GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(RAILWAY BOARD)

2024/Proj./MMRC/NATM/DBR/30/70 New Delhi, dated 12.02.2024

Managing Director,
Mumbai Metro Rail Corporation Ltd (MMRCL),
E –Block, Bandra Kurla Complex,
Bandra East, Mumbai,
Maharashtra - 400051

Sub: Approval of Design Basis Report (DBR)s for Underground Work by NATM (New Austrian Tunnelling Method) Tunnelling Method and Cut and Cover Method (January, 2024) of Mumbai Metro Rail Corporation (MMRC).

Ref: MMRCL's letter No. MMRC/ML-3/CBS/77/DBR/115 dated 09.01.2024

The Design Basis Report (DBR)s for Underground Work by NATM (New Austrian Tunnelling Method) Tunnelling Method and Cut and Cover Method (January, 2024) of Mumbai Metro Rail Corporation (MMRC) have been examined in consultation with RDSO and approval of Railway Board is hereby conveyed for the same.

Accordingly, approved copy of DBRs is enclosed.

Encl: As above

12.02.24
(F. A. Ahmad)
Director/Gati Shakti (Civil)-IV
Railway Board
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Copy to:

1. **ED/UTHS**, RDSO, Manak Nagar, Lucknow-226011 w.r.t letter No. UT/107/MMRCL/Civil dated 19.01.2024

2. **OSD/UT & Ex-Officio Joint Secretary**, Ministry of Housing & Urban Affairs (MoHUA), Nirman Bhawan, New Delhi-11001

MMRC

DESIGN BASIS REPORT (DBR)

UNDERGROUND WORKS BY
NATM (NEW AUSTRIAN TUNNELLING METHOD)
TUNNELLING METHOD

January 2024

MUMBAI METRO RAIL CORPORATION

Examined and found in order

Director/UT/Civil/RDSO

Project Directorate Approved on 12/02/2024 Railway Board

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Quality Information

Document	General Consultancy for Mumbai Metro Rail Line-3 (Colaba-Bandra-SEEPZ) Design Basis Report
Ref	
Date	**January 2024**
Prepared by	Harshavardhan S Deshpande
Reviewed by	**Ron Mickell**

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
06	Jan 2024	RDSO Design Basis Report	Ron Mickell (PM)	
05	Oct 2023	RDSO Design Basis Report	Ron Mickell (PM)	
04	Mar 2020	RDSO Design Basis Report	Ron Mickell (PM)	
03	Jan 2020	RDSO Design Basis Report	Ron Mickell (PM)	
02	August 2019	RDSO Design Basis Report	Ron Mickell (PM)	
01	July 2019	RDSO Design Basis Report	Ron Mickell (PM)	
00	August 2016	RDSO Design Basis Report	Ron Mickell (PM)	

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1. GENERAL

Wherever applicable provisions of approved model DBR of Viaduct shall be followed.

Table1: Geometric Design Criteria:

Sr. No.	CRITERIA	DIMENSIONS
1.	Gauge	1435 mm
2.	Maximum operating speed	85km/h
3.	Design Speed	95km/h
4.	Max. Axle load, loaded condition,	17MT (Metric ton) or 170kN
5.	Max. Gradient running track	4%
6.	Gradient Depot connecting track	4%
7.	Minimum vertical curve radius	1500 m
8.	Minimum horizontal curve radius	200 m (main line track)
9.	Traction power collection	Overhead catenary system (OCS) at 25kV (AC). Rails shall be used for traction return current
10.	Inclination of rail	1 in 20
11.	Wheel thread profile	UIC 510-2 (S1002)
12.	Rail profile	UIC 60 (861-3)
13.	Maximum cant	125 mm
14.	Maximum cant deficiency	100 mm

1.1 Brief Description of Project

Mumbai is a fast-growing Metropolis of the country and is expected to continue to grow in the future. Mumbai Metropolitan Region (MMR) comprises of 7 municipal corporations, 13 municipal councils and 996 villages and extends over an area of 4,355 sq.km. The existing transport facilities are overcrowded, and the road network is congested and there is a large gap between the demand and supply. To decongest the public transport and to increase the mobility across the city Under Ground Rapid Transit System under the aegis of MMRC a fully under-ground line is planned, which is called MML-3. MML-3 covers the total length of 33.508 kms traversing from Colaba in the south via Bandra to SEEPZ, this line consists of 26 under ground stations.

Due to dense urbanization along the alignment of the Metro line, space availability to accommodate cut and cover station at certain locations was a constraint. Therefore, to accommodate the station in the congested areas the station platforms were constructed with NATM methods. Similarly, due

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MUMBAI METRO LINE 3 GENERAL CONSULTANTS MAPLE to space constraints and availability of good strata, the crossovers are planned are planned as NATM crossovers.

The line consists of 3 cross overs, 2 sidings and 26 Under Ground stations of which 7 stations are NATM stations (Hybrid Stations with NATM & Cut and cover works). NATM Cross passage are provided as per NFPA-130. The details of all Stations, NATM Stations and NATM Crossovers are tabulated below.

Table 2: All Stations in Mumbai Metro Line-3

Sr.no.	Stations	Sr.no.	Stations
1	Cuffe Parade Station	14	Sidhivinayak
2	Vidhan Bhavan	15	Dadar
3	Church-gate	16	Shitaladevi
4	Hutatma Chowk	17	Dharavi
5	CST Metro	18	BKC
6	Kalbadevi	19	Vidya Nagari
7	Girgaon	20	Santacruz
8	Grant Road	21	CSIA- Domestic
9	Mumbai Central	22	Sahar Road
10	Mahalaxmi Worli	23	CSIA- International
11	Science Museum	24	Marol Naka
12	Acharya Atre Chowk	25	MIDC
13	Worli	26	SEEPZ

Table 3: NATM Stations

Sr.no	Station Name (NATM Stations)	Sr.No.	Station Name (NATM Stations)
1.	Hutatma Chowk	5.	Shitaladevi Temple
2.	Kalbadevi	6.	Santacruz Station
3.	Girgaon	7.	Marol Naka Station
4.	Grant Road		

Table 4: NATM Crossovers Near Stations

Sr.no	Cross over Location (Station near Cross overs)	NATM Center Chainage (approx.)
1.	CST (North side)	4+196.723 m
2.	Acharya Atre Chowk (South Side)	11+281.200 m
3.	Sahar Road (South Side)	27+809.736 m

Table 5: NATM at Stabling Siding

Sr.No.	Station Locations	Chainages
1	BKC (South Side)	12+143.500 m
2	BKC (North Side)	12+638.500 m
3	Cuff Parade	-0+100 m

This Design Basis report deals in the NATM tunnelling methods for the Mumbai Metro Line-3 (MML3).

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1.2 Geology of Mumbai

Mumbai is a part of Deccan volcanic province like other areas of Maharashtra. Deccan province is majorly covered with basalt. In the coastal Area like Mumbai the top virgin soil is Marine clay. In Mumbai, the top layer encountered now is fill brough from outside, especially for the road works. Tunnels along MML3 alignment @ rail level the stratum encountered mostly hard basalt, with presence of soft breccia, tuff layers and exceptions of sedimentary layers at some locations.

In Mumbai, substrate can be defined as top 3.0 to 4.0 as backfill soil i.e., soil brought from outside filled over the original soil stratum. Second layer is predominantly chemically non-aggressive Marine clay, underlain be highly to moderately weathered rock (defined as grade V & IV rock), followed by Slightly weathered rock (defined as grade III rock), below this stratum is less weather or compact rock (defined as Grade II & I Rock). Along the alignment of MML-3 the distribution of soil and rock layers is irregular, the thickness of the weathered rock varies for different areas of the station. The stratification is as follows-

1. Top Strata is back-fill soil with depth varying from 1.0 m to 4.0m.
2. Below the top layer Clayey, silty, stratum is observed from depth of 3.0m to 8.0m. Sometimes sandy soil in pockets or as a layer is observed too.
3. Below rock Stratum is Volcanic Breccia, with irregular rock layer of different weathering. The top 4.0m to 6.0 m is Grade V / IV rock.
4. Below the Gade V/ IV stratum, Grade III rock is observed of thickness 5.0 -7.0 m.
5. Grade II / I are also encountered at some locations.

The rock mass classification is made in accordance with the Austrian Guidelines for NATM tunnelling (mentioned by Austrian Society for Geomechanics, 2001, 2008, 2009, Guideline for the geotechnical design of underground structures with conventional excavation). NATM geotechnical design procedure that involves rock mass classification is required to identify potential hazards (or mode of failures), distinguishing rock types as well as structural characteristics and singularities (joint setup, faults, etc.), and the determination of factors influencing the behavior (stresses, water, size and shape of underground opening, etc.).

Table 6: Generalized stratification of Soil and rock

Weathering Class & Grade	Description of Rock & Rock Mass	Strength	Index Properties	
			ROD (%)	CR (%)
Fresh (I)	No visible sign of Material Weathering. Near Boundary with Grade II some slight discoloration on major Defects.	Very High	90-100	95-100
Slightly Weathered (II)	Discoloration indicates weathering of rock material and defect surface. Discoloration ranges from defects surface only to completely stained.	Very high to 50-60% of fresh rock strength	75-90	90-95
Moderately Weathered (III)	Less than 50% of the material decomposed and disintegrated to intact soil. Rock core discolored and weakened	30% of the fresh rock	40-75	60-90

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Highly Weathered (IV)	More than 50% of the material decomposed and disintegrated to intact soil. Rock core discolored and weakened	15% of Fresh Rock	10-40	30-60
Completely Weathered (V)	Intact Friable soil which may be weakly cohesive. Soil has fabric of parent rock	Extremely low	0-10	0-30
Residual Soil (VI)	Friable soil with original rock fabric completely destroyed.	Extremely Low	0	0

The strata available in MML-3 is good quality basaltic rock at the required depth and due to space constraints the NATM works are adopted for construction of tunnel/ stations. NATM method takes into account the inherent strength of the strata and integrates into a ring like support structure forming a part of the support structure, NATM can also be adopted in soils with stiff consistency.

2. SCOPE OF DBR

The Scope of this DBR covers the design of NATM works and specifies minimum standards that are to govern the design, construction observation and monitoring of underground NATM tunnels, used for either trackways or for stations. The design basis report shall be read in conjunction with the Outline Construction Specifications where appropriate.

The design of the permanent and temporary support works shall comply with code of practice and standards at the time of submission of Tender Documents, Regulations made, and requirements issued by the Indian Government and by relevant utility authorities shall be followed and specified.

NATM construction for the tunnel works is generally adopted to widen the TBM tunnel as required to accommodate the Stations and to provide a cross-section for the tracks wherever required. NATM works are adopted at following locations.

1. Cross passage in Tunnels
2. Station Adits and NATM stations
3. Crossovers @ CST Station, Acharya Atre Chowk Station & Sahar Road Station
4. Station Stabling Siding Tunnel @ BKC Station
5. Turn Back / Stabling Siding Tunnel @ Cuff Parade Station

3. MATERIALS

3.1 Cement

1. Ordinary Portland cement (OPC) of 53 grade conforming to IS 12269-1987 and OPC of 43 Grade conforming to IS-8112-1989, shall be used.
2. Portland Pozzolana Cement (PPC) conforming to IS 1489 may be used.
3. Use of sulphate-resistant Portland cement conforming to IS 12330 for structural elements exposed to soil.
4. In all cases, the cement shall meet the 28 days strength requirement.
5. For foundation and substructure, OPC substitution by Blast furnace slag cement conforming to IS:455.

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3.2 Concrete

1. The density of concrete adopted shall be as below –
   a. 24 kN/m³ for reinforced concrete with 2% or less reinforcement (IS: 875 part-1 Table-1 item 22 value rationalized)
   b. 25 kN/m³ for reinforced concrete with above 2% reinforcement (IS: 875 part-1 Table-1 item 22 value rationalized).
   c. 24 kN/m³ for plain cement concrete (PCC) (IS875: part-1 table-1 item 20)
   d. 25 kN/m³ for pre-stressed concrete (IS 875: part-1 table-1 item 21 value rationalized)
2. Short term modulus of elasticity 'Ec' and Modular Ratio 'm' shall be as per clause no. 6.2.3.1 & B-1.3 (d) of IS-456-2000 respectively.
3. The minimum Grade of concrete shall be M35 and of shotcrete shall be M30.
4. Thermal expansion coefficient: 1.17 X 10-5 / ℃ (cl 2.6.2 IRS Bridge Rule).
5. Poisson's ratio 0.15 for all concretes.
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 150mm cube at 28 days.
8. Minimum concrete cover shall be as per IS: 456 & as per durability criteria conforming to ODS.
9. Maximum aggregate size shall not be more than 12mm for wet process and 16mm for dry process.

3.3 Reinforcement

Only thermo-mechanically treated (TMT) reinforcement bars of grade Fe 500-D with minimum Yield Stress of 500 MPa and minimum total elongation of 14.5% (for seismic zone III, IV, V) conforming to IS:456 for Plain and Reinforced Concrete shall be adopted.

3.4 Sprayed Concrete (Shotcrete)

Conformity and specifications for the sprayed concrete shall conform to BS-EN-14487-part-1. Execution of the sprayed concrete shall conform to BS-EN-14487-part-2. Sampling of fresh and hardened concrete shall conform to BS-EN-14488-part-1, similarly the compressive strength and flexural strength of sprayed concrete shall conform to BS-EN-14488-part-2 and BS-EN-14488-part-3 respectively.

1. Materials for sprayed concrete shall comply with concrete Material requirements specified in the Design.
2. Sprayed concrete can be used both in initial support (primary support), as well as permanent support (final support).
3. Sprayed concrete shall be applied in one or more layers of appropriate thickness to achieve the design thickness.

3.5 Steel Fibers/ Steel Mesh/ Polymer Fiber

Sprayed concrete shall be reinforced with wire/ reinforcement mesh, or fibers as required. These fibers may be steel fibers or macro-synthetic fibers. In MML-3 steel fibers conforming to Outline

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Construction Specification (OCS) is used. Steel fibers may be collated or uncollated deformed steel fibers. Specification of the steel mesh, steel fibers, polymer fibers are as mentioned in table -

Material	Steel Mesh Fe500D	Steel Fibers	Micro/ Macro Polymer Fiber extruded polypropylene/ polyethylene
Thermal Expansion Coefficient	12 x 10^{-6}/℃	12 x 10^{-6}/℃	12 x 10^{-6}/℃
Shrinkage for a temp. decrease of 30℃ on a 50mm long fiber	0.018 mm	0.018 mm	0.23 mm
Creep behavior in tension (Tg glass transition temp.)	+370℃	+370℃	-20℃
Melting Point (℃)	-	1500℃	165℃
Young's Modulus	210000 MPa	210000 MPa	3000 – 10000 MPa
Tensile Strength	565 MPa	500 – 2000 MPa	200 – 600 MPa
Density	7850 kg/m³	7850 kg/m³	910 kg/m³
Resistance to UV light	-	-	Degradation will occur
Typical length of fiber	Mesh size 150x150x6 conforming to OCS	Fiber length of 30 – 60 mm Fiber Dia. of 0.5 – 1.0 mm	For Microfiber: 6-20 mm For Macrofibre: 30–65 mm
Typical diameter of fiber	-	-	Microfiber dia.:0.015-0.03 mm Macrofibre dia.: 0.5 – 1.0 mm
Bekaert brands	-	Dramix, Wiremix	Micro: Duo mix /Macro: Syndic
Confirming to codes	i) IS 1786: 2008 ii) BS 4483: 2005 iii) EN 10080: 2005	i) ASTM A820/ A820M-22 ii) ISO 13270 iii) BS-EN-14889-part-1	i) BS-EN-14889-part-2

3.6 Structural Steel: General

Structural Section, such as open sections, closed hollow sections and Rods are provided for Lattice girder, Fore poling (bars of Tubes), pipe roof Umbrella and Rock bolts. The properties for these Structural members shall conform to the following.

1. Design of Structural steelwork for Lattice Girders shall comply with IS 800.
2. Types of structural steel to be used and shall comply with the following standards:
   a. IS: 4923-1997 "Hollow steel sections for structural use with Yst 310"
   b. IS: 2062-2006 "Steel for General Structural Purposes (Grade B- Designation 410-B)"
   c. IS-1786-2008 for HYSD Rock bolts.
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 meters) 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.

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5. The connection within the steel structure shall be designed as direct welded members with or without gusset plates. The minimum thickness of metal for SHS/RHS section for main chord members as well as bracing shall be 4mm as applicable for steel tubes in clause 6.3 of IS-806.

3.6.1 Material Properties

Material properties: Material Properties shall be as follows:

Steel Type	Young's Modulus	Tensile Stress	Yield Strength	Density	Poisson's Ratio	Coeff. Of Thermal Expansion	Elongation %
Hollow Steel Sections (IS-4923)	200,000 MPa	450 MPa	310 MPa	78.5 kN/m³	0.3	1.2x10⁻⁵/ °C	8%
Structural Steel (IS-2062)		410 MPa	250 MPa (t<20) 240 MPa (t~20-40) 230 Mpa (t>40) t= thickness in mm				23%
HYSD Rock bolts Fe500D (IS-1786)		565 Mpa	500Mpa				16%

3.7 Water Proofing

Waterproofing of the tunnel shall be achieved by the continuous membrane installed at the interface between the primary and the final lining. The waterproofing system consists of –
a) Protective Felt,
b) Water Proofing Membrane.

3.7.1 Protective felt:

The protective felt shall be non-woven poly-propylene geotextile of uniform thickness and surface texture meeting the following requirements.

- Unit weight conforming to BS-EN-ISO- 9864-2005 > 500 g/m²
- Thickness at 0.02 bar conforming to BS-EN-ISO- 9863-1-2005 > 3.9 mm
- Thickness at 2.0 bar conforming to BS-EN-ISO-9863-1-2005 > 1.9 mm
- Tensile strength conforming to BS-EN-ISO- 10391-2008 > 10 N/mm²
- Extension at break conforming to BS-EN-ISO- 9864-2005 > 70%
- Extension at 30% of tensile strength conforming to BS-EN-ISO- 10391-2008 > 20%
- Resistance to CBR punching conforming to BS-EN-ISO- 12236-2006 > 6 kN

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3.7.2 Waterproofing membrane

The waterproofing membrane shall be made of one of the following materials or similar one meeting the requirements listed below.

A. PVC (soft poly-vinyl chloride) sheet waterproofing membrane.

• Thickness conforming to BS-EN-1849-2-2001	> 2.0 mm
• Tensile strength conforming to BS-EN-12311-2-2000	> 15 N/mm^2
• Elongation at failure conforming to BS-EN-12311-2-2000	> 200%
• Tear Resistance conforming to BS-EN-12310-2-2000	> 80 N/mm
• Resistance under water pressure conforming to BS-EN-1928-2000	10bars / 10 hrs.
• Strength of welded seam conforming to BS-EN-12317-2-2000	> 13.5 N/mm^2

B. EVA (Ethylene-Vinyl-Acetate polymer) spray applied waterproofing membrane.

• thickness conforming to BS13501-1-2007	> 2mm application thickness
• Bond Strength conforming to BS-EN-1542-1999	> 1.5 N/mm^2 to concrete
• Bond Strength conforming to BS-EN-1542-1999	> 2.0 N/mm^2 to steel
• Permeability conforming to BS-EN-12390-8-2000	0 penetration.
• Crack Bridging conforming to BS-EN-1062-7-2004	Class A-5 (20°C)

All material specifications and testing shall conform to document "ITAtech design guidance for spray applied waterproofing membrane".

C. HDPE (High Density Polyethylene) sheet waterproofing membrane conforming to IS10889-2004: High Density Polyethylene films.

• Thickness	> 2.0 mm
• Tensile strength (at yield)	> 29 N/mm
• Elongation at failure	> 700%
• Bulk density g/cm3	>0.94
• Puncture resistance	0.64 kN

3.8 Fireproofing

3.8.1 RCC Final Lining

Final lining constructed in RCC, the cover to reinforcement for a fire rating of 4.0 hours conforming to IS-456:2000 clause 21.4 & 26.4.3, Figure-1 and table- 16A.

3.8.2 Sprayed Concrete Final Lining

For Fire protection of the Sprayed concrete final lining, minimum structural thickness shall be considered, and the properties of the fire protection layers shall be as follows.

• Thickness	≥50 mm
• Water Cement Ratio	0.09-0.15

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- Poly Propylene Fibers ~2.0 kgs/ m^3
- Bond Strength to Final Lining >0.5 MPa
- Fire Resistance
  - Integrity ~240 minutes conforming to BS-EN-1363-1
  - Insulation ~240 minutes conforming to BS-EN-1363-1
- Bulk Density ~ 2250 kg/m^3

4. GEOTECHNICAL DESIGN

Ground uncertainties plays an important role in deciding the excavation sequence and construction method. This involves determination of type of excavation, primary and final support measures, drainage conditions, ground improvement requirement. The key parameters governing geotechnical design are ground condition and ground behavior.

Geotechnical deign is covered under two phases – design phase and construction phase.

4.1 Design phase

Geotechnical design Phase involves determination of ground properties like ground type classification (GT), assessment and categorizing of ground behavior (BT), determining support measures, determining system behavior.

1. Determining Ground Types (GT): Geotechnical parameters are determined from information available and geologic studies and geotechnical investigations. Ground with similar properties is classified into Ground Types (GT). The number of Ground Types elaborated depends on the project specific geological conditions. Ground types are classified based on intact ground properties like mineral composition, strength, anisotropy, grain size, surface texture, weathering grade, swelling properties, time-dependent behaviour, intercalation of rock, rock joints or discontinuities, shear strength/ toughness, and any other parameter to be added based on project site conditions. For determining the GT type the mechanical and hydraulic properties shall be determined.

Recommended Field tests in rock strata are –

- Core recovery and rock quality designation
- Pressure-meter tests
- Packer permeability tests

Recommended laboratory tests for rock samples are –

- Saturated moisture content
- Water absorption
- Porosity
- Saturated density
- Specific gravity
- Dry density
- Point load index of intact rock

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- Tensile strength of intact rock
- Uniaxial compressive strength test (saturated and dry)

2. Determining Ground Behaviour type (BT): This involves evaluating the potential ground behaviour of each Ground Type and local influencing factors. For each section, which has similar ground properties and influencing factors, the Behaviour Type (BT) is determined and corelated with with description given in Table 07 to identify possible failure modes, magnitude and characteristics of displacements, amount of water inflows and its effects on ground stability.

Ground behaviour is determined by evaluating following conditions –

- Kinematical analysis for determination of discontinuity, controlled overbreak and sliding of wedges.
- Ground unitization ratio of ground strength and spatial stress distribution in vicinity of ground opening through analytical and/or numerical method
- Analysing and determining qualitatively the possible failure mechanism of ground

The local influencing factors for evaluation of ground behaviour are –

- Ground type
- In situ stress conditions
- Shape and size of underground structure
- Position of underground structure in relation to surface or existing structure
- Relative orientation of underground structure and discontinuities for kinematical analysis and assessment of stress distribution
- Boundaries between different ground types
- Ground water, seepage force, hydraulic head

Table 7: General categories of different Ground Behaviours

S.No.	Basic Categories of Behaviour Types (BT)	Description of potential failure modes/ mechanisms during excavation of the unsupported ground
1.	Stable	Stable ground with the potential of small local gravity induced falling or sliding of blocks
2.	Potential of discontinuity-controlled block fall	Voluminous discontinuity controlled, gravity induced falling and sliding of blocks, occasional local shear failure on discontinuities
3.	Shallow failure	Shallow stress induced failure in combination with discontinuity and gravity-controlled failure
4.	Voluminous stress induced failure	Stress induced failure involving large ground volumes and large deformation
5.	Rock burst	Sudden and violent failure of the rock mass, caused by highly stressed brittle rocks and the rapid release of accumulated strain energy
6.	Buckling	Buckling of rocks with a narrowly spaced discontinuity set, frequently associated with shear failure
7.	Crown failure	Voluminous overbreaks in the crown with progressive shear failure
8.	Ravelling ground	Flow of dry or moist, intensely fractured, poorly interlocked rocks or soil with low cohesion

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9.	Flowing ground	Flow of intensely fractured, poorly interlocked rocks or soil with high water content
10.	Swelling ground	Time dependent volume increase of the ground caused by physical-chemical reaction of rock and water in combination with stress relief, leading to inward movement of the tunnel perimeter.
11.	Ground with frequently changing deformation characteristics	Combination of several behaviours with strong local variations of stresses and deformations over longer sections due to heterogeneous ground (I.e., in heterogeneous fault zones, block-in-matrix rock, tectonic melanges)

3. Determining construction concept: Based on the ground characteristics and ground behaviour for each characteristic situation a feasible construction concept shall be chosen, including excavation method, sequence of excavation, support, and auxiliary methods. The purpose of the selected construction concept is to mitigate the hazards identified in step 2).

4. For the chosen construction concept, including sequence of construction, stability of the face and perimeter, and the spatial stress distribution, the system behaviour in the excavation area shall be assessed.

5. The evaluated system behaviour shall be verified with the design requirements, if in case it does not comply with the given requirements the system behaviour shall be revaluated by modifying the excavation and support method.

6. A geotechnical framing plan shall be prepared defining different zones based on the excavation and support methods identified in steps 1) to 5).

7. Determining excavation classes: excavation classes shall be defined evaluated based on the excavation type and support method. Numerical methods shall be used to analyse the ground deformations, progressive failure condition, sequential support instalments for the stability of the advancing tunnel. While establishing the excavation class along the tunnel alignment the geological parameters, geotechnical parameters and heterogeneity of the ground shall be considered.

4.2 Construction phase: all the ground parameters considered in the design phase are evaluated and verified with the parameters recorded in the construction phase. Actual system behaviour in the excavation is assessed according to design stipulations.

1. Determination of encountered Ground type and prediction of ground characteristics.
2. Assessment of system behaviour in excavation area
3. Determination of excavation and support measures and prediction of system behaviour in supported section
4. Verification of system behaviour

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5. TUNNEL PROFILE, CONSTRUCTION METHODS

The NATM tunnel is comprised of single-track or multiple tracks with & without station platform, adit, cross passages, and cross overs. The design parameters shall be based on the geology and geotechnical conditions of the ground, support design and good monitoring system to carry out smooth tunneling operations using NATM technology. The finished tunnel profile shall meet all services and SOD (schedule of dimension) requirements.

NATM tunnels shall be excavated using modern blasting methods, road header, excavator or breaker, expansive chemical agents etc. depending on ground condition and site constraints. Initial tunnel support is generally sprayed concrete, rock bolts, lattice girders, steel sets or fore poles etc. to prevent the disintegration and falling of loosened rock mass after excavation of the tunnel. Tunnel final lining shall be precast segments or cast-in-situ concrete or sprayed concrete with reinforcement or mesh type of steel fibers in concrete.
NATM design and construction shall comply with all the provisions/ stipulations of contract.

5.1 GENERAL CONSTRUCTION SEQUENCE

Construction of NATM is an observational approach method, which relies on the interpretation of geological analysis and instrumentation monitoring data. This method gives flexibility to modify the designed support system at any point of time as the work progresses by evaluating actual site condition based on face mapping data and instrumentation monitoring data.

1. **Profile marking:** To Achieve the designed shape profile marking as marked by the survey team, this is intended to achieve most optimum excavation.

2. **Face drilling:** Where there is variation in the strata, probe holes up to the intended excavation depth can be drilled on the face of the tunnel along the tunnel alignment to obtain the geotechnical information and obtain the optimum tunneling efficiency.

3. **Excavation:** The Excavation is mostly carried out with Jack Hammers or boomers as per the availability of strata. Holes are drilled on the excavated face up to the depth and spacing of hole where the depth and spacing of 1.0 to 3.0 depending on the rock type.

   - **Charging & blasting:** if blasting is adopted, the charge, the depth of hole and the spacing is designed and provided as per the rock quality observed. Blasting is controlled, limiting the peak pulse velocity to 5 mm /sec. Moreover, the blasting shall be planned in such a way so to prevent shattering of loose / weak rocks, limit vibrations and noise and to prevent adverse effects on the Existing Buildings.
   - **De-fuming:** After blasting, the area is filled with fumes caused due to blast fumes. These fumes do not move in the tunnel and are gathered towards the upper part of the excavated part of the tunnel. As these are poisonous in nature appropriate ventilation is installed to remove these gases and to maintain the flow of fresh air.
   - Mucking & Scaling: Fragmented rock gathered after excavation shall be removed using backhoe loaders and dumper trucks. The muck is temporarily stored in the station area and then shifted

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to the designated dumping yard. To achieve accurate final excavated profile and installation of Lattice girder support, Scaling shall be done.

4. The Monitoring Instrumentation Equipment to monitor, deformation, anchor forces shall be installed and monitoring of Defined AAA levels shall be done in regular intervals.

5. **Geological Face Mapping**: Based on Observational approach and as per the number joints and rock condition of the excavated face Geological Mapping is carried as per the face log, primary support system is adopted and if prior design is provided adequacy of the primary support is checked based on the Mapping. This step is carried out after each round of excavation.

6. **Face sealing Shotcrete & Lattice Girder Erection**: Lattice Girder as per the required shape / profile, alignment and coordinates are installed. Protecting layer on the face is applied to prevent falling of any loose material to act as protecting layer.

7. **Fore poling as per requirement:** if weak rock of grade III or weaker is encountered additional support shall be provided. This activity is to assess the strength of the over burden over the tunnel crown and helps in identifying loose pockets, water ingress, and cavities if any and helps in preventing collapse. Based on these fore-poling activities, rock bolting spacing and depth and thickness of the shotcrete, as proposed in the design can be reassessed.

8. **Primary Lining (Shotcrete):** Shotcrete is main component of initial or primary support system in NATM tunnel. According to design or in accordance with the data obtained from Face Mapping and fore poling the Shotcrete thickness is laid to prevent falling of loose material of the excavated face. Depending on the condition of the rock observed Shotcrete can be done with and without Wire mesh and with and without fiber reinforced concrete.

9. **Rock Bolting & Grouting:** Rock Bolting in the Tunnel is done after Shotcrete is laid to stitch shotcrete with Rock so that the shotcrete and rock forms a composite system to support the overburden on the tunnel. Rock bolts shall also help in stitching he joints and form monolithic body. The rock bolts spacing, length and diameter are provided as per design or modified as per the Face mapping and fore-poling details. Generally, SN- Type rock bolts are used.
10. **Water proofing:** Suitable waterproofing materials and methods shall be used to meet the water tightness requirement and the proposed system shall be approved by the Engineer. The waterproofing membrane and methods used shall comply with the relevant BS/ASTM codes and the Contract.

    - **Waterproofing for Final Lining of RCC:**
      Water Proofing Membrane shall be heat welded impermeable sheet of thickness 2.0 mm minimum. Following material shall be adopted.
        - High Density Polyethylene (HDPE) conforming to IS 10889:2004 ("High Density Polythelen Films")
        - Poly Vinyl Chloride (PVC)
    - **Waterproofing for Final lining of Sprayed Concrete:**
      The Ethylene-Vinyl-Acetate (EVA), sprayed water proofing membrane is used in MML-3 for Sahar station NATM cross-over works, sandwiched between temporary lining and permanent

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lining. Due to humid climate of Mumbai the membrane cures quickly and bonds with the substrate with the evaporation of water from the surface. The water ingress is managed by providing drainage pipe, strip drain and injection grouting, drain regulating layer and finally the sprayed waterproofing membrane.

11. **Fire Protection:** The design shall consider following considerations along with the provisions of fire control system installation –
    - Providing safe, smoke-free egress/ escape of the commuters and staff at place of incident
    - Ensure structure shall withstand major service loads after event of fire.
    - Ensure good quality control to minimize the concrete spalling and detrimental impact of fire.
    - Ensure that damage shall be repairable so that all the operations are resumed quickly.
    - Placing the system to early detect the fire in real time and reducing the response time.

    Fire control measures shall be –
    - Choosing appropriate temperature curve
    - Active fire suppression system
    - Use of polypropylene fibers in concrete mix
    - Use of panels of calcium silicate aluminate material
    - Application of Cementitious coatings
    - Cover to reinforcement.

5.2 Construction tolerance (tolerance for lining)

1. Depending on the quality of rock / ground the proposed theoretical excavation profile is taken into consideration to provide space for radial deformations and construction tolerances.
2. Actual thickness shall not be less than the designed thickness of the final support unless agreed by the Engineer.
3. The primary shotcrete (initial support), rock bolts and steel ribs shall not penetrate the theoretical outer boundary of the inner lining (final support).

5.3 Over break

1. Over break is space created when ground breaks beyond theoretical excavation line due to unavoidable geological conditions. In case of excessive over break support shall be installed immediately to stabilize the ground.
2. Remedial measures shall be taken prior to the face mapping of the excavated ground surface.
3. If over break exceeds 150mm beyond theoretical excavation line, Engineer shall inspect and decide to backfill the gap with either shotcrete or concrete of same grade as lining.

5.4 Instrumentation & Monitoring (I &M)

5.4.1 Instrumentation and monitoring are done with a purpose of-

1. Verification of parameters obtained from Soil investigation and are useful in characterization of common parameters like pore pressure, permeability etc.

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2. Design verification: Data obtained helps is verification of design parameters and provide the opportunity to modify the design.
3. Construction control: Monitor the effects of construction, helps in ascertain any effect on the strata and EBS due to tunneling activity, load cells indicate the stresses in excavated tunnels and rock bolts, helps in ascertain the deformations.
4. Safety: Instrumentation Monitoring provides early warning of impending failure through real time monitoring for any excessive and undue ground movements and effects on adjoining structures, utilities, existing railway lines, power lines and Metro viaduct. Helps in ascertain and adopt preventive remedial actions well within time.
5. Performance: Instruments are used to monitor the in-service performance of a structure like leakages, deformations, loads and stresses etc.
6. Legal protection: data obtained from the Instrumentation and monitoring provide basis & supoort for design assumptions and for construction methodology adopted. This is important as the alignment of the metro passes to through densely populated areas having high rise buildings.

Monitoring and interpretation of deformations, strains and stresses are important to optimize working procedures and support requirements, which vary from one project to the other. In-situ observation is therefore essential to prevent failures during construction period.

Based on the Design and Analysis, I&M shall assess and indicate that is an acceptable probability that the behavior is in acceptable limits. The range of behavior shall be assessed, and limits of the acceptable range shall be presented in the design. A plan of monitoring shall be devised which will reveal whether the actual behavior lies within the acceptable limits The monitoring shall make this clear at a sufficient early stage; and with sufficiently short intervals to allow contingency actions to be undertaken successfully. Planned contingency actions shall be prepared and adopted if the monitoring reveals behavior outside acceptable limits. During Construction the monitoring shall be carried out as planned and additional monitoring shall be undertaken if this becomes necessary. Alert, Alarm and Action (AAA) levels are determined as per the analysis and design and monitored regularly during construction.

Monitoring of tunnel with shotcrete lining is carried out using following instruments –

1. Bore hole extensometer to measure deformations of rock mass & Ground surrounding the tunnel and surface settlements.
2. Load cells & Strain Gauges to measure load and strain in rock bolts & in Lattice Girders.
3. Strain gauges & Stress Cells to measure strain & Stress in shotcrete.
4. Pore pressure meter to measure pore water pressure around tunnel and underground.
5. Convergence measurement by mechanical methods-tape extensometer
6. Convergence measurement by optical methods - Bireflex and Prism Targets
7. Inclinometer and magnetic settlement devices.

To monitor and measure the parameters are within the expected threshols and if check there is any adjustment or modification are required in design, following instruments shall be provided.

1. Tunnel
   - Convergence measurement by mechanical and optical methods
   - Roof leveling points.
   - Shotcrete and rock bolts load cells

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2. Surrounding Strata
   - Borehole Extension meter
   - Inclinometer
   - Piezometer
   - Stress Cells & Strain Gauges
3. Surface
   - Settlement points
4. Adjoining Structures
   - Deformations
   - Levels
   - Tilt meters
5. Real time monitoring & Evaluation

5.4.2 Alert levels considered in design and monitored are tabulated below –

Trigger level	Description	Action to be taken
Alert Level	0.5 x Serviceability Limit	Review of all total, differential movements/ distortions. If trends suggest "Action Level", remedial measures shall be suggested.
Action Level	0.8 x Serviceability Limit	Updated review of total and differential movement including remedial works that have been implemented.
Alarm Level	1.0 x Serviceability Limit	All work shall be suspended within 30m of instrument installed till next corrective level is suggested.

Serviceability shall be lesser of the following –

1. Calculated design value for serviceability limit movement.
2. Movement which would theoretically cause service disruption.
3. Structure ground movement worse than "Slight" Damage Classification and "Negligible" for Heritage Structures.

Element	Alert	Action	Alarm
Ground settlement	50%	80%	100%
Groundwater level			
Buried utilities settlement			
Ground borne noise/ Air borne/ Vibration noise	90%	95%	98%

Table 8: Serviceability Limits for AAA Trigger levels

Element	Response values		
	Alert	Action	Alarm
Ground surface (vertical)	12mm	20mm	25mm
Ground surface (Horizontal)	12mm	20mm	25mm
Groundwater level	0.5m	0.8m	1m
Water main	The trigger levels for total settlement and rotation shall be determined based on the type of service and agreed with relevant authorities. The AAA trigger levels shall be established and agreed with the Engineer and stakeholders before commencement of construction works.		
Gas main			
Buildings & Structures			

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6. Tunnel and tunnel support design methods

6.1 Numerical approach

Tunnel support design is done considering geological conditions, in-situ stress conditions expected to be encountered along tunnel alignment by making an assessment from available geotechnical data. Support recommendation is done based on this study and verified with numerical modelling for reliability.

Different considerations to carry out numerical analysis are –

1. Geometry of the tunnel is uniform along the tunnel length and thus 3D model can be analysed as 2D as plane-strain model.
2. Rock mass around the tunnel is homogeneous, isotropic in all directions.
3. In FEM analysis rock mass is subjected to Mohr-coulomb yield criterion and shear strength parameters have been evaluated accordingly.
4. Upper boundary modelled as fixed or free to simulate presence of tunnel.
5. The primary tunnel lining is modeled as elastic beam elements in 2D plane strain.
6. Final lining takes the entire load and is not shared by primary lining.

7. Design of Tunnel Support system

7.1 Design Life

Design life of final support shall be minimum of 120 years and that of non-structural components as 50 years.

7.2 Tunnel design Principles stagewise:

1. Excavated rock mass being primary load bearing structure, it's capacity shall be maintained without disruption of rock mass.
2. The rock strength is mobilized by regulating the surrounding soil deformations.
3. Deformations shall be controlled using preliminary support system within rock stand-up time. Preliminary support can be rock bolts, thin sprayed shotcrete lining.
4. Thin sprayed concrete lining shall be strengthened using wire mesh, tunnel ribs and anchors to avoid increased thickness of sprayed concrete lining.
5. Excavated unsupported rock standing time shall be kept short.
6. Deformations of support and ground shall be constantly monitored with installation of instruments in lining, ground, and boreholes.
7. Tunnel internal convergence to be predicted and monitored.

7.3 Tunnel Design

1. The design of the NATM tunnel shall be fully compatible with the construction methodology and shall be carried out using suitable software.

2. The design Fire Resistance Period for the final support of the tunnel shall be 4 hours.

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3. The excavation sequences for heading, benching and invert shall be designed in such a manner that the deformations inside the tunnel shall be limited to the design deformations as considered in fixing the excavation profile.

4. The design method shall consider in-situ ground stresses.

5. 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 and the rock loading as worked out from the rock-mechanics engineering principles. The effect of the over-consolidation of ground shall be ignored in design of final ground support of tunnel.

6. The design shall consider all additional loads, stresses and strains imposed by or on adjacent EBS and assumed distortions and loads by or on the proposed NATM tunnels.

7. Where NATM 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 by the Contractor as agreed with the Engineer.

8. The design shall also consider the relative rates of loading / unloading in both the lateral and vertical directions, and the resultant induced tunnel deformations whether temporary or permanent.

9. The design of the NATM tunnel linings shall consider the proximity of other tunnels one to another, the sequence and timing of construction and the proximity of adjacent EBS.

7.3.1 Initial tunnel support

1. Knowing the ground conditions the strength and stand-up time of ground shall be determined.

2. Presence of groundwater shall be catered with provision of efficient drainage system or providing a water-proof membrane. The detail design shall take this into account.

3. Additional temporary supports like rock bolts, lattice girders, steel bonded mesh and steel fibre shall be used. The Design of all these shall conform to the relevant standards and may be used together with appropriate ground pre-treatment as deemed necessary for the ground conditions likely to be encountered.

4. Continuous monitoring of the ground deformations and stresses on lining shall be carried out.

5. Steel sets and lattice arch girders shall be rolled to suit the dimensional requirements of the designed opening. The designer shall provide dimensional details of the steel sets or lattice

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arches girders and lagging which include all calculations regarding imposed loads before and after any ground pre-treatment.

6. Spiles shall be steel rods or tubes of outside diameter not less than 32 millimeters.

7. Pipe piles shall be steel tubes of outside diameter not less than 40 millimeters.

8. Rock dowels shall be un-tensioned 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 fiber reinforced resin rods.
9. Rock bolts shall be tensioned bar manufactured out as one of the following types - solid steel bar, slit or deformed steel tube, glass fiber reinforced resin rods.

10. Alternative materials shall be subject to the notice of the Employer's discrete.

7.3.2 Final tunnel support

1. The tunnel final support constructed by NATM method shall be cast-in-place concrete or sprayed concrete.
2. Waterproofing of the NATM tunnel shall be PVC water proofing member appropriately provided to prevent any water ingress.
3. In MML-3, a drain regulating layer was provided on which sprayed water-proofing membrane can be applied and cured. Thereby, reducing the ground water pressure on sprayed membrane and invert until full final lining is placed and acquires design strength.
4. Design of Final lining
   - 4.1 The Stress resultants i.e., Axial force, Moments and Shear Forces are obtained from Software analysis. Software's used are STAAD, Plaxis etc.
   - 4.2 The design of Cast in Place / Situ (CIP / CIS) concrete lining adopts the principles of RCC design, the stresses induced in the lining i.e., Axial force, accompanying shear and moments are considered and designed conforming to IS-456:2000.
   - 4.3 Steel Fiber Reinforced Sprayed Concrete Lining is adopted in Sahar Road NATM cross over. The design of Sprayed Concrete Final Lining (SCL).

a) The permissible stress i.e., Compressive stress, Bond Strength and Flexural tensile strength are considered in accordance with the tests conducted on SCL samples conforming to the following codes.
   - BS-EN-14488 Part-1: Sampling Fresh & Hardened Concrete
   - BS-EN-14488 Part-2: Compressive Strength of Young Sprayed Concrete
   - BS-EN-14488 Part-3: Flexural Strength (First Peak, Ultimate and Residual) of Fiber Reinforced beam Specimen
   - BS-EN-14488 Part-4: Bond Strength of Cores by Direct Tension

b) Values obtained from at least 5 tests conducted on the samples conforming to the above-mentioned codes, Permissible compressive and flexural strength of the SCL shall be considered an adopted in Design.

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c) The design of combined Compression & Bending Moment, Similarly for Combined Compression and Shear force shall be checked conforming to Euro Code EC-2.
d) Principle minor and Major resultant stresses shall be checked and compared with the adopted permissible stresses obtained from the test results.

5. Following criteria shall be considered while arriving at the size and shape of the Tunnel -
   a) The internal dimensions required to accommodate the Kinematic Envelope, Structure Gauge, and track-bed arrangement as provided by the Track work Contractor and the OHE (Overhead contact system) arrangement as provided by the Traction Contractor.
   b) Due allowance for relative movement between tunnels and cut-and-cover structures as described in the Contract.
   c) Stiffness of permanent lining shall be such as to keep the deflection on radius under expected loading with a maximum longitudinal distortion and transverse distortion within the prescribed limits.
   d) Short-term (during construction) intermediate (immediately after construction) and long-term (full design life) loading conditions.
   e) Stresses induced by grouting.
   f) Ground pre-treatment, wherever applicable.
   g) Reinforcement of in-situ concrete lining shall be bonded to mitigate stray currents. Reinforcement detailing shall be such that there is no electrical continuity across circle joints.
   h) For Bonding and Earthing of Tunnel Support (Stray Current Protection), the designer shall provide stray current protection for the tunnel support.
   i) The formation of blind holes and all other fixings for brackets and equipment shall be detailed such that they have no adverse effect on the integrity, watertightness, and design life of the linings.

8. Design Loads and Loading Conditions

8.1 Loads

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

a) Dead Load from self-weight of structure.
b) Superimposed surface loads from traffic, existing structures over and adjacent to the NATM tunnel, and any specified future loads.
c) Appropriate ground loads, water pressure, and seismic loads.
d) Railway loads wherever appropriate.
e) Long- and short-term ground yield or squeeze.
f) Unequal grouting pressures.
g) Adjacent bored/NATM tunneling or excavation.
h) Openings in, or extensions to, the lining.
i) Long- or short-term loads induced by construction.
j) Temperature and shrinkage.
k) Accidental loading such as fire and derailment.

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8.2 Loading Condition

1. Dead load comprises the self-weight of the basic structure and secondary elements supported and the ground load. The depth of cover shall be the actual depth or a minimum of one tunnel diameter. The depth of cover shall be measured from the ground surface to the tunnel crown.
2. Traffic surcharge shall be as per the loading of IRC/IRS as applicable.
3. Loads from existing or known future adjacent structures above or within the area of influence, which will remain in place above the NATM 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.
4. Additional support, ground treatment or additional lining thickening shall be provided unless it can be shown that adequate provision already exists. Non-Metro structures shall not be supported directly by the NATM tunnel lining.
5. Where provision for a specific future structure is not made a minimum uniformly distributed surcharge of 60 kPa at the design finished ground level shall be assumed.
6. Hydrostatic pressure, ignoring pore pressure relief arising from any seepage into the tunnel. For derivation of hydrostatic pressure, the maximum groundwater level shall be taken as the 1 in 50-year return period water level or actual water level at the time of construction whichever is the higher, plus a 1.0m allowance for contingencies.
7. Loads and load changes due to known construction activity in the vicinity of the NATM tunnel, such as the excavation and the formation of underpasses, basements, pile groups, bridges, diaphragm walls and cable ground anchors.
8. The permanent NATM tunnel support shall be designed and checked for all possible combinations of applied loads and forces.

8.3 Floatation

For floatation check, the water table is assumed to coincide with the Ground level. Where the tunnels are relatively shallow, they shall be checked for the possibility of floatation 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 floatation shall not be less than 1.1 for any of the condition.

In MML-3 floatation checks are made for both the service stage and construction stage with water levels considered as –

1. Ground water level measured at max. elevation + 1m for construction stage.
2. Max. flooding level above ground level at 1 in 50 year + 1 m for service/ operation stage
3. Ground water level at ground water level for accidental case
4. Maximum flooding level (above ground level) at 1 in 50 year + 2.0 m for Extreme case.

8.4 Crack Width

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

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8.5 Load cases, Load factors and Combinations

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

8.5.1 Load Cases

Following load cases shall be considered at each design section:

i) Load case 1: Ground water table at the ground surface+1m with uniform surcharge of 50 kN/m^2
iv) Load case 2: Ground water table at the ground surface +1 with no uniform surcharge.
v) Load case 3: Ground water table at 3m below existing ground water level with uniform surcharge of 50 kN/m^2.
vi) Load case 4: Ground water table at 3m below existing ground water level with no surcharge.
vii) Load case 5: Ground water table at extreme water level with no surcharge.

8.5.2 Load factors and combinations

The design forces are derived based on load factors tabulated below in accordance with codal provisions of IS:456-2000, BS 8110-part 1-1997 and Hong Kong DSM-section4- 2009.

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

NOTES:
- 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 be 1.5.
- 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
** -Water level for serviceability is to be at ground level

9. CROSS-PASSAGES

1. Passenger emergency evacuation design for cross-passages between running tunnels shall be in accordance with the requirements of NFPA-130-2010 standard for fixed guideway transit and passenger Rail system as follows.
2. In single-track tunnels the distance from a station (platform end) to a mid-tunnel escape shaft (to the surface) or to the next station (platform end) shall not exceed 762 meters. Cross-passages shall be permitted to be used in lieu of emergency exit stairways to the surface where train ways are divided by a minimum 2 hours rated walls or where train ways are in twin bores.

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a) The distance between adjacent cross-passages in the tunnel shall be provided as per clause NFPA 130-2010, clause 6.2.2.3.2
b) Track cross over shall not be considered as cross passages.

3. The locations of cross-passages shall be chosen to avoid critical sections of the alignment where their construction could have an adverse effect on adjacent structures.
4. The openings into the running tunnels shall have a width of 1.2 meters and a height of 2.1 meters. Throughout the cross-passage a minimum headroom of 2.1 meters shall be maintained over a width of 1.2 meters.
5. The cross-passage floor screed shall be laid to fall and drain into the running tunnel drainage system. Floor level shall correspondence with the level of the bored tunnel escape route.
6. 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, clause 6.2.2.4.2.
7. 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).
8. 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.
9. The cross-passages and junctions shall comply with same water-tightness criteria as the bored tunnels.
10. Where openings for cross-passages and the like are to be formed in running tunnels with segmental concrete linings, 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 openings 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.

10. TUNNEL MAINTENANCE WALKWAYS

1. Walkway to be designed as per approved SOD.
2. The Escape walkway shall provide continuous access from the trains to the cross-passages and/or station platforms.

11. DRAINAGE ARRANGEMENT IN RUNNING TUNNELS

1. The Designer shall coordinate with the adjacent station plumbing design before finalizing 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.
   $VR = A * v * t * F.O.S. * 10^{-3}$ Where,
   VR = Volume of reserve, m^3

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A = lining/wall area, m^2
v = Maximum leakage rate, $l/m^2/day$
t = Maximum response time, (day)
F.O.S. = Factor of Safety

3. For running tunnel/underground structures', 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

1. Subject to the requirements of this design basis report and Contract documents, all design work shall comply with the appropriate current standards issued by the Bureau of Indian Standards (BIS). If such a standard does not exist, then the appropriate current standard issued by the British Standard Institute (BSI), or European code shall be referred. If appropriate standard from BIS, BSI or EN does not exist, then subject to Notice by the Engineer, an appropriate current standard or research study material from a reputable institution may be used for design.
2. All standards shall be that including Amendments and Addenda, current at the date of submission of tender.
3. Reference codes
   - IS-456: Plain Reinforced Concrete – code of Practice.
   - EC-2: Design of Concrete Structures
   - EC-7: Geotechnical design
   - EC-8: Design of structures for earthquake resistance
   - EN206-1:2000/A2:2005. Concrete – Part 1: Specification performance, production and conformity.
   - IS-14487 part-1: Sprayed Concrete- Definitions, Specifications & conformity.
   - IS-14487 part 2: Sprayed Concrete- Execution
   - BS-EN-14488 Part-1: Sampling Fresh & Hardened Concrete
   - BS-EN-14488 Part-2: Compressive Strength of Young Sprayed Concrete
   - BS-EN-14488 Part-3: Flexural Strength (First Peak, Ultimate and Residual) of Fiber Reinforced beam Specimen
   - BS-EN-14488 Part-4: Bond Strength of Cores by Direct Tension
   - BS-EN-14488 Part-5: Testing Sprayed Concrete: Determination of Energy Absorption Capacity of Fibre Reinforced Slab Specimen.
   - BS-EN-14488 Part-6: Testing Sprayed Concrete: Thickness of Concrete on Substrate.
   - BS-EN-14488 Par-7: Testing Sprayed Concrete: Fiber content of Fiber Reinforced Concrete.

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4. Alternative or additional codes, standards and specifications proposed by the Contractor shall be internationally recognized codes including Indian Railway Standards (IRS) and Indian Road Congress (IRC) and shall be equivalent to or better than Indian Standards issued by the Bureau of Indian Standards, or any other Indian professional bodies or organizations subject to being in the opinion and Notice of the Engineer suitable for incorporation into the Specifications.

   The order of Preference of codes will be as follows: -
   1. BIS (Bureau of Indian Standards)
   2. BS / EN (British and Euro codes)
   3. IRS (Indian Railway Standards
   4. IRC (Indian Road Congress)
   5. AASHTO (American Association of State Highway and Transportation Officials)

13. MECHANICAL & ELECTRICAL SYSTEMS

The items like Fire detection System, Fire Suppression system, Fire Alarm PA System, Emergency Lighting, Power Supply System, Tunnel Ventilation etc. shall be designed and conformed to best international standards NFPA130, NFPA101 etc. and to the best international practices. These sub-systems shall obtain Notice of No Objection from concerned STATE Authorities.

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DESIGN BASIS REPORT (DBR)

UNDERGROUND WORKS BY CUT AND COVER METHOD

January 2024

MUMBAI METRO RAIL CORPORATION

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Quality Information	
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MUMBAI METRO LINE 3 GENERAL CONSULTANTS MAPLE

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1. INTRODUCTION

1.1 Brief Description and Salient features of the Project

Mumbai is a fast-growing Metropolis of the country and is expected to continue to grow in the future. Mumbai Metropolitan Region (MMR) comprises of 7 municipal corporations, 13 municipal councils and 996 villages and extends over an area of 4,355 sq.km. The existing transport facilities are overcrowded, and the road network is congested and there is a large gap between the demand and supply. To decongest the public transport and to increase the mobility across the city Under Ground Rapid Transit System under the aegis of MMRC a fully under-ground line is planned, which is called MML-3. MML-3 covers the total length of 33.508 kms traversing from Colaba in the south via Bandra to SEEPZ, this line consists of 26 under ground stations.

The line consists of 3 cross overs, 2 sidings and 26 stations of which 7 stations are NATM stations (Hybrid stations with NATM & Cut and Cover works). The details of all Stations, NATM Stations and NATM Crossovers are tabulated below.

Table 1: All Stations in Mumbai Metro Line-3

Sr.no.	Stations	Sr.no.	Stations
1	Cuffe Parade Station	14	Sidhivinayak
2	Vidhan Bhavan	15	Dadar
3	Church-gate	16	Shitaladevi
4	Hutatma Chowk	17	Dharavi
5	CST Metro	18	BKC
6	Kalbadevi	19	Vidya Nagari
7	Girgaon	20	Santacruz
8	Grant Road	21	CSIA- Domestic
9	Mumbai Central	22	Sahar Road
10	Mahalaxmi Worli	23	CSIA- International
11	Science Museum	24	Marol Naka
12	Acharya Atre Chowk	25	MIDC
13	Worli	26	SEEPZ

Table 2: NATM Stations (Hybrid stations with NATM & Cut and Cover)

Sr.no	Station Name (NATM Stations)	Sr.No.	Station Name (NATM Stations)
1.	Hutatma Chowk	5.	Shitaladevi Temple
2.	Kalbadevi	6.	Santacruz Station
3.	Girgaon	7.	Marol Naka Station
4.	Grant Road		

Considering geology of Mumbai, it is a part of Deccan volcanic province like other areas of Maharashtra. Deccan province is majorly covered with basalt. In the coastal Area like Mumbai the top virgin soil is

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Marine clay. In other land area, the top layer encountered is fill brought from outside, especially for the road works. The top substrate is 3.0m to 4.0m of backfill soil i.e., soil brought from outside filled over the original soil stratum. Second layer is predominantly chemically non-aggressive Marine clay, underlain be highly to moderately weathered rock (defined as grade V & IV rock), followed by Slightly weathered rock (defined as grade III rock), below this stratum is less weather or compact rock (defined as Grade II & I Rock). Along the alignment of MML-3 the distribution of soil and rock layers is irregular, the depth and thickness of the weathered rock varies for different areas of the station.

In MML-3, underground cut and cover bottom-up construction approach is adopted for stations, subways, utility ducts, box tunnels, ramps. In this method the ground surface is excavated progressively to the required level and constructing from the excavation bottom level i.e., base slab, walls, concourse, and roof slab. The surface opening is covered with steel or concrete decking as per the site condition and design requirement to allow the traffic and pedestrian movement while the excavation/ construction work continues underneath. As the construction of the station box progresses upwards the removal of the soil support system is done sequentially. Finally, the construction ends with backfilling station box and instating the top ground or the road under which the station is constructed. The top of rail is varying from -20.0 MSL to -30.0 MSL and bottom of the base slab from -23.0 to -33.0 MSL.

The excavation support system includes secant piles, walers, struts and/or anchors. Excavation in rock require supports system like rock bolts and shotcrete with weep holes.

This Design Basis report deals in underground cut and cover construction for the Mumbai Metro Line-3 (MML3).

1.2 Geometric Design Criteria:

Wherever applicable provisions of approved model DBR of Viaduct shall be followed.

Table 3: Geometric Design Criteria

Sr. No.	CRITERIA	DIMENSIONS
1.	Gauge	1435 mm
2.	Maximum operating speed	85km/h
3.	Design Speed	95km/h
4.	Max. Axle load, loaded condition,	17MT (Metric ton) or 170kN
5.	Max. Gradient running track	4%
6.	Gradient Depot connecting track	4%
7.	Minimum vertical curve radius	1500 m

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8.	Minimum horizontal curve radius	200 m (main line track)
9.	Traction power collection	Overhead catenary system (OCS) at 25kV (AC). Rails shall be used for traction return current
10.	Inclination of rail	1 in 20
11.	Wheel thread profile	UIC 510-2 (S1002)
12.	Rail profile	UIC 60 (861-3)
13.	Maximum cant	125 mm
14.	Maximum cant deficiency	100 mm

2. SCOPE OF DBR

The design basis report hereto provides minimum standards that are to govern the design of track ways; underground stations and ancillary structures etc. constructed by cut and cover method. The design basis report shall be read in conjunction with the Outline Construction Specifications where appropriate. It may be noted that, the basis for developing Design & Construction Reference Drawings shall be the tender document.

The design of the permanent and temporary support works shall comply with code of practice and standards at the time of submission of Tender Documents, Regulations made, and requirements issued by the Indian Government and by relevant utility authorities shall be followed and specified.

In addition to design, data and criteria, key design data extracted from reference design standards, approach towards design of various elements, a summary of design methods, assumptions and software used have been provided in this document.

Extended platform portion, which is generally on level-change station structure, shall be designed as part of viaduct, if any.

For design of soil support system software used are-

a. Plaxis
b. WALLAP
c. RS-2 (Rock and Soil 2D analysis software)
d. SEEP-W for seepage analysis in rock

For structural analysis of cut and cover structures software used are-

a. Plaxis
b. MIDAS

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3. DESIGN PRINCIPLE

Cut-and-Cover structures include all stations, station entrances/exits, vent shafts, pedestrian subways, utilities, services, ducts, Cut & Cover ramp structure (where applicable) and the like, other than bored & NATM tunnels. However, the provisions/ stipulations in these specifications shall also be applied to all other works under the Contract, wherever considered applicable and relevant.

1. The proposed structure of underground station may be a rigid box section with permanent walls as external wall support system and flat slab with column forming the internal structural framing. The roof slab shall support the soil and vehicular surcharge (as applicable) while the passenger and plant/services/structural loads are carried by the concourse slab/intermediate slabs. The track and platform loads including passenger and plant/services/structural loads shall be supported by the base slab. The permanent walls shall resist the lateral earth and hydrostatic pressures in addition to the surcharge and services/structural loads.

2. In the design of Underground station structures, following factors should be taken into account: -
   a. Method of construction, including temporary works and construction sequence.
   b. Ground/structure interaction, including the effects of temporary works.
   c. Ground pressure, shear force and bending moment distribution during construction and in the long-term.
   d. Short- and long-term ground and groundwater response.
   e. Other static loads changes such as excavation, surcharge, traffic loadings and the like;
   f. Long-term surface water level changes.
   g. Dynamic (such as seismic or vibratory plant) loads and displacements.
   h. Safe evacuation of passengers in case of accident/derailment/fire etc.

3. For the purpose of assessing ground and ground water pressures, the underground station structures may be considered to be effectively impermeable rigid box structures subject to the earth pressure.

4. The design shall minimize the effects (such as movement, distortion of the ground and the like) on all Existing Building Structures (EBS) that may be affected by the works and shall comply with all the requirements/provisions of the Contract. Wherever necessary the additional support for these EBS will be provided.

5. The Design of all cut-and-cover shall take into account, but not limited to the following –
   a. The variation in ground conditions along the alignment. The geological/hydro geological features and their variations including rock joint orientation and spacing etc.
   b. The variation in engineering properties of soil or rock within the influence of the proposed Works.
   c. All dewatering and groundwater cut-off systems required to maintain dry and stable conditions within all excavations required for these works.
   d. Any ground treatment required before, during or after construction of the works (e.g. groundwater recharge), to stabilize the ground and existing building structures (EBS) in order to minimize ground and EBS movement and distortion.

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e. Methods by which the completed structure shall be secured against flotation (Any temporary dewatering system shall not be turned off unless and until provisions have been made to satisfy that, the structure will not be subject to leakage or flotation when the groundwater returns to the design levels).
f. Differential groundwater pressures.
g. Methods of waterproofing the completed structure.
h. Any difficulties that are envisaged at site respect of access, clearances, working space and obstruction to excavation.
i. Maintenance of traffic flows along/on roads including access to adjoining properties and roads.
j. Control of heave, swell, piping and instability of the excavations.
k. Noise/vibration levels produced during construction, and subsequent operation of the railway.
l. The depth of construction required.
m. The effects of earthquake, vibrations, and its induced movements.

6. Construction method for the station is cut and cover bottom-up construction. The NATM and TBM works are covered in respective DBR's. Following method of construction is adopted -
    a. Secant Piles: Particular attention shall be paid to the construction/installation of the piles and ground support systems to ensure their integrity and watertightness and to provide adequate support to the ground during excavation.

7. Secant pile wall with waler, strut and/or anchor is used as temporary support system for the proposed bottom-up construction. Secant pile shall be provided with adequate rock socketing. This pile support system shall provide adequate watertightness, depending upon the geological and hydrological conditions. Other methods of support may be used for the other relatively shallow excavations such as station entrances/exits, pedestrian subways, utilities and services as applicable.

8. For excavation support, following design parameters shall be taken into account -
    a. Earth pressure.
    b. Hydrostatic pressure.
    c. Deck load. (Traffic and construction equipment load)
    d. Surcharge loads.
    e. Seismic and/or vibratory loads
    f. Support types and arrangement.
    g. Any other incidental load.
    h. Construction/deconstruction sequence.
    i. Calculated ground and adjacent EBS movements and distortions.
    j. Calculated fluctuations in groundwater levels both within and outside of the excavation and support walls.
    k. Calculated changes in EBS loading conditions.

9. Method statement: A Method Statement giving the full details of materials, plant and operations involved in the construction of excavation support walls shall be prepared and incorporated into the Design Report and shall include but not be limited to the following details:
    a. Sequence of excavation and concreting of panels.

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b. Method of producing the workable concrete.
c. Methods of handling within the excavations and disposing of groundwater outside of the excavation.
d. Formation of the joints between panels and installation of water stops.
e. Methods of instrumenting, monitoring and reporting of the performance of all adjacent EBS that may be affected by the works.
f. Type and construction of permanent lining wall.
g. Emergency procedures to be implemented in the event of monitoring indicates tolerances associated with the excavation support wall may be exceeded.

Where temporary ground support is to be provided using bentonite slurry, the following additional information may be provided in the Method Statement for these works.

a. Mixing, transporting, and placing equipment for the bentonite slurry.
b. Method of disposal of contaminated bentonite slurry.
c. Type, source, chemical and physical properties of the bentonite to be used.
d. Stability, dimensions, and details of guide walls.
e. Cleaning and re-use of the bentonite slurry.
f. Calculations to show that the density of the bentonite and lowest head of slurry are sufficient to maintain the stability of the trench excavated for the support wall, in the ground, conditions envisaged, to its full depth.

4. UNITS

The main units used for design will be: [t], [kN], [N] [m], [mm], [KN/m²], [KPa] [MPa], [kN/m³], [°C], [degrees] [rad].

5. MATERIALS

5.1 Cement

For Plain and Reinforced Concrete structures cement shall be as per Outline design specifications or tender document of a Project, confirming to Clause 5.1 of IS 456
In MML3, Ordinary Portland cement (OPC) of 43 and 53 grade conforming to IS 8112-1989 and IS 12269-1987 respectively, are used.

Portland Pozzolana Cement (PPC) conforming to IS 1489 and the usage of sulphate-resistant Portland cement conforming to IS 12330 for structural elements exposed to soil/ground may also be used.
In all cases, the cement shall meet the 28-day strength requirement.

5.2 Concrete

1. In case of Plain and Reinforced Concrete structures concrete material properties shall be as per clause 6, 7, 8, 9 and 10 of IS:456 2000.
2. Short-term modulus of elasticity (Ec) shall be as per clause. 6.2.3.1 of IS:456 for Plain and Reinforced concrete structures.
3. The modular ratio for concrete grade shall be as per clause B-1.3, Annex B of IS:456.

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4. Thermal expansion coefficient shall be taken as per clause 6.2.6 of IS:456.
5. Density of concrete shall be 25 kN/m³ for reinforced cement concrete (RCC) and 24 kN/m³ for plain cement concrete (PCC).
6. For use of Ground Granulated Blast furnace Slag (GGBS) in concrete shall conform to IS 16714 and for Silica fume as per specification given in IS 15388.

5.3 Prestressing steel for tendons

Shall be a per clause 5.6.1 of IS:1343.

5.4 Reinforcement

Only thermo-mechanically treated (TMT) reinforcement bars of grade Fe 500-D with minimum Yield Stress of 500 MPa unless specified or shall be as per clause 5.6 of IS:456 for Plain and Reinforced Concrete structures.

Note: For seismic zone III, IV, V, HYSD steel bars having minimum total elongation of 14.5% and conforming to requirements of IS:1786 shall be adopted.

Table 5: Material properties used at MML-3 are:

Young's Modulus MPa	Yield Stress MPa	Diameters mm	Density kN/m^3	Poisson's Ratio	Thermal coefficient per °C
200,000	Fe 500-D	8, 10, 12, 16, 20, 25, 32, 36,40	78.5	0.3	$12X\ 10^{-6}$

5.4.1 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 Pre-stressed concrete structures. Ductile detailing of seismic resisting RC elements shall comply with ductile requirements of IS: 13920.

5.5 Structural Steel

Design of Structural steelwork shall confirm to
1. Hollow steel sections conforming to IS:4923/ IS 806
2. Steel for General structural purposes conforming to IS:2062
3. Steel tubes for structural purpose shall conforming to IS:1161.

Hollow steel sections shall be square (SHS), rectangular (RHS) & circular (CHS). Other traditional rolled sections like plates, angles, channels, joists can also be used where required.

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The connection with concrete shall be effected by internally threaded bolt sleeves (hot dipped galvanized @ 300 grams per square meters) 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.

The connections or/and bolted within the steel structure shall be designed welded members with or without gusset plates. The minimum thickness of metal for SHS/RHS sections for main chord members as well bracings shall be 4 mm as applicable for steel tubes in cl. 6.3 of IS: 806.

Table 6: Material properties considered in MML-3 are

Steel Type	Young's Modulus	Tensile Strength	Yield Strength	Density	Poisson's Ratio	Thermal Expansion Coefficient
Hollow Steel Sections (IS: 4923)	200,000 MPa	450 MPa	310 MPa	78.5 kN/m³	0.3	$1.2X10^{-5}$ per ° C
Structural Steel (IS:2062)		410 MPa	250MPa (for t < 20 mm); 240MPa (for 20mm < t < 40 mm); 230MPa (for t > 40mm)			

Note:

(i) Grade of steel to be used shall be indicated, 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 will be governed by IRS Steel Bridge Code in case structure is taking moving loads of Metro, otherwise will be governed by IS: 800. In case of composite (steel-concrete) structures it will be governed by 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.

6. DESIGN LIFE AND DURABILITY CRITERIA

The 'design life' of all Civil Engineering Underground Structure shall be minimum of 120 years unless

otherwise specified or agreed upon. The design life of non-load bearing elements such as utility support, vent shaft etc. shall be 50 years.

Adequate measures shall be taken to ensure minimum of 120 years serviceability of civil structures, producing durable concrete with Micro silica (Or other suitable admixtures). The concrete shall be tested for permeability (penetrability) according to DIN 1048 and ability to resist chloride ion

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penetration according to ASTM C1202. The rapid chloride penetration test (RCPT) value was limited to 1000 coulmbs and permeability for RCC based slab was limited to $5x10^{-13}$ m/sec.

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.

6.1 Concrete Grade

The minimum grade of concrete for underground structures shall be M35. However, for structural elements that might come in contact with Nallah / River Water the minimum concrete grade shall be M45.

Where concrete is to be placed under the slurry or water, such as secant pile and barrettes, the design compressive strength and shear strength of structural concrete shall be reduced in comparison to the adopted concrete grade. The characteristic strength of the compressive and shear stress shall be taken to be 80% of the characteristic strength of the adopted concrete grade.

6.2 Cover to Reinforcement

As per clause 26.4 of IS:456 for Plain and Reinforced Concrete Structures.

6.3 Fire Resistance Period

6.3.1 Main Station Structures

1. All structures shall be designed for fire protection as specified by the applicable standards and codes. Materials specified for the Works shall be non-combustible and shall not emit toxic fumes when subject to heat or fire. In all cases where there is significant fire risk, materials shall be self-extinguishing, low flammability, low smoke and low toxicity.
2. All the main elements of the station structures (like roof slab, concourse slab, Base slab, Columns, RCC walls, Staircase etc.) shall be designed for a minimum fire resistance period of 4 hours. The Fire Resistance of non-load bearing separation walls shall be determined by their fire-compartmentation requirements.
3. The minimum element thicknesses for this fire resistance shall be as per clause 21 of IS:456 and IS: 1642 for concrete structures.
4. The minimum element thicknesses for this fire resistance shall be as per clause 16 of IS:800 of steel structures.

6.3.2 Ancillary Structures

All the structural elements other than main structural elements as stated in para 6.3.1 shall be designed for a minimum fire resistance period of 2 hours or as approved by local fire safety authority.
The minimum element thickness for this fire resistance shall be as per clause 21 of IS: 456.

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For above-ground ancillary structures the following contents shall be adopted. The environmental exposure condition for the above-ground structures shall be as per Table 3 of IS: 456. The minimum grade of concrete shall be as per exposure condition & as per Table 5 of IS: 456.

6.4 Crack width

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 clause 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, irrespective of whether any additional protection, such as waterproofing membrane, is provided to the members at the exposed face of the structure.

Table7: cover and crack width criteria considered in the MML-3 design is tabulated below:

Elements	Exposure	Max Crack Width (mm)	Minimum Required Cover (mm)	Nominal Cover to be considered for Crack width check (mm)
Secant Pile	Severe (for ground face)	0.2	80	45
	Moderate (for non-ground face)	0.3	80	40
RCC Walls	Severe (for ground face)	0.2	50	45
	Moderate (for non-ground face)	0.3	40	40
RCC Slabs	Severe (bottom surface cast against ground)	0.2	70	45
	Moderate (top surface i.e. non-ground face)	0.3	45	40
Water Tanks	Severe (for ground face)	0.2	45	45

Notes:

- Nominal cover is measured to the outermost reinforcement.
- Nominal cover does not include any allowance for construction tolerance.

6.5 Clearances

1. Clearances for Metro Traffic: As per approved SOD of specific Metro system.
2. For utility services: The clearances to utilities, drainage etc. shall be as mandated by the utility owner/ department.
3. Clearance for Railway Traffic: As per the case, Indian -Railways Schedule of Dimensions (SOD) shall be applicable.
4. Clearance for Road Traffic: As per relevant IRC specifications and Road Authority requirements.

6.6 Early Age Thermal and Shrinkage Cracking

1. Suitable reinforcement shall be designed to prevent early age thermal and shrinkage cracking for

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walls and slabs more than 250 millimetres thick and subjected to internal and external restraints during construction. The thermal and shrinkage strains due to early age temperature differences and shrinkage shall be accounted for in the design of reinforcement for cracking.

2. It is preferred that smaller diameter bars in any direction are placed at closer intervals to prevent early age thermal and shrinkage cracks. Guidance can be sought from CIRIA-C 660-2007 on Early Age Thermal Control of concrete.
3. Minimum reinforcement shall be higher of –
   a. 0.125% of cross-sectional area of structural member on each face in each direction
   b. Reinforcement required as pre–Early Age Thermal (EAT) control of concrete.

7. LOADS

The structure shall be designed for the most onerous combinations of loads using relevant safety factors. For the purpose of computing stresses and deformations, the following minimum loads and consequential effects shall be taken into account as applicable.

• Dead loads	DL
• Super Imposed Dead Load	SIDL
• Imposed (Live) loads	LL
• Railway Live Loads	RL*
• Earthquake Loads	EQ
• Wind Load	WL
• Accidental/ Collision	AC/CL*
• Derailment Load	DR*
• Construction/Erection	ER
• Shrinkage	SH
• Creep	CP
• Earth Pressure	ER
• Hydrostatic Pressure	WP
• Buoyancy/ Uplift	BU
• Surcharge Loads (Traffic, buildings etc.)	SR
• Pres-stress force	PR
• Fatigue	FG
• Long Welded Rail force	LWR
• Differential settlement	DS
• Movement/Distortion	2)
• Redundancy	R
• Dynamic Effects	DY
• Temperature Effects	TE

* Load as applicable shall be taken

7.1 Dead Load

Dead load shall be based on the actual cross section area and unit weights of materials and shall include the

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weight of the materials that are structural components of Underground Station and permanent in nature. It shall be calculated in accordance with IS:875 Part 1.

7.2 Superimposed Dead Load

Superimposed dead dead loads include all the weights of materials on the structure that are not structural elements but are permanent.
The minimum distributed and concentrated loads shall be in accordance to IS: 875, unless otherwise mentioned in the Outline Design Specifications or tender document.

7.3 Imposed Loads

Imposed loads on station buildings are those arising from occupancy and the values includes 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 IS: 875 (Part 2).

Table 8: Superimposed Dead Loads (SIDL) & Imposed (Live) Load considered in MML-3

Description	Superimposed Dead Load			Imposed Load	
	Finishes (kPa)	Partitions (kPa)	Ceiling & Services (kPa)	U.D.L. (kPa)	Concentrated Load (Note 3) (kN)
Station					
Concourse Area	2.4 (Note 5)	1.0 (Note 6)	1.0 (Note 6)	6.0 (Note 1)	5.0
Platform Area	2.4 (Note 5)	1.0 (Note 6)	-	6.0 (Note 1)	5.0
Track	Note 10			Refer Section 8.4	
Stairs & Landing	1.2 (Note 5)	-	1.0 (Note 6)	6.0 (Note 1)	5.0
General Plant Room, Pump Room	1.2 (Note 5)	-	1.0 (Note 6)	6.0 (Note 7)	10.0
General Office	2.4 (Note 5)	1.0 (Note 6)	1.0 (Note 6)	6.0	5.0
Staff Room	2.4 (Note 5)	-	1.0 (Note 6)	6.0	5.0
Toilet, Changing Room	2.4 (Note 5)	1.0 (Note 6)	1.0 (Note 6)	6.0	5.0
Store	2.4 (Note 5)	-	1.0 (Note 6)	10.0	10.0
Water & Fire Tank	2.4 (Note 5)	-	-	Water Height + 0.3m	-

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Description	Superimposed Dead Load			Imposed Load	
	Finishes (kPa)	Partitions (kPa)	Ceiling & Services (kPa)	U.D.L. (kPa)	Concentrated Load (Note 3) (kN)
Chiller Rooms	2.4 (Note 5)	-	1.0 (Note 6)	10.0 (Note 7)	15.0 (Note 7)
Transformer Rooms, Substation	2.4 (Note 5)	-	1.0 (Note 6)	20.0 (Note 7)	20.0 (Note 7)
Switch Gear Plant Room	2.4 (Note 5)	-	1.0 (Note 6)	20.0 (Note 7)	10
Roof Slab	2.4 (Note 5)	-	1.0 (Note 6)	Soil Load (Note 8) + 20.0 (Note 9)	-

Notes:

1. Stairs and landings to be designed for the same load as the floors to which they give access with a minimum of 2.5 kPa and a maximum of 10 kPa
2. Concentrated loads act on a square of 300 mm each side.
3. As specified or wall loads in accordance with layout in architectural plan, whichever is greater.
4. All loads are unfactored.
5. Minimum of 100 mm thick screed on top of slab with unit weight of 24 kN/m^3
6. As specified above or the imposed load from services fixed to the underside of floor whichever is greater.
7. The design loads shall be actual plant/equipment loads or the ones specified above, whichever is maximum. For seismic design, plant/machinery loading shall be considered as Super Imposed Dead Load.
8. Backfill / Earth Load Shall be calculated for the available soil depth for a unit weight of soil of 20 kN/m^3. This shall be considered as Ground Load for the purpose of load combinations.
9. Allowance for vehicular (Live Load) surcharge as per IRC 6 – 2014
10. The Track loads shall be as follows:
    a) Track work - Load due to 60 Kg (UIC) rails and guard rail and fittings
    b) Track bed - RCC blocks or concrete pour or precast slabs in RCC with inserts and fittings in case of un-ballasted track (450 to 600 mm thick) or PSC sleepers over 250/300 mm of ballast for ballasted track.
    c) All other loads shall conform to all relevant Indian Railway Standards (IRS) and Bureau of Indian Standards (BIS).

7.4 Railway Loads

7.4.1 Vertical Train Live Load

Live Load (LL): The train live load will be as per the "Modern Rolling Stock" axel load configuration (Light, Medium or Heavy). The loading envelope chosen shall be as per the Rolling Stock specified in the outline design specifications of a project.

Loads other than standard trains like track machines, cranes, any new rolling stock etc. which may come on this structure should be within the loading envelope initially decided by the metro as above.

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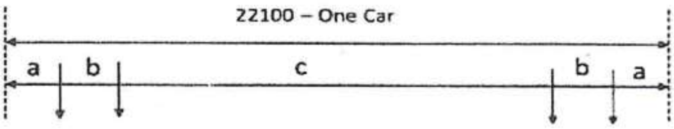
In MML-3 load considered,

All axle loads = 17 tons

Maximum number of successive cars: 8, Configuration is
a =2.45 m
b = 2.20m
c =12.50m (2a+2b+c=21.8m)



7.4.2 Coefficient of Dynamic Augmentation CDA) shall be adopted as per IRS Bridge Rules unless specified.

7.4.3 Horizontal Train Live Load

1. Braking and Traction: The value of braking and traction forces will be taken as per rolling stock used, to be decided by Metro.
2. Centrifugal Force: Design for centrifugal force to be as per IRS: Bridge Rules unless specified.

7.5 Earthquake Loads

1. **Seismic Design For Under-Ground Structures:** Seismic design of Underground Structures may be carried by using Free Field Racking Deformation method as per "Seismic Design and Analysis of Underground Structures" by Youssef M. A. Hashash, Jeffrey J. Hook, B Schmidt, J. C. Yao.

2. **Seismic Design For Above-Ground Structures (Ancillary Structures):** The design base shear shall be calculated based on recommendation given in IS: 1893.

7.6 Wind Loading

Wind loading may affect the surface elements of underground structures such as vent-shafts, entranceways, cooling towers and ancillary structures, temporary structures etc. The wind load shall be calculated as per IS 875: Part 3

Wind effects from venting in belowground areas shall be designed appropriately.

7.7 Air Pressure

A minimum air Pressure of +/- 2.5Kpa (atmospheric pressure) is considered for Cut & Cover station/tunnel design as per Outline Design Specification (ODS) document of the project.

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7.8 Accidental Load/ Collision Load

Collision Load for traffic shall be as per IRC:6.

In design considered minimum impact i.e., Accidental load of 50 kN acting at any position and at any direction on temporary works or on partially completed permanent works as given in Outline Design Specification (ODS) of the project. Reference for this load is given in Clause 10.6.4 of CIRIA C517 and Clause 3.10.5 of Technical reference for Deep Excavation (TR 26: 2010).

7.9 Derailment Loads

As per latest Design Code ACI 358. 1R-92, derailment load corresponds to the application of 50% of one coach weight, applied horizontally as a 5m long uniform impact load.

7.10 Construction/Erection Forces

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

7.11 Shrinkage

Provision shall be made for the effects of shrinkage within concrete structure. This includes interface shear transfer mechanisms as a result of residual shrinkage effects from staged casting of concrete elements.

The shrinkage strains shall be evaluated as per clause 6.2.4 of IS:456 for the Plain and Reinforced Concrete structures and clause 6.2.4 of IS:1343 for prestressed concrete structures. The limits specified in section 7.6 of IS 456 shall be applied.
For structure supporting Metro train loading the effects of shrinkage as per Cl. 5.2.3 of IRSCBC shall be considered.

7.12 Creep

Provision shall be made for the effects of creep within concrete structure. This includes interface shear transfer mechanisms as a result of differential creep effects from staged casting of concrete elements.

The creep stains shall be evaluated as per clause 6.2.5 of IS:456 for the 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.

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7.13 Earth Pressure

Underground vertical elements that are in direct contact with the ground shall be designed as permanent retaining walls to resist the lateral earth pressure at rest. In the design of structures or parts of structures below ground level, 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).

7.14 Hydrostatic Pressure

All foundation slabs/footings subjected to water pressure shall be designed to resist a uniformly distributed uplift equal to the full hydrostatic pressure. Checking of overturning of foundation under submerged condition shall be done considering buoyant weight of foundation. Effect of seasonal weather changes shall be considered as per para 9 of IS: 1904.

If any of the structure supporting Metro loading is subjected to earth pressure, the loads and effects shall be calculated in accordance with Cl. 5.7 of IRS-Substructure Code. For calculation of Angle of friction between soil and wall, CIRIA 760 code may also be referred.

The effects of temporary drawdown, seepage and base heave effects shall be considered in design of the temporary works, and catered for in the permanent works if there is a 'locked-in' effect from carry-over forces. The extent of the temporary walls shall be sufficient to mitigate the effects of such loads during construction.

The effects of flotation loads shall be allowed for in the design both in the temporary and permanent design stages.

The proposed structures (primarily the stations) may act as obstructions to groundwater movement. The Designer shall design and subsequently construct for unobstructed movement of the groundwater through and around these structures so that these structures do not result in changes to the phreatic surface that exceed normal expected diurnal fluctuations.

If liquefaction of soils be a potential risk then the design water table level for permanent structures shall include layers affected by liquefaction if this is above the design groundwater levels.

7.15 Surcharge

Traffic surcharge shall be adopted in the design as per IRC:6 for highway loading and as per IRS: Bridge rules for Railway loading respectively.

For existing buildings and other existing structures occupying areas around the excavation, detailed assessments based on building and foundation type, and loading are to be carried out to determine the applied loads and other impacts of such building loads on the proposed structures, For future buildings

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or planned infrastructure, the appropriate authorities and Employer's Representatives shall be consulted for details.

7.16 Pres-stressing Force

The pre-stressing force shall be as per IS-1343.

7.17 Fatigue Load

The nominal loading for the design of members in accordance with fatigue requirements (BS 5400: Part 10) shall comprise of trains with eight individual cars each having four axles.

Fatigue load history shall be evaluated to provide valid and representative design spectra, with stress histories analysed by the rain flow or equivalent method, both in conjunction with annual tonnages of rail traffic per track. The provision of BS 5400 Part 10 Clause 9.3.3 or other relevant method may be used as a rigorous method of evaluation or compliance with fatigue criteria.

7.18 Long welded Rail force

Guidelines vide BS report no. 119: "RDSO guidelines for carrying out Rail structure interaction studies on Metro system (version 2)" shall be followed.

7.19 Differential Settlement

Maximum and differential settlement shall not exceed, as provided in Clause 16 of IS: 1904.

7.20 Movement and Distortion

Consideration of the forces resulting from differential movement (distortion) of foundation elements shall be checked as appropriate. All movements and distortions must not be greater than limits adhered to in the relevant codes or acceptable to the relevant Authority. These may be architectural, structural, rail performance or other types of limitations currently in force.

7.21 Redundancy loads

The temporary structure shall allow for the effects of a 'one-strut failure' condition. A single strut/anchor failing at any position and at any stage shall be evaluated with Ultimate Limit State (ULS) condition with a FOS of not less than 1.05.

7.22 Differential Movement between In-Line Structures

Differential movement between adjacent in-line structures arising from static and/or dynamic loading shall be evaluated. Due allowance for such shall be incorporated into the size of the structures and detailing of joints to ensure that the total and differential movements, including distortion and relative

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rotation, between in-line structures shall not exceed the serviceability limits of the structures for the design life of the structures.

7.23 Temperature Load

Forces may arise from a thermal gradient within a structural element; this may be from external sources or, in the case of fresh concrete, from the internal heat of hydration during curing. These forces shall be considered in combination with those from other types of loads to determine the worst loading condition. 'Locked-in' forces from temperature effects (e.g. from curing of concrete) shall be considered as a permanent load and due allowance shall be considered in the design.

Temporary works with structural steel bracing elements or similar may also suffer adverse effects from thermal strains. These thermal strains shall be suitably accounted for, and suitable measures shall be taken to avoid losses in preloading and subsequent excessive deformations in structural members.

7.24 Other forces and effects

Any other loads shall be as per clause 19.6 of IS:456.

8 DESIGN LOADING COMBINATIONS

8.1 Ultimate Limit state 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.

1. Load factors and load combinations as per Table 18 and clause 19.7 of IS:456, IS:875 part-5 for Plain and Reinforced concrete shall be considered.
2. Load factors and load combinations as per section 5 and section 3.5 of IS:800 shall be considered for Steel structures.
3. Load combination and load factors as per Table 7 of IS: 1343 for prestressed concrete structures.
4. Load combinations for construction stage and collision/ accidental case considered is given in the table below -

Table 9: Ultimate Limit State Load Combination other than

Load Combination	Dead Load (DL)		Imposed Load (IL)		Ground & Water Loads		Wind Load (WL)	Seismic Load (EQ)
	Adverse	Beneficial	Adverse	Beneficial	Adverse	Beneficial		
Construction Stage (**)	1.5	-	1.3	-	1.5	-	-	-
Collision / Accidental	1.5	1.0	1.5	-	1.5	1.0	-	-

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Notes:

- Load combination (**) shall be used in checking temporary works proposals and checking the structure during temporary construction stages. The imposed load is the construction-imposed load.
- For checking structures at the Extreme water levels, the reduced partial factors of safety for water loads are to be 1.05.
- Earthquake loads are reversible.
- 50%-imposed load is to be used in line with the building mass calculated for seismic loads in load case 2 & 3.
- Creep, shrinkage, temperature and differential settlement are not considered in combination with the lateral loads at ultimate limit state. Creep and shrinkage effects will usually be minor for building type structures, no specific calculation will be necessary for Ultimate limit state.
- Wind load combinations are applicable for above-ground structures and shall be considered in addition to the other combinations.
- (**) For those structural members, which are load bearing during construction stage and subsequently form part of the Permanent works, the serviceability Limit State (SLS) checks shall be carried out, both for Construction and service/ Operation stages.

8.2 Serviceability Limit state load combinations

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

1. Load factors and load combinations as per Table 18 and clause 19.7 of IS:456 for Plain and Reinforced concrete structures.
2. Load combination and factors as per Table 7 and clause 20 of IS: 1343 for prestressed concrete structures.
3. The load factors as per section 3 and factors as per Section 5 of IS:800 shall be considered for Steel structures.

8.3 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. For Steel structures, Designs shall comply with the limits defined in IS: 800.

Dewatering outside the station or cut and cover walls shall not be permitted.

These requirements are in addition to any other requirements imposed by applicable government agencies and the owner.

8.4 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 check for –

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- RCC and PSC structures – As per clause 13.4 of IRS CBC.
- Steel Structures – As per Section 13 of IS: 800.

9 DESIGN GROUNDWATER LEVELS

Ground water level to be assumed in design for the various stages shall commensurate the ground water fluctuation in the area of construction. Following values are indicated for guidance only.

- "Construction" – Groundwater level at measured maximum elevation plus 1.0 m.
- "Service/Operation" – Maximum flooding level at 1 in 50 years plus 1.0 m.
- "Accidental" – Groundwater level at ground level.
- "Extreme" – Maximum flooding level at 1 in 50 years plus 2.0m.

10 FLOTATION

1. The minimum depth of cover to underground structures shall be 2.0m or depth to the underside of major utilities (e.g., sewer mains, storm water mains and the like) whichever is the greater.
2. For protection against flotation in the fully dry internal condition, the following shall apply.
   - A load factor of 0.9 shall be applied to the self-weight of the structure, including the first stage only of the track concrete.
   - A load factor of 0.9 shall be applied to the weight of backfill material over the structure.
   - The skin friction between the concrete surface and the soil shall be assumed only below the concourse level.
   - The overall factor of safety against flotation shall not be less than 1.1 for any of the condition defined above.
3. Design to be checked for all proposed cut & cover structures for the possibility of flotation due to differential water pressure and shall design each and every underground structure such that the factors of safety against flotation are achieved for all load cases.
4. Design to ensure that his method and sequence of construction is such that an adequate resistance to uplift is maintained at all times.
5. Suitable measures such as those listed below to counteract flotation forces for the Permanent Works shall be incorporated in the design. The measures chosen shall suit the particular conditions and the method of construction.
   a. Toe-in (keying-in) of the base slab into the surrounding ground.
   b. Increasing the dead weight of the structure by:
      - thickening of structural members, providing an extra thickness of concrete beneath the base slab tied into the structural base slab.
      - extending the excavation support walls.
      - providing counterweights in parts of the structure with high density material.
      - providing tension piles.
6. Where the base slab is toed-in to the surrounding ground a partial factor of safety 2.0 shall be applied to the shear resistance of the ground above the toe and the adhesion factor shall not apply. The value of the weight of ground above the toe shall be calculated as for the backfill material.
7. The value of the weight of any additional thickness of concrete shall take account of the increased volume of water displaced.

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11 FOUNDATIONS

Whatever 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.

11.1 Design of 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.

IS : 12070 hall be followed for fo datio i rock.

11.2 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

11.3 Design of Pile

For design of pile, load capacity etc. for piles resting on soil, IS:2911 shall be followed. For piles resting on rock, IS:14593 shall be followed.

11.4 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.

12 DESIGN OF WATER RETAINING STRUCTURE

It should be designed as per IS: 3370.

13 CIVIL EXECUTION WORKS

13.1 Excavation Base Stability

1. The Design shall include adequate precautions against base heave, piping and failure of his excavations during construction. The stability of the excavation bases shall be checked in accordance

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with an acceptable method of analysis, which shall allow for all reasonable loads within and outside of the excavation.

2. The design calculations shall explain the contribution made to the base stability of the excavation by his proposed method of construction and shall state the factor(s) of safety used in the design. The factor(s) of safety shall relate to the method of construction and to the particular location of the Works.

13.2 Excavation Toe Stability

1. The design will ensure adequate toe stability of retaining structure during construction. The toe stability will be checked in accordance with an acceptable method of analysis which shall allow for all reasonable loads within and outside of the excavation.
2. The conventional approach based on active and passive pressures shall be preferred with suitable factor of safety.

13.3 Waterproofing

1. Groundwater leakage rates into the completed Permanent structures shall be limited to damp patches only and shall not exceed under any circumstances an overall value of 0.1 liters per square meter per day.

2. The quality and grade of the concrete, treatment of construction joints, areas of slab pours and external waterproofing membranes shall be chosen such that the required standard of waterproofing can be achieved and maintained. Waterproofing membrane shall be provided to base slabs of all cut-and-cover structures and to walls where the structure is built in an open excavation or by bottom-up method.

3. An external waterproofing membrane shall be provided over the roof of the structure so that the roof of the permanent underground structure is completely watertight.

4. Detailing of structure shall include provision of splays, chamfers and fillets as appropriate to facilitate the laying and performance of waterproofing membranes.

5. Materials for expansion joints, caulking, grouting and the like shall have acceptable fire performance for use on an underground metro system.

6. Exposed permanent walls in cut-and-cover structures shall be rendered or shotcrete and troweled, as necessary, to provide a uniform finish without distinct changes in color or line. All rendered or shotcrete walls shall be provided with a controlled drainage system to direct any seepage permitted under the Contract to the floor drainage system.

13.4 Water Control in Excavations

1. During construction in water-bearing ground, seepage water shall be controlled by suitable means and the design shall provide for the same.

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2. The piezo metric pressure outside of the excavations shall at all times remain within the normal expected groundwater variation and permissible safe limits.
3. Notwithstanding the limits on groundwater leakage rates, the design shall aim to ensure that no loss of ground or groundwater occurs through any part of the structure.

13.5 Underpinning of Existing Building Structures (EBS)

1. Where the construction of bored tunnels or other underground works necessitates the removal of existing support or foundations to existing buildings, structures, utilities, services, wells, pavements, road furniture and the like (collectively termed EBS) the Designer shall carry out investigations on the extent of the existing works, their design and loading conditions.

2. The design to be carried out of such works as are necessary to maintain the integrity of the EBS at all times including their entire design life.

13.6 Drainage and Flood Protection

All openings into the Metro Rail Structures shall be located above the 1 in 50-year flood level plus an allowance for a 0.5m rise in sea level, as applicable. In general, structures located on flat land shall have a minimum flood protection of 1.2 meters above the surrounding ground level. This may be achieved with a combination of steps up into entrances and removable flood boards.

13.7 Seepage Barriers

1. The design shall be done for seepage gap with a seepage drainage channel such that discoloration or water damage to the seepage walls cannot occur. Access panels to inspect and maintain the drains shall be included. All such finishes, panels and fixings and the like shall be non-corrodible and comply with the Contract design life requirements.

2. At platform level in the stations, the visual aspect of the platform walls must be aesthetically pleasing, and exposed secant pile walls (if any) must be provided with a surface which will give a uniform finish without distinct changes in color or alignment. All external trackside secant pile walls (if any) must be either rendered or shotcreted.

14 TEMPORARY WORKS

14.1 General Principles

1. In general, Temporary Works shall be designed in accordance with the same design standards as the Permanent Works. However, Temporary Works design may take into account the limited duration over which such temporary works are expected to function. The calculations and drawings shall make clear where provision for limited duration has been allowed for, particularly where this may have a substantial influence on the stability of the Temporary Works.

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2. The design of Temporary Works shall take account of all the applied external forces and imposed structural deformations and, where applicable, the effects of removal of load from the ground.

14.2 Design of Temporary Excavation Support

1. Excavations for cut-and-cover structures in soft ground shall be supported by secant piles walls, which may be incorporated into the Permanent Works. Design of these elements shall include full step-by-step analyses of the progressive change in the loading (including deflections of these elements and the resultant settlements/distortions of the ground surface) and required temporary support conditions as the excavation proceeds and subsequently as these temporary elements are integrated into the Permanent Works.

2. Braced/anchored excavations shall be analysed by finite element or similar methods in which the changes in ground stresses are properly related to the deflections, which occur in the structural elements, by the use of appropriate stiffness and other parameters. Relevant empirical evidence from similar excavations must be referred to in support of the conclusions of the analyses. Simplified analytical models and methods shall be employed to calibrate and support finite element analyses of the various permutations of structure geometry and loading.

3. Temporary works shall be designed as far as possible to be removed when no longer required and shall not be left in the ground. Temporary works which are viewed as being impossible to remove on completion of the Permanent Works shall be dismantled to a minimum depth of 2 meters below the finished ground surface and designed so that there will be no risk of ground settlement or other deleterious effects as a consequence of decay and/or collapse of these Temporary Works.

14.3 Ground Movements

1. The Temporary and Permanent Works designs shall limit ground movement and distortions around the site to avoid damage to adjacent EBS.

2. Before dewatering, a risk assessment for all EBS within the influence zone shall be carried out. The analyses for the Temporary Works shall be properly related to the conclusions of the risk assessment.
   a. Temporary dewatering of construction excavations will be required to provide an undisturbed, stable and dry subgrade to permit construction and backfilling of the Permanent Works under dry conditions.

   b. In general, the groundwater within the excavations shall be maintained at a level that permits achievement of the above and avoids heave, piping or base failure of the excavation.

   c. Drawdown of the groundwater levels outside the UG station and cut and cover tunnel walls shall be limited to not more than 2 metres from the existing average groundwater level in the zone of construction. Recharging pits shall be provided in case there is a danger of reduction in water table outside area of construction. This is necessary to prevent settlement of ground outside area of construction. In general, groundwater levels interior to construction excavations shall not be depressed more than 1.0 m below final base slab level.

d. The construction dewatering design shall include determination of subsurface conditions and geotechnical design parameters, analyses to establish feasible methods, and system definition in sufficient detail to demonstrate that the general objectives can be achieved without adverse effect on adjacent EBS. The selected system shall generally provide for continuous (24-hour-per-day) operation, adequate reserve equipment, and standby power.

14.4 Ground Improvement

Ground-improvement may be required along certain alignment segments of the Contract to control ground and EBS movement and distortion that may be induced by excavation for underground structures.

15 INSTRUMENTATION AND MONITORING

The construction shall include a complete comprehensive instrumentation scheme including Real Time Monitoring with the Preliminary Design to achieve the following: -

1. Safety during and after the construction by providing early warning of any excessive and undue ground movement of adjoining premises/structures/utilities.
2. To provide settlement, deflection and deformation data for the verification of initial design of the permanent structures and the temporary works supporting excavations.
3. To provide information on ground movements to ensure that the tolerances associated with various structures/elements within the zone of influence are not exceeded.
4. To record generated pore water pressures to confirm the flow nets previously used to predict seepage rates and to confirm that drawdown outside station and cut and cover walls is within acceptable limit.
5. To estimate and monitor during construction the expected ground movement (allowable total settlement, differential settlement, angular distortions, wall movement, earth pressure, strut load, bottom heave etc.). If the estimates are exceeded remedial measures shall be prepared and implemented.

16 LIST OF DESIGN CODES AND STANDARDS

Subject to the requirements of this design basis report and Contract 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) and Euro Standards (EN) shall be referred. If appropriate standard from BIS, BSI or EN standards do not exists, then subject to Notice by the Engineer, an appropriate current standard or research study material from a reputable source or institution may be used.

The order preference of codes will be as follows -

- IS (Indian Standards)

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- IRS (Indian Railway Standards)
- IRC (Indian Road Congress)
- BS / EN (British Standard or Euro Codes)
- AASHTO (American Association of State Highway and Transportation Officials)

A list of reference codes and Standards/Specifications but not limited to is provided below for reference only. All reference codes / standards shall include all the Amendments and Addenda.
(Note: the years of the code mentioned below are notional; hence, each time designer shall adopt latest code with the latest correction slip).

Indian Railway Standards (IRS)	
IRS 2008	Bridge Rules
IRS 1997	Concrete Bridge Rules
IRS 1991	Bridge Structures and Foundation Codes
IRS 1997	Steel Bridge Code
IRS 1998	Indian Railway Bridge Manual
IRS 1985	Manual on Design and Construction of Well and Pile Foundations
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

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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 Training and Control Works for Road Bridges
IRC 112-2014	Code of Practice for Concrete Road Bridges
IRC: SP 11	1988 Handbook of Quality Control for Construction of Roads and Runways
Bureau of Indian Standards Codes	
SP 7: 2005	National Building Code
IS 73: 1992	Paving Bitumen
IS 150: 1950	Ready mixed paint brushing, finishing stoving for enamel colour as required
IS 205: 1992	Non-ferrous metal Butt Hinges
IS 206: 1992	Tee and strap hinges
IS 207: 1964	Gate and shutter hooks and eyes
IS 208: 1987	Door handles
IS 210: 1993	Grey iron castings
IS 215: 1995	Road tar
IS 217: 1988	Cutback Bitumen
IS 269: 1989	33 grade Ordinary Portland Cement.
IS 278: 1978	Galvanised steel barbed wire for fencing
IS 280: 1978	Mild Steel wire for general engineering Purposes
IS 281: 1991	Mild Steel sliding door bolts for use with Padlocks
IS 362: 1991	Parliament hinges
IS 363: 1993	Hasps and staples
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 453: 1993	Double-acting spring hinges
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

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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 771 1979	Glazed fire-clay sanitary appliances Part 1 General requirements Part 2 Specific requirements of Kitchen and laboratory sinks Part 3/Sec. 1 Specific requirements of Urinals - Slab Urinals Part 3/Sec. 2 Specific requirements of Urinals - Stall Urinals
IS 774: 1984	Flushing cistern for water closets and urinals
IS 775: 1970	Cast iron brackets and supports for wash basins and sinks
IS 777: 1988	Glazed earthenware wall tiles
IS 778: 1984	Copper Alloy gate, globe and check valves for water works purposes
IS 779: 1994	Water meters
IS 780: 1984	Sluice valves for water works purposes (50 to 300 mm size)
IS 781: 1984	Cast copper alloy screw down bib taps and stop valves for water services
IS 783: 1985	Code of practice for laying of concrete pipes
IS 800: 2007	Code of practice for general construction in steel
IS 814: 1991	Covered electrodes for manual metal arc welding of carbon and carbon manganese 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 909: 1992	Under-ground fire hydrant, sluice valve type
IS 1003	Timber panelled and glazed shutters Part 1 1991 Door shutters Part 2 1994 Window and ventilator shutters
IS 1030:1989	Carbon steel castings for general engineering purposes
IS 1038:1983	Steel doors, windows and ventilators
IS 1077:1992	Common burnt, clay building bricks
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 1195:1978	Bitumen mastic for flooring.
IS 1200 - Part 1	Methodology of measurement of Building and Civil Engineering Works
IS 1230:1979	Cast iron rainwater pipes and fittings
IS 1237:1980	Cement concrete flooring tiles
IS 1239:1990	Mild steel tubes, tubular and other wrought steel fittings

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	Part 1 Mild steel tubes Part 2 Mild steel tubular and other wrought steel pipe fittings
IS 1322:1993	Bitumen felts for water proofing and damp-proofing
IS 1341:1992	Steel butt hinges
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 1536:1989	Centrifugally cast (spun) iron pressure pipes for water, gas and sewage
IS 1537:1976	Vertically cast iron pressure pipes for water, gas and sewage
IS 1538:1993	Cast iron fittings for pressure pipes for water, gas and sewage
IS 1566:1982	Hard-drawn steel wire fabric for concrete reinforcement
IS 1592:1989	Asbestos cement pressure pipes
IS 1703:1989	Copper alloy float values (horizontal plunger type) for water supply fittings
IS 1726:1991	Cast iron manhole covers and frames
IS 1729:1979	Sand cast iron spigot and socket soil waste and ventilating pipes, fitting and accessories
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) 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 1948:1961	Aluminium doors, windows and ventilators
IS 1949:1961	Aluminium windows for industrial buildings
IS 1977:1976	Low Tensile Structural steel

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IS 2004:1991	Carbon steel forgings for general engineering purposes
IS 2062:2006	Steel for general structural purposes
IS 2074:1992	Ready mixed paint, air-drying, red oxide-zinc chrome, priming
IS 2090:1983	High tensile steel bars used in pre-stressed concrete
IS 2114:1984	Code of practice for laying in-situ terrazzo floor finish
IS 2116:1980	Sand for masonry mortars
IS 2119:1980	Code of practice for construction of brick-cum-concrete composite
IS 2202:1991	Wooden flush door shutters
IS 2326:1987	Automatic flushing cisterns for urinals
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 2548:1996	Plastic seats and covers for water closets
IS 2681:1993	Non-ferrous metal sliding door bolts (aldrops) for use with padlocks
IS 2690:1993	Burnt - clay for flat terracing Tiles
IS 2692:1989	Ferrules for water services
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 2906:1984	Specification for sluice valves for water works purposes (350 to 1200 mm size)
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.
IS3067 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 3564:1995	Hydraulically regulated door closers
IS 3812:1981	Fly ash for use as pozzolan and admixture

IS 3847:1992	Mortice night latches
IS 3955:1967	Code of practice for design and construction of well foundations
IS 3989:1984	Centrifugally cast (spun) iron spigot and socket soil, waste and ventilating pipes, fittings and accessories
IS 4082:1996	Recommendations on stacking and storage of construction materials and components at site
IS 4138:1977	Safety code for working in compressed air
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
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 prestressed 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 6760:1972	Slotted countersunk head wood screws
IS 6911:1992	Stainless steel plate, sheet and strip
IS 7181:1986	Horizontally cast iron double flanged pipes for water, gas and sewage
IS 7196:1974	Hold fast
IS 7205:1974	Safety code for erection of structural steel work
IS 7231:1984	Specifications for plastic flushing cisterns for water closets and urinals
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

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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 9013:1978	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 13630: 1994	Ceramic tiles – methods of tests
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
ASTM Standards	
ASTM C-1202	Test methods for Electrical indication of concrete's ability to resist chloride ion penetration.
ASTM C-1240	Micro Silica/Silica fume in concrete
ASTM D-297	Methods for Rubber Products-Chemical Analysis
ASTM D-395	Compression set of vulcanized rubber
ASTM D-412	Tension testing of vulcanized rubber
ASTM D-429	Adhesion of vulcanized rubber to metal
ASTM D-573	Accelerated aging of vulcanized rubber by the oven method
ASTM D-624	Tear resistance of vulcanized rubber

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ASTM D-797	Young's modulus in flexure of elastomer at normal and subnormal temperature
ASTM D-1075	Effect of water on cohesion of compacted bituminous mixtures
ASTM D-1143	Test method for piles under static axial comp. test
ASTM D-1149	Accelerated ozone cracking of vulcanized rubber
ASTM D-1556	In-situ density by sand replacement
ASTM D-1559	Test for resistance to plastic flow of bituminous mixtures using Marshall apparatus
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-3689	Testing method of testing individual piles under static axial tensile load
ASTM D-4945	Test method for high strain dynamic testing of piles
ASTM E-11	Specification for wire cloth sieve for testing purpose
ASTM :Section 4:	Construction, Volume 04.08: Soil and Rock I, and Volume 04.09: Soil and Rock II,
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
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 port-land 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
AASHTO T96-77	Resistance to abrasion of small size coarse aggregate by use of the Los Angeles machine
AASHTO T99-81	The moisture-density relations of soils using a 5.5-lb (2.5kg) rammer and a 12-in (305mm) Drop
ASHTO 104-77	Soundness of aggregate by use of sodium sulphate or magnesium sulphate

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AASHTO T176-73	Plastic fines in graded aggregates and soil by use of the sand equivalent test
AASHTO T180-74	The moisture density relations of soils using a 10-lb (4.54kg) rammer and an 18-in (457mm) Drop
AASHTO T182-82	Coating and stripping of bitumen-aggregate mixtures
AASHTO T191-61	Density of soil In-place by the sand-cone method
British Standards	
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 6031	Code of Practice for Earthworks.
BS 6105	Corrosion-resistant stainless steel fasteners
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

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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	Eurocode 7: Geotechnical design
BS EN 1998	Eurocode 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

Other Publications

- Standard Method of Measurement for Civil Engineering Works, Edition 1, 4/92
- American Petroleum Industry (API) Standard 1104
- UIC/772-R The International Union of Railways Publication
- SS 460 48 66 1991 Swedish Standard Vibration and Shock Guidance Levels for Blast-Induced Vibrations
- NS8141 1993 Vibration and Shock in Structures, Guidance Limits for Blasting –induced Vibrations
- National Fire Protection Association, NFPA 130-2010: Standard for Fixed Guideway Transit and Passenger Rail Systems
- International Society for Rock Mechanics (ISRM), Suggested Test Methods, (various dates).
- British Tunnelling Society Specification for Tunnelling
- Austrian Society for Rock Mechanics: Geotechnical Underground Structures Design
- International Tunnel Association: Guidelines for the Design of Tunnels
- ITA/AITES Accredited Material: Seismic Design and Analysis of Underground Structures
- Muir Wood, A.M. (1975) The Circular Tunnel in Elastic Ground
- D.J. Curtis et al (1976) Discussion Paper - Circular Tunnel in Elastic Ground
- CG Lai et al (2000) Probabilistic Seismic Hazard Assessment and Stochastic Site Response Analysis at the Archaeological Site of Kancheepuram in Southern India. IUSS Press

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