC T-girders and the remaining 7 spans are of RCC Bow String girder type superstructure. Total length and of this major bridge is 245.08 m and deck width is 8.0 m. The span arrangement of the structure is 2x12.80 + 6x36.58 m. The sub-structure consists of RCC circular type piers having a maximum height around 7.50m. The foundation type could not be seen as all of them were either under water or under ground. However, it is apparent that deep foundation (either well or pile foundation) must have been adopted. Metallic rocker-roller type bearing has been used. Distresses observed were as under:

- **Pier:** No crack other than minor in nature has been noticed, however in a few circular column type piers separation of concrete lifts have been noted. The gap is through and through.
- **Bottom of slab:** A few cracks are noticed, however no major distressing has been observed
- **5th span Girder:** Entire girder bottom is found to contain seepage with growth of fungus. Around 1.5M from end crack/voids at the bottom of girder has been observed.
- Considerable vibration was noted on bridge deck during movement of Trucks.
- The railing at either side of the bridge dismantled and found hanging from the bridge deck.

Bridge at Km 66/850: This Major Bridge over Safaiye River is of five spans having span configuration of 2x26.85 + 3x47.20 m. The superstructure of the end two span is of RCC deck slab on PSC T-Girder and the remaining three mid spans are of PSC Box Girder. The piers are wall type with semi-circular cut water at ends and having a maximum height of about 7.5m. Well foundation has been provided on this bridge. Total length of the bridge is 195.30 and carriageway width is 7.5 m.

The condition of the bridge is very good and the deck width is sufficient for 2-lanes.

Major Bridge at Km 117/975 (Structure No. 118/1): This major bridge is a three span RCC Box Girder Bridge of span arrangement 3x23.50 m. The piers are wall type with semi-circular cut water at ends and having a maximum height of about 7.9m. Total length of the major bridge is 70.50 m and carriageway width is about 7.5m. Condition of all components of the bridge is good.

Distresses observed were as under:

- **Abutment:** A few superficial cracks have been observed which disappeared after rubbing with Carborandum stone.
- Slant slab of Girder box: On slant portion a few cracks are observed originating from 2.5M to 1.0m.
- Pier and Slab bottom: No visible crack has been observed.

Major Bridge at Km 144/975 (Structure No. 145/1): This major bridge is a four span RCC T- Girder Bridge resting on RCC substructure with bearing. Span arrangement is 4x15.15 m. Total length of the major bridge is 60.60 m and clear carriageway width is 7.5m respectively. The piers are wall type with semi-circular cut waters and having a maximum height of about 7.2m. It appears that raft foundation has been adopted on the existing bridge.

- The condition of the bridge is very good and the deck width is sufficient for 2-lanes.

Major Bridge at Km 154/450 (Structure No.155/1): The Major Bridge has seven spans with span configuration of (2x16.20 + 5x17.00) m. The superstructure comprises of 4 nos. of RCC T- girder with 4 cross girders and RCC deck. The substructure is wall type with semi-circular cut waters resting on twin well foundation. Total length of the major bridge is 117.40 m and clear carriageway width is 7.5m.

Distresses observed were as under:

- Girder: Voids and honey combs near cross girder at Sambalpur end has been observed. Other than above no visible crack is notice on main girder.
- Pier: A few cracks in piers of varying width have been noticed below 3M to 7M. However, from the crack pattern it seems that shrinkage types are generated. Piers adjacent to Span2 are of Twin well foundation and the concrete appears to have become rough with washing of cement bonding

exposing the aggregates. This might have occurred due to splashing of water or any other effect which would require repair.

- Slab: The bottom of the slab has been examined and in a few places spalling of concrete is noticed. Seepages have been noticed in few locations with exposure of rusted reinforcements. Below foot Bridge 30-40 reinforcement bars have been found to be exposed as cover to concrete very less.

Major Bridge at Km 165/780 (Structure No.166/2): This Major Bridge has four spans of configuration 4x15.25 m. The superstructure comprises of 4 nos. of RCC T- girder with 4 cross girders and RCC deck. The substructure is wall type with semi-circular cut waters resting on open raft foundation. Total length of the major bridge is 61.00 m and carriageway width is 7.5m.

- The condition of the bridge is good.

Minor Bridges

All 39 minor bridges (i.e., bridges with overall length less than 60 m) lie across natural drains and generally cross the road at right angles. All the bridges are in satisfactory condition and are proposed for retention, except for Structure No. 30/2 which requires reconstruction due to the poor condition of superstructure and sub-structure. The sub-structures and wing/return walls are of C.C and masonry type. Minor distresses are observed in some of the existing structures. On visual inspection various types of minor distresses as observed in general are given below:

- Bed protection damaged;
- Vegetation growth on part of the structural element;
- Drainage spouts choked;
- Wearing course damaged;
- Parapet handrail damaged;
- Crack in dirt wall;
- Spelling of concrete; and
- Exposed reinforcement.

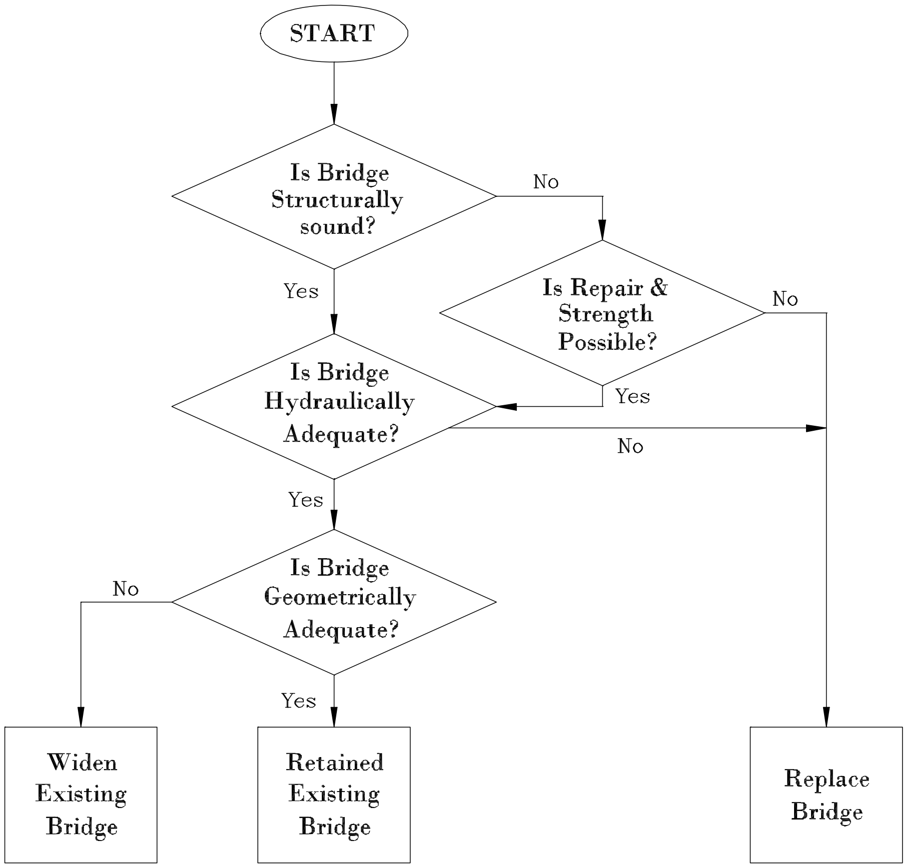
Culverts

Mainly there are three types of culverts i.e. Slab, Pipe and box culverts. The structural condition of both types of culverts is generally good. At some locations distress has been observed in the form of exposed reinforcement, spalling of concrete cover, damaged return/head wall, cracks in abutment, damaged/ missing handrails/ parapets, vent way choking and vegetation growth in structural components.

7.4 ASSESMENT OF STRUCTURES

7.4.1 Chart of Bridge Assessment Process

The process of assessment for each bridge is shown in the flow chart given hereunder:



Form the above flow chart it is clear that the decision on retention or widening or replacement of an existing structure is dependent on the following three aspects:

- Structural Adequacy
- Possibility of repair and strengthening
- Hydraulic Adequacy
- Geometric Adequacy

7.4.2 Structural Adequacy

The structural adequacy of existing CD structures has been based mainly on assessment of structural status through visual inspection. Verification of structural adequacy against the present design loading standard could not be carried out in absence of the history of the bridge viz. as-built drawing, loading standard for which the bridge was designed and details of repair or strengthening works done in the past are made available.

7.4.2.1 Non-Destructive Tests

Non-Destructive Tests (NDT) have been carried out in four major bridges in which some signs of distresses were noticed during visual inspection and were under consideration for retention. The purpose of conducting NDT Tests was to assess:

- Residual concrete strength of concrete
- Reinforcement cover sufficiency
- Status of reinforcement corrosion

From the report of NDT Test carried out by specialist Consultant M/s S.K. Mitra and Associates, Kolkata (**Appendix 7.3**, Volume IIA of this report), the following may be noted:

1. **Schmidt Hammer Test:** The results are very satisfactory and the most probable residual compressive strength varies form 27.8 to 67.4 MPa at different bridges and different components of the bridges.

2. **Ultrasonic Pulse Velocity Test:** In general the concrete may be termed as “Medium” to “Good”, excepting deck slab of Bridge no. 118/1, where the integrity is “Doubtful”. Voids or discontinuity have been observed in a few cases on indirect tests. Apart from above, a few crack depths have been measured and found to vary from 10mm to 30 mm.

3. **Test for Corrosion Analysis:** The test results show generally no signs of corrosion ai all the bridge component except in South face of slab of Bridge No. 155/2, which shows sever corrosion.

4. **Cover of Rebar test:** Random measurement of concrete shows cover vary from 20 to 53 mm, at different bridges and different components of the bridges, which indicates repair work for additional concrete cover to increase the durability of the structure is necessary at some places.

5. **Concrete core extracting and testing:** High speed concrete core extractor manufactured by “ADAMAS” Holland has been deployed. 50mm core drill is affected to avoid interference of reinforcement.

7.4.3 Hydraulic Adequacy

Local enquiries were made during the condition survey to ascertain history of overtopping of the road in and around the bridge. This information obtained from signs of erosion at side shoulders also facilitates ascertaining approximate lengths and locations of overtopped stretches. In case distresses are apparent. The hydraulic adequacy has been assessed on the basis of visual inspection and through local enquiry. At the same time hydraulic analysis has also been carried out and has been presented in Chapter 3 of Volume II of this report. In case of irrigation canals, considerations shall be given to take care of future development/ expansion plans.

7.4.4 Deck Width Adequacy for Projected Future Traffic Volume

Ideally, the overall width of all bridges irrespective of their lengths or location should be compatible with that of the adjacent road. As such, all bridges should have widths between the outermost faces of the railing kerbs equal to the roadway width of the approaches. But structures on an existing road are difficult to widen due to the inherent construction problems, hazards to running traffic and cost. Therefore, it may not be worthwhile widening all the existing bridges to match with the approach road width. In view of the above, an existing structure having carriageway width same as approach road carriageway width have been recommended for retention provided the structure is found adequate from structural as well as hydraulic considerations. On similar considerations, whenever an existing structure needs widening or reconstruction, it has been recommended to provide full deck width.

7.5 PROPOSAL FOR IMPROVEMENT OF STRUCTURES

7.5.1 Recommendations

Recommendation for improvement of the bridges and culverts can be categorised as:

- New bridge of 2-lane carriageway on the side of the existing structure
- Widening of the existing structure to match four-lane requirement
- Reconstruction for structurally inadequacy
- 2 separate new bridge each of 2-lane carriageway construction
- Repair and rehabilitation
- Protection of pier foundation against scours and bank protection.

The summary of recommendation is given in Tabular form below:

7.5.2 Summary of Recommendation of Structures

Table 7-7: Bridges, Culverts and Underpasses

Type of Structures	New Construction	Major Repair	Minor Repair	Widening	Reconstruction	No Work
1. Major Bridge	5	3	2	1	-	1
2. Minor Bridges	31	3	8	26	1	9
3. ROB	2		1	1	-	-
4. RUB	-		-	1	-	1
4. Flyovers	2		-	-	-	-
5. Underpass	22		-	-	-	-
6. Slab Culverts	-		-	209	-	-
7. Box Culverts	13		-	8	-	-
8. Hume Pipe	10		-	49	39	-
Total Nos. of Structures	**85**	**6**	**11**	**295**	**40**	**11**

7.5.3 Improvement Proposal for Major Bridges

Table 7-8: Construction of New Major Bridges

Sl. No.	Type of Structure	Design Chainage	EXISTING STRUCTURE			PROPOSED STRUCTURE				
			Span Arrangement (c/c Exp. Jt.)	Skew Angle (Degree)	Type of Structure	Span Arrangement (c/c Exp. Jt.)	Type of Superstructure	Proposed Sub Structure	Proposed Foundation	Proposed Deck width
1	MJBR	41/253	12.75 + 6x36.08 + 12.75		End spans RCC T-Girder and intermediate spans string arch superstructure. Substructure RCC circular column on pile foundation.	12.75 + 6x36.08 + 12.75	RCC solid slab for 12.75m span and PSC T-Girder for 36.08m span	RCC wall type pier / abutment	Pile Foundation	14.00 with FP
2	MJBR	65/253	26.85 + 3x47.2 + 26.85	0	End spans RCC T-Girder and Intermediate Spans are PSC Box Girder. Substructure RCC wall type on well foundation.	26.85 + 3x47.2 + 26.85	PSC T-Girder for 26.85m span and PSC Box Girder for 47.2m span	RCC wall type pier / abutment	Pile Foundation	14.00 with FP
3	MJBR	115/347	3x23.5	0	Superstructure RCC Box Girder. Substructure RCC wall type on well foundation.	4x17.625	RCC T-Girder	RCC wall type pier / abutment	Open Foundation	14.00 with FP
4	MJBR	142/661	4x15.15	0	RCC T-Girder Substructure RCC wall type on Open foundation.	2x30.3	PSC T-Girder	RCC wall type pier / abutment	Open Foundation	14.00 with FP
5	MJBR	152/520	2x16.2+5x17	0	RCC T-Girder. Substructure RCC wall type on well foundation.	1x33.2+1x51+1x33 .2	PSC T-Girder for 33.2m span and PSC Box Girder for 51m span	RCC wall type pier / abutment	Pile Foundation	14.00 with FP
6	MJBR	163/600	4x15.25	0	RCC T-Girder. Substructure RCC wall type on Open foundation.	2x30.5	PSC T-Girder	RCC wall type pier / abutment	Open Foundation	14.00 with FP

7.5.4 Improvement Proposal for Minor Bridges

Table 7-9: Construction of New Minor Bridges

Sl. No.	Type of Struc.	Design Chainage	EXISTING STRUCTURE			PROPOSED STRUCTURE				
			Span Arrangement (c/c Exp. Jt.)	Skew Angle (Degree)	Type of Structure	Span Arrangement (c/c Exp. Jt.)	Type of Superstructure	Proposed Sub Structure	Proposed Foundation	Deck width
1	MNBR	5+473	1x7.50	0	Box Type	1x7.50	RCC Box on new CW	RCC Box	RCC Box	24.00 (after widening)
2	MNBR	7+047	1x7.70	0	Cantilever Solid Slab	1x7.70	RCC Box on new CW	RCC Box	RCC Box	23.00 (after widening)
3	MNBR	10+670	2x8.55	0	Solid Slab	1X17.1	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
4	MNBR	11+526	4x7.1	0	Solid Slab	4x7.1	RCC Box on new CW	RCC Box	RCC Box	12.00 (for new CW)
5	MNBR	16+029	3x6.56	0	LHS Solid Slab and RHS Arch	1X20	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
6	MNBR	20+944	1x7.2	0	Solid Slab	1x7.20	RCC Box on new CW	RCC Box	RCC Box	
7	MNBR	23+002	3x13.3	0	RCC Deck Slab over 5 nos RCC T-Girder(4 nos Cross Girders)	3x13.30	RCC Slab Bridge as for Bypass on both CW	RCC Pier / Abutment	Open Found.	12.00 (for both CW)
8	MNBR	28+901	7x8.55	0	RCC Deck Slab over Steel Plate Girder	1x17.1+1x25.65+1x17.1	RCC/PSC Girder Bridge on both CW	RCC Pier / Abutment	Open Found.	12.00 (for both CW)
9	MNBR	31+822	2x7.7	0	RCC Deck Slab over 3 nos RCC T-Girder (Both side widened with solid slab)	1X15.4	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
10	MNBR	34+293	2x5.2	0	Solid Slab	1X10.4	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
11	MNBR	37+329	1x6.2	0	Solid Slab	1x6.1	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)

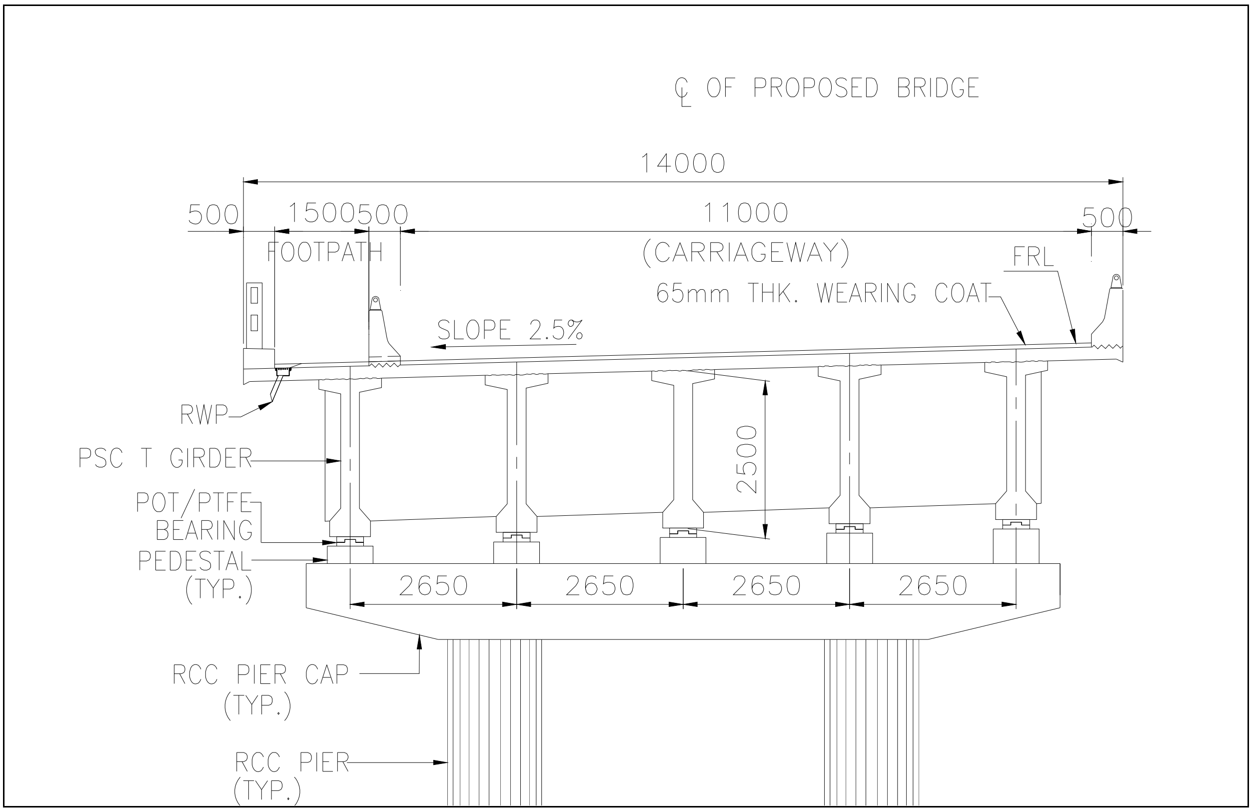
Sl. No.	Type of Struc.	Design Chainage	EXISTING STRUCTURE			PROPOSED STRUCTURE				
			Span Arrangement (c/c Exp. Jt.)	Skew Angle (Degree)	Type of Structure	Span Arrangement (c/c Exp. Jt.)	Type of Superstructure	Proposed Sub Structure	Proposed Foundation	Deck width
12	MNBR	42+211	1x6.9	0	Solid Slab	1x6.9	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)
13	MNBR	50+721	3x13.3	0	RCC Deck Slab over 4 nos RCC T-Girder(4 nos Cross Girders)	3X13.30	RCC/PSC Girder Bridge on new CW	RCC Pier / Abutment	Open Foundation	12.00 (for new CW)
14	MNBR	56+720	2x7.1	0	Cantilever Solid Slab	1x14.20	RCC Slab Bridge for Bypass on both CW	RCC Abutment	Open Found.	12.00 (for both CW)
15	MNBR	58+264	3x6.9	0	Cantilever Solid Slab	1x21	RCC T-Girder Bridge for Bypass on both CW	RCC Abutment	Open Found.	12.00 (for both CW)
16	MNBR	59+661	3x7	0	Solid Slab	1x21	RCC T-Girder Bridge for Bypass on both CW	RCC Abutment	Open Found.	12.00 (for both CW)
17	MNBR	63+922	2x6.9	0	Cantilever Solid Slab	1X13.8	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
18	MNBR	72+410	1x8.3	0	Cantilever Solid Slab	1x8.3	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
19	MNBR	77+388	3x6.45	0	Cantilever Solid Slab	1X19.35	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
20	MNBR	77+827	2x5.85	0	Cantilever Solid Slab	1X11.70	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
21	MNBR	84+011	5x7.15	0	Solid Slab	1X21.45+1X14.4	RCC T-Girder Bridge on new CW	RCC Pier / Abutment	Open Found.	12.00 (for new CW)
22	MNBR	88+716	1x7.5	0	Solid Slab	1X7.5	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)
23	MNBR	89+017	2x3.75	0	Solid Slab	1X7.5	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)

Sl. No.	Type of Struc.	Design Chainage	EXISTING STRUCTURE			PROPOSED STRUCTURE				
			Span Arrangement (c/c Exp. Jt.)	Skew Angle (Degree)	Type of Structure	Span Arrangement (c/c Exp. Jt.)	Type of Superstructure	Proposed Sub Structure	Proposed Foundation	Deck width
24	MNBR	96+018	1x9.25	0	Solid Slab	1X11.70	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
25	MNBR	99+184	4x6.95	0	Solid Slab	2X13.9	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
26	MNBR	100+451	5x6.95	0	Solid Slab	1X13.9+1X20.85	RCC T-Girder Bridge on both CW	RCC Pier / Abutment	Open Found.	12.00 (for both CW)
27	MNBR	104+030	2x5.25	0	Cantilever Solid Slab	1X10.5	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
28	MNBR	106+612	3x7.5	0	Cantilever Solid Slab	1X22.5	New RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
29	MNBR	116+795	1x8	0	RCC Box	1x8	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)
30	MNBR	118+106	3x6.45	0	Cantilever Solid Slab	1X19.35	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)
31	MNBR	120+323	2x11.2+11.0	0	RCC Deck Slab over 4 nos RCC T-Girder(4 nos Cross Girders)	3X11	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
32	MNBR	132+826	3x11	0	RCC Deck Slab over 4 nos RCC T-Girder(4 nos Cross Girders)	3X11	RCC Slab Bridge on new CW	RCC Abutment	Open Found.	26.00 (after widening)
33	MNBR	133+740	1x8	0	RCC Box	1x8	RCC Box	RCC Box	RCC Box	26.00 (after widening)
34	MNBR	136+870	1x8	0	Cantilever Solid Slab	1x8	RCC Box	RCC Box	RCC Box	28.47 (after widening)
35	MNBR	140+272	3x6.45	0	Cantilever Solid Slab	1X19.35	RCC T-Girder Bridge on new CW	RCC Abutment	Open Found.	12.00 (for new CW)

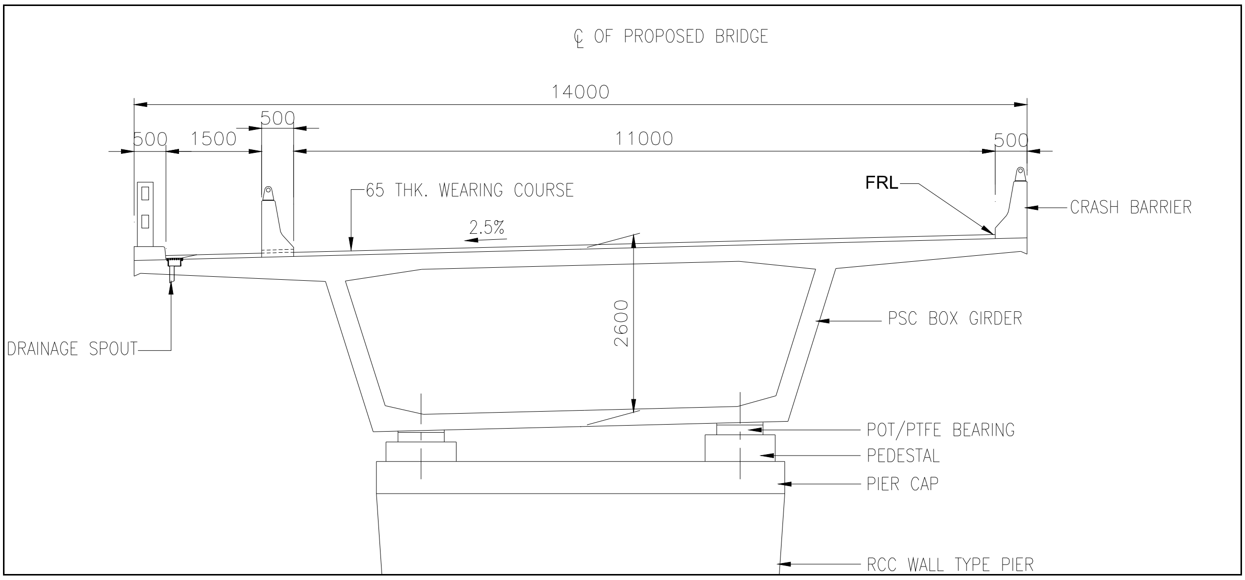
Sl. No.	Type of Struc.	Design Chainage	EXISTING STRUCTURE			PROPOSED STRUCTURE				
			Span Arrangement (c/c Exp. Jt.)	Skew Angle (Degree)	Type of Structure	Span Arrangement (c/c Exp. Jt.)	Type of Superstructure	Proposed Sub Structure	Proposed Foundation	Deck width
36	MNBR	142+226	1x7.2	0	Solid Slab	1x7.2	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)
37	MNBR	143+086	1x7	0	Solid Slab	1x7.2	RCC Box on new CW	RCC Box	RCC Box	24.00 (after widening)
38	MNBR	152+150	1x7.2	0	Solid Slab	1x7.2	RCC Box on new CW	RCC Box	RCC Box	26.00 (after widening)
39	MNBR	156+557	2x8.4	0	Solid Slab	1X16.8	One New RCC T-Girder Bridge	RCC Abutment	Open Found.	12.00 (for new CW)

For detailed proposals (including rehabilitation and repair) for **Major bridges, Minor bridges and Culverts** refer to **Appendices 7.4, 7.5 and 7.6 respectively** in Volume IIA of this report.

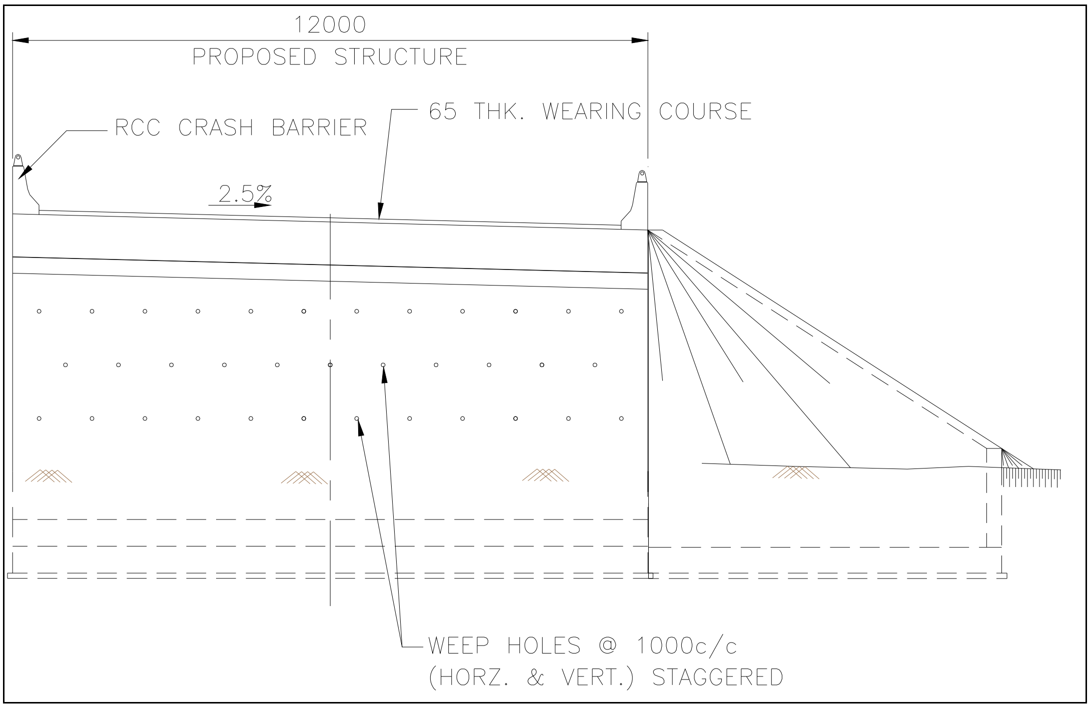
7.5.5 Proposed Cross-Section of New Structures:



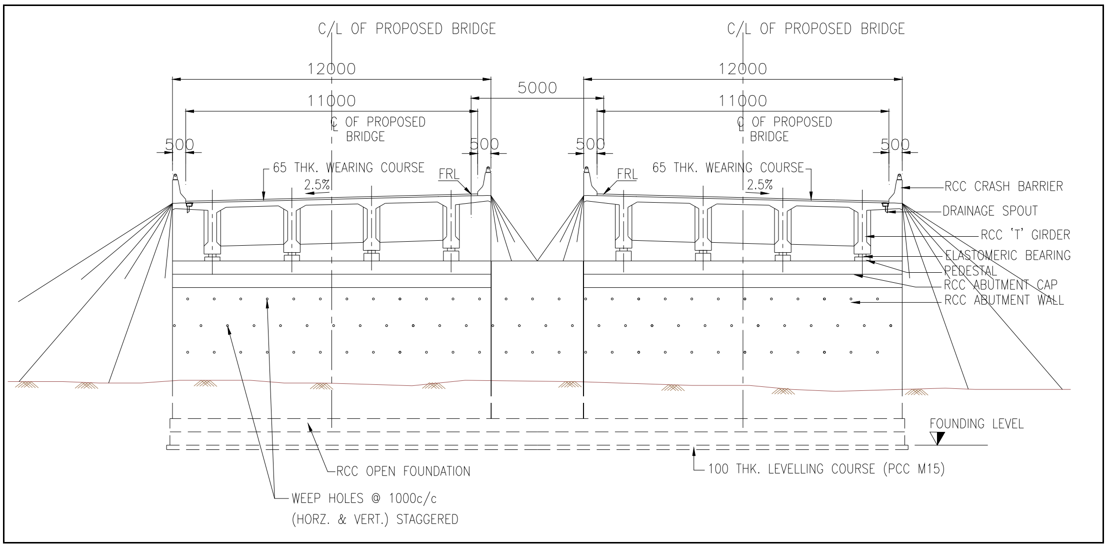
TYPICAL CROSS SECTION OF MAJOR BRIDGE WITH PSC I-GIRDER



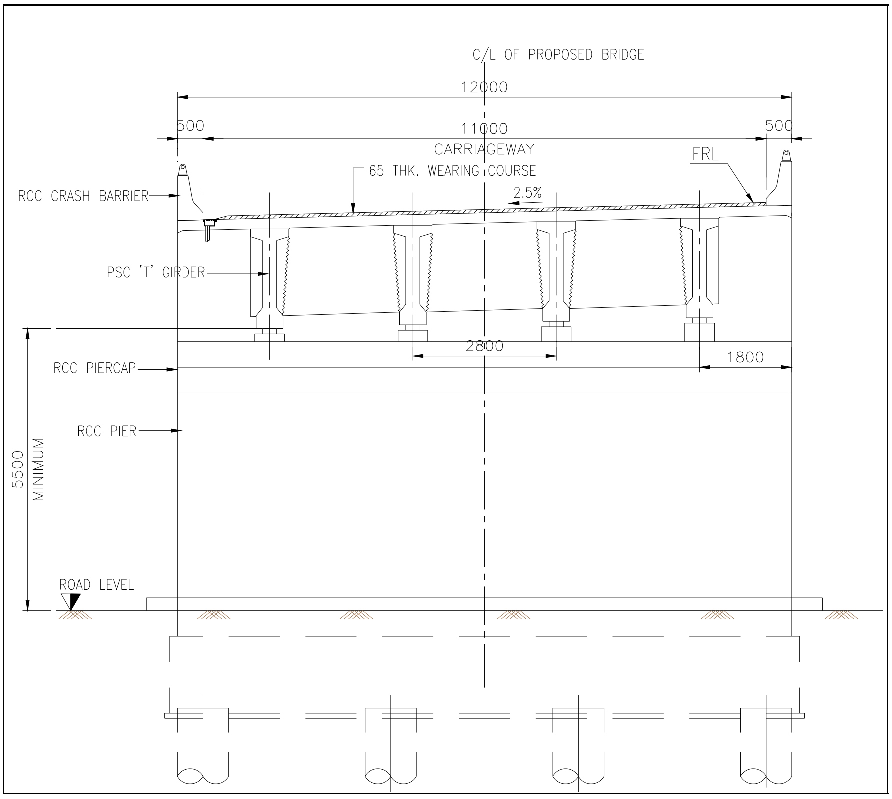
TYPICAL CROSS-SECTION OF MAJOR BRIDGE WITH PSC BOX GIRDER



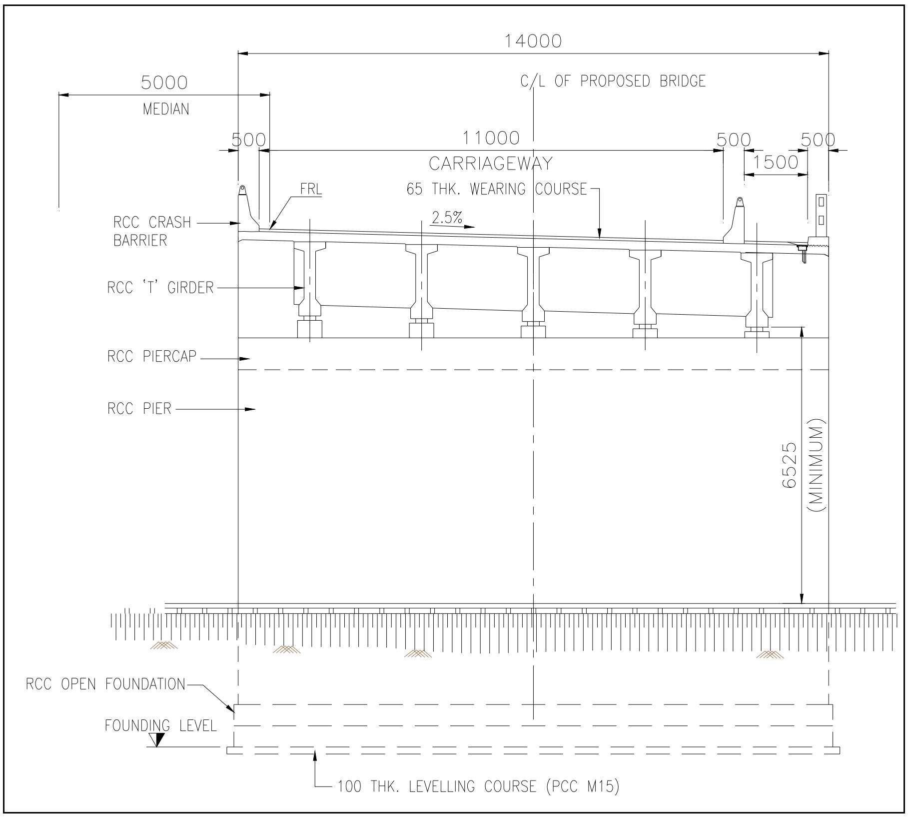
TYPICAL CROSS-SECTION OF MINOR BRIDGE WITH RCC SLAB



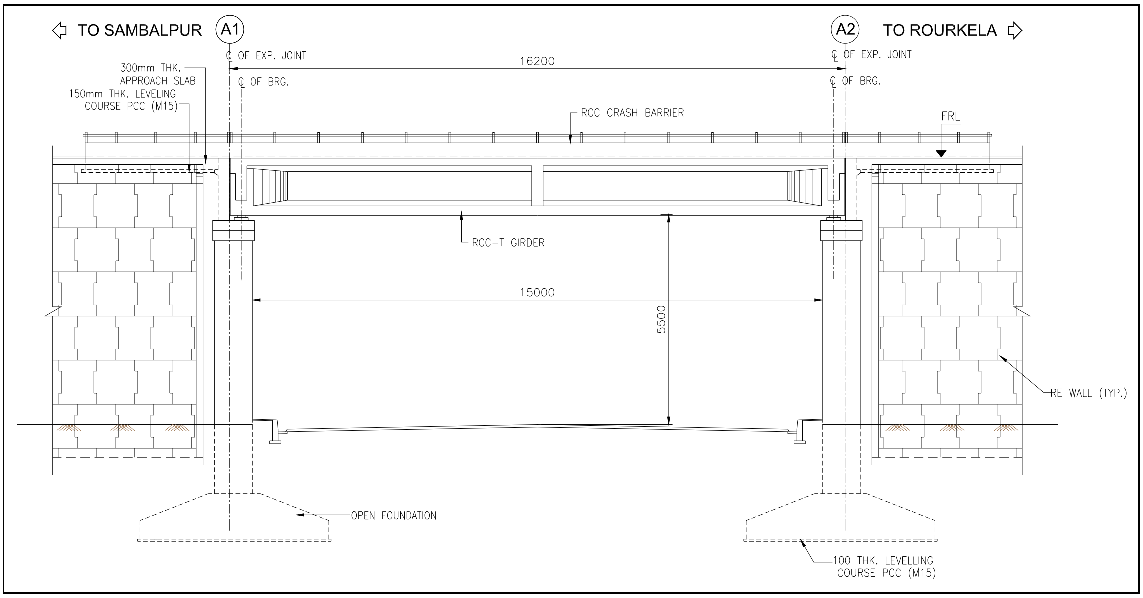
TYPICAL CROSS-SECTION OF MINOR BRIDGE WITH RCC T-GIRDER



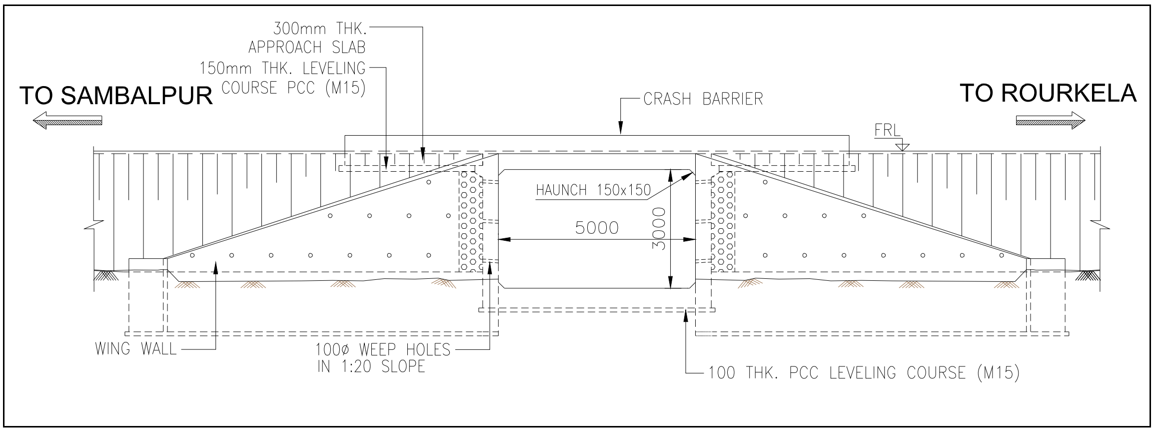
TYPICAL CROSS-SECTION OF FLYOVER



TYPICAL CROSS-SECTION OF ROB



TYPICAL ELEVATION OF VUP



TYPICAL CROSS-SECTION OF PUP

7.6 REHABILITATION, RETROFITTING AND UP GRADATION OF BRIDGES

7.6.1 Introduction

The repair strategy for the existing bridges (Major, Minor and Culverts) are based on visual inspection as per the guidelines laid in SP-37 and SP-40 and Non Destructive Tests carried out. The condition of the existing bridges is generally good, requiring minor repairs, except existing structure no. 30/2, which is significantly distressed and as such recommended for reconstruction on the RHS. Condition of the culverts in the corridor is good.

7.6.2 Types of repair works expected in the bridges:

General Distress:

Concrete Structures (RCC or PSC)

- Honeycombing;

- Spalling of concrete (small area);
- Corroded and Exposed reinforcement;
- Visible cracks (less than 1 mm or more than 1 mm);
- Large area of soffit of slab is distressed with spalling of concrete;
- Distressed wearing coat;
- Damage drainage spout;
- Damaged Expansion joint;
- Damaged Railing/ parapet; and
- Bearing Replacement.

Masonry Structure

- Cracks; and
- Vegetation growth.

7.6.2.1 Recommendations for Repair and Rehabilitation works

Repair/ rehabilitation measures recommended are given below:

Crack Repairs (for Distress 'd')

For cracks smaller than 0.3 mm, high thermoset monomers such as Monopol of Krishna Conchem or equivalent is recommended. For crack between 0.3 mm to 1.0 mm, low viscosity epoxy inject such as 'KP 250/HP 259 of Krishna Conchem or equivalent is recommended. For the cracks more than 1 mm, polymer modified cement grout Rendroc –RG of Fosroc Chemical or equivalent is recommended.

Spalling (for Distress 'b')

For minor distress repair of concrete, this is carried out with anticorrosive polymer modified mortar such as 'Monoband 2000 of Krishna Conchem or equivalent.

Guniting (for Distress 'e')

At places where large area of soffit of deck slab (RCC) is distressed and shows spalling of concrete, corroded and exposed reinforcement, guniting is recommended with the help of Sicken – Gunit 133/143 of Krishna Conchem or equivalent. Before Guniting the corroded reinforcement shall to be cleaned by sandblasting and if it is found that the during cleaning operation the diameter of the reinforcement bar has gone down substantially, then this has to be replaced by new reinforcement. A spray of EPCO – KP – 199 of Krishna Conchem or equivalent is to be applied before carrying out guniting activity.

Anchoring of Reinforcement Bars

At several locations it is required to replace the reinforcement bar and for that 'LoKset' of Fosroc or an equivalent anchor grout is recommended, which is epoxy based.

Concrete Bonding Agents

To ensure good bonding between old and new concrete, structural grade epoxy bonding agent is recommended Nitobond – FP of Fosroc chemicals or equivalent is recommended.

Coating for Old Reinforcement Bars

Epoxy phenolic based coating is preferred for their better affinity and crust penetrating quality, one coat of EPCO – KP – 100 migratory corrosion barrier followed by a coating of IPNET-RB of 'Krishna Conchem or equivalent is recommended.

Repair of Corroded/ Exposed Reinforcement (for distress 'c')

Corroded reinforcement shall to be cleaned by wire brushing/ grit blasting, thereafter Ziwerech of FOSROC or equivalent shall be applied and then concreting should be allowed.

Replacement of Expansion Joint (for Distress 'h')

The expansion joint has to be replaced by strip-seal expansion joint of METCO or equivalent for PSC T-Girder bridges, Asphaltic Plug expansion joint for RCC Box and RCC T – girder and copper strip expansion joint for Solid slab superstructure.

Reinstatement of Distressed Structural Concrete

Free flowing micro concrete such as 'Renderoc RG of Fosroc or equivalent is recommended for reinstatement of distressed structural concrete.

Bearing Replacement (for Distress 'j')

The superstructure has to be jacked up and new bearing is to be replaced, the pedestal is to be repaired using micro concrete and properly providing reinforcement. The bearing shall be neoprene type from approved manufacturer; METCO or equivalent is recommended.

Wearing Coat Replacement (for Distress 'f')

The old concrete wearing course generally cracked with any built-up on it is not warranted both from durability and structural viewpoint.

If the wearing coat for the bridges is to be replaced; in case of slab bridges, it is recommended to carryout profile corrective course to achieve unidirectional camber before laying 65mm thick Asphaltic wearing coat. The two-way cross fall which has been provided earlier is generally flatter than required. The existing fall of 1:72 to 1:60 requires to be improved to 1:40. In case of bridges with RCC/PSC T-girder/Spine beams, we have to replace the wearing coat by RCC wearing coat for the cases where widening is not done, but where widening is done in such case profile corrective course is recommended.

Drainage Spout Replacement (for Distress 'g')

In case the drainage through waterspout have been found to be deficient and damaged, drainage spouts shall be replaced with down take pipe for bridges as per MOST guideline.

Replacement of Existing Railing (for Distress 'i')

All railings shall be replaced by metallic crash barrier for Bridges with slab type super-structure, where as for the Major bridges having PSC girder system the existing railing is recommended for repair.

7.6.2.2 Widening Scheme for CD Structures and Underpasses

Maximum number of minor bridges and culverts in the corridor are structurally in good condition. Hence in most of the cases widening of the present structure is recommended. There are two types of widening

- Asymmetrical widening
- Symmetrical widening

Both types of widening are required to be carried out along the corridor depending upon the geometry.

Widening of Pipe Culverts

Pipes shall be placed properly in order to maintain the required slope. It is recommended that full section of the road as well as full median shall run over culverts as per MOST specifications. Stone pitching shall be provided for slope protection.

Widening of RCC Box Structures

For widening of box culverts same material for the substructure and the same depth of slab as that of existing structure is recommended. In many locations spread type wing walls are present, which in case of widening shall be dismantled and reconstructed at the new location.

For four laning of bridges supported on deep foundation, the existing bridge shall be retained to carry two-lane traffic in one direction. A new bridge of two-lane width is proposed to be constructed adjacent to the existing bridge to cater for the other direction. A minimum gap of 30m between the centerline of existing and proposed bridge is kept to avoid any overlapping of influence zone.

Widening of RCC Slab Bridges

As per the Geotechnical Investigations carried out, the SBC at all Bridge locations having shallow foundation are found to be generally good and is varying from 20t/sqm to 30 t/sqm. Therefore the bridges having shallow open foundation are considered technically feasible to widen even by joining together the existing and new substructure and foundation, as the differential settlement may not be significant.

7.6.2.3 Traffic Diversion

It is not possible to complete the widening of bridges without traffic diversion. Asymmetric (one side) widening is preferred to avoid traffic diversion. For some cases such as for bridge 42/2, 155/2 and 166/2 where extensive repair has to be carried out, the repair activity shall be taken up after the construction of new bridge and diversion of traffic to it.