GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(RAILWAY BOARD)

2024/Proj./MPMRCL/DBR/UG_Structure/30/78 New Delhi, dated 09.05.2024

Managing Director,
Madhya Pradesh Metro Rail Corporation Limited (MPMRCL),
2nd Floor, Zone-14, Bhopal Municipal Corporation,
Smart City Building, BHEL, Govindpura,
Near Natraj Petrol Pump, Bhopal-462023,
Madhya Pradesh

Sub: Approval of Design Basis Report (DBR) for construction of Underground Structures by Cut and Cover Method - Version 00 (October 2023) for Bhopal and Indore Metro Rail Projects of Madhya Pradesh Metro Rail Corporation Limited (MPMRCL).

Ref: MPMRCL letter no. P&D/RDSO/2023 dated 06.11.2023

The Design Basis Report (DBR) for construction of Underground Structures by Cut and Cover Method - Version 00 (October 2023) for Bhopal and Indore Metro Rail Projects of Madhya Pradesh Metro Rail Corporation Limited (MPMRCL) has been examined in consultation with RDSO and approval of Railway Board is hereby conveyed for the same.

Accordingly, approved copy of DBR is enclosed.

Encl: As above

09.05.24

(**F. A. Ahmad**)
Director/Gati Shakti (Civil)-IV
Railway Board
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Email: **dmtp@rb.railnet.gov.in**

Copy to:

1. **Executive Director/UTHS**, RDSO, Manak Nagar, Lucknow w.r.t letter No. UT/120/MPMRCL/Civi dated 01.05.2024
2. **OSD/UT & Ex-Officio Joint Secretary**, Ministry of Housing & Urban Affairs (MoHUA), Nirman Bhavan, New Delhi-110001

MADHYA PRADESH METRO RAIL CORPORATION LIMITED (MPMRCL)

MPMETRO

BHOPAL AND INDORE METRO RAIL PROJECTS

DESIGN BASIS REPORT (DBR)

For

CONSTRUCTION OF UNDERGROUND STRUCTURES BY CUT & COVER METHOD

Version 00

Examined and found in order

October 2023

Director/UT/Civil/RDSO

Madhya Pradesh Metro Rail Corporation Limited (MPMRCL)
2nd Floor, Bhopal Smart City Development Ltd.
Sector A, Berkheda, Bhopal, 462022,
Madhya Pradesh, India

Project Directorate Approved on 09/5/2024

Pankaj Kumar
GM/P&D

Director (Project)
Madhya Pradesh Metro Rail Corporation Limited

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Director/UT/Civil/RDSO

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Parbej Kumar
GM/RDSO

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1. INTRODUCTION

1.1 Brief Description and Salient features of the Project.

1.1.1 Bhopal Metro Rail project

- Bhopal Metro Rail Project is Rail-based Metro System on Standard Gauge Tracks (1435mm). It also has Underground section comprising of twin tunnels and Underground Stations to be constructed with cut & cover.

1.1.2 Indore Metro Rail project

- Indore Metro Rail Project is Rail-based Metro System on Standard Gauge Tracks (1435mm). It also has Underground section comprising of twin tunnels and Underground Stations to be constructed with cut & cover.

1.2 Geometric Design Criteria

The Gauge, Max. Operating speed, Max. Axle load, Max./ Min. gradient, Min. Vertical/horizontal curve radius, Max. Cant /cant deficiency, Rail profile, Inclination of rail, Wheal thread profile, Type of power supply, etc. shall be as per approved Schedule of Dimensions (SOD).

2. SCOPE OF DBR

The DBR is only for structural design of Underground Stations/sections, station entrance/exit, box tunnels, open U ramp structures etc. construction by cut and cover method (other than bored tunnels).

This is meant to serve as guide to the designer but compliance with the rules there in does not relieve them in any way of their responsibility for the stability and soundness of the structure designed. The design of Underground Stations requires an extensive and thorough knowledge and entrusted only to specially qualified engineers with adequate practical experience in structure designs. Extended platform portion, which is generally on level-change station structure, shall be designed as part of viaduct, if any.

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Structures, where Metro Live loads are not applicable, the design of Plain and Reinforced Concrete structures will generally be governed by IS:456, pre-stressed concrete structures shall generally be governed by IS:1343, Steel structures design shall generally be governed by IS:800.

The design of the permanent and temporary supporting works shall comply with code of practice and standards. Regulations made and requirements issued by the Indian Government and by relative 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 shall be provided in this document.

Design of structural part of bored tunnel, in Underground station, shall be dealt as per approved DBR for Bored tunnel."

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Director (Project)

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3. DESIGN PRINCIPLES

3.1 The proposed structure of Underground station shall be a rigid box section with permanent walls as external wall support system and beam-slab & column forming the internal structural framing. The roof slab shall support the soil and vehicular surcharge, while the passenger and plant loads shall be carried by the concourse slab. The track and platform loads shall be supported by the base slab. The permanent walls shall resist the lateral earth and hydrostatic pressures in addition to the surcharge, services/structural loads.

3.2 In the design of Underground station structures, following factors should be taken into account: -

i. Method of construction, including temporary works and construction sequence.

ii. Ground/structure interaction, including the effects of temporary works;

iii. Ground pressure, shear force and bending moment distribution during construction and in the long-term;

iv. Short- and long-term ground and groundwater response;

v. Other static loads changes such as excavation, surcharge, traffic loadings and the like;

vi. Long-term surface water level changes;

vii. Dynamic (such as seismic or vibratory plant) loads and displacements.

viii. Safe evacuation of passengers in case of accident/derailment/fire etc.

3.3 For the purposes of assessing ground and groundwater pressures, the underground station structures shall be effectively impermeable rigid box structures subject to earth pressure.

3.4 The Design shall minimise the effects (such as movement, distortion of the ground and the like) on all Existing Building Structure (EBS) that may be affected by the Works. Wherever necessary, the additional support for these EBS shall be provided.

3.5 The design of all cut-and-cover structures shall take into account, but not be limited to the following: -

i. The variation in ground conditions along the alignment; The geological/ hydro geological features and their variations including rock joint orientation and spacing etc.

ii. The variation in engineering properties of soil or rock within the influence of the proposed Works.

iii. All dewatering and groundwater cut-off systems required to maintain dry and stable conditions within all excavations required for these works;

iv. Any ground treatment before, during or after construction of the works (e.g., groundwater recharge), which is required to stabilise the ground and existing building structures (EBS) in order to minimise adjacent ground and EBS

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movement and distortion.

v. 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 subjected to leakage or flotation, when the groundwater returns to the design levels);

vi. Differential groundwater pressures;

vii. Methods of waterproofing the completed structure;

viii. Any difficulties that are envisaged at site with respect of access, clearances, working space and obstruction to excavation.

ix. Maintenances of traffic flows along/on roads including access to adjoining properties and roads.

x. Control of heave, swell, piping and instability of the excavations;

xi. The noise levels produced, during construction and subsequent operation of trains.

xii. The depth of construction required;

xiii. The effects of vibration and vibration induced movements – eg, earthquake.

3.6 The following methods of construction shall be used in soft/hard ground either individually or in combination depending upon the particular requirements of the location, size and type of structure.

i. **Diaphragm Walls**

Design for diaphragm walls is to be as per IS:9556. Particular attention needs to be paid to the wall and panel alignment, the stability of excavation, the mix and condition of the slurry, placement of the reinforcement cage, methods for forming and locating box-outs, waterproofing of the vertical panel joints, placement of concrete, and the overall integrity and water-tightness of the constructed wall.

ii. **Secant Piles/Sheet Piles/Soldier Piles and Horizontal Planks**

Particular attention shall be paid to the construction/installation of the piles and ground support systems to ensure their integrity and water-tightness and to provide adequate support to the ground during excavation.

3.7 Diaphragm walling may be adopted as support method for the proposed deeper station, vent shaft and tunnel excavations. Other methods of support may also be used for the other relatively shallow excavations such as station entrances/exits, pedestrian subways, utilities and services.

3.8 For excavation support, following design parameters shall be taken into account:

i. Earth pressure.

ii. Hydrostatic pressure.

iii. Deck load.

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iv. Surcharge loads.

v. Seismic and/or vibratory loads.

vi. Support types and arrangement.

vii. Any other incidental load.

viii. Construction/deconstruction sequence.

ix. Calculated ground and adjacent EBS movements and distortions.

x. Calculated fluctuations in groundwater levels both within and outside of the excavation and support walls.

xi. Calculated changes in EBS loading conditions.

3.9 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. This Method Statement shall be prepared and incorporated into the Design Report and shall include but not be limited to the following details:

i. Sequence of excavation and concreting of panels.

ii. Method of producing the workable concrete.

iii. Methods of handling within the excavations and disposing of groundwater outside of the excavation.

iv. Formation of the joints between panels and installation of water stops.

v. Methods of instrumenting, monitoring and reporting of the performance of all adjacent EBS that may be affected by the works.

vi. Type and construction of permanent lining wall.

vii. Emergency procedures to be implemented in the event that monitoring indicates tolerances associated with the excavation support wall may be exceeded.

viii. Temporary ground support shall be provided using suitable support fluids for piles and or diaphragm walls.

a) Mixing, transporting and placing equipment for the support fluid.
b) Method of disposal of the support fluid.
c) Type, source, chemical and physical properties of the support fluid to be used.
d) Stability, dimensions and details of guide walls.
e) Cleaning and re-use of the support fluid.
f) Calculations to show that the density of the support fluid 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.

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4. UNITS

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

5. MATERIALS

5.1 Cement

For plain and reinforced concrete structures, cement shall be used as per clause 5.1 of IS:456 and in case of prestressed concrete structures as per clause 5.1 of IS:1343.

5.2 Concrete

5.2.1 In case of Plain and Reinforced Concrete structures, as per clause 6, 7, 8, 9 and 10 of IS:456, and Clause 6, 7, 8, 9 and 10 of IS:1343 for pre-stressed concrete structures.

5.2.2 Short term modulus of elasticity (E_c) shall be taken as per clause 6.2.3.1 of IS: 456 for Plain and Reinforced Concrete structures and IS: 1343 for Pre-stressed concrete structures.

5.2.3 Density

For density of concrete consider the IS :875 (part1), table-1, item value 20,21,22.

5.2.4 Poisson's Ratio

Poisson's ratio for all concrete: 0.15

5.2.5 Thermal expansion coefficient

It should be as per clause 6.2.6 IS 456 :2000

5.2.6 Modular ratio

Modular ratio for all concrete grades is taken as per Annex B of IS: 456

5.3 Prestressing Steel for Tendons

As per clause 5.6.1 of IS: 1343.

5.4 Reinforcement

Reinforcement is taken as per clause 5.6 of IS :456 for plain and reinforced concrete structures and clause 5.6.2. of IS:1343 for prestressed concrete structures.

Note: *For Seismic zone III, IV & V, HYSD steel bars having minimum elongation of 14.5 percent and conforming to requirements of IS:1786 shall be used.*

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 prestressed concrete structures.

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5.4.2 Structural Steel

Structural steel used shall confirm to

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i. Hollow steel sections as per IS: 4923.

ii. Steel for General Structural Purposes as per IS: 2062.

iii. Steel tubes for structural purposes shall be as per IS: 1161.

Note:

a. 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 (b) and (c) below.

b. Design of steel structure shall be governed by IRS Steel Bridge Code in case structure is taking moving loads of Metro, otherwise shall be governed by IS: 800. In the case of composite (steel-concrete) structures it shall be governed by IS:11384 & IS: 3935.

c. 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 Structures shall be a minimum of 100years unless otherwise specified or agreed upon. The design life of non-load bearing element such as utility supports, vent shafts etc., shall be 50years.

Adequate measures shall be taken to ensure minimum of 100years serviceability of Civil Structures, producing durable concrete with Micro silica (or other suitable admixtures) that shall be tested for impermeability according to DIN 1048 and ability to resist chloride ion penetration according to ASTM C1202.

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 Grades

The minimum grade of Concrete for all structural elements including piles shall be as per IS:456 for plain and reinforced concrete structures and as per IS:1343 for prestressed concrete structures. Minimum grade of concrete for blinding layers and levelling courses shall be indicated.

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6.2 Cover to Reinforcement

As per clause 26.4 of IS: 456 for Plain and Reinforced Concrete Structures and clause 12.3.2 of IS:1343 for prestressed concrete structures. Cover to prestressing steel shall be in accordance with clause 12.1.6 of IS: 1343. Cover to reinforcement in diaphragm wall shall be considered in accordance with IS: 9556.

6.3 Fire Resistance Period

6.3.1 Main Station Structures

i. All structures shall be designed for fire protection as specified by the

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applicable standards and codes and as approved by concerned fire safety authority. Materials specified for the Works shall be non-combustible and should not emit toxic fumes when subjected to heat or fire, except where specifically permitted. In all cases where there is significant fire risk, materials shall be self-extinguishing, low flammability, low smoke, and low toxicity.

ii. All the main elements of the station structures (like roof slabs, concourse slabs, base slab columns, staircases etc.,) shall be designed for a minimum fire resistance period of 4 hours.

iii. The minimum element thickness for this fire resistance shall be as per clause 21 of IS: 456 and IS: 1642 for concrete structures.

iv. The minimum element thickness for this fire resistance shall be as per Section 16 of IS: 800 for 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.

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 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.

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6.5 Clearances

6.5.1 Clearances for Metro Traffic

Shall be as per approved SOD.

6.5.2 For utility services:

The clearances to utilities, drainage etc. shall be as mandated by the utility owner/ department.

6.5.3 Clearance for Railway Traffic

As per the case, Indian Railways Schedule of Dimensions (SOD) shall be applicable.

6.5.4 Clearance for Road Traffic

As per relevant IRC specifications and Road Authority requirements.

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6.6 Early age Thermal and Shrinkage Cracking

i. Suitable reinforcement shall be designed to prevent early age thermal and shrinkage cracking for walls and slabs more than 250mm 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.

ii. 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 C660-2007 on Early Age Thermal Control of Concrete.

iii. 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 per Early age Thermal (EAT) control of concrete.

7. LOADS

The structures 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 load types and consequential effects shall be taken into account as applicable.

• Dead loads (including notion loads)	DL
• Superimposed dead loads	SIDL
• Imposed (Live) loads	LL
• Railway Live loads	RL*
• Earthquake Loads	EQ
• Wind Loads	WL
• Air pressure	AP
• Accidental/Collison Loads	CL*
• Derailment Load	DR*
• Construction/Erection	ER
• Shrinkage	S
• Creep	C
• Earth Pressure & Water Pressure	EP & WP
• Surcharge loads (Traffic, building etc.)	SR
• Pre-stress force	PR
• Fatigue	FG
• Long welded Rail Force	LWR

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- Differential Settlement DS
- Movement/Distortion MD
- Redundancy R

*Loads as applicable shall be taken

7.1 Dead Loads (DL)

Dead load shall be based on the actual cross section area and unit weights of materials and shall include the weight of the materials that are structural components of Underground Station and permanent in nature. It shall be calculated in accordance with IS:875 Part 1.

7.2 Superimposed Dead Loads (SIDL)

Superimposed deadloads 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, Part 2. Metro may specify the loads not covered in IS:875.

7.3 Imposed (Crowd Live) Load

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 fumiture, or the moving or stacking of objects during times of re-organization and refurbishment, this shall be as per IS: 875 Part 2.

7.4 Railway Loads

7.4.1 Vertical Train Live Load

Live Load (LL): The train live load & axle load shall be as pe the approved DBR for Elevated and Bored tunnel section.

7.4.2 Coefficient of Dynamic Augment (CDA)

The Coefficient of Dynamic Augment shall comply with IRS Bridge Rules. No reduction for double track loading shall be considered.

7.4.3 Horizontal Train Live Load

i. **Braking and Traction**

- Braking load is taken as 18% of the unfactored vertical loads.
- Traction load is taken as 20% of the unfactored vertical loads.

ii. **Centrifugal Force**

On curved track, the centrifugal forces shall be determined in accordance with IRS Bridge Rules.

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7.5 Earthquake Load (EQ)

7.5.1 For underground structures

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Dynamic earth pressure calculations for underground structures shall be carried out by using Mononobe-Okabe method and shall be adopted in EQ combination.

Seismic design of Underground Structures shall 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.

7.6 Wind Loads

Wind loading may affect the surface elements of underground structures such as vent-shafts, entranceways, cooling towers and pedestrian bridges, the wind loads shall be taken as per IS: 875-1987 Part-3.

7.7 Air Pressure

It may be considered from the condition prevailing for the train entering and leaving the station.

7.8 Collision/Impact Loads

For road traffic as per IRC-6.

7.9 Derailment Loads

Derailment load shall be considered according to ACI 358.1 (with latest revision).

7.10 Construction and erection loads

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

7.11 Shrinkage

The shrinkage strains shall be evaluated as per clause 6.2.4 of IS: 456 for Plain and Reinforced Concrete Structures and clause 6.2.4 of IS:1343 for prestressed concrete structures. For structure supporting Metro train loading the effects of shrinkage as per Cl. 5.2.3 of IRS-CBC shall be considered.

7.12 Creep

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

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

7.13 Earth Pressure & Water 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. 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

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weight of soil diminished by buoyancy and the full hydrostatic pressure (As per IS: 875 Part 5).

All foundations, 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 Clause 5.7 of IRS-Substructure Code. For calculation of Angle of friction between soil and wall, CIRIA 760 code shall be referred.

The effects of temporary drawdown, seepage and base heave effects shall be considered in design of the temporary works, and catered to 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 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.

7.14 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 assessment 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 or planned infrastructure, the appropriate authorities and MPMRCL shall be consulted for details.

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7.15 Pre-stressing Force (PR)

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

7.16 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.

7.17 Differential Settlement

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

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7.18 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.

7.19 Redundancy loads

The temporary structure shall allow the effects of One-Strut failure condition. A single strut or a single ground anchor failure at any position and at any stage shall be evaluated for an Ultimate load (ULS) condition with a minimum FOS of 1.05.

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

7.21 Other Forces and Effects

Other forces shall also be considered as per clause 19.6 of IS:456.

8. DESIGN LOAD COMBINATIONS

8.1 Ultimate Load Combinations

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

8.1.1 Load combinations and factors as per Table 18 and clause 19.7 of IS: 456, IS: 875 Part 5, for Plain and Reinforced Concrete Structures.

8.1.2 Load combination and factors as per Table 7 of IS: 1343, IS: 875 for prestressed concrete structures.

8.1.3 Load combination as per Section 3.5 and factors as per Section 5 of IS: 800 for Steel structures.

8.1.4 Load combinations as per IRS-CBC where Metro live loads are applicable.

8.1.5 Load combination for construction load case shall be decided by Metro as per methodology of construction.

8.1.6 Reference of IRC-6 be taken for collision case if collision of road vehicles is anticipated.

8.2 Serviceability Load Combinations

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

8.2.1 Load combinations and factors as per Table 18 and clause 19.7 of IS: 456 for Plain

and Reinforced Concrete Structures.

8.2.2 Load combination and factors as per Table 7 and clause 20 of IS: 1343 for prestressed concrete structures.

8.2.3 Load combination as per Section 3 and factors as per Section 5 of IS: 800 for Steel structures.

8.2.4 Load combinations as per IRS-CBC where Metro live loads are applicable.

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.

For Diaphragm Wall Deflection limit, a detailed analysis of the induced effects on buildings shall be performed depending on their vulnerability. Accordingly, displacement for Diaphragm wall shall be limited. The design shall also include provisions to limit angular distortions to 1:500 maximum.

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 MPMRCL.

8.4 Fatigue Check

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

Fatigue checks shall be carried out as follows:

8.4.1 Reinforced Concrete and Pre-Stressed Concrete structures shall comply with IRS-CBC Clause 13.4.

8.4.2 Steel Structures shall comply with IS: 800 Section 13.

9. DESIGN GROUNDWATER LEVEL

Ground water level shall be assumed at ground level for all design calculations for Construction, Service, Operation & Extreme scenarios.

10. FLOTATION

10.1 The minimum depth of cover to underground structures shall be decided by Metro authority according to design requirements and by laws of local authority.

10.2 For protection against flotation in the fully internally dry condition following shall apply.

i. A load factor of 0.9 shall be applied to the self-weight of the structure.

ii. A load factor of 0.9 shall be applied to the weight of backfill material over the structure.

iii. The skin friction between the concrete surface and the soil shall be assumed as per the method of construction of station i.e. Top Down or Bottom Up. FOS to be

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applied for Skin Friction of D Wall and Tension Pile are 2 & 3 respectively.

iv. The overall factor of safety against flotation shall not be less than 1.1 for service stage only.

10.3 Design to be checked for all proposed cut-and-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.

10.4 Design to ensure that the method and sequence of construction is such that an adequate resistance to uplift is maintained at all times and shall put forward his proposal to this effect.

10.5 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.

i. Toeing-in of the base slab into the surrounding ground.

ii. Increasing the dead weight of the structure by:

a. thickening of structural members; providing an extra thickness of concrete beneath the base slab tied into the structural base slab.

b. extending the excavation support walls.

c. providing counterweights in parts of the structure with high density material.

d. providing tension piles.

10.6 Where the base slab is toed-in to the surrounding ground a partial safety factor of 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.

10.7 The value of the weight of any additional thickness of concrete shall take account of the increased volume of water displaced.

11. FOUNDATIONS

Whatever the type of foundation to be adopted, the following performance criteria shall be satisfied:

i. Foundation must not fail in shear.

ii. 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.

11.2 Computation of Settlements of Foundations

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

i. IS:8009 Part-1 for shallow foundations

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ii. 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 and, 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

13.1.1 The design shall include adequate precautions against base heave, piping and failure of excavations during construction. The stability of the excavation bases shall be checked in accordance with an acceptable method of analysis which shall allow for all reasonable loads within and outside of the excavation.

13.1.2 The Design calculations has to explain the contribution made to the base stability of the excavation by proposed method of construction and shall state the factor(s) of safety used in the design.

13.2 Excavation Toe Stability

13.2.1 The design shall ensure adequate toe stability of retaining structure during construction.

13.2.2 The toe stability shall be checked in accordance with an acceptable method of analysis which shall allow for all reasonable loads within and outside of excavation.

13.2.3 The conventional approach based on active and passive pressure shall be preferred with suitable factor of safety.

13.3 Waterproofing

13.3.1 Groundwater leakage rates into the completed Permanent structures shall be limited to damp patches only and shall not under any circumstances exceed a general value of 0.1 liter per square meter per day.

13.3.2 The quality and grade of the concrete, treatment of construction joints, areas of slab pours, and external 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.

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

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

13.3.5 Exposed diaphragm walls in cut-and-cover tunnels shall be rendered or shotcrete and trowelled, as necessary, to provide a uniform finish without distinct changes in colour or line. All rendered or shotcrete walls shall be provided with a controlled drainage system to direct any seepage permitted to the floor drainage system.

13.4 Water Control in Excavations

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

13.4.2 The piezometric pressure outside of the excavations shall at all times remain within the normal expected groundwater variation and permissible safe limits.

13.4.3 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)

13.5.1 Where the construction of subways 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.

13.5.2 The design to be carryout such works as are necessary to maintain the integrity of the EBS at all times including its 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 1.2m above the surrounding ground level. This shall be achieved with a combination of steps up into entrances and removable flood boards.

13.7 Seepage Barriers

13.7.1 Design shall be done for the seepage gap with a seepage drainage channel such that discolouration 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 shall comply with the design life requirements.

13.7.2 At platform level in the stations, the visual aspect of the platform walls must be aesthetically pleasing and exposed diaphragm walls must be provided with a surface which will give a uniform finish without distinct changes in colour or alignment.

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14. TEMPORARY WORKS

14.1 General Principles

14.1.1 In general, Temporary Works shall be designed in accordance with the same design standards as the Permanent Works. However, Temporary Works design shall 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.

14.1.2 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

14.2.1 Excavations for cut-and-cover structures in soft ground shall be supported by diaphragm walls, secant piles or similar which shall 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 deflection 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.

14.2.2 Braced 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.

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14.2.3 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.

15. GROUND MOVEMENTS

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

ii. Before Dewatering, a risk assessment for all EBS within the influence of the Construction Works shall be carried out.

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.

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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.

15.1 Ground Improvement

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

16. INSTRUMENTATION AND MONITORING

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

i. Safety during and after the construction by providing early warning of any excessive and undue ground movement of adjoining premises/structures/utilities.

ii. To provide settlement, deflection and deformation data for the verification of initial design of the permanent structures and the temporary works supporting excavations.

iii. To provide information on ground movements to ensure that the tolerances associated with various structures/elements within the zone of influence are not exceeded.

iv. 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.

v. 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.

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17. LIST OF DESIGN CODES AND STANDARDS

The designs of underground station buildings & cut and cover structures shall be carried out as per provisions of this Design Specifications. Reference shall be made to following codes for any additional information.

Order of preferences of codes shall be as follows: -

i. BIS

ii. IRS

iii. IRC

iv. BS or Euro Code

v. AASHTO

vi. Other references shall be listed

(*Note:* Each time latest code with the latest correction slip shall be adopted)

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