GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(RAILWAY BOARD)

2023/Proj./CMRL/PH-II/DBR/30/55 New Delhi, dated 31.10.2023

Managing Director,
Chennai Metro Rail Limited,
Admin Building, CMRL Depot,
Poonamallee High Road, Koyambedu,
Chennai, Tamil Nadu-600107

Sub: Approval of Design Basis Reports (DBRs) (March 2023) for Viaduct, Elevated stations and Underground Bored Tunnels of Chennai Metro Project, Phase-II of Chennai Metro Rail Limited (CMRL).

Ref: DBR's uploaded on RDSO's online portal by CMRL on 30.09.2023

The Design Basis Reports (DBRs) (March 2023) for Viaduct, Elevated stations and Underground Bored Tunnels of Chennai Metro Project, Phase-II of Chennai Metro Rail Limited (CMRL) has been examined in consultation with RDSO and approval of Railway Board is hereby conveyed for the same.

Accordingly, approved copies of DBR's are enclosed.

Encl: As above

31.10.23

(F.A. Ahmad)
Director/Gati Shakti (Civil)-IV
Railway Board
Ph. 011-47845480

Copy to:

1. **ED/UTHS,** RDSO, Manak Nagar, Lucknow-226011 w.r.t RDSO's letter No. UT/CMRL/CMRL/P02/072023 dated 19.10.2023
2. **OSD/UT & Ex-Officio Joint Secretary**, Ministry of Housing & Urban Affairs (MoHUA), Nirman Bhawan, New Delhi-110011

DESIGN BASIS REPORT (DBR)

FOR

VIADUCT OF CMRL PHASE II

MARCH 2023

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

Table of Contents

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI-600035

Project Directorate Approved on 31/10/2023 Railway Board

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI-600035

Project Directorate Approved on 31/10/2023 Railway Board

1 INTRODUCTION

1.1 Brief Description of the Project

CMRL is a joint venture of Government of India and Government of Tamil Nadu. The Phase II project consists of three corridors which have both Underground and Elevated sections.

i. Corridor 3 – 45.80 km length from Madhavaram Milk Colony to SIPCOT via Perambur, Royapettah, Thiruvanmiyur and Sholinganallur.

ii. Corridor 4 – 26.10 km length from Light House to Poonamallee Bypass via Nandanam, Kodambakkam and Porur

iii. Corridor 5 – 47.00 km length from Madhavaram Milk Colony to Sholinganallur via Koyembedu, Virugambakkam, Mugalivakkam, Manapakkam, Alandur and Medavakkam.

Table-1 CMRL Phase II – Alignment details

Corridor	No of Stations	Alignment length in kms
1. Corridor - 3		
Underground	30	26.70
Elevated	20	19.10
2. Corridor - 4		
Underground	12	10.10
Elevated	18	16.00
3. Corridor - 5		
Underground	6	5.80
Elevated	42	41.20
Overall total	128	118.90

1.2 Geometric Design Features:

- Gauge adopted is Standard Gauge (1435mm)
- Gradient of superstructure: Variable, (level to 4.0%) [Loads and forces on structures shall be worked out based on the actual gradient at the particular pier under consideration]
- Horizontal alignment of superstructure comprises of straight, transition and curved stretches. Minimum design radius of curvature in plan is 120m.
- Centre to centre of track should be as per approved SOD for Chennai Metro Phase II (proposed minimum c/c of tracks is 3.65m for elevated viaduct). Extra clearances required on curves shall be as per approved SOD requirements.

1.3 Scope of Design Basis Report (DBR)

This Design Basis Report is prepared to standardize the design methodology for CMRL Phase II Viaduct bridge structure made of RCC, PSC and Steel for the Project.

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

2 PROPOSED STRUCTURAL SYSTEM OF VIADUCT

2.1 Superstructure system

Viaduct:

- Precast U-Girder,
- Pre/Post tensioned I Girders with cast-in-situ deck slab are proposed for viaduct, transition span and crossover spans.
- Steel girders with concrete Composite deck unit are proposed in obligatory spans.
- The standard spans (c/c of pier) proposed 25m and 30m.
- Minimum Span of viaduct is 8m.
- Maximum Span of viaduct is 110m.

2.2 Emergency Walkway: Track level walkways to be designed as per approved SOD of CMRL.

2.3 Bearings

Two types of bearings are proposed to be used depending upon the structural requirement of viaduct geometry.

a. Elastomeric Bearing

b. Pot cum PTFE Bearing

2.4 Substructure System

Substructure shall consist of Cast-in-situ pier. Piers are normally Rectangular, Circular or Double D shape and designed as per IRS CBC. Proposed precast or cast in situ pier caps are at different locations.

2.5 Foundation system

Predominantly, pile foundations shall be adopted with piles of 1.0 and 1.2m diameter. Open foundations will be adopted in rocky strata at few locations.

2.6 Parapets

Precast integral web acts as parapets in case of U-girders, which is structural part.

Precast RCC Parapet, which is non-structural part stitched with deck slab, in case of I-Girder or steel composite girder locations.

3 CLEARANCES FOR STRUCTURES

3.1 Clearance for Road Traffic: As per relevant IRC specifications, Minimum Vertical Clearance of 5.50m is provided as shown in fig.1

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Project Directorate
Approved on
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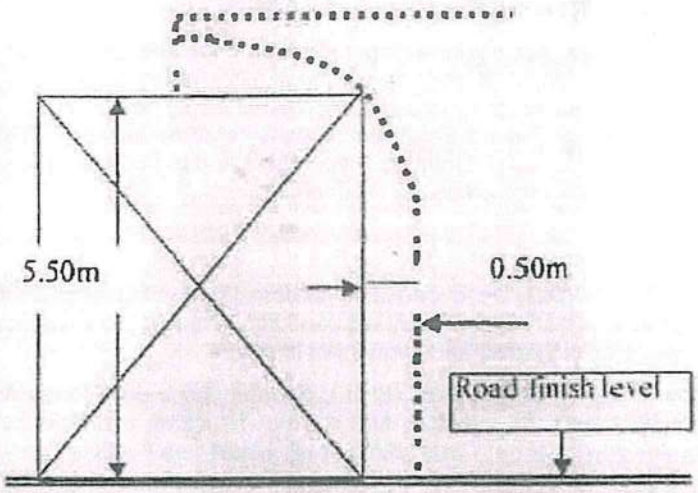
Railway Board



3.2 Clearances for Railway Traffic: Indian Railways Schedule of Dimensions (SOD) shall be applicable.

3.3 **Clearance for Metro Traffic:** As per approved SOD of CMRL Phase II.

4 STRUCTURAL MATERIALS AND PROPERTIES

4.1 Cement: Clause 4.1 of IRS CBC.

4.2 Concrete

4.2.1 Density: 24/25 kN/m³ for PSC and RCC based on reinforcement percentage, 23 kN/m³ for plain cement concrete (IS: 875 Part 1).

4.2.2 Young's Modulus: Clause 5.2.2.1 of IRS CBC.

4.2.3 Modular Ratio: Clause 5.2.6 of IRS CBC.

4.2.4 Minimum Grade of Concrete for Structural Elements: Clause 5.4.4 of IRS CBC.

4.2.5 Thermal Expansion Coefficient: $\varepsilon = 1.17 \times 10^{-5}$ /°C (Clause 2.6.2 of IRS Bridge Rules.)

4.2.6 Poisson's Ratio: 0.15 for all concretes.

4.3 Reinforcing Steel: As per Clause 4.5 & 7.1.5 of IRS CBC. All properties of TMT bars shall confirm to IS: 1786.

4.4 Prestressing Hardware

4.4.1 Pre-stressing Steel for Tendons:

4.4.1.1 As per Clause 4.6 of IRS CBC.

4.4.1.2 Characteristic Strength: As per clause 16.2.4.3 of IRS CBC.

4.5 Prestressing Units:

4.5.1 Jacking Force: Jacking force (maximum initial prestressing force) shall be as per clause 16.8.1 of IRS CBC.

4.5.2 Prestress Losses: As per clause 16.8.2 and 16.8.3 of IRS CBC.

4.5.3 Sheathing: As per clause 7.2.6.4.2 of IRS CBC.

4.5.4 Anchorages: As per clause 7.2.6.4.3 and Clause 16.8.3.4 of IRS CBC.

4.6 Structural Steel for Steel and Composite Bridges

4.6.1 Steel shall confirm to IS: 2062.

4.6.2 Fabrication shall be done as per provisions of IRS B1 (Fabrication Code).

4.6.3 Design of Steel Structures shall be done as per IRS Steel Bridge Code.

4.6.4 IS codes may be referred for Steel-RCC composite construction.

4.6.5 Welding shall be done following IRS Steel Bridge Code and IS 2751: 1979.

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

4.7 Structural Steel for Miscellaneous Use

4.7.1 Design shall be done as per IS: 800 and related provisions.
4.7.2 Hollow Steel sections for structural use shall be as per IS: 4923.
4.7.3 Steel tubes for structural purpose shall be as per IS: 1161.
4.7.4 Steel for General Structural purposes shall be as per IS: 2062
4.7.5 IS 16651: 2017 Stainless Steel rebars and IS 6603-2001 for stainless steel plates shall be followed as per requirement.

5 LOADS

5.1 **Dead Loads (DL):** Dead load shall be based on the actual cross section area and unit weights of materials and shall include the weight of the materials that are structural components of viaduct and permanent in nature.

5.2 **Superimposed Dead Loads (SIDL):** Superimposed dead loads include all the weights of materials on the structure that are not structural elements but are permanent. It includes weight of track from plinth / rails / fasteners / cables / parapet / handrail / OHE mast & fixing / cable trough / signalling equipment etc and will be considered in the design as per the site conditions.

5.2.1 **SIDL1 (Fixed SIDL or Non-variable SIDL):** Rail Plinth, Precast Parapet and roof structure will be considered as Dead Load for the purpose of analysis of structures. The weight of the rail plinth and parapet will remain same throughout the life of the structure. This is incorporated in the maintenance manual of CMRL.

5.2.2 **SIDL2 (Variable SIDL):**
The following items shell be considered as variable SIDL
Rails + pads
Third rail & fixtures
Hand rail
Cables
Cable trough cell
Cable trays
Miscellaneous (OFC, Signaling etc.).

5.3 **Shrinkage & Creep (SC):** Shrinkage & creep effects will be calculated as per IRS-CBC.

5.4 **Live Load (LL):** Simply supported structures shall be designed for 16MT Metro loading envelop and the EUDL chart for CMRL metro loading is tabulated in **Annexure I**.

Loads other than standard trains like track machines, cranes, any new rolling stock etc. which may come on this structure should be within this loading envelope.

For special structures like continuous structures, cable stayed bridges, etc., the actual train loads will be used for design.

5.5 **Coefficient of Dynamic Augment (CDA)**: CDA shall be in adopted as per IRS Bridge Rules.

5.6 **Footpath Live Load:** As per clause 2.3.2 of IRS Bridge Rules.

5.7 **Braking and Traction (BR/TR):** The value of braking force (BR 18%) and traction forces (TR 20%) will be taken as per rolling stock. For twin tracked decks carrying traffic in opposite directions, consideration should be given to braking forces from one train and traction forces from another, acting simultaneously which will be maximum longitudinal loading on a deck. For more than 2 tracks, Clause 2.8.4 of IRS Bridge Rules shall be considered.

As per Clause 2.8.5 of IRS Bridge Rules, when considering seismic forces, in transverse/ longitudinal seismic condition, only 50% of gross tractive effort / braking force will be considered.

Dispersion of longitudinal forces is not allowed as per Clause 2.8.3.4 of IRS Bridge Rules.

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5.8 Centrifugal Force (CF): On curved track, centrifugal forces shall be determined in accordance with Clause 2.5 of IRS Bridge Rules.

5.9 Gradient Effect: Shall be considered as per site conditions.

5.10 Wind Load (WL): As per clause 2.11 of IRS Bridge Rules.

5.11 Seismic load (EQ): "Seismic Code for Earthquake Resistant Design of Railway Bridges" shall be followed. This code also covers load combination and ductile detailing aspects.

5.12 Temperature effect: Clause 2.6 of IRS Bridge Rules.

5.12.1 Overall Temperature (OT): As per clause 215.2 of IRC: 6.
5.12.2 Differential Temperature (DT): As per IRC: 6.
5.12.3 Temperature Gradient: As per clause 215 of IRC: 6.

5.13 Differential Settlement: Considered only in the design of continuous structures, Differential settlement between two adjacent viaduct piers will be:

- 12 mm for Long Term Settlement.
- 6 mm for Short Term Settlement (50% of Long Term).

5.14 (a) Vehicle Collision Load on Piers: As per Clause 222 of IRC: 6.

(b) Rules specifying the loads for design of super structure and sub structure of bridges and for assessment of the strength of existing bridges should be done as per IRS Bridge Rules.

5.15 Buffer Load: Provision of Buffers is contemplated at the end of temporary terminal stations during stage opening of the Corridors, at Pocket track ends and at the terminal stations of the corridors (at the end of turn back / stabling lines). Such buffers will be of friction type. These buffers will be designed to have stopping performance based on mass of fully loaded train and its deceleration, to avoid damage to the train or buffer.

Viaduct elements need to be designed for such Buffer load. The exact buffer loads need to be interfaced and ascertained during the detailed design.

5.16 Long Welded Rail (LWR) Forces: Long welded rail forces shall be as per Guidelines vide BS Report No 119 "RDSO guidelines for carrying out Rail-structure Interaction studies on Metro System (version – 2)".

5.17 Racking forces: As per Clause 2.9 of IRS Bridge Rules

5.18 Vibration Effect: Effect of vibration due to movement of metro train on station bridge structure will be taken into consideration.

5.19 Forces on Parapets: As per clause 2.10 of IRS Bridge Rules.

5.20 Derailment Loads:

Derailment loads shall be considered as per Appendix XXV of IRS Bridge Rules with Standard Gauge in place of Broad Gauge. For ULS and stability check, loading shall be proportioned as per maximum axle load.

Sacramento derailment criteria may be used for U-girders. This criterion corresponds to the application of 40% of one coach weight applied horizontally as a 3m long uniform impact load on the U-girder top flange. This derailment load corresponds to an ULS load. For SLS Combination 5 of IRS-CBC, a $\frac{1}{1.75}$ co-efficient shall be applied to the derailment load.

5.21 **Erection Forces:** As per clause 2.13 of IRS Bridge Rules.

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Director/UT/Civil/RDSO

6 LOAD COMBINATIONS

6.1 **Methodology:** Provisions of Bridge Rule / IRS Concrete Bridge Code and Seismic Code for Earthquake Resistant Design of Railway Bridges shall be followed for load combinations.

6.2 The superstructure/bearing, sub-structure and foundation will be checked for one track loaded condition as well as both track loaded condition, for single span and both spans loaded conditions, as the case may be.

6.3 Design of viaduct shall be done in accordance with the construction methodology/ construction sequence to be adopted during execution.

7 DESIGN PARAMETERS

7.1 **Units for Design:** [t], [m], [mm], [kN], [kN/m²], [kN/m³], [MPa], [°C], [rad].

7.2 **ULS Check:** As per IRS Concrete Bridge Code.

7.3 **SLS Check:** As per IRS Concrete Bridge Code.

7.3.1 **Crack Width**

Crack width in reinforced concrete members will be checked for SLS combination-I. Crack width will be as per clause 15.9.8.2 of IRS CBC. Crack width shall not exceed the admissible value based on the exposure conditions given in clause 10.2.1 of IRS CBC.

For crack control in columns, clause15.6.7 of IRS CBC will be modified to the extent that actual axial load will be considered to act simultaneously.

7.3.2 Clause No. 10.4.1, 11.3.4 and 13.3 of IRS CBC shall be kept in view while calculating vertical deflection at mid span.

7.4 **Fatigue Check**

7.4.1 **RCC and PSC Structures:** Clause 13.4 of IRS CBC shall govern.

7.4.2 **Steel Structures:** Clause 3.6 of IRS Steel Bridge Code shall govern. If 'λ' values are required to be used, the train closest to the actual train formation proposed to be run on the metro system shall be used. Otherwise, detailed counting of cycles shall be done.

7.5 **Durability**

7.5.1 Provisions of clause 5.4 of IRS CBC shall be followed to meet durability requirements.

7.5.2 Cover to reinforcement shall be in accordance with clause 15.9.2 of IRS CBC.

7.6 **Design Life:** As per Clause 15.1.3 and 16.1.3 of IRS CBC.

7.7 **Drainage**

The drainage of deck shall be designed to cater the maximum envisaged rainfall intensity and suitable longitudinal and transverse slope should be provided. Moreover, the provisions of clause 10.4.1.1 and 15.2.2 of IRS:CBC shall be followed.

8 DESIGN METHODOLOGY

8.1 **Bearing System:**

8.1.1 Elastomeric bearings shall be designed in accordance with EN 1337 Part-1 and Part-3.

8.1.2 Design of Pot- PTFE bearings shall be as per IRC: 83 Part-III.

8.1.3 Spherical and Cylindrical Bearings shall be designed as per IRC: 83 Part IV.

8.1.4 Clause 15.9.11.3 and 15.9.11.4 of IRS CBC should be followed for considering replacement of bearings.

8.1.5 If bearings cannot accommodate the seismic forces, concrete shear keys / seismic restrainer shall be provided.

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8.2 Pier cap and pier

8.2.1 For designing the pier cap as corbel, the provisions of Clause 17.2.3 of IRS CBC should be followed.

8.2.2 In case of shear span to effective depth ratio being more than 0.6, pier cap will be designed as flexural member.

8.2.3 The effective length of a cantilever pier for the purpose of slenderness ratio calculation will be taken as per IRS CBC.

8.3 Foundation

8.3.1 Foundation shall be designed as per IRS Bridge Substructure and Foundation Code, IRS Concrete Bridge Code, Manual on the design and construction of Well and Pile Foundation, IS 2911 and IRC 45 should be followed.

8.3.2 **Soil Structure Analysis:** When designing elements forces or estimating displacements, the soil stiffness shall be assessed based on the actual ground data.

9 PROJECT SPECIFIC ADDITIONAL INFORMATION/DETAILS (IF ANY)

NIL

10 DESIGN CODES AND STANDARDS

The IRS codes shall be followed in principle. Although main clauses have been mentioned in the DBR, the other relevant clauses as available in the IRS codes shall also be followed. If provisions are not available in IRS, Order of preferences shall be as follows, unless specifically mentioned otherwise in the relevant clause of DBR:

<u>For Railway loading related issues:</u>

i. UIC Codes

ii. Euro Codes

iii. Any other code which covers railway loading.

<u>For other Design/Detailing related issues:</u>

i. IRC

ii. IS

iii. Euro Code

iv. Other national codes.

List of various design codes and standards to be used at various stages of works is appended as Annexure II. These codes with latest revisions including all addendums / notifications and correction slips only shall be used.

11 DESIGN SOFTWARE

Any commercial or proprietary software can be used for analysis / design provided the same is validated with manual computations or other standard software in multiple scenarios.

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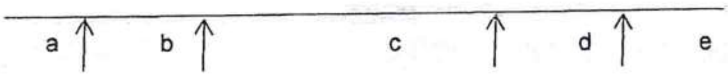
Project Directorate Approved on 31/10/2023 Railway Board

Annexure-I EUDL Loading

EQUIVALENT UNIFORMLY DISTRIBUTED LOAD & LONGITUDINAL FORCE CHART FOR LIGHT METRO LOADING

1. Standard Train Formation Considered:	2DMC+1TC+2DMC+1TC+2DMC
2. Standard Axle Distances Considered:	a=2.35m, b=2.3m, c=12.55m, d=2.3m, e=2.35m overall Length of DMC/MC for combination 1=21.85m (CMRL).



3. Standard Maximum Height of Centre of Gravity from Rail Level: 1700mm for 1435mm Gauge

4. Maximum Axle Load	16.0 t
5. Tractive Effort (TE)	20% Vertical Axle Load for DMC/MC.
6. Braking Force (BF)	18%of Vertical Axle Load for DMC/MC/TC.
7. Loaded Length	For Bending Moment, L is equal to the effective span in meters. For Shear, L is the loaded length in meters to give the maximum Shear in the Member under consideration.
8. EUDL (BM)	The Equivalent Uniformly Distributed Load (EUDL) for Bending Moment (BM), for spans up to 10m, is that uniformly distributed load which produces the BM at the center of the span equal to the absolute maximum BM developed under the standard loads. For spans above 10m, the EUDL for BM, is that uniformly distributed load which produces the BM at one-sixth of the span equal to the BM developed at that section under the standard train loads considered.
9. EUDL (SF)	EUDL for Shear Force (SF) is that uniformly distributed Load which produces SF at the end of the span equal to the maximum SF developed under the standard train loads considered.

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L (M)	EUDL (Tonne)		LF (Tonne)	
	SF	BM	TE	BF
0.5	32.000	32.000	3.200	2.900
1.0	32.000	32.000	3.200	2.900
1.5	32.000	32.000	3.200	2.500
2.0	32.000	32.000	3.200	2.900
2.5	34.120	32.000	6.400	5.750
3.0	38.765	32.000	6.400	5.750
3.5	42.090	32.000	6.400	5.750
4.0	44.750	32.230	6.400	5.750
4.5	46.890	34.894	6.400	5.750
5.0	48.600	37.256	6.400	5.750
5.5	51.500	39.246	6.400	5.750
6.0	51.190	40.944	6.400	5.750
6.5	52.570	42.504	8.100	7.300
7.0	54.875	43.894	8.100	7.300
7.5	57.165	45.117	9.600	8.650
8.0	59.590	46.209	9.600	8.650
8.5	61.730	48.213	9.600	8.650
9.0	63.940	49.998	11.300	10.150
9.5	66.675	51.690	12.800	11.500
10.0	69.745	53.559	12.800	11.500
11.0	75.040	64.830	12.800	11.500
12.0	79.455	69.744	12.800	11.500
13.0	83.150	74.225	12.800	11.500
14.0	86.385	78.066	12.800	11.500
15.0	89.165	81.395	12.800	11.500
16.0	91.590	84.308	12.800	11.500
17.0	93.730	86.878	12.800	11.500
18.0	95.635	89.163	12.800	11.500
19.0	97.340	91.207	12.800	11.500
20.0	98.870	93.047	14.300	12.850
21.0	100.590	94.711	15.500	13.950
22.0	103.025	96.224	16.000	14.400

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23.0	105.975	97.606	18.600	16.750
24.0	108.965	98.872	19.200	17.300
25.0	112.285	100.248	19.200	17.300
26.0	115.350	102.149	19.200	17.300
27.0	118.185	104.438	19.200	17.300
28.0	121.360	106.958	19.200	20.150
29.0	124.900	109.534	19.200	20.150
30.0	128.375	112.283	19.200	22.300
31.0	132.395	115.734	19.200	23.050
32.0	136.260	419.117	19.200	23.050
33.0	139.885	422.372	20.700	23.050
34.0	143.300	126.194	21.700	23.050
35.0	146.520	129.903	23.200	23.050
36.0	149.560	133.406	23.200	23.050
37.0	152.440	136.989	24.800	23.050
38.0	155.165	139.858	24.800	23.050
39.0	157.750	142.436	25.600	23.050
40.0	160.225	145.665	25.600	24.400
41.0	162.920	148.356	25.600	25.100
42.0	165.490	150.919	25.600	25.100
43.0	168.335	153.363	25.600	27.250
44.0	171.395	155.696	25.600	27.900
45.0	174.315	157.925	25.600	27.900
46.0	177.415	160.320	25.600	28.800
47.0	180.450	162.675	25.600	28.800
48.0	183.570	164.947	25.600	30.700
49.0	186.655	167.689	25.600	30.700
50.0	190.065	170.441	25.600	33.050
51.0	188.195	172.996	25.600	33.500
52.0	197.025	175.752	25.600	34.550
53.0	200.555	178.474	25.600	34.550
54.0	203.950	181.095	25.600	34.550
55.0	207.225	183.880	25.600	34.550
56.0	210.380	186.632	25.600	34.550
57.0	213.425	189.583	25.600	34.550

58.0	216.365	192.642	25.600	34.550
59.0	219.210	195.648	25.600	34.550
60.0	221.970	198.787	27.100	35.900
61.0	324.870	201.824	27.100	35.900
62.0	227.670	204.762	27.900	36.250
63.0	230.580	207.456	29.400	37.600
64.0	233.450	710.581	31.000	39.050
65.0	236.480	213.479	31.000	39.050
66.0	239.430	216.328	31.000	39.050
67.0	242.410	219.279	32.000	40.300
68.0	245.585	222.142	33.500	41.650
69.0	248.735	224.923	34.100	41.850
70.0	251.875	227.815	35.600	43.200
71.0	255.215	230.676	37.200	44.650
72.0	300.720	233.474	37.200	44.650
73.0	261.810	236.568	38.400	46.100
74.0	265.200	239.627	38.400	46.100
75.0	268.490	242.668	33.400	46.100
76.0	271.695	245.765	38.400	46.100
77.0	274.810	248.820	38.400	46.100
78.0	277.850	251.975	38.400	46.100
79.0	280.820	255.052	38.400	46.100
80.0	283.725	258.089	39.900	47.450
81.0	286.725	261.224	39.900	47.450
82.0	289.660	264.282	40.300	47.450
83.0	292.655	267.266	41.800	48.800
84.0	395.625	270.180	41.800	48.800
85.0	298.525	273.024	43.400	50.200
86.0	301.480	275.803	43.400	50.300
87.0	304.440	278.515	3.400	50.300
88.0	307.480	281.334	44.800	53.200
89.0	310.665	284.094	44.800	53.200
90.0	313.845	286.826	44.800	54.550
91.0	317.010	289.629	44.800	55.800
92.0	320.255	292.372	44.800	56.050

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600

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93.0	323.510	295.056	46.300	56.050
94.0	326.695	297.820	46.300	56.050
95.0	329.955	300.580	47.800	57.600
96.0	333.190	303.443	48.000	57.600
97.0	336.350	306.387	48.000	57.600
98.0	339.440	309.301	49.600	57.600
99.0	342.480	312.298	49.600	57.600
100.0	345.475	315.432	49.600	58.950
101.0	348.540	318.378	49.600	58.950
102.0	351.545	321.364	49.600	58.950
103.0	354.610	324.387	51.200	60.300
104.0	357.640	327.421	51.200	60.300
105.0	360.615	330.398	51.200	61.400
106.0	363.535	333.319	51.200	61.400
107.0	366.445	336.186	51.200	61.850
108.0	369.510	338.999	51.200	63.200
109.0	372.560	341.861	51.200	64.150
110.0	375.735	344.708	51.200	66.050
111.0	378.970	347.504	51.200	66.050
112.0	382.135	350.380	51.200	66.950
113.0	385.255	352.709	51.200	66.950
114.0	388.455	355.987	51.200	67.600
115.0	391.605	358.718	51.200	67.600
116.0	394.770	361.401	51.200	69.100
117.0	397.960	364.039	51.200	69.100
118.0	401.100	366.825	51.200	69.100
115.0	404.180	369.642	51.200	69.100
120.0	407.225	372.441	52.700	70.450
121.0	410.330	375.493	52.700	70.450
122.0	413.385	378.554	52.700	70.450
123.0	416.495	381.610	54.200	71.800
124.0	419.570	384.694	54.200	71.800
125.0	422.600	387.728	55.800	72.550
126.0	425.575	390.844	55.800	72.550
127.0	428.510	393.918	55.800	72.550

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128.0	431.485	396.940	57.300	73.900
129.0	434.565	400.201	57.400	74.700
130.0	437.655	403.507	60.400	76.700

Note: (1) For any other combination/ Vehicle to be permitted on the metro system, its EUDL for vertical load as well as longitudinal force (LF) shall be worked out and compared with design EUDL & LF given in table above.

(2) When loaded length lies between the values given the table above, the EUDL for Bending Moment and shear can be interpolated.

(3) When loaded length lies between the values given in the Table, the tractive effort or braking force shall be assumed as that for the longer loaded length.

(4) Impact Load to be considered separately.

Examined and found in order

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Project Directorate
Approved on
31/10/2023
Railway Board

Annexure-II DESIGN CODES AND STANDARDS

A.1 Indian Railway Standards (IRS)

IRS - Bridge Rules for Loading (Min. of Railways)

IRS - Code of Practice for Steel Bridges

IRS - Code of practice for Plain, Reinforced and Pre-Stressed Concrete for General Bridge Construction (IRS CBC)

IRS - Code of practice for the design of substructures and foundation of bridges.

IRS - Code for Earthquake resistant design of railway bridges (Seismic code)

A.2 Indian Roads Congress (IRC) Standards

IRC 5: 1998 Standard Specifications and Code of Practice for Road Bridges, Section I General Features of Design

IRC 6: Standard Specifications and Code of Practice for Road Bridges, Section II Loads and Stresses

IRC 10: Recommended Practice for Borrow pits for Road Embankments Constructed by Manual Operation

IRC 18: Design Criteria for Prestressed Concrete Road Bridges (Post-Tensioned Concrete)

IRC 19: Standard Specifications and code of Practice for Water Bound Macadam

IRC 21: Standard Specifications and Code of Practice for Road Bridges Section III–Cement Concrete (Plain and Reinforced)

IRC 22: Standard Specifications and Code of Practice for Road Bridges, Section VI – Composite Construction for Road Bridges

IRC 24: Standard Specifications and Code of practice for Road Bridges, Section V – Steel Road Bridges

IRC 36: Recommended Practice for the Construction of Earth Embankments for Road Works

IRC 37: Guidelines for the Design of Flexible Pavement

IRC 45: Recommendations for Estimating the Resistance of Soil below the maximum Scour Level in the Design of Well Foundations of Bridges

IRC 48: Tentative Specifications for Bituminous Surface Dressing using Precoated Aggregates

IRC 75: Guidelines for the Design of High Embankments

IRC 78: Standard Specifications and Code of Practice for Road Bridges, Section VII (Parts 1 and 2), foundations and Substructure

IRC 83: Standard Specifications and code of practice for Road Bridges, Section IX - Bearings Part I, II & III: Bearings (Metallic, Elastomeric and POT cum PTFE bearings)

IRC 87: Guidelines for the Design and Erection of False Work for Road Bridges

IRC: SP 11: Handbook of quality Control for Construction of Roads and Runaways

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A.3 Bureau of Indian Standards (BIS)

IS SP 7: 2005 National Building Code

IS 73: 1992 Paving Bitumen

IS 215: 1995 Road Tar

IS 217: 1988 Cutback Bitumen

IS 226: 1975 Structural steel (standard quality)

IS 269: 2015 33 grade Ordinary Portland Cement.

IS 278: 2009 Galvanised steel barbed wire for fencing

IS 280: 2006 Mild Steel wire for general engineering purposes

IS 281: 2009 Mild Steel sliding door bolts for use with Padlocks

IS 383: 2016 Coarse and fine aggregates from natural Sources for concrete

IS 432: 1982 Mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement

(Part 1) Mild steel and medium tensile steel bars

(Part 2) Hard-drawn steel wire

IS 455: 2016 Portland slag cement

IS 456: 2000 Code of practice for plain and reinforced concrete

IS 460: 1985 Test sieves

IS1905: 1987 Code of practice for Structural use of unreinforced Masonry

IS 1977: 1976 Low Tensile Structural steel (Superseded)

IS 2062: 2006 Steel for general structural purposes

IS 2090: 1983 High tensile steel bars used in prestressed concrete

IS 2116: 1980 Sand for masonry mortars (first revision)

IS 2119: 1980 Code of practice for construction of brick-cum-concrete composite

IS 2386: 1963 Methods of test for aggregate for concrete

(Part 1) Particle size and shape

(Part 2) Estimation of deleterious materials and organic impurities

(Part 3) Specific gravity, density, voids, absorption and bulking

(Part 4) Mechanical properties

(Part 5) Soundness

(Part 6) Measuring mortar making properties of fine aggregates

(Part 7) Alkali – aggregate reactivity

(Part 8) Petrographic examination

IS 2430: 1986 Methods of sampling of aggregate for concrete

IS 2502: 1963 Code of practice for bending and fixing of bars for concrete reinforcement

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IS 2751: 1979	Recommended practice for welding of mild steel plain and deformed bars used for reinforced construction
IS 2911: 2010	Code of practice for design and construction of pile foundations
(Part 1) Concrete piles	
Section 1 Driven cast –in-situ concrete piles	
Section 2 Bored cast-in-situ concrete piles	
Section 3 Driven precast concrete piles	
Section 4 Bored precast concrete piles	
(Part 3) Under-reamed piles	
(Part 4) Load test on piles	
IS 2950: 1981	Code of practice for design and construction of raft foundations
IS 3812: 2013	Flyash for use as pozzolanans and admixture
IS 3955: 1967	Code of practice for design and construction of well foundations
IS 4082: 1996	Recommendations on stacking and storage of construction materials at site
IS 4138: 1977	Safety code for working in compressed air
IS 4326: 2013	Earthquake resistant design and construction of buildings code of practice
IS 4656: 1968	Form vibrators for concrete
IS 4736: 1986	Hot-dip zinc coatings on mild steel tubes
IS 4826:1979	Hot-dipped galvanised coatings on round steel wires
IS 10379:1982	Code of practice for field control of moisture and compaction of soils for embankment and subgrade
IS: 12070 1987	Code of Practice for design and construction of shallow foundation on rocks
IS 12269: 2013	53 grade ordinary Portland cement
IS 12894: 2002	Fly ash lime bricks
IS 13920: 2016	Ductile detailing of Reinforced Concrete Structures subjected to Seismic Forces
IS 14268: 2017	Uncoated stress relieved low relaxation seven-ply strands for Pre-stressed Concrete
IS 14593: 1998	Design and construction of Bored cast-in-situ piles founded on Rocks-Guidelines

A.4 Foreign Standards

BS 410: 1986	Specification for test sieves
BS 812:	Testing aggregates
BS 1154: 1992	Specification for natural rubber compounds
BS 1137: 1990	Methods of test for soils for Civil Engineering purposes

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20

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BS 4447:1983	Specifications for the performance of prestressing anchorages for post-tensioned construction
BS 4486:	Specifications for High Tensile Steel bars used for Prestressing
BS 5400: 1990	Steel concrete and composite bridges
BS 5930 1981	Code of Practice for Site Investigations
BS 5950	Structural use of steel work in buildings
BS 6177: 1982	Guide to selection and use of Elastomeric Bearings for Vibration Isolation in Buildings
BS 8007: 1987	Code of Practice for Design of Concrete Structures for Retaining Aqueous Liquids
BS 8110	Parts I & II Structural use of Concrete – with load and materials strength factors as per IS:456-2000

Part 9 Section 9.1 Code of Practice for Design of Bridge Bearings

ASTM D-297	Methods for Rubber Product Chemical Analysis
ASTM D-395	Compression set of vulcanised rubber
ASTM D-412	Tension testing of vulcanised rubber
ASTM D-429	Adhesion of vulcanised rubber to metal
ASTM D-573	Accelerated ageing of vulcanised rubber by the oven method
ASTM D-624	Tear resistance of vulcanised rubber
ASTM D-797	Young's Modulus in flexure of elastomer at normal and subnormal temperature
ASTM D-1149	Accelerated Ozone cracking of vulcanised rubber
ASTM D-1559	Test for resistance to plastic flow of bituminous mixtures using Marshall apparatus
ASTM D-2166	Test methods for Unconfined Compressive Strength of Cohesive Soils
ASTM D-2172	Extraction, quantitative, of bitumen from bituminous paving mixtures
ASTM D-2240	Indentation hardness of rubber and plastic by means of a Durometer
ASTM D-2434	Test methods for permeability of Granular Soils
ASTM D-3080	Method for direct shear test of soils under consolidated drained condition
ASTM E-11	Specification for wire cloth sieve for testing purpose
AASHTO DM 57-80	Materials for embankments and subgrade
AASHTO DM 147-67	Materials for aggregate and soil (1980) base and surface courses
AASHTO DM 282-80	Joints sealments, not poured, elastomeric type, (ASTM: D 3406) for Portland cement cure rate pavements

Note: - The above list is not exhaustive and shall be augmented during detailed design and construction of the Viaduct.

A.5 Other Publications

Indian Standard Handbook on Steel Sections Part I

Ministry of Road Transport & Highway, Specifications for Road and Bridge Works

Indian Railways Manual on Design and Construction of well and pile foundations.

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UIC/772 – R The International Union of Railways Publication.

IEC International Electromechanical Commission

FIP Recommendations for the acceptance of Post-Tensioning Systems

MOST Specifications for Road and Bridge Works

The design relating to fire safety and escape shall be in accordance with the requirements of NFPA 130 Standard for Fixed Guideway Systems.

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

DESIGN AND CONSTRUCTION OF ELEVATED STATIONS

DESIGN BASIS REPORT (DBR)

CMRL PHASE II

MARCH 2023

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

Table of Contents

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Director Approved on 31/10/2023 Railway Board

1 INTRODUCTION

1.1 Brief Description of the Project

CMRL is a joint venture of Government of India and Government of Tamil Nadu. The Phase II project consists of three corridors which have both Underground and Elevated sections.

i. Corridor 3 – 45.80 km length from Madhavaram Milk Colony to SIPCOT via Perambur, Royapettah, Thiruvanmiyur and Sholinganallur.
ii. Corridor 4 – 26.10 km length from Light House to Poonamallee Bypass via Nandanam, Kodambakkam and Porur
iii. Corridor 5 – 47.00 km length from Madhavaram Milk Colony to Sholinganallur via Koyembedu, Virugambakkam, Mugalivakkam, Manapakkam, Alandur and Medavakkam.

Table-1 CMRL Phase II – Alignment details

List of Corridor	No of Stations	Alignment length in kms
Corridor - 3		
Underground	30	26.70
Elevated	20	19.10
Corridor - 4		
Underground	12	10.10
Elevated	18	16.00
Corridor - 5		
Underground	6	5.80
Elevated	42	41.20
Overall total	128	118.90

1.2 Scope

The DBR is only for structural design of Elevated Stations. Extended platform portion which is generally on single column or portal type of structure shall be designed as part of viaduct.

The structural elements connected to the member on which metro live loads are supported may also be designed with taking loads applicable as specified in "Design Basis Report (DBR) for Viaduct, CMRL Phase II". Load combination as per "Design Basis Report (DBR) for Viaduct CMRL Phase II" shall also be considered. Other structural elements such as secondary beams, stub columns etc, Entry/Exit Structures etc., maybe designed as per IS: 456:2000.

Structures, where Metro live loads are not applicable, the design of Plain and Reinforcement Concrete structures will generally be governed by IS:456. Pre-stressed concrete structures shall generally be governed by IS:1343, Steel structures design shall generally be governed by IS:800. Seismic design shall be governed by IS:1893.

1.3 Units:

The main units used for design shall be: [t], [m], [mm], [kN], [kN/m^2], [MPa], [°C], [rad]

2 DESIGN SPECIFICATIONS FOR STATION BUILDINGS

2.1 Materials

2.1.1 Cement:

For Plain and Reinforced Concrete structures cement shall be used as per clause 5.1 of IS:456 and Prestressed Concrete structures as per clause 5.1 of IS:1343.

2.1.2 Concrete:

As per clause 6, 7, 8, 9 and 10 of IS:456 in case of Plain and Reinforced Concrete structures and Clause 6, 7, 8, 9 and 10 of IS:1343 for Prestressed Concrete structures.

Short term Modulus of Elasticity (Ec) shall be taken as per clause 6.2.3.1 of IS:456 for Plain and Reinforced Concrete structures and IS:1343 for Prestressed Concrete structures.

Modular ratio for concrete grades shall be taken as per Annex B of IS:456.

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Density of concrete shall be as per IS:456.

2.1.3 Prestressing Steel for Tendons

As per clause 5.6.1 of IS:1343

2.1.3.1 Young's Modulus:
As per prestressing steel used in accordance with Para above.

2.1.3.2 Prestressing Units:
As per clause 13 of IS:1343.

2.1.3.3 Maximum Initial Prestress:
As per clause 19.5.1 of IS:1343

2.1.3.4 Density:
Weight of strands shall be as per relevant clauses of IS codes for material being used as indicated in para 2.1.3 above.

2.1.3.5 Sheathing
As per clause 12.2 of IS:1343.

2.1.4 Structural Steel
Structural steel used shall conform to

a) Hollow steel sections as per IS: 4923-1997
b) Steel for General Structural Purposes as per IS:2062.
c) Steel tubes for structural purpose shall be as per IS: 1161.

Note: (i) Grade of steel shall be indicated in report, shall not be less than minimum grade as applicable, based on whether structure is taking moving loads or not and relevant code as indicated in note (ii) and (iii) below.
(ii) Design of steel structure shall be as per IRS Steel Bridge code in case structure is taking moving loads of Metro, otherwise shall be as per IS 800. In case of composite (Steel – Concrete) structures it shall be as per IS:11384 & IS:3935.
(iii) Fabrication shall be done in accordance with IRS B1(Fabrication Code) in case structure is taking moving loads of Metro, otherwise shall be done as per IS: 800

2.1.5 Reinforcement
As per clause 5.6 of IS:456 for Plain and Reinforced Concrete structures and as per clause 5.6.2 of IS:1343 for Prestressed Concrete structures.
Note: For Seismic zone III, IV & V HYSD steel bars having minimum elongation of 14.5% and conforming to requirements of IS:1786 shall be used.

2.1.5.1 Reinforcement Detailing
All reinforcement shall be detailed in accordance with clause 12 and 26 of IS:456 for Plain and Reinforced concrete structures, as per clause 12.3 and 19.6.3 of IS:1343 for Prestressed Concrete structures. Ductile detailing for seismic resisting RC elements shall comply with ductile requirements of IS: 13920.

2.2 Durability
Durability of Concrete shall be as per clause 8.0 of IS: 456 for Plain and Reinforced Concrete structures, as per clause 8.0 of IS:1343 for Prestressed Concrete structures and Section 15 of IS:800 for Steel Structures.

2.2.1 Concrete Grades
The minimum grade of concrete for all structural elements including piles shall be M35.
The minimum grade of concrete for blinding layers and levelling courses shall be M15.

2.2.2 Cover to Reinforcement
As per clause 26.4 of IS:456 for Plain and Reinforced Concrete structures and clause 12.3.2 of IS:1343 for Prestressed Concrete structures. Cover to prestressing steel shall be in accordance with clause 12.1.6 of IS:1343.

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28

2.2.3 Fire Resistance period

All the structural elements in the station building shall be designed for a minimum fire resistance period of 2 hours. The minimum element thicknesses for this fire resistance shall be as per clause 21 of IS:456 for Concrete structures and as per Section 16 of IS:800 for Steel structures.

2.2.4 Crack Width Check

All structural concrete elements shall be designed to prevent excessive cracking due to flexure, early age thermal and shrinkage. Flexural crack width shall be checked in accordance with clause 35.3.2 and 43 of IS:456 for Plain and Reinforced Concrete Structures and clause 20.3.2 and 24.2 of IS:1343 for Prestressed Concrete structures.

2.3 Clearances

(i) Clearance for Road Traffic: As per relevant IRC specifications, Minimum Vertical Clearance of 5.50m as per Viaduct DBR CMRL Phase II.

(ii) Clearance for Railway Traffic: Indian Railways Schedule of Dimensions (SOD) shall be applicable..

(iii) Clearances for Metro Traffic: As per approved Schedule of Dimensions (SOD) of CMRL Phase II.

(iv) For utility services: The clearances to utilities, drainage etc shall be as mandated by the utility owner/ department.

2.4 Design Loads

Elementary Loads to be considered for design are:-

Dead loads (including notional loads)	DL
Superimposed Dead loads	SIDL
Train Live loads	LL
Earthquake Loads	EQ
Wind Loads	WL
Collision Load / Impact Loads / Derailment Loads	CL*
Construction and Erection Loads	EL
Temperature loads	OT
Shrinkage	S
Creep	C
Earth & Water Pressure	EP
Surcharge Loads (Traffic, building etc.)	SR
Pre-stress force	PR
Long Welded Rail Force	LWR
Differential Settlement	DS

*Loads as applicable shall be as taken

2.4.1 Dead Load (DL):

Dead load shall be based on the actual cross section area and unit weights of materials and shall include the weight of the materials that are structural components of Elevated Station and permanent in nature.

2.4.2 Superimposed Dead Load (SIDL):

Superimposed dead loads include all the weights of materials on the structure that are not structural elements but are permanent.

***2.4.2.1* SIDL1 (Fixed SIDL or Non-variable SIDL):**

Rail Plinth, Precast Parapet and roof structure will be considered as Dead Load for the purpose of analysis of structures. The weight of the rail plinth and parapet will remain same throughout the life of the structure. This is incorporated in the maintenance manual of CMRL.

Examined and found in order

Director/UT/Civil/RDSO

IASH, DD/PROJECT(AV), DD/PROJECT, Project Directorate on 31/10/2023 11:13 am

Project Directorate Railway Board — Approved on 31/10/2023

2.4.2.2 SIDL2 (Variable SIDL):

The following items shell be considered as variable SIDL
Rails + pads
Third rail & fixtures
Hand rail
Cables
Cable trough cell
Cable trays
Miscellaneous (OFC, Signaling etc.).

2.4.3 Imposed (Crowd Live Load):

Imposed loads on station buildings are those arising from occupancy and the values include normal use by persons, furniture and moveable objects, vehicles, rare events such as concentrations of people and furniture, or the moving or stacking of objects during times of re-organisation and refurbishment, this shall be as per clause 19.3 of IS:456.

2.4.4 Earthquake Load:

Earthquake design shall follow the seismic requirements of IS: 1893 (Part-I). The provision as per Design Basis Report for Viaduct of CMRL Phase II shall be followed where structures are taking moving loads of metro.

2.4.4.1 Drift Limitation

The storey drift in the building shall satisfy the drift limitation specified in cl.7.11.1 in IS 1893.

2.4.4.2 Seismic Detailing

(i) For reinforced concrete structures as per IS: 13920
(ii) For other structures as per IS: 4326

2.4.5 Wind Load

The wind load shall be calculated as per IS:875 Part -3.

2.4.6 Collision/Impact Loads/Derailment Loads

(i) For road traffic as per IRC 6
(ii) For metro as per IRS Bridge Rule.

2.4.7 Construction and Erection loads

The weight of all temporary and permanent materials together with all other forces and effects which can operate on any part of structure during erection shall be taken in to account. Allowances shall be made in the permanent design for any locked in stresses caused in any member during erection.

2.4.8 Temperature

As per clause 19.5 of IS: 456, Temperature gradient shall be considered as per Clause 215 of IRC: 6, if applicable.

2.4.9 Shrinkage

The shrinkage strains shall be evaluated as per clause 6.2.4 of IS:456 for Plain and Reinforced Concrete structures and clause 6.2.4 of IS:1343 for Prestressed Concrete structures.

For structure supporting Metro train loading the effects of Shrinkage as per Clause 5.2.3 of IRS CBC. shall be considered.

2.4.10 Creep

The creep strains shall be evaluated as per clause 6.2.5 of IS:456 for Plain and Reinforced Concrete structures and clause 6.2.5 of IS:1343 for Prestressed Concrete structures.

For structure supporting Metro loading the effects of creep as per Cl. 5.2.4 of IRS CBC shall be considered.

2.4.11 Earth & Water Pressure

In the design of structures or parts of structures below ground level, such as retaining walls and underground pump room / water tank etc, the pressure exerted by soil or water, or both shall be duly accounted for. When a portion or whole of the soil is below the free water surface, the lateral earth pressure shall be evaluated for weight of soil diminished by buoyancy and the full hydrostatic pressure (as per IS: 875 Part 5).

All foundation slabs / footings subjected to water pressure shall be designed to resist a uniformly distributed uplift equal to the full hydro static pressure. Checking of overturning of foundation under submerged condition shall be done considering buoyant weight of foundation.

If any of the structure supporting Metro loading is subjected to earth pressure, the loads and effects shall be calculated in accordance with Clause 5.7 of IRS Substructure Code.

2.4.12 Surcharge Load

In the design of structures or parts of structures below ground level, such as retaining walls and underground pump room / water tank etc, the pressure exerted by surcharge from stationary or moving load, shall be duly accounted for.

2.4.13 Pre-stressing Force (PR)

The Prestressing force shall be as per IS:1343.

2.4.14 Long Welded Rail Force

Long welded rail force shall be followed as per Guidelines vide BS Report No 119 "RDSO guidelines for carrying out Rail-structure interaction studies on Metro System (Version – 2)".

2.4.15 Settlement

Maximum and differential settlement shall not exceed, as provided in Table 1 of IS:1904.

2.4.16 Other Forces and Effects:

As per Clause 19.6 of IS:456.

2.5 Design Load Combinations

2.5.1 Ultimate Load Combinations

Each component of the structure shall be designed and checked for all possible combinations of applied loads and forces. They shall resist effect of the worst combination. Following shall be considered:

(i) Load combinations and factors as per Table 18 of IS: 456 for Plain and Reinforced Concrete Structures.
(ii) Load combination and factors as per Table 7 of IS:1343 for Prestressed Concrete Structures.
(iii) Load combination as per Section 3 and factors as per Section 5 of IS: 800 for Steel Structures.
(iv) Load combination as per clause 6.3 of IS:1893 (Part-I).
(v) Load combinations as per IRS CBC and Seismic code for Earthquake resistant design of Railway Bridges (First revision 2020) by RDSO, where Metro live loads are applicable.

Note: (i) Load combination for construction load case shall be decided by CMRL as per methodology of construction.
(ii) Reference of IRC:6 be taken for collision case if collision of road vehicles is involved.

2.5.2 Serviceability Load Combinations

The following load combinations and load factors shall be used for design for serviceability limit state:

(i) Load combinations and factors as per Table 18 IS: 456 for Plain and Reinforced Concrete Structures.
(ii) Load combination and factors as per Table 7 of IS: 1343 for Prestressed Concrete Structures.
(iii) Load combination as per Section 3 and factors as per Section 5 of IS: 800 for Steel structures.
(iv) Load combinations as per IRS CBC and Seismic code for Earthquake resistant design of Railway Bridges (First revision 2020) by RDSO, where Metro live loads are applicable.

Examined and found in order

Director/UT/Civil/RDSO

2.6 Deflection Criteria

The deflection limitations as per clause 23.2 of IS: 456 for Plain and Reinforced Concrete Structures and clause 20.3.1 of IS: 1343 for Prestressed Concrete Structures shall be followed.

2.6.1 Lateral Sway

The lateral sway at the top of the building due to wind loads should not exceed H/500, where H is the height of the building.

2.7 Fatigue Check

Fatigue phenomenon needs to be analysed only for those structural elements that are subjected to repetition of significant stress variation (under traffic load). Fatigue checks for

(i) **RCC and PSC structures** – As per clause 13.4 of IRS CBC.

(ii) **Steel Structures** –

(a) In case of Metro live loads, as per clause 3.6 of IRS Steel Bridge Code shall govern. If λ* values are to be used, the train closest to the actual train formation proposed to be run on the metro system shall be used. Otherwise, detailed counting of cycles shall be done.

(b) For other cases as per Section 13 of IS:800.

* Damage equivalence factors (As per IRS Steel Bridge Code).

2.8 Foundations

2.8.1 Types of Foundation

Considering the nature of ground, type of proposed structures, expected loads on foundations, the following type of foundations are considered practical.

a) Spread or pad footing.
b) Raft foundation
c) Pile foundation

No matter the type of foundation to be adopted, the following performance criteria shall be satisfied:

1) Foundation must not fail in shear.
2) Foundation must not settle by more than the settlements permitted as per Table-1 of IS:1904.

2.8.2 Design of Pile

IS 2911 shall be followed for design of pile, load capacity etc.,

Pile Settlement

Methods of estimating the settlement of deep foundations depend upon the type of deep foundation and the manner of transfer of loads from the structure to the soil. Theoretical estimation of settlement shall be done in accordance with IS 8009 (Part II), by integrating the vertical strain for the entire depth of soil and rock formation.

The settlement of each pile and / or pile group should be determined, and it should be demonstrated that such total and / or differential settlement can be tolerated by the structure.

2.8.3 Foundations

IS:1904 shall be followed for design of foundations in soil. The safe bearing capacity for shallow foundations shall be calculated in accordance with IS: 6403.

Computation of Settlements of Foundations

The calculation for settlement of foundations shall be done as per:

- IS:8009 Part-1 for shallow foundations
- IS:8009 Part-2 for deep foundations

2.9 Design of Water Retaining Structure

It should be designed as per IS: 3370.

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3 LIST OF DESIGN CODES AND STANDARDS

The designs of Station Buildings shall be carried out as per provisions of this Design Basis Report. Reference shall be made to the following codes for any additional information.

Order of preference of codes shall be as follows;

i. IS
ii. IRS
iii. IRC
iv. BS or Euro Code
v. AASHTO

The latest version of the codes with latest correction slip to be used.

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CMRL PHASE 2

DESIGN BASIS REPORT (DBR)

FOR

UNDERGROUND BORED TUNNELS

(MARCH 2023)

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

Table of Contents

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1 INTRODUCTION

1.1 Brief Description of the Project

CMRL is a joint venture of Government of India and Government of Tamil Nadu. The Phase II project consists of three corridors which have both Underground and Elevated sections.

i. Corridor 3 – 45.80 km length from Madhavaram Milk Colony to SIPCOT via Perambur, Royapettah, Thiruvanmiyur and Sholinganallur.

ii. Corridor 4 – 26.10 km length from Light House to Poonamallee Bypass via Nandanam, Kodambakkam and Porur

iii. Corridor 5 – 47.00 km length from Madhavaram Milk Colony to Sholinganallur via Koyembedu, Virugambakkam, Mugalivakkam, Manapakkam, Alandur and Medavakkam.

Table 1 CMRL Phase II – Alignment details

S. No.	Corridor	No. of Stations	Alignment length in km
(1)	**Corridor - 3**		
	Underground	30	26.70
	Elevated	20	19.10
(2)	**Corridor - 4**		
	Underground	12	10.10
	Elevated	18	16.00
(3)	**Corridor - 5**		
	Underground	6	5.80
	Elevated	42	41.20
	Overall total	**128**	**118.90**

2 SCOPE OF DBR

The scope of this DBR is for Bored Tunnels by TBM. The design basis report hereto provides minimum standards that are to govern the design. The Design Basis Report shall be read in conjunction with the Outline Construction Specifications where appropriate.

The design of the permanent and temporary supporting works shall comply with code of practice and standards listed in S.No.12 below, regulations made and the requirements issued by the Indian Government and by related utility authorities shall be followed and specified.

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3 MATERIALS

3.1 Cement

1) Ordinary Portland cement (OPC) of 33 grade, 43 grade and 53 grade conforming to IS:269, IS:8112-1989 and IS:12269-1987, respectively, shall be used.
2) Portland pozzolana cement (PPC) conforming to IS:1489 may also be used.
3) The Engineer may give notice for the usage of sulphate-resistant Portland cement conforming to IS:12330 for structural elements exposed to soil.
4) For foundation and substructure, the Engineer may direct the OPC substitution by Blast Furnace Slag Cement confirming to IS:455.

3.2 Concrete

1) The Density of concrete adopted shall be as below:
   a) 24kN/m^3 for Prestressed concrete (IS:875 Part-1 Table-1 Item-21, value rationalized).
   b) 24kN/m^3 for Reinforced concrete with 2% or less reinforcement (IS: 875 Part-1 Table-1 Item-22, value rationalized).
   c) 25kN/m^3 for Reinforced concrete with above 2% reinforcement (IS: 875 Part-1 Table-1 Item-22, value rationalized).
   d) 23kN/m^3 for Plain concrete (IS: 875 Part-1 Table -1 Item-20).
2) Short term modulus of elasticity 'Ec' & Modular Ratio 'm' shall be as per Clause No. 6.2.3.1 & Annex B-1.3 (d) of IS:456 respectively.
3) Minimum grade of concrete shall be M35.
4) Thermal Expansion Coefficient: 1.17×10^{-5}/°C (Clause No.2.6.2 IRS Bridge Rules).
5) Poisson's Ratio: 0.15 for all concrete.
6) Minimum cement content and Maximum Water-Cement ratio as per Table 5 of IS: 456.
7) Strength of concrete is the specified characteristic compressive strength of 150 mm cube at 28 days.
8) Minimum concrete cover as per IS: 456.

3.3 Reinforcement

Only Thermo-Mechanically treated reinforcement bars conforming to IS:1786 shall be adopted. (For seismic zone III, IV & V, with minimum total elongation of 14.5%).

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3.4 Structural Steel: General

1) Design of Structural steelwork shall comply with IS: 800.
2) Two types of structural steel to be used and shall comply with the following standards:
   a) IS:4923 "Hollow steel sections for structural use with Y_{st} 310".
   b) IS:2062 "Steel for general structural purposes (Grade B-Designation 410-B)".
3) Hollow steel sections shall be square (SHS) or rectangular (RHS). Other traditional rolled sections like plates, angles, channels, joists can also be used, where required.
4) The connection with concrete shall be affected by internally threaded bolt sleeves (hot dipped galvanized @ 300 grams per square metres), manufactured from IS:2062, Grade B, mild steel. The sleeve shall receive hexagon-head bolt M20, Class 8.8, as per IS:1364 (Part 1) with galvanized spring washer.
5) The connections within the steel structure shall be designed as direct welded members with or without gusset plates. The minimum thickness of metal for SHS / RHS sections for main chord members as well as bracings shall be 4 millimetres as applicable for steel tubes in Clause. 6.3 of IS: 806.

3.4.1 Material Properties

Material properties shall be as follows:

Table 2

Steel Type	Young's Modulus	Tensile Strength	Yield Strength	Density	Poisson's Ratio	Thermal Expansion Coefficient
For Hollow Steel Sections (Conforming to IS:4923)	200,000 Mpa	450 Mpa	310MPa	78.5 kN/m^3	0.3	1.2x10^{-5} per °C
Structural Steel (Conforming to IS:2062)		410 Mpa	250MPa(for t<20mm), 240MPa(for 20mm<t<40 mm), 230MPa(for t>40mm)			

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4 TUNNEL PROFILE, CONSTRUCTION METHODS

The bored tunnels comprise twin single-track tunnels. The spacing between the tunnels shall be based on the soil strata and determined by numerical analysis. The minimum internal diameter for bored tunnel shall meet all Services and SOD (Schedule of Dimensions) requirements. Bored tunnels in rock and soil will be excavated mainly using tunnel boring machines. Other methods, if required based on geological and hydrological condition to be decided. Initial tunnel support will generally include precast concrete segments, shotcrete / wire mesh, rock bolts, lattice girders, steel sets, or forepoles, wherever necessary.

5 DESIGN LIFE/ DESIGN SPECIFICATIONS/ REQUIREMENTS/ PRINCIPLES

5.1 Design Life

Design life is to be kept minimum 100 years.

5.2 Tunnel Design

1) The design of the bored tunnel shall be fully compatible with the construction methodology and shall be carried out using suitable software.
2) The design shall also consider all expected loads prescribed in Item No.6.
3) The design shall consider all additional loads, stresses and strains imposed by or on adjacent Existing Building Structures (EBS) and assumed distortions and loads by or on the proposed bored tunnels.
4) Where bored tunnels are adjacent to or beneath EBS, the design shall demonstrate that these EBS shall not be subjected to unacceptable movement, distortion or loss of support which endangers the stability of the EBS and that any resulting movements and distortions will be within prescribed limits determined by the authority for that EBS, the Engineer, or the Owner.
5) The Designer shall ensure that ground movements and distortions, and changes to the loads and piezometric pressures which may affect adjacent EBS either at surface or underground, are within the allowable tolerances for each of those EBS.
6) The design shall consider and minimise the short and long-term influence of the bored tunnels on the groundwater regime and similarly the influence of the groundwater on the bored tunnels.

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7) During tunnelling, Designer to constantly review the ground conditions based on envisaged and actual condition encountered, to allow excavation to be carried out in the safest and most efficient manner. This review shall be fully integrated into the construction risk control and should typically include:
   a) Probing ahead of and around the bored tunnel face in rock conditions.
   b) Interpretation of fresh data and correlation with previous information.
   c) Prediction of ground conditions likely to be encountered.
   d) Investigation on the surface for the presence of water wells / bore wells for domestic use in residential areas that intersect the alignment.
8) Ground information from all construction activities shall be collated and interpreted.

5.3 Tunnel Lining segment

1) The design of the segments shall be adequate for all stresses induced during stacking, lifting, transport, erection jacking and impact, including in-service stress & impact.
2) The design shall consider in-situ ground stresses and shall provide evidence and / or measurements in support of the parameters adopted in the design as part of the calculations. The ground load on the tunnel shall be based on the actual height of overburden above the tunnel lining and the coefficient of earth pressure at rest of the soil strata surrounding the tunnel.
3) The design of the bored tunnel linings shall take into account the proximity of the bored tunnels one to another, the sequence and timing of construction and the proximity of adjacent EBS.
4) The design shall also consider the relative rates of loading / unloading due to TBM jacking force in both the lateral and vertical directions and the resultant induced tunnel deformations whether temporary or permanent.
5) The segment has to be designed for 4hour fire rating as per IS:456.
6) The design method shall take into account the interaction between the lining and the ground, the deflection of the lining and the redistribution of the loading dependent upon the relative flexibility of the lining, the variability and compressibility of the ground.
7) The designer shall consider and conform to all durability aspects of the permanent bored tunnel lining including permeability / transmissivity and electrical resistivity.

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Project Directorate Approved on 31/10/2023 Railway Board

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8) The design shall take into account the proximity of the lining to the tunnel face at the time of installation and the potential for additional ground loads as the face advances.
9) The design shall allow for the expected variation in ground conditions and the size, proximity, timing and method of construction of adjacent excavations. The lining flexibility shall make due allowance for likely deflection of the lining during construction and operation.
10) Where a permanent or secondary lining is to be installed inside a temporary or primary lining, the ground loads used in permanent lining design shall consider all loads as described in the contract and any additional ground loads that may arise from time-dependent ground strains.
11) The stiffness of the permanent lining should be such that the deflections are within permissible limits as per BS: 8110, Part-1 and IS:456.
12) The thickness of segments shall suit the method of construction and shall not be so large that part shoving of the shield becomes a general necessity.
13) The thickness of the segments shall be consistent with the capacity of the circle bolting arrangements to withstand the shear forces induced in linings built with staggered joints and for the planned reinforcement and required concrete cover.
14) A groove for a single elastomeric gasket shall be provided on all joint faces of each segment and key in accordance with the gasket dimensions. The elastomeric gasket shall be suited to the conditions under which it is required to operate for the design life. The gasket grooves shall allow for accurate mating of the gaskets of adjacent segments.
15) A groove for post-construction grouting / caulking as necessary shall be provided on the intrados for each segment joint.
16) The lengths of segments shall be chosen with regard to bending stresses during handling, storage and erection and the long term stresses due to ground loading and the resultant deflections.
17) The design of linings shall include tapered rings in order to negotiate the alignment curvature and to correct for line & level during construction with the minimum use of circumferential joint packers, consistent with attaining the required degree of water-tightness of the bored tunnels in accordance with the contract.

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Project Directorate Approved on 31/10/2023 Railway Board

18) The design for segment lining shall address aspects including the following, as appropriate

   a) Ring configurations.
   b) Segment size and form.
   c) Fixing details including for:
      - Ring to Ring fixings.
      - Segment to Segment fixings.
      - Fixings for all equipment to be installed.
      - Handling, stacking and installation of segments.
      - Holes, recesses and fixtures for other system components.
   d) Tolerances in production and installation of segments shall be accounted in the design.
   e) Installation of components, such as:
      - Grout hole valves.
      - Gaskets.
      - Bedding and packing materials.
   f) Cavity grout between lining and ground.
   g) Instrumentation and monitoring to demonstrate performance of the installed linings.
   h) Short-term(during construction),Intermediate(immediately after construction) and long-term (full design life) loading conditions.
   i) Stresses induced by grouting and ground pre-treatment, where applicable.

6 DESIGN LOADS AND LOADING CONDITIONS

6.1 Loads

Linings shall be designed to withstand all environmental loadings, distortions and other effects without detriment. In general, bored tunnel linings shall be designed to fulfil the following requirements and to resist the following loads:

a) Dead Load
b) Superimposed surface loads from traffic, existing structures over and adjacent to the bored tunnel and any specified future loads
c) Appropriate ground loads, water pressure and seismic loads
d) Railway loads where appropriate
e) Long-term and Short-term ground yield or squeeze
f) Unequal grouting pressures
g) Adjacent bored tunnelling or excavation

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Project Directorate Approved on 31/10/2023 Railway Board

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

h) Long-term or Short-term loads induced by construction

i) Temperature and shrinkage

j) Handling loads, including impact, especially in the case of unreinforced segments

k) Jacking forces, where appropriate

l) Accidental loading, such as fire and derailment

6.2 Loading Conditions

a) Dead load comprises the self-weight of the basic structure and secondary elements supported and the weight of earth cover. The depth of cover shall be the actual depth or minimum one diameter of tunnel. The depth of cover shall be measured from the ground surface to the tunnel crown.

b) Traffic surcharge shall be as per the loading of IRC / IRS as applicable.

c) Loads from existing or known future adjacent structures above or within the area of influence, which will remain in place above the bored tunnels or any specified future loading. The applicable foundation load and its influence shall be computed based on the type and use and the foundation type, which supports that structure.

d) Additional support, ground treatment or additional lining thickening shall be provided, unless it can be shown that adequate provision already exists. Any structure surrounding tunnel should be supported by grouting and shotcreting techniques and should not be supported from tunnel lining.

e) Where provision for a specific future structure is not made, a minimum uniformly distributed surcharge of 60kPa at the design finished ground level shall be assumed.

f) Hydrostatic pressure, ignoring pore pressure relief arising from any seepage into the tunnel. Water at ground level to be considered for design.

g) Loads and load changes due to known construction activity to the vicinity of the bored tunnel, such as the excavation and the formation of underpasses, basements, pile groups, bridges, diaphragm walls and cable ground anchors.

h) The grouting pressure will not exceed the hydrostatic pressure by more than 1 bar, However the actual pressure will be decided by the Engineer based on the geological conditions.

i) Structural requirements for resisting buckling is to be checked since tunnel is being designed as compression member.

j) Additional loads / stresses in adjacent rings due to openings at cross passage locations to be considered.

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Project Directorate Approved on 31/10/2023 Railway Board

Director/UT/Civil/RDSO

6.3 Floatation

For floatation check, the water table is assumed to coincide with the ground level. Where the bored tunnels are relatively shallow, they shall be checked for the possibility of flotation due to differential water pressure at representative typical locations. Uplift due to displaced water to be considered in the design. The overall factor of safety against flotation shall not be less than 1.1 for any of the conditions.

6.4 Crack Width

All structural concrete elements shall be designed to prevent excessive cracking due to flexure, early age & long-term thermal shrinkage. Flexural crack width shall be checked in accordance with Appendix-F of IS:456. The limits specified in Clause.35.3.2 of IS:456 has to be followed.

6.5 Load cases, Load factors and combinations

All analysis shall clearly show the designs achieve the design factors of safety.

6.5.1 Load Cases

The following load cases will be considered at each design section:

1. Load Case-1: Ground water table at the ground surface with uniform surcharge of 60kN/m^2.
2. Load Case-2: Ground water table at the ground surface with no surcharge.
3. Load Case-3: Ground water table at 3m below existing ground water level with uniform surcharge of 60kN/m^2.
4. Load Case-4: Ground water table at 3m below existing ground water level with no surcharge.
5. Load Case-5: Ground water table at extreme water level with no surcharge.

6.5.2 Load factors and combinations

The design forces will be derived based on the following load factors based on IS 456-2000, BS 8110-Part 1 -1997 and Hong Kong DSM Section 4-2009

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Table 3

Load factors

Load Case	Dead Load	Hydro Static Pressure	Earth Pressure	Surcharge Load
Load Case-1	1.4	1.4	1.4	1.4/1.5/1.6#
Load Case-2	1.4	1.4	1.4	-
Load Case-3	1.4	1.4	1.4	1.4/1.5/1.6#
Load Case-4	1.4	1.4	1.4	-
Load Case-5	1.4	1.4*	1.4	-
Serviceability	1.0	1.0	1.0	1.0

- If Surcharge load is taken as per British Standards, then load factor should be 1.6

- If Surcharge load is taken as per Indian Standards, then load factor should be1.5

- For Special cases of conservative surcharge load (such as future flyover construction etc.), load factor of 1.4 can be adopted.

* - Load factor for extreme water table (flooding case) can be reduced to 1.0

Serviceability -Water level for serviceability is to be at ground level.

7 GENERAL CONSTRUCTION METHODS

1) Initial ground support for the bored tunnels is expected to comprise ground pre-treatment (where necessary) and / or precast concrete segments.

2) Methods for excavation, spoil removal, ground treatment, installation of initial support and the permanent lining construction to be prepared.

3) Excavation shall be carried out in a uniform and controlled manner, over-cutting shall be kept to a minimum.

4) Appropriate methods and necessary steps to be taken to control flows and movement into and to maintain the stability of the excavation.

5) Instrumentation and monitoring arrangements for ground and existing building structures (EBS) movement & distortion and changes to the groundwater table(s) and the trigger (Alert, Action & Alarm) levels for each and every identified EBS to be performed. Designer has to specify the required instrumentation and monitoring arrangement to maintain the safety of the EBS.

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Project Directorate Approved on 31/10/2023 Railway Board

7.1 Tunnel Lining — General

7.1.1 Tunnel Lining - Temporary Support

1) Steel sets and lattice arch girders shall be rolled to suit the dimensional requirements of the designed opening. The Contractor shall provide dimensional details of the steel sets or lattice arches girders and lagging which include all calculations regarding imposed loads before and after any ground pre-treatment.

2) Spiles shall be steel rods or tubes of outside diameter not less than 25 millimetres.

3) Pipe piles shall be steel tubes of outside diameter not less than 100 millimetres.

4) Rock dowels shall be untensioned steel bars threaded at one end and provided with a face plate, shim plates and a conical seated washer and nut, or split or deformed steel tubes, or glass fibre reinforced resin rods.

5) Rock bolts shall be tensioned bar manufactured out as one of the following types - solid steel bar, slit or deformed steel tube, glass fibre reinforced resin rods.

6) Alternative materials shall be subject to the notice of the Engineer.

7.1.2 Tunnel Lining - Permanent Support

1) The permanent bored tunnel support or lining comprise segmental precast concrete (plain or reinforced) rings that are held securely in place and the same will remain so for all known possible future conditions.

2) Exceptions to these permanent linings may be at cross-passages (links between tunnels), enlargements of the bored tunnel and at the junction between cut-and-cover and bored tunnel sections. In such locations cast-in- place linings shall be used, or alternative types of permanent lining may be proposed subject to the notice of the Engineer.

3) The reinforcement for segmental concrete lining shall be detailed such that there is no electrical continuity across the circle joints. To prevent the stray current effects and to inhibit the corrosion, suitable property enhancers shall be added into concrete. Such concrete shall be tested in accordance with ASTM C 1202 and DIN 1048. All concrete reinforcement shall be bonded to mitigate stray currents. The bonding shall be part of the corrosion control system designed and installed by the Contractor to the notice of the Engineer. The corrosion control system shall be tested and proven to the satisfaction of the Designer that the corrosion control system functions as designed in all locations.

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7.1.3 Gasket Grooves

Gasket grooves shall be provided around all joint faces of each segment and key, in accordance with the dimensions as approved by the Engineer-in-Charge. The design shall incorporate sealing gaskets in the segmental design.

7.1.4 Grout holes

Grout holes shall be provided in segment as per design, excluding the key.

7.1.5 Waterproofing

Suitable waterproofing materials and methods shall be used to meet the service requirements.

7.1.6 Cavity grouting

General purpose cement grout with suitable admixture shall be mixed in accordance with the proposed design mix and purpose of use. Grout shall be used within one hour of mixing.

7.2 Underpinning of Existing Structures

Where the construction of tunnels or other underground works would necessitate removal of existing support or foundations to existing structures, the Designer shall carry out investigations of the extent of the existing works, their design and loading conditions and propose a suitable supporting / underpinning arrangement, whereever is applicable.

8 CROSS-PASSAGES

1) Where tunnelling is carried out not using TBM (i.e., by hand or face excavator) temporary support using pipe piles, spiles, structural-steel sets, lattice-arch girders, baseplates, ties & connections and lagging, sprayed concrete (shotcrete) or cast-in-place concrete, all of which complying with the relevant standards, may be used together with appropriate ground pre-treatment as deemed necessary, for the expected ground conditions
2) Passenger emergency evacuation design for cross-passages between running tunnels which are constructed by either cut-and-cover or bored method shall generally be in accordance with the requirements of NBC 2016 Part -4 Fire and Life Safety as follows.

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a) Within enclosed trainways, the maximum distance between emergency exits / exit stairways shall not exceed 750m. For trainways in twin bore tunnels or trainways in a tunnel divided by a minimum 120 min fire rated wall separation, cross-passageways shall be permitted to be used in-lieu of emergency exit stairways.
b) The distance between cross passages in the tunnel shall be provided as per clause K-4.1.5 of NBC 2016.
c) Track cross overs shall not be considered as cross passages.

3) The openings into the running tunnels shall have a width of 1.2m and a height of 2.1m. Throughout the cross-passage, the minimum headroom of 2.1m shall be maintained over a width of 1.2m.
4) The cross-passage floor screed shall be laid to fall and drain into the running tunnel drainage system. Floor level shall correspond with the level of the bored tunnel escape route.
5) A concrete bulkhead fitted with steel door and frame shall be constructed to isolate the cross-passage from each running tunnel. This door shall be self-latching, have a fire resistance of 2 hours minimum and shall be capable of withstanding the maximum differential pressures on either side created by the passage of trains. The maximum force to open the door shall be as per NFPA 130 2010 6.2.2.4.2.
6) The cross-passage permanent lining shall comprise concrete lining designed generally in accordance with the requirements of these documents with the following exception that the maximum allowable deflection on radius shall be as per IS:456 clause 23.2(b).
7) The junctions with the running bored tunnels shall be steel-framed and encased with concrete. The junctions shall be designed to fully support the running tunnel linings at the openings together with the ground and groundwater loads on the junction itself.
8) The cross-passages and junctions shall comply with same water-tightness criteria as the bored tunnels.
9) Where openings for cross-passages and the like are to be formed in running tunnels with segmental concrete, temporary internal supports to the running tunnel lining shall be provided. These supports shall adequately restrain the ground and lining such that on completion of the opening and removal of the temporary supports the total deflection of the linings in either the opening, junction or running tunnel and water ingress do not exceed the limits.

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9 TUNNEL WALKWAYS

(1) Track level Walkways to be designed as per approved SOD

(2) The Escape way shall provide continuous access from the trains to the cross-passages and/or station platforms.

10 TUNNEL BORING MACHINES

The TBM shall be robust with adequate safety margins for the anticipated duty, designed and manufactured to comply with all safety standards. The TBM procured must be capable of efficient excavation and installation of support within the expected site and ground conditions. This includes soil, rock, soil / rock mixture and existing EBS (notably wells), all mainly below the groundwater table.

General design requirement of TBM as follows.

a) TBM design shall ensure that the cutter-head can be retracted back from the unexcavated ground to minimise the risk of the TBM jamming and to facilitate maintenance.

b) TBM design shall make adequate provision for the safety of the workmen and the application of safe methods of tunnelling.

c) TBM shall be designed for and equipped with a supplemental ground stabilisation system. This system shall comprise regularly spaced grout ports built into the shield for drilling into and grouting the ground ahead of the tunnel face. The location and number of ports shall be adequate for implementation of face stabilisation measures needed for access to the face in all ground conditions. All ports shall be readily accessible and fitted with valves.

d) TBM shall be designed to enable the void between the segment lining and the ground (tunnel extrados) to be grouted continuously from the shield as the shield is propelled forward by synchronised operation. TBM design shall allow control of the grouting volume, pressure and pipes to be cleaned in the event of a blockage. Grout pipes shall be integral within the thickness of the TBM tail skin. A minimum of four (4) separate grout pipes shall be provided. External grout pipes will not be permitted.

e) The TBM shall be designed to maintain a pressure on the excavated ground at all times. This pressure shall at-least balance the in-place soil and hydraulic pressures making up the total overburden pressure and shall be capable of varying the face pressure as the overburden pressure changes. The design shall also take into account the soil type, density, gradation, strength and abrasion.

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11 DRAINAGE ARRANGEMENT IN RUNNING TUNNEL

1) The Designer shall coordinate with the adjacent station plumbing design before finalising the design for drainage arrangement and sump location.

2) The reserve capacity of a groundwater seepage sump shall be calculated on the basis of the area of bored tunnel lining applicable to the sump in accordance with the following formula.

$$V_R = A * v * t * F.O.S. * 10^{-3}$$

Where,

V_R = Volume of reserve, m^3

A = Bored tunnel lining area, m^2

V = Maximum leakage rate, litres/m^3/day

T = Maximum response time, (day)

F.O.S = Factor of Safety

3) For running tunnel low point sumps, the response time "t" shall be 24 hours and the factor of safety shall be 1.5.

4) The sump design shall include outlets for the longitudinal drain pipe and discharge mains, pumps of suitable capacity and power connection. Sumps shall be fitted with steel covers and provided with step irons or access ladder. Permanent discharge mains shall be installed as well as embedment of conduits for permanent electric power cables to the pumps.

5) The linings of the sumps shall be designed for the appropriate ground and groundwater loads.

12 LIST OF DESIGN CODES AND STANDARDS

Subject to the requirements of this specification and other Control documents, all design work shall comply with the appropriate current standards issued by the Bureau of Indian Standards (BIS), or if such a standard does not exist, then the appropriate current standard issued by the British Standard Institute (BSI). If appropriate standard from BIS and BSI does not exist, then subject to approval by Engineer, an appropriate current standard from a reputable Institution may be used.

The designer shall follow updated codes with latest correction slips. The list of codes and standards are mentioned in the Annexure-I. (Note: The years of the codes mentioned in Annexure-I are notional, hence each time the designer shall adopt latest code with the latest correction slip).

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Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate
31/10/2023

The Order Preferences of codes will be as follows: -

i. BIS

ii. BSI or Euro Code

iii. IRC

iv. IRS

v. AASHTO

13 UNDERGROUND STATION BUILDING

For design of Underground station building load factors and other provisions in IS:456 shall be adopted as in case of Elevated stations.

14 MECHANICAL & ELECTRICAL SYSTEMS

The items like Fire Detection System, Fire Suppression System, Fire Alarm PA System, Emergency Lighting, Power Supply System, Tunnel Ventilation etc. should be designed and commissioned as per best International Standards like NFPA130, NFPA101 etc. and the best International practices. These sub-systems should be got approved from the concerned State Authorities.

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CHENNAI METRO RAIL LIMITED CHENNAI 600035

Project Directorate Approved on 31/10/2023 Railway Board

ANNEXURE-I

Bureau of Indian Standards Codes

SP 7: 2005	National Building Code
IS 269: 1989	33 grade Ordinary Portland Cement.
IS 280: 1978	Mild Steel wire for general engineering Purposes
IS 383: 1970	Coarse and fine aggregates from natural Sources for concrete
IS 432: 1982	Mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement Part 1 Mild steel and medium tensile steel bars Part 2 Hard-drawn steel wire
IS 455: 1989	Portland slag cement
IS 456: 2000	Code of practice for plain and reinforced concrete
IS 457: 1957	Code of practice for general construction of plain and reinforced concrete for dams and other massive structures
IS 458: 1988	Precast concrete pipes (with and without reinforcement)
IS 459: 1992	Corrugated and semi-corrugated asbestos cement sheets
IS 460: 1985	Test sieves
IS 516: 1959	Method of test for strength of concrete
IS 650: 1991	Standard sand for testing cement
IS 733: 1983	Wrought aluminium and aluminium alloy bars, rods and sections for general engineering purposes
IS 737 1986	Wrought aluminium and aluminium alloy sheet and strip for general engineering purposes
IS 783: 1985	Code of practice for laying of concrete pipes
IS 800: 2007	Code of practice for general construction in steel
IS 875: 1987	Code of practice for design loads (other than earthquake) for buildings and structures
IS 883: 1994	Code of practice for design of structural timber in building
IS 1030:1989	Carbon steel castings for general engineering purposes
IS 1080:1986	Design and construction of shallow foundation in soil (other than raft ring and shell)
IS 1161:1979	Steel tubes for structural purposes
IS 1322:1993	Bitumen felts for water proofing and damp-proofing
IS 1343:1980	Code of practice for Pre-stressed Concrete
IS 1346:1991	Code of practice Waterproofing of roofs with bitumen felts
IS 1458:1965	Railway bronze ingots and casting
IS 1489:1991	Portland Pozzolana Cement.
IS 1732:1989	Dimensions for round and square steel bars for structural and general engineering purposes
IS 1785:1983	Plain hard-drawn steel wire for prestressed concrete Part 1 Cold-drawn stress – relieved wire Part 2 As drawn wire
IS 1786:1985	High strength deformed steel bars and wires for concrete reinforcement.
IS 1791:1985	Batch type concrete mixers
IS 1795:1982	Specifications for pillar taps for water supply purposes
IS 1834:1984	Hot applied sealing compounds for joint in concrete
IS 1838:1983	Pre-formed fillers for expansion joint in concrete pavements and structures (non extruding and resilient type)

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Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023

Part 1 Bitumen impregnated fibre
IS 1888:1982 Method of load tests on soils

IS 1892:1979 Code of practice for sub surface investigations for foundations
IS 1893:1984 Criteria for earthquake resistant design of structures
IS 1893:2002 Criteria for earthquake resistant design of structures,
Part 1 General Provisions and Buildings
IS 1904:1986 Design and construction of foundations in soils General Requirements
IS 1977:1976 Low Tensile Structural steel
IS 2004:1991 Carbon steel forgings for general engineering purposes
IS 2062:2006 Steel for general structural purposes
IS 2090:1983 High tensile steel bars used in pre-stressed concrete
IS 2116:1980 Sand for masonry mortars
IS 2119:1980 Code of practice for construction of brick-cum-concrete composite
IS 2386:1963 Methods of test for aggregates for concrete
Part 1 Particle size and shape
Part 2 Estimation of deleterious materials and organic impurities
Part 3 Specific gravity, density, voids, absorption and bulking
Part 4 Mechanical properties
Part 5 Soundness
Part 6 Measuring mortar making properties of fine aggregates
Part 7 Alkali – aggregate reactivity
Part 8 Petrographic examination
IS 2430:1986 Methods of sampling of aggregate for concrete
IS 2720: 1972 - 2002 Methods of Tests for Soils (all Parts)
IS 2751:1979 Recommended practice for welding of mild steel plain and deformed bars used for reinforced construction
IS 2911:2010 Code of practice for design and construction of pile foundations
Part 1 Concrete piles
I. Section 1 Driven cast –in-situ concrete piles
II. Section 2 Bored cast-in-situ concrete piles
III. Section 3 Driven precast concrete piles
IV. Section 4 Bored precast concrete piles
Part 3 Under-reamed piles
Part 4 Load test on piles

IS 2950:1981 Code of practice for design and construction of raft foundations.
IS 3067 1988 Code of Practice for General Design Details and Preparatory Work for Damp Proofing and Water- Proofing of Buildings.
IS 3370:2009 Code of practice for concrete structures for the storage of liquids
IS 3812:1981 Fly ash for use as pozzolana and admixture
IS 3955:1967 Code of practice for design and construction of well foundations
IS 4082:1996 Recommendations on stacking and storage of construction materials and components at site
IS 4326:1993 Earthquake resistant design and construction of buildings – code of practice
IS 4656:1968 Form vibrators for concrete
IS 4736:1986 Hot-dip zinc coatings on mild steel tubes
IS 4826:1979 Hot-dipped galvanised coatings on round steel wires
IS 4925:1968 Concrete batching and mixing plant
IS 4926:1976 Ready mixed concrete
IS 4968:1976 Method for sub surface sounding for soils
IS 5525:1969 Recommendations for detailing of reinforcement in reinforced concrete works
IS 5529:1985 Code of practice for in-situ permeability tests

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

IS 5640:1970 Method of test for determining aggregate impact value of soft coarse aggregate
IS 5816:1970 Method of test for splitting tensile strength of concrete cylinders
IS 5889:1994 Vibratory plate compactor
IS 5892:1970 Concrete transit mixers and agitators
IS 6003:1983 Specification for indented wire for pre-stressed concrete
IS 6006:1983 Specification for uncoated stress relieved strands for pre-stressed concrete
IS 6051:1970 Code for designation of aluminium and its alloys
IS 6248:1979 Specification for metal rolling shutters and rolling grills
IS 6403:1981 Code of practice for determination of bearing capacity of shallow foundations
IS 6603:1972 Stainless steel bars and flats
IS 7196:1974 Hold fast
IS 7205:1974 Safety code for erection of structural steel work
IS 7273:1974 Method of testing fusion-welded joints in aluminium and aluminium alloys
IS 7293:1974 Safety code for working with construction machinery
IS 7320:1974 Concrete slump test apparatus
IS 7534:1985 Sliding locking bolts for use with padlocks
IS 7861:1975 Code of practice for extreme weather concreting
Part 1 For Hot Weather concreting
Part 2 For Cold Weather concreting
IS 7969:1975 Safety code for handling and storage of building materials
IS 8009:1976 Calculation of settlement of foundations
IS 8041:1990 Rapid – hardening Portland cement
IS 8112:1989 43 grade ordinary Portland cement
IS 8142:1994 Method of test for determining setting time of concrete by penetration resistance
IS 8500:1991 Structural steel-micro alloyed (medium and high strength qualities)
IS 9013:197 Method of making, curing and determining compressive strength of accelerated cured concrete test specimens
IS 9103:1979 Admixtures for concrete
IS 9284:1979 Method of test for abrasion resistance of concrete
IS 9417:1989 Recommendations for welding cold worked bars for reinforced concrete construction
IS 9595:1996 Recommendations for metal arc welding of carbon and carbon manganese steels
IS 9762:1994 Polyethylene floats (spherical) for float valves
IS10262:2009 Recommended guidelines for concrete mix design
IS 10379:1982 Code of practice for field control of moisture and compaction of soils for embankment and subgrade
IS 10500:1991 Drinking water specification
IS 12269:1987 53 grade ordinary Portland cement
IS 12894:1990 Fly ash lime bricks
IS 13920:1993 Ductile detailing of reinforced concrete structures subjected to seismic forces
IS 15388:2003 Specifications for Silica Fume
SP 36 (Part 1): Compendium of Indian Standards on Soil Engineering (Laboratory Testing)
SP 36 (Part 2): Compendium of Indian Standards on Soil Engineering (Field Testing) Indian Standard Hand Book on Steel Sections Part-I
CRRI and IOC, New Delhi Bituminous Road Construction Hand Book

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023

Director/UT/Civil/RDSO

Indian Railway Standards (IRS)

IRS 2008	Bridge Rules
IRS 1997	Concrete Bridge Rules
IRS 1991	Bridge Structures and Foundation Codes
IRS 1997	Bridge Code
IRS 1998	Indian Railway Bridge Manual
IRS 1985	Manual on Design and Construction of Well and Pile foundation

Indian Roads Congress Standards (IRC)

IRC 5:1998	Standard Specifications and Code of Practice for Road Bridges, Section I – General Features of Design
IRC 6: 2000	Standard Specifications and Code of Practice for Road Bridges, Section II – Loads and Stresses
IRC 11: 1962	Recommended Practice for the Design of Layout of Cycle Tracks
IRC 18:2000	Design Criteria for Pre-stressed Concrete Road Bridges (Post-Tensioned Concrete)
IRC 19:1977	Standard Specifications and Code of Practice for Water Bound Macadam
IRC 21:2000	Standard Specifications and Code of Practice for Road Bridges Section III–Cement Concrete (Plain and Reinforced)
IRC 22:1986	Standard Specifications and Code of Practice for Road Bridges, Section VI – Composite Construction
IRC 24:1967	Standard Specifications and Code of Practice for Road Bridges, Section V – Steel Road Bridges
IRC26:1970	Recommended Practice for the Construction of Earth Embankments for Road Works
IRC 37:1984	Guidelines for the Design of Flexible Pavement
IRC 45: 1972	Recommendations for Estimating the Resistance of Soil below the maximum Scour Level in the Design of Well Foundations of Bridges
IRC 48:1972	Tentative Specifications for Bituminous Surface Dressing Using Pre-coated Aggregates
IRC 75:1979	Guidelines for the Design of High Embankments
IRC 78:2000	Standard Specifications and Code of Practice for Road Bridges, Section VII Parts 1 and 2, Foundations and Substructure
IRC 83:1987	Standard Specifications and code of practice for Road Bridges, Section IX Bearings Part I & II: Bearings (Metallic and Elastomeric)
IRC 87:1984	Guidelines for the Design and Erection of False Work for Road Bridges
IRC 89:1997	Guidelines for Design and Construction of River raining and Control Works for Road Bridges

IRC: SP 11 1988 Handbook of Quality Control for Construction of Roads and Runways

AASHTO Standards

AASHTO M6-81	Fine aggregate for Portland cement concrete
AASHTO M31-82	Deformed and plain billet-steel bars for concrete reinforcement
AASHTO M42-81	Rail-steel deformed and plain bars for concrete reinforcement
AASHTO M54-81	Fabricated steel bar or rod mats for concrete reinforcement
AASHTO M 81-75	Cut-back asphalt (rapid-curing type)
AASHTO M 82-75	Cut-back asphalt (medium-curing type)
AASHTO M85-80	Portland cement
AASHTO M 140-80	Emulsified asphalt

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023 Railway Board

Examined and found in order

Director/UT/Civil/RDSO

AASHTO M 147-67	Materials for aggregate and soil–aggregate sub-base, base and surface courses
AASHTO M148-82	Liquid membrane-forming compounds for curing concrete
AASHTO M154-79	Air-Entraining admixtures for concrete
AASHTO M173-60	Concrete joint-sealer, hot-poured elastic type
AASHTO M194-82	Chemical admixtures for concrete
AASHTO M213-81	Preformed expansion joint fillers for concrete paving and structural construction
AASHTO M 282-80	Joints sealants, hot poured, elastomeric-type, for Portland cement concrete pavements
AASHTO M 294-70	Fine aggregate for bituminous paving mixtures
AASHTO T22-82	Compressive strength of cylindrical concrete specimens
AASHTO T23-80	Making and curing concrete compressive and flexural strength test specimens in the field
AASHTO T26-79	Quality of water to be used in concrete
ASHTO 104-77	Soundness of aggregate by use of sodium sulphate or magnesium sulphate
AASHTO T191-61	Density of soil In-place by the sand-cone method

British Standard Institute

BS 812	Testing Aggregates - Parts 117 to 119.
BS 1377	Methods of Test for Civil Engineering Purposes – Parts 1 thru 9.
BS 4395 Part 2	High strength friction grip bolts and associated nuts and washers for Structural Engineering Higher Grade
BS 4447	The performance of pre-stressing anchorages for post tensioned construction
BS 4449	Specification for Carbon Steel Bars for the Reinforcement of Concrete
BS 4486	Hot rolled and hot rolled & processed high tensile alloy steel bars for pre-tensioning of concrete
BS 4550	Methods of testing cement
BS 4592	Industrial Type Metal Flooring, walkways and stair treads
BS 4604 Part 2	The use of high strength friction grip bolts in structural steel work. Higher grade (parallel shank)
BS 4870	Approval testing of welding procedures
BS 4871	Approval testing of welders working to approved welding procedures
BS 4872	Approval testing of welders when welding procedure approval is not required
BS 5075	Concrete admixtures
BS 5135	Process of arc welding of carbon and carbon manganese steels
BS 5212 Part 2	Cold poured joint sealants for concrete pavements
BS 5328	Methods for specifying concrete, including ready mixed concrete
BS 5400	Steel, concrete and composite bridges
BS 5400 Part 4	Code of practice for design of concrete bridges
BS 5400 Part 6	Specification for materials and workmanship, steel
BS 5606	Accuracy in building
BS 5896	High tensile steel wire and stand for the pre-stressing of concrete.
BS 5930	Code of Practice for Site Investigations.
BS 5950 Part 2	Specification for materials, fabrication and erection: hot rolled sections
BS 5950 (2000)	Structural use of Steelwork in Buildings (part 1)
BS 6031	Code of Practice for Earthworks.
BS 6105	Corrosion-resistant stainless steel fasteners

Examined and found in order

Director/UT/Civil/RDSO

CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023

BS 6164	Safety in tunnelling in the construction industry.
BS 6349	Code of Practice for Dredging and Land Reclamation.
BS 6443	Penetrant flaw detection
BS 6681	Specification for malleable cast iron
BS 7079	Preparation of Steel substrates before application of paints and related products
BS 7385 Part 2	Evaluation and measurement for Vibrations in Buildings– E to Damage levels from Ground-Borne Vibrations
BS 7542	Method of test for curing compound for concreter
BS 8000 Part 4	Code of Practice for Waterproofing.
BS 8000 Part 5	Code of Practice for Below Ground Drainage.
BS 8002	Code of Practice for Earth Retaining Structures.
BS 8004	Code of Practice for Foundations.
BS 8007	Design of Concrete Structures for Retaining Aqueous Liquids
BS 8081	Code of Practice for Ground Anchorages
BS 8110	Structural use of concrete
BS 8301 Section 5	Code of practice for building drainage
BS 8550	Concrete – Specification of Materials

BS EN 1997 Euro code 7: Geotechnical design
BS EN 1998 Euro code 8: Design of structure for earthquake resistance

CIRIA Report 44	Medical Code of Practice for working in compressed air
CIRIA Report 80	A review of instruments for gas and dust monitoring underground
CIRIA Report 81	Tunnel water proofing
CIRIA Report C515	Groundwater Control – Design and Practice
CIRIA Report C580	Embedded Retaining Walls – Guidance for Economic Design
CIRIA Report C660	Early Age Thermal Crack Control in Concrete
IStructE Report	Design and construction of deep basements including cut-and-cover structures

Reference Documents

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- Chadeisson Abacus, Publication Soletanche Bachy
- Hashash, Y.M.A., Hook, J. A., Schimdt, B. Yao., J., "Seismic Design and analysis of underground structures"
- Wang, J., "Seismic Design of Tunnels"
- Kuesel, R. K., "Earthquake design criteria for subways"
- Anchor, "Design of Liquid Retaining Structures"
- Merritt, Ricketts, "Building Design and Construction Handbook", McGraw Hill
- Terzaghi, Peck, G Hoamreza "Soil Mechanics in Engineering Practice", Jhon Wiley
- R.W. Day" Soil Mechanics & Foundation Engineering"
- Kempfert "Excavations and Foundations in Soft Soil", Springer Verlag
- National Fire Protection Association, NFPA 130-2010: Standard for Fixed Guideway Transit and Passenger Rail Systems
- International Tunnel Association: Guidelines for the Design of Tunnels
- Austrian Society for Rock Mechanics: Geotechnical Underground Structures Design
- Muir Wood, A.M. (1975) The Circular Tunnel in Elastic Ground
- D.J. Curtis et al (1976) Discussion Paper - Circular Tunnel in Elastic Ground

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CHENNAI METRO RAIL LIMITED CHENNAI - 600035

Project Directorate Approved on 31/10/2023