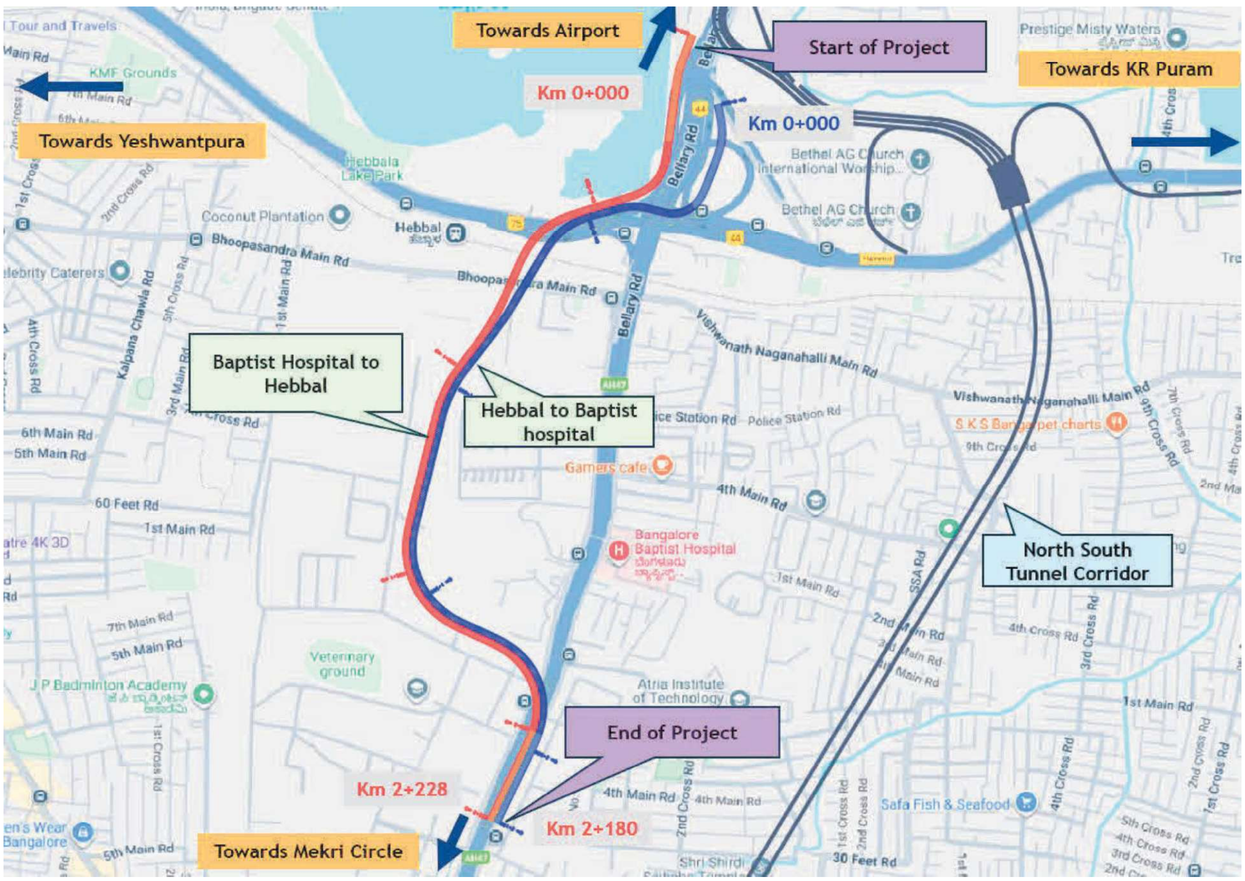
GOVERNMENT OF KARNATAKA

Consultancy Service for Preparation for DPR for short length transitory 3 lane bi-directional vehicular underpass connecting Hebbal flyover junction to Veterinary college via GKVK premises.



REVISED FINAL DETAILED PROJECT REPORT

VOLUME – I MAIN REPORT

SEPTEMBER 2025

Bengaluru Smart Infrastructure Limited

Rodic Consultants Pvt. Ltd

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. General

Bengaluru, the capital of Karnataka, has witnessed exponential urban growth and a steep rise in vehicular population over the past two decades. This has placed significant stress on the city's road infrastructure, particularly at critical junctions like the Hebbal Flyover, which serves as a key node connecting the airport, central business districts, Outer Ring Road (ORR), and multiple arterial roads.

The Hebbal Flyover junction is a major congestion hotspot where traffic from the north (Kempegowda International Airport), east (KR Puram), west (Yeshwantpur), and central Bengaluru converges. The existing multi-tiered flyovers and loops are functioning beyond their capacity, often resulting in gridlock during peak hours. With a proposed BMRCL Metro line and an existing railway corridor passing through this area, further expansion of surface or elevated infrastructure is no longer feasible.

To address this, the Government of Karnataka, through Bangalore Smart Infrastructure Limited (B-SMILE), has proposed the construction of **Consultancy Service for Preparation for Preliminary Project Report and DPR for short length transitory 3 lane bi-directional vehicular underpass connecting Hebbal flyover junction to Veterinary college via GKVK premises.** This project will provide a seamless, grade-separated corridor for Airport-City through traffic, enabling uninterrupted movement from Hebbal (Esteem Mall) toward CBI Road, bypassing conflict points at the flyover.

Rodic Consultants Pvt. Ltd. was appointed to carry out the Preliminary Project Report (PPR) and Detailed Project Report (DPR) for this strategic infrastructure development. The Client Bangalore Smart Infrastructure Limited (B-SMILE) is a special purpose vehicle (SPV) tasked with executing major infrastructure projects. B-SMILE will oversee the construction of tunnel roads, elevated corridors, underpasses, storm water drains.

1.2. The Consultants

The consultancy services for the Preparation of DPR have been entrusted to Rodic Consultants Pvt. Ltd.

The Corporate office of consultants is located at

Rodic Consultants Pvt Ltd,

6, Sarojni House,

Agha Khan Hall (1st Floor),

Bhagwan Dass Road,

New Delhi -110001 (India)

Ph:- 011 6921 7900

The Regional office of the Consultant is located at,

Rodic Consultants Pvt Ltd,

6 & 7, Classic Terraces, 60 ft. Road,

Behind ICICI., Sahakarnagar, G Block,

Bengaluru-560092

1.3. Problem Statement

The Bellary Road Section of Hebbal junction to Mekri Circle gets fully congested during the peak traffic hours and fails to provide adequate service to the commuters.

Hebbal Junction faces heavy traffic from all sides (Airport side to the North, Bangalore city to city, Yeshwantpura side to West and KR Puram side to East), sometimes making traffic at a standstill for longer time.

Figure 1: Traffic congestion near Baptist Hospital

At the Hebbal Junction there are already numerous elevated ramps/loops which provide connectivity to different roads passing through Hebbal,

- Flyover loop from Bellary Road to Outer Ring Road (ORR) towards Yashwant Pura,
- Another Flyover Ramp from ORR to Bellary Road which provides connectivity to Traffic Coming from Yashwantpur side to Bellary Road.

- Flyover connecting Bellary Road to ORR Providing connectivity to traffic going towards KR Puram from Bellary Road.
- Flyover Ramp Connecting traffic going on ORR towards KPR Puram side from Airport side
- Recently inaugurated Flyover connecting ORR to Bellary Road for traffic coming from KR Puram side towards Bangalore city.

The railway line also passes through the Hebbal Junction and there is a proposal of BMRC metro line that will pass near the Hebbal Junction.

All the Existing structures and proposed projects makes the widening of existing roads and proposal of new elevated structures infeasible.

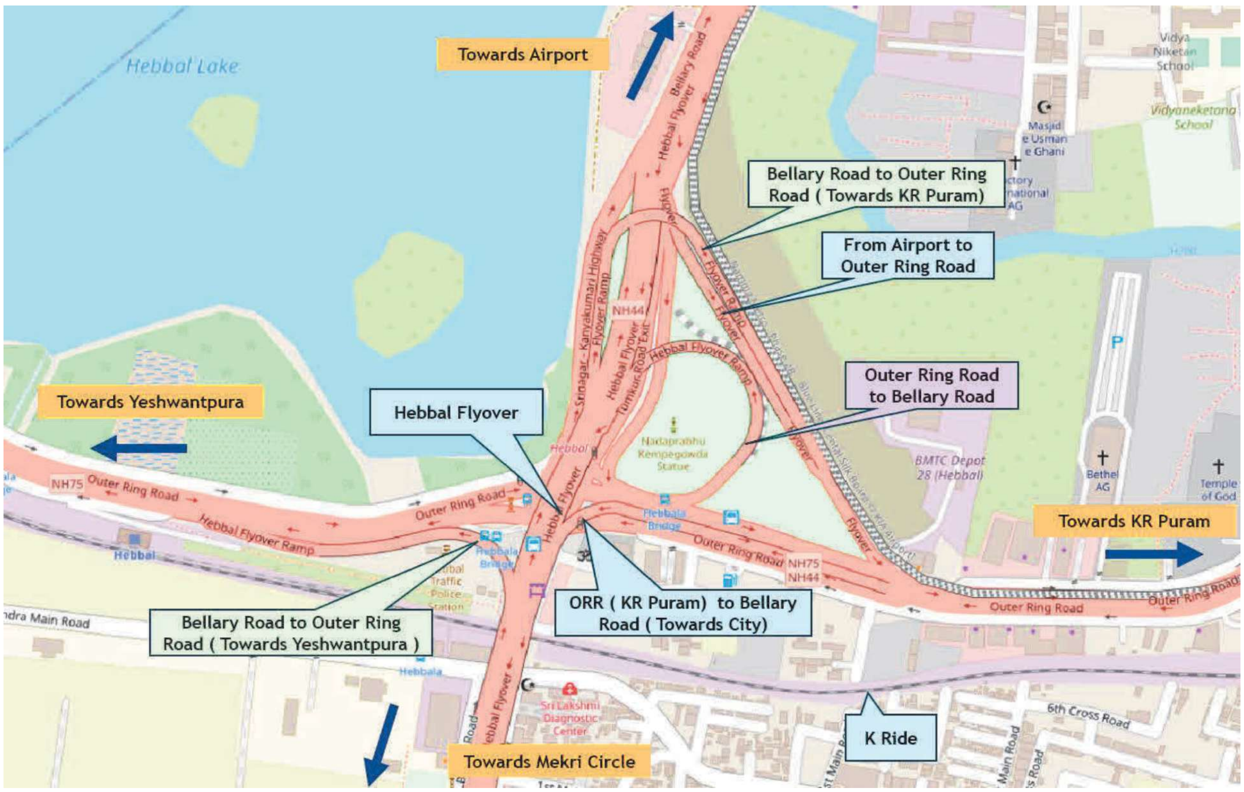


Figure 2: Flyovers at Hebbal

1.4. Objective

The project proposes to construct an approximately 2.228 km, underground 3-lane twin-tube road to segregate through-traffic from local flows and eliminate recurrent congestion at the Hebbal Flyover junction. Each tube, carrying three 3.5 m lanes and flanked by maintenance walkways, is designed for a 60 km/h operating speed and sized to divert nearly half of the corridor’s daily vehicle volumes underground, thereby restoring reliable Level of Service on the surface network. The alignment threads seamlessly beneath existing railway tracks and the future Metro corridor while tying into the current service roads, minimizing conflicts with flyovers, utilities, and pedestrian routes.

Geometric, structural, ventilation, fire-safety, lighting, and drainage elements conform to IRC and MoRTH standards to ensure operational safety and durability over a 20-year horizon, accommodating anticipated 4-5 % annual traffic growth. Cut-and-cover construction will be executed in phased stages with robust traffic management, utility protection, and environmental and social safeguards, ultimately reducing travel time, emissions, and operating costs to enhance urban mobility in North Bengaluru.

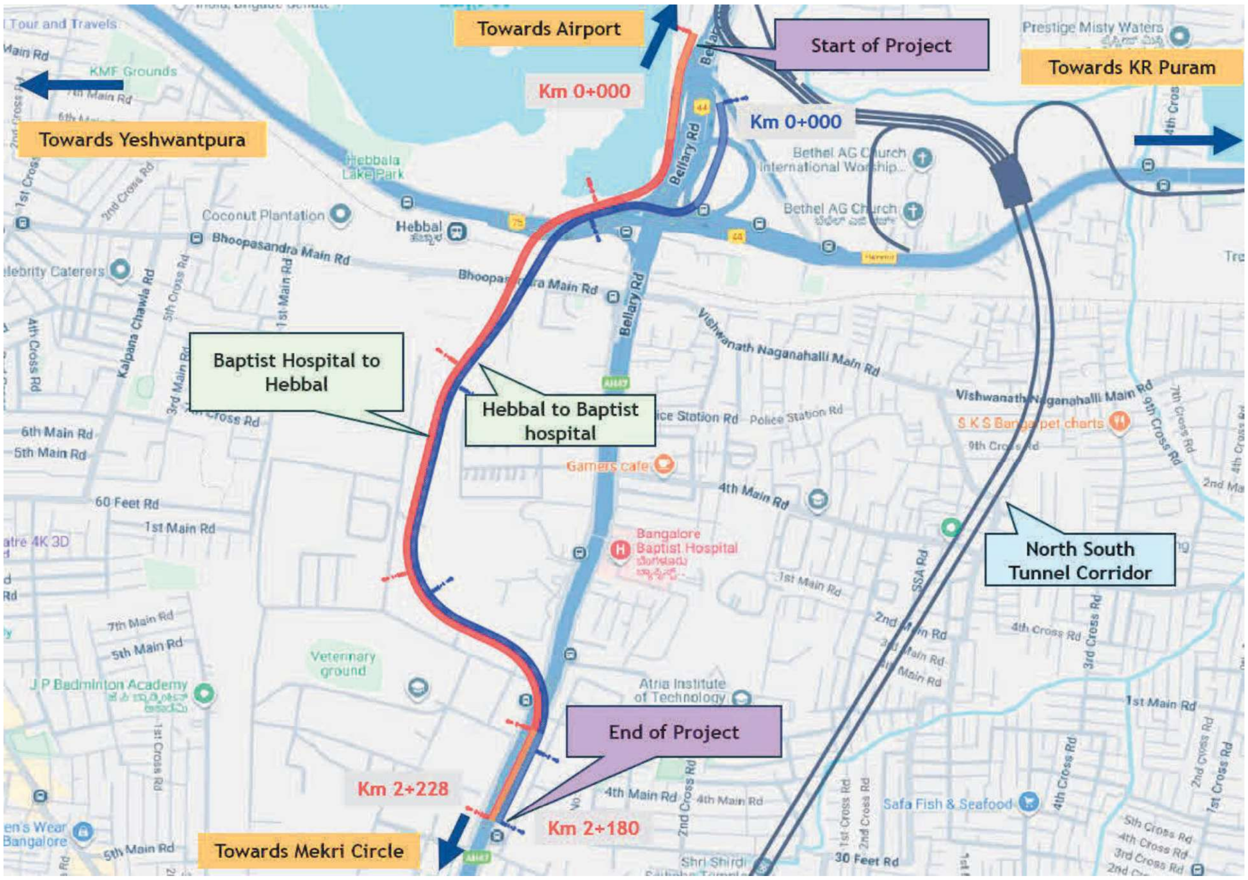


Figure 3: Project Alignment

Various joint Site visits with the Director-Technical, B-SMILE and other officials were conducted at various possible alignment alternatives. After evaluating the alternatives an alignment Option No 2 passing over the GKVK land has been finalized vide letter No. BSMILE/D(T)/PR/43/2-25-26 Dated 19.06.2025.

1.5. Infringement with Other Planned and Existing Projects

- Alignment infringement with Railway

  The project passes below the Existing Railway line as indicated in the Image below.

Figure 4: Infringe Location with Railway

- Alignment Infringement with Proposed BMRCL metro.
  The alignment passes through the alignment of proposed BMRCL metro line. The alignment is shown below.

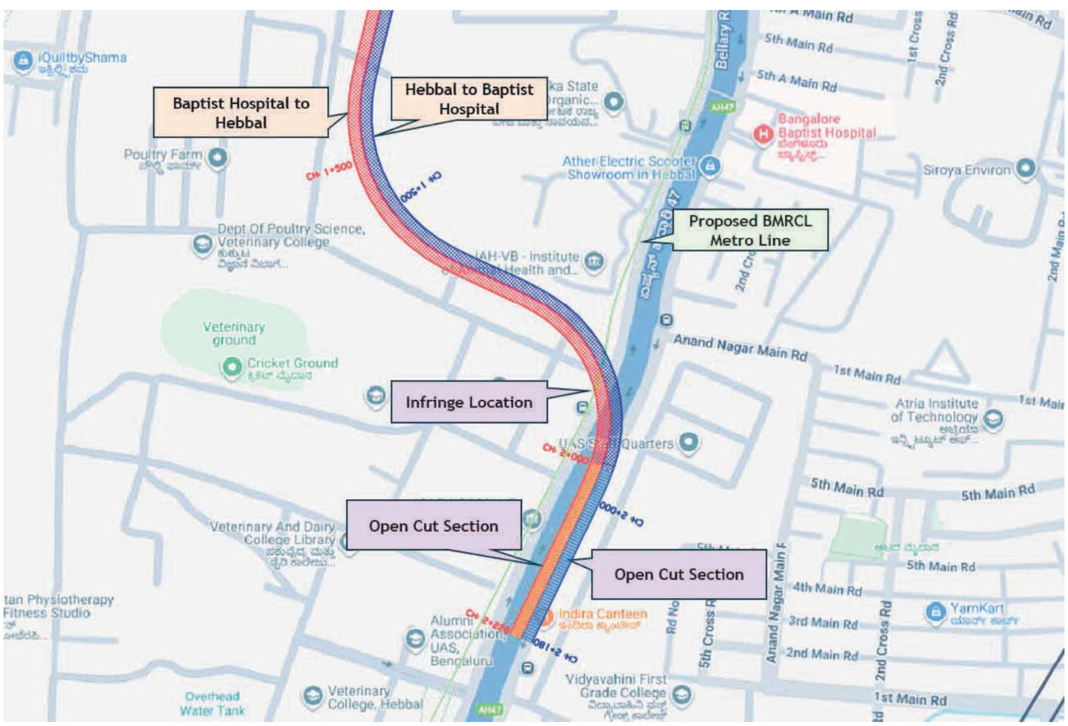


Figure 5: Infringe Location with Proposed BMRCL Metro Line

1.6. Surveys and Investigation Conducted

Based upon the objectives of the project and with careful planning and efficient use of resources, different tasks have been done simultaneously.

A work plan was prepared based on the methodology developed. A competent team of suitably qualified key professionals as per the requirements and other supporting staff was selected to carry out the services fieldwork and office work.

1.6.1. Reconnaissance Survey

A preliminary survey was conducted to gather general information about the project area. The purpose of the reconnaissance survey is to get a broad understanding of the terrain, conditions, Environmental and Social Considerations, Safety and Risk Assessment of the project area.

1.6.2. Road Inventory

Road inventory was carried out in the first week of June 2025 over the possible locations of the project alignment. The Ballery road is an elevated road with 3+3 Lane configurations and also have service lanes having width of intermediate lane the elevated corridor.

1.6.3. Geotechnical Survey

Geotechnical Survey has been conducted at the 6 locations whose details are provided below and detailed report is enclosed in chapter.

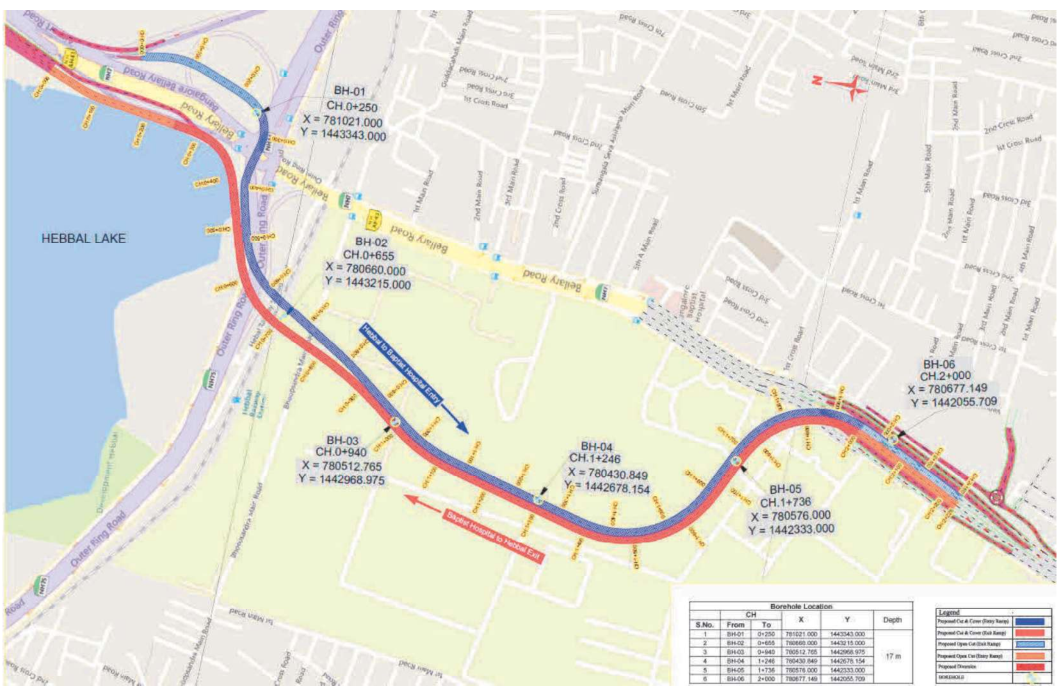


Figure 6: Borelog locations

1.6.4. Topography Survey

The topography survey was carried out using DGPS (Differential Global Positioning System) and Total Station equipment as per the requirement of site for development of Topographical maps.

1.6.5. Traffic At Site

Extensive Traffic Survey has been conducted on the site, whose details are presented in Traffic Chapter later in report.

1.7. Design Standards

1.7.1. Geometry Design

Geometric design of a highway is the process whereby the layout of the road in specific terrain is designed to meet the needs of the road users keeping in view the road function, type and volume of traffic, potential traffic hazards and safety as well as convenience of the road users. The principal areas of control for fulfilment of this objective are- the horizontal alignment, vertical alignment and the road cross-section.

The Consultants have referred to the latest IRC publications and MORT&H circulars regarding design standards for National Highways in India. After careful review of all available data and requirements of the project road the proposed Design Standards for adoption on the project road have been recommended.

The geometry has been designed as per IRC:86-2018 (Geometric Design Standards for Urban Roads and Streets), IRC:SP:91-2019 (Guidelines for Road Tunnels), IRC:38-1988 Guidelines for Design of Horizontal Curves for Highway and Design Tables, IRC:SP:23-1993 Vertical Curves of Highway.

1.7.2. Design Speed

The project road passes through plain terrain. For geometric design of the highway, design speed is used as an index which links road function, traffic flow and terrain. An appropriate design speed should correspond to general topography and adjacent land use. The speed selected for design should also cater to travel needs and behaviour of the road users.

For the project design speed of 60 kmph is adopted as per IRC:86-2018 (Geometric Design Standards for Urban Roads and Streets).

Table 1: Design Standard Details

Sr. No.	Description	Details
1	Design Speed	60 Kmph
2	Lane Configurations	3+3 Lanes
3	Carriageway Width for 3 Lanes	10.5 m
4	Kerb Shyness	500 mm
5	Crash barrier	500 mm
6	Single Lane width	3.5 m
7	Walkway	750 mm
8	Maximum Vertical Gradient Adopted	4.8 %
9	Maximum Superelevation	5%
10	Minimum Radius of Horizontal Curve Adopted	60 m

1.7.3. Ventilation

Detailed design of ventilation was carried out as per IRC: SP:91-2019, PIARC and others applicable European Standards, keeping in view the length, shape, size, tunnel environs and complexion of the likely traffic for which tunnel has been designed.

For the current project longitudinal ventilation system is recommended.

Longitudinal ventilation system is an easy and cheap way to ventilate road tunnels generally above 500 m to 4000 m in length and light traffic density. A longitudinal ventilation system creates a uniform longitudinal flow of air all along the tunnel. Air enters the tunnel from the portal, practically clean, and gets gradually polluted with substances emitted by vehicles, thus reaching the tunnel exit with a higher percentage of pollution. This system is relatively cheap and easy to install and is particularly suitable for tunnels carrying one-way traffic, where the "piston effect" assists the airflow. In tunnels with longitudinal ventilation, the concentration of noxious substances increases in the direction of the airflow and decreases with the fresh air rate. The maximum concentration increases according to the tunnel length.

The longitudinal airflow velocity has a practical upper limit; consequently, for a given traffic and slope of the roadway, the tunnel length for which longitudinal ventilation is possible has a maximum limit too. As a first estimate, this upper limit could be evaluated knowing the cross-sectional area of the tunnel and the maximum air velocity (today considered to be about 8 to 14-m/s) which is cost effective and does not disturb vehicles and the staff operating within the tunnel.

1.7.4. Fire Safety

The following facilities is provided in the tunnel which will be active during Operational phase as a fire Safety Considerations:

- Smoke detection systems: Early fire detection systems are essential to activate the ventilation system promptly in case of a fire and the same has been provided here.
- Fire suppression systems: Automatic sprinkler systems/mist or other fire suppression methods to be installed to contain a fire in its early stages.
- A rough guideline for Fire load assessment is provided in IRC:SP:91-2019. Therefore a 50 MW fire load is considered for the Tunnel.

Traffic Type	Fire Exposure Time	Representative Nominal Fire Curve
Trailor/Hay Wagon	90 – 120 min	Hydrocarbon
Car (5 – 10 MW)	30 – 60 min	Standard/Hydrocarbon
Container/Shuttle	120 (+) min	Hydrocarbon
Lorry (100 MW)	120 (+) min	Hydrocarbon
Tanker (300 MW)	120 min	RWS and/or
	240 min	Standard/Hydrocarbon
Bus	90 – 120 min	Hydrocarbon
Metro/Light Rail (40 MW)	120 min	RWS/Hydrocarbon
Train (300 MW)	120 min	RWS
	240	Standard/Hydrocarbon

Figure 7: Rough Guideline on Typical Fire Load (As per Annexure-F of IRC:SP:91-2019)

1.8. Typical Cross Sections and TCS Schedule

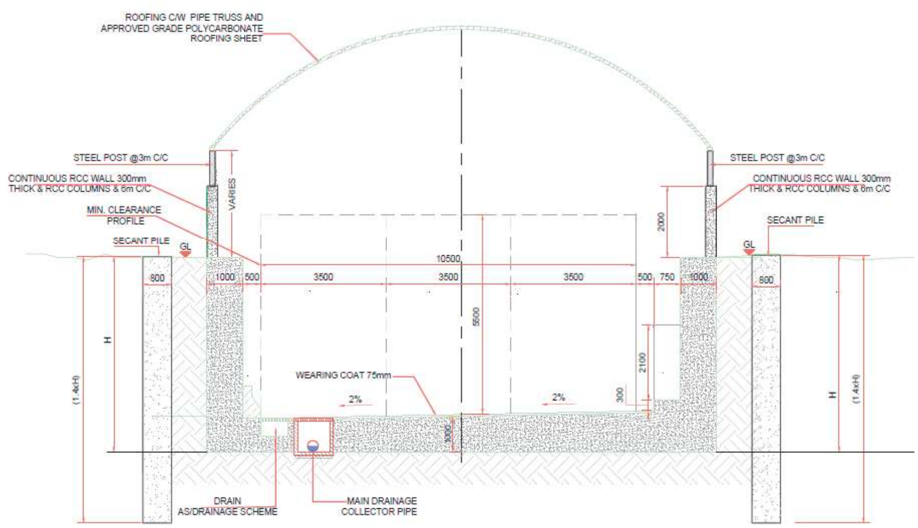
The Typical Cross Section and Schedule has been prepared based on cross sectional width, type of tunnel (Cut & Cover Section and Open Cut Sections) and design requirements. The Open Cut sections have been proposed on approach to Cut & Cover Tunnel Sections and its TCS Schedules are mentioned below.

Table 2: TCS Schedule

Hebbal to Baptist Hospital Entry				
Sr. No.	**Form**	**To**	**Length (m)**	**TCS Type**
Hebbal to Baptist Hospital Entry				
1	00+000	00+250	250	TCS-1
2	00+250	00+627	377	TCS-2
3	00+627	00+647	20	**As per GAD**
4	00+647	00+950	303	TCS-2
5	00+950	01+950	1000	TCS-3
6	01+950	02+180	230	TCS-4
	Total Length		**2180**	

Table 3: TCS Schedule

Baptist Hospital to Hebbal Exit				
Sr. No.	**Form**	**To**	**Length (m)**	**TCS Type**
1	00+000	00+250	250	TCS-1A
2	00+250	00+565	315	TCS-2A
3	00+565	00+686	121	TCS-2
4	00+686	00+706	20	**As per GAD**
5	00+706	01+000	294	TCS-2
6	01+000	02+000	1000	TCS-3
7	02+000	02+228	228	TCS-4
	Total Length		**2228**	



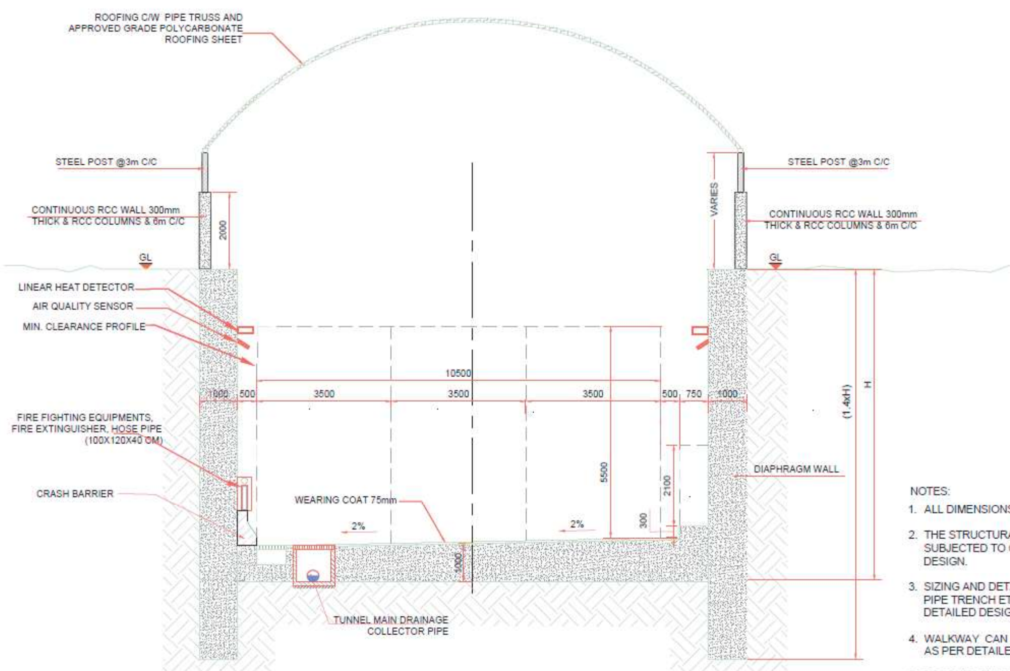
TYPICAL CROSS SECTION-01
OPEN RAMP (3 LANES)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:

GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D



TYPICAL CROSS SECTION-01A
OPEN RAMP (3 LANE) WITH D WALL
SCALE 1:50

NOTES:
1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
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MATERIALS:
GRADE OF CONCRETE - M35
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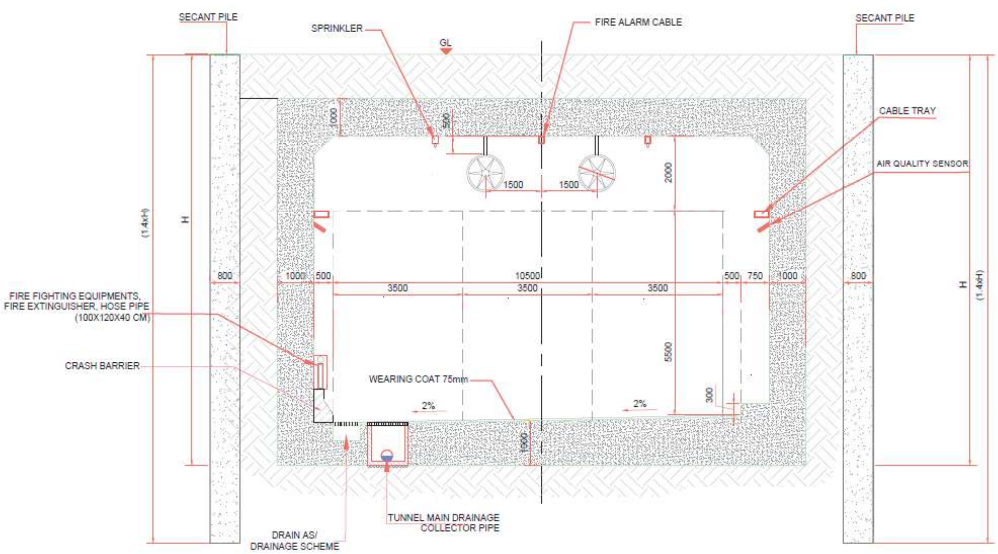


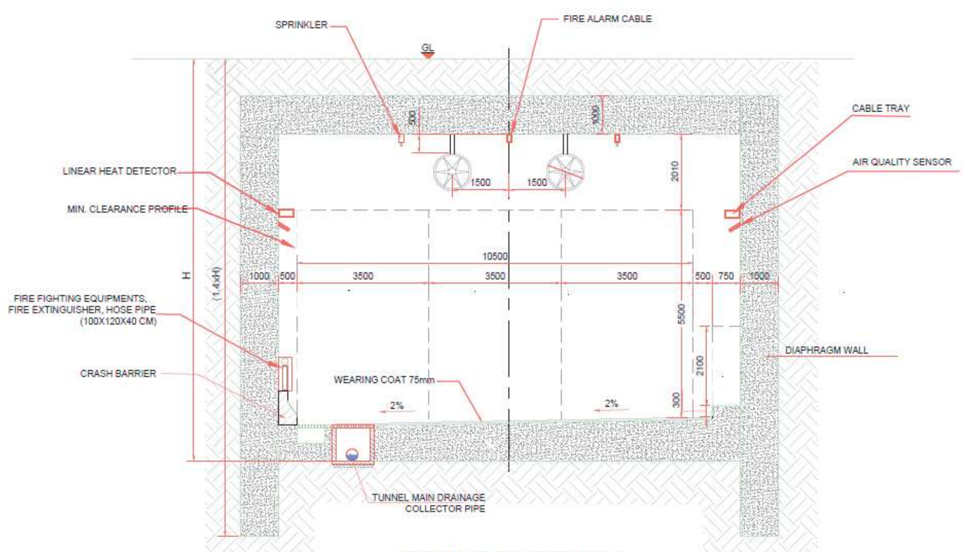
TYPICAL CROSS SECTION -02
CUT/COVER SECTION (3 LANES)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN. DETAILED DESIGN OF LINING SHALL BE DONE BY CONTRACTOR.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:

GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D

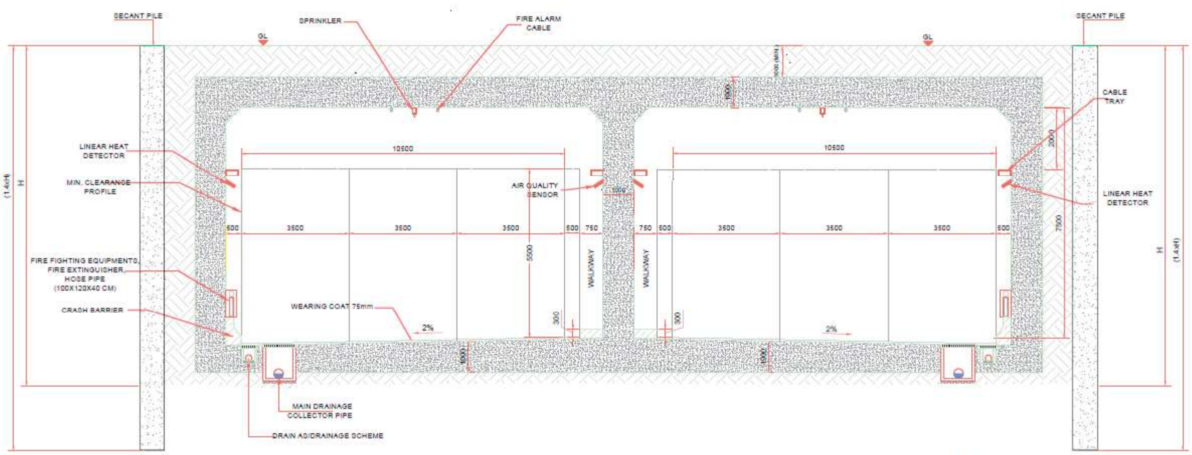


TYPICAL CROSS SECTION-02A
CUT/COVER SECTION (3LANE) WITH D WALL
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN. DETAILED DESIGN OF LINING SHALL BE DONE BY CONTRACTOR.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:
GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D



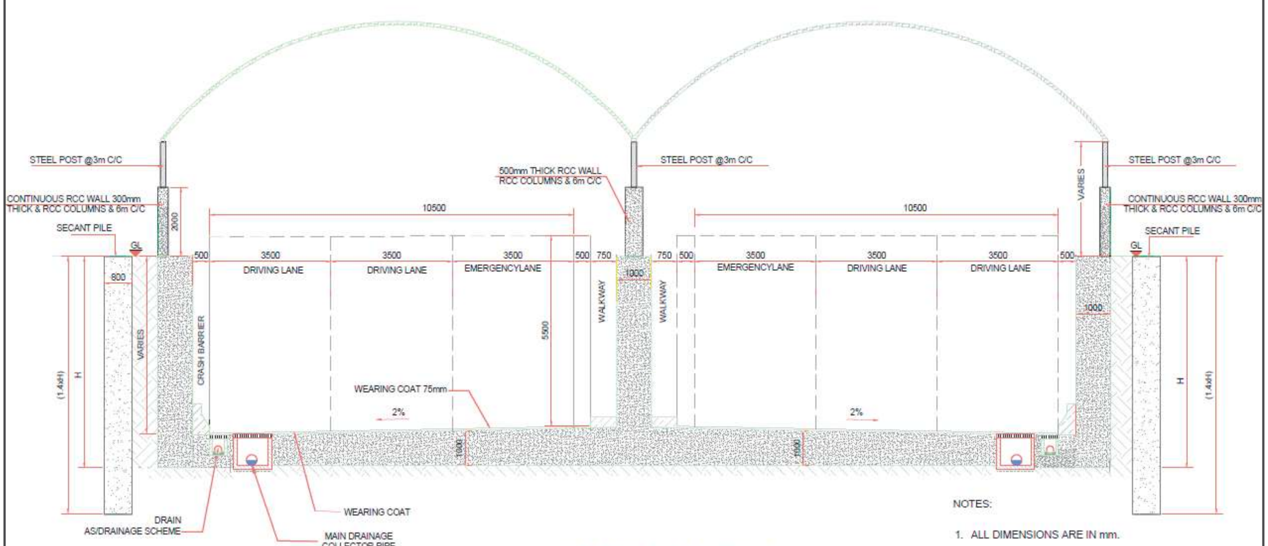
TYPICAL CROSS SECTION-03
CUT AND COVER (3 LANE+MEDIAN WALL+ 3 LANE)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
3. SIZING AND DETAILS OF TYPICAL DETAILS OF CRASH BARRIER , UTILITY PIPE TRENCH , MAIN DRAINAGE ETC. MAY CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN .
5. DRAWINGS SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS: -

GRADE OF CONCRETE -M35 ,
STEEL GRADE Fe550D



TYPICAL CROSS SECTION -04
OPEN RAMP SECTION 3LANE+MEDIAN WALL+3LANE
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
3. SIZING AND DETAILS OF TYPICAL DETAILS OF CRASH BARRIER, UTILITY PIPE TRENCH, MAIN DRAINAGE ETC. MAY CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWINGS SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS: -
GRADE OF CONCRETE -M35 , STEEL GRADE Fe550D

1.9. Preconstruction activities

- Land Acquisition: The land acquisition will be required at tunnel approaches in cut & cover section and open cut section. DPR Consultant will provide LA Plan (on revenue map) and schedule (Titles of the land parcels) in due course of time for the land parcels indicated in Land Plan.
- The cost for Land acquisition and rehabilitation in cut & cover section has been considered in cost estimate on Lump Sum basis as per discussion held with all stakeholders.
- Utility Shifting: The utilities shifting (Electrical, Tele communication and PHED) at the approach of the main tunnel approaches in cut & cover section and open cut section. The cost for shifting utilities has been considered in cost estimate on Lump Sum basis.
- Trees relocation: The tree cutting or relocation number will be finalized after completion of land acquisition schedules and joint measurement survey of forest department and revenue department, compensation/CA will be as per state policy. The cost for tree relocation and felling has been considered in cost estimate on Lump Sum numbers of the trees.
- In addition to the available data from other projects along the alignment DPR consultant has carried out Geological survey, Geo physical investigations. The intrusive investigations are being carried out.

1.10. Construction Timeline

The project shall be constructed withing 18 months with efficient planning of resources.

1.11. Traffic Control and Safety Measures

Road Marking & Traffic Signs

Road markings will be made for centre and edge lines using reflective thermoplastic paints. Appropriate road markings will be provided at junctions and crossings. Road signs are to placed according to IRC: 67-2022. The location of each sign is to be decided in accordance with the guidelines their in.

Illumination

Tunnel illumination/lighting shall be designed and provided as per MoRTH Guidelines for Expressway and IRC:SP:91-2019.

Underground road Furnishing

Provisions shall be made for installation furnishing such as sign boards, firefighting arrangements, cable trays for telephone and power lines etc. in consultation with relevant local authorities.

Signages and Carriageway Markings

Variable messages signs shall be provided for the information of traffic of lane blockage/closure due to incidents related to vehicles/non-vehicles, weather and human hazards etc. or maintenance operations as also to warn of possible hazard ahead due to any abnormal situation. Signage system shall be complemented by providing traffic lights above each lane at the entry portal end and inside. Signages indicating distance travelled, distance/ direction to an exit on evacuation route shall be provided inside the tunnel.

Carriageway markings consisting of a discontinuous line separating the traffic lanes and continuous line separating the lateral traffic lane from the paved shoulder, shall have good day/night visibility and conform to IRC:35. The markings shall be done by means of self-propelled machine which has a satisfactory cut-off capable of applying broken line automatically.

1.12. Cost Estimates

1.12.1. General

Cost estimation is an important component of the study as it provides vital input & financial evaluation and insights for proper planning of project execution. Over and above construction costs, provision has been made for land acquisition social and environmental mitigation measures. Cost Estimates are done based on the detailed engineering designs and detailed drawings presented in drawing volume.

1.12.2. Methodology

The cost of the underground twin road cut & cover sections has been worked out based on the cross-sections and the plan and other drawings for the project.

The quantification of various items of work related to tunnels have been detailed out from the structural drawings.

Quantities of traffic signs, marking and other road appurtenances and various project facilities are worked out in the plan drawing and costing has been accordingly.

1.12.3. Unit Rates of Materials

The Rates of materials for different components of projects are referred from the government issued data and prevailing market rates.

The cost of materials is referenced from a combination of government-issued data and market rates.

The Government data referenced for rates of items include: Karnataka PWD Common Schedule of Rates (CSR) 2023-24.

MoRTH Standard Data Book, 2019

CPWD Plinth Area Rates 2023

Rates of items have also been referenced to similar recent projects.

Rates of items have also been referenced to market rates.

Rates of GNSS tolling system have not been established in India, these rates are based on approximate market rates.

A transportation lead of 45 km is assumed for muck disposal.

1.12.4. Summary of Cost Estimate

Table 4: Summary of Cost Estimate

s.no	Description	Length	Amount (A)
1	Entry and Exit open Ramp 3 Lane TCS-1	250.0	37,64,43,542
2	Entry and Exit open Ramp 3 Lane TCS-1A	250.0	31,46,17,487
3	Cut and cover 3-Lane TCS-2	1095.0	3,16,21,96,826
4	Cut and cover 3-Lane TCS-2A	315.0	55,80,99,759
5	Cut and cover (3-Lane+Median wall+3 Lane) TCS-3	2000.0	4,28,04,27,022
6	Open Ramp (3-Lane+Median wall+3 Lane) TCS-4	458.0	60,94,20,698
7	Rail Under Bridge(RUB)	40.0	13,58,22,959
	Sub total (A)	**4408.0**	**9,43,70,28,292**
8	**Other Works**		
a	Instrumentation & Monitoring cost @ 1% of (A)		9,43,70,283
b	Electro- Mechanical Works		54,76,77,102
c	Tunnel Ventilation & Fire Fighting		12,42,81,490
d	Traffic Signs, Markings , Appurtenances etc.		1,00,19,702
e	Restoration of Existing Road, Site Clearence, Junction improvement, Approach Area & Ramps (Road ,Footpath, Lighting etc.)		22,78,57,575
f	Miscellaneous (Landscaping on roads and Art Work in Tunnel etc.)		4,53,25,285
g	Control centre etc		1,32,72,880
	Sub total		**10,49,98,32,609**
	Escalation as per SoR 2023-24		**4,80,07,073**
9	**Estimated Construction Cost Without GST =B**		**10,54,78,39,682**
a	Labour Cess @ 1% (On the Amount of Non SOR items)		1,55,96,307
b	GST @ 18% Payable On Construction Cost Only (On B)		1,89,86,11,143
10	**Construction Cost Including Labour cess & GST**		**12,46,20,47,131**
11	Contingencies charges @1% of (B)		10,54,78,397
12	Planning & designing Charges @ 1% of (B)		10,54,78,397
13	Construction Supervision Charges @ 2% Of (B)		21,09,56,794
14	Tunnel Maintenance For 10 Years i.e., @ 0.25% for the first 5 years, 0.35% for the next five years of (B)		31,64,35,190
15	Land acquisition and rehabilation of building Structures at GKVK/Veterinary college premisses	Lump Sum	25,00,00,000
16	Shifting of utilities Cost	Lump Sum	35,00,00,000
17	Deposit for Indian Railways for supervision	Lump Sum	4,50,00,000
18	Environmental Impact Assessment Charges	Lump Sum	75,00,000
	Total Project Cost (10+11+12+13+14+15+16+17+18)		**13,85,28,95,909**

CHAPTER 2 : INTRODUCTION

2.1. Project Background and Need

Bengaluru, the capital of Karnataka, has witnessed exponential urban growth and a steep rise in vehicular population over the past two decades. This has placed significant stress on the city's road infrastructure, particularly at critical junctions like the Hebbal Flyover, which serves as a key node connecting the airport, central business districts, Outer Ring Road (ORR), and multiple arterial roads.

The Hebbal Flyover junction is a major congestion hotspot where traffic from the north (Kempegowda International Airport), east (KR Puram), west (Yeshwantpur), and central Bengaluru converges. The existing multi-tiered flyovers and loops are functioning beyond their capacity, often resulting in gridlock during peak hours. With a proposed BMRCL Metro line and an existing railway corridor passing through this area, further expansion of surface or elevated infrastructure is no longer feasible.

The Bellary Road Section of Hebbal junction to Mekri Circle gets fully congested during the peak traffic hours and fails to provide adequate service to the commuters.

Hebbal Junction faces heavy traffic from all sides (Airport side to the North, Bangalore city to city, Yeshwantpura side to West and KR Puram side to East), sometimes making traffic at a standstill for longer time.

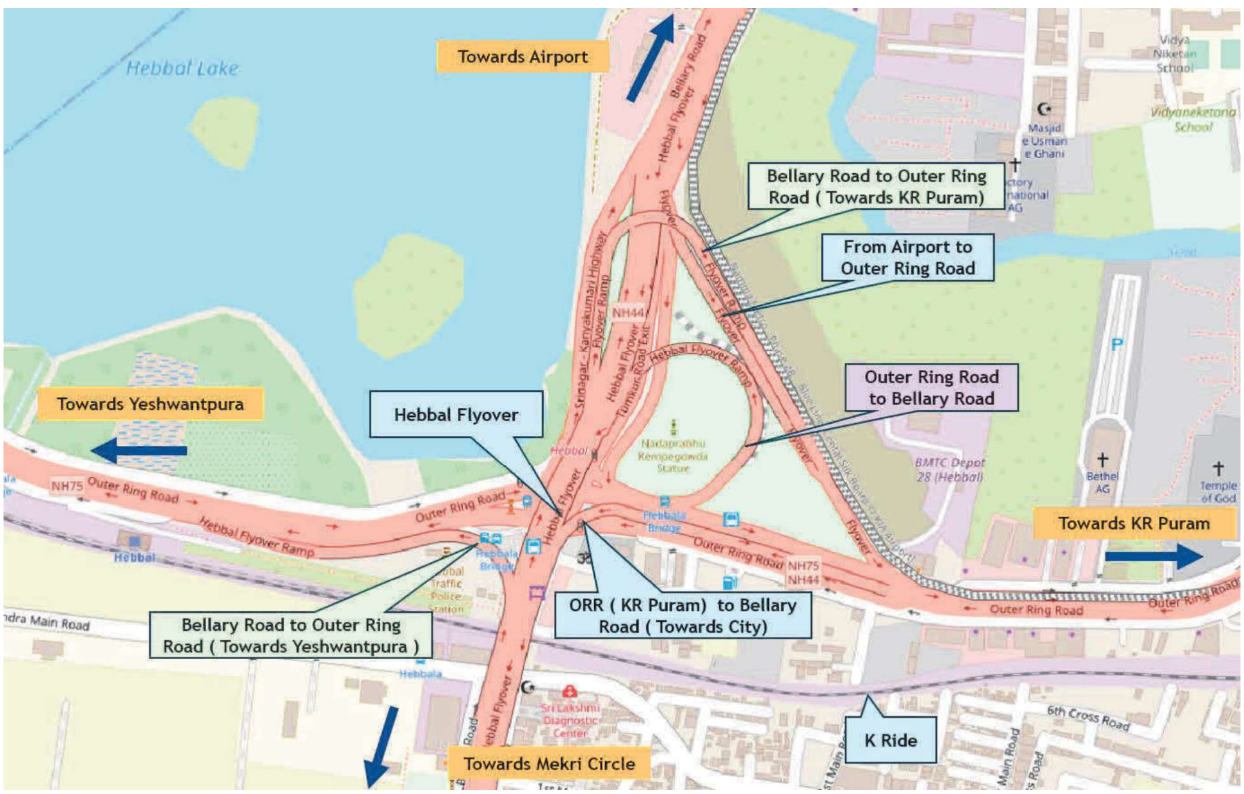


Figure 8: Flyovers at Hebbal

At the Hebbal Junction there are already numerous elevated ramps/loops which provide connectivity to different roads passing through Hebbal,

- Flyover loop from Bellary Road to Outer Ring Road (ORR) towards Yashwant Pura,

- Another Flyover Ramp from ORR to Bellary Road which provides connectivity to Traffic Coming from Yashwantpur side to Bellary Road.
- Flyover connecting Bellary Road to ORR Providing connectivity to traffic going towards KR Puram from Bellary Road.
- Flyover Ramp Connecting traffic going on ORR towards KPR Puram side from Airport side
- Flyover connecting ORR to Bellary Road for traffic coming from KR Puram side towards Bangalore city was recently inaugurated.

The railway line also passes through the Hebbal Junction and there is also proposal of BMRC metro line that will pass near the Hebbal Junction.

All the Existing structures and proposed projects makes the widening of existing roads and proposal of new elevated structures infeasible.

2.2. Project Proponent

To address this, the Government of Karnataka, through Bengaluru Smart Infrastructure Limited (B-SMILE), has proposed the construction of 2.228 Kms of Vehicular Underpass for which Consultancy Service for Preparation for Preliminary Project Report and DPR for short length transitory 3 lane bi-directional vehicular underpass connecting Hebbal flyover junction to Veterinary college via GKVK premises has been taken up. This project will provide a seamless, grade-separated corridor for Airport-City through traffic, enabling uninterrupted movement from Hebbal (Esteem Mall) toward CBI Road, bypassing conflict points at the flyover.

2.3. Study Area

The project is focused on providing immediate relief to commuters by providing a vehicular under pass that will bypasss the through traffic from Mekri circle to Hebbal Flyover.

- The project will start at Hebbal Flyover.
- The underground vehicle underpass will pass through GKVK premises.
- The project will end near Veterinary College.

2.4. Methodology

The project will be constructed with cut and cover methodology with cast in situ box structures. While the approaches for the project will be open cut portions.

The cut and cover methodology will enable the restoration of the land through which alignment passes.

At the railway location Box pushing method to be used which will enable the speedy construction of project without affecting the railway operations.

Diaphragm wall will be used to construct in the area near to Hebbal lake to stop the water ingress during construction.

Secant piles will be used in other locations to minimize the slope of cut and reduce the working area required hence reducing the muck.

CHAPTER 3 : PROJECT DESCRIPTION

3.1 Project Location Map

The project starts at the Hebbal Junction and ends near the Baptist Hospital. The alignment map is shown below for reference.

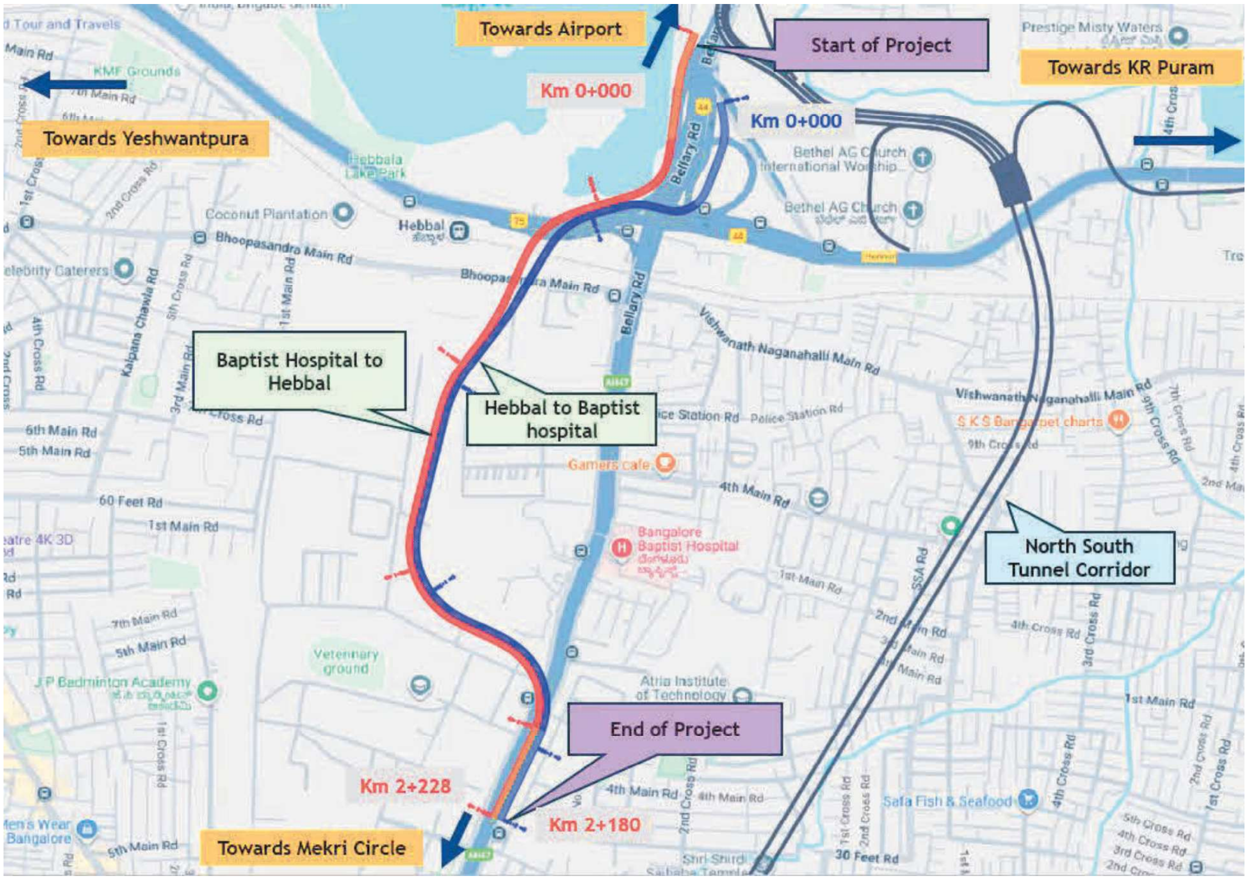


Figure 9: Project Alignment

3.2 Description of Vehicular Underpass

The vehicular underpass will be 6 lane bi-directional cut and cover underpass portion. Where 3 lane will provide service to commuters travelling from Hebbal to Mekri circle side and other 3 lanes will serve commuters travelling to Mekri circle to Hebbal side.

The project lies in plain terrain and has a length of 2.228 km, out of which the cut and cover portion length is 1750 m while open cut length is 0.478 m.

Each tube is designed for a 60 km/h operating speed. The alignment passes seamlessly beneath existing railway tracks and the future Metro corridor while tying into the current service roads, minimizing conflicts with flyovers, utilities, and pedestrian routes.

The design considerations are discussed in detail in later chapters of the report.

Sr. No.	Description	Details
1	Design Speed	60 Kmph
2	Lane Configurations	3+3 Lanes
3	Carriageway Width for 3 Lanes	10.5 m
4	Kerb Shyness	500 mm
5	Crash barrier	500 mm
6	Single Lane width	3.5 m
7	Walkway	750 mm
8	Maximum Vertical Gradient Adopted	4.8 %
9	Maximum Superelevation	5%
10	Minimum Radius of Horizontal Curve Adopted	60 m

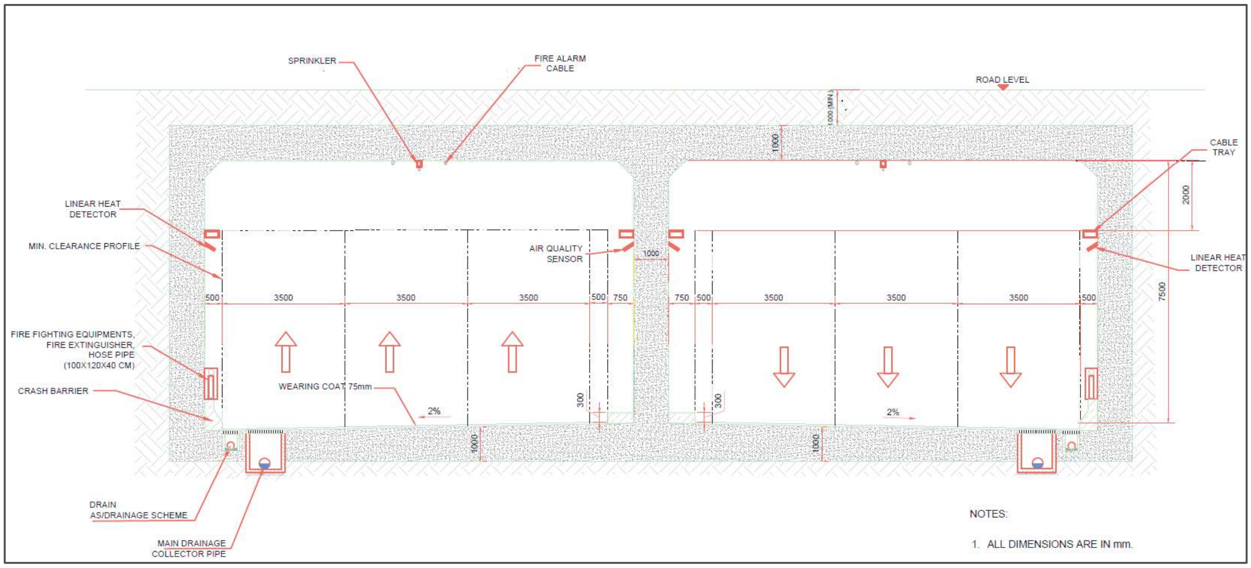


Figure 10: Typical Cross Section

3.3 Adjacent Infrastructure

The project starts at Hebbal flyover on Bellary Road then passes through the GKVK campus (which runs parallel to Bellary Road) and then merges again in Bellary Road near Veterinary College, Hebbal. The Ballery road is an elevated road with 3+3 Lane configurations which also have service lanes with varying width of intermediate lane the elevated corridor.

At the start of project i.e., near Hebbal there are existing flyovers and its ramps/loops, Railway Line, Proposal for metro which are also mentioned in earlier chapters.

And at the end of project the project mergers in the

3.3.1 Infringement with Other Planned and Existing Projects

- Alignment infringement with Railway
  The project passes below the Existing Railway line as indicated in the Image below.

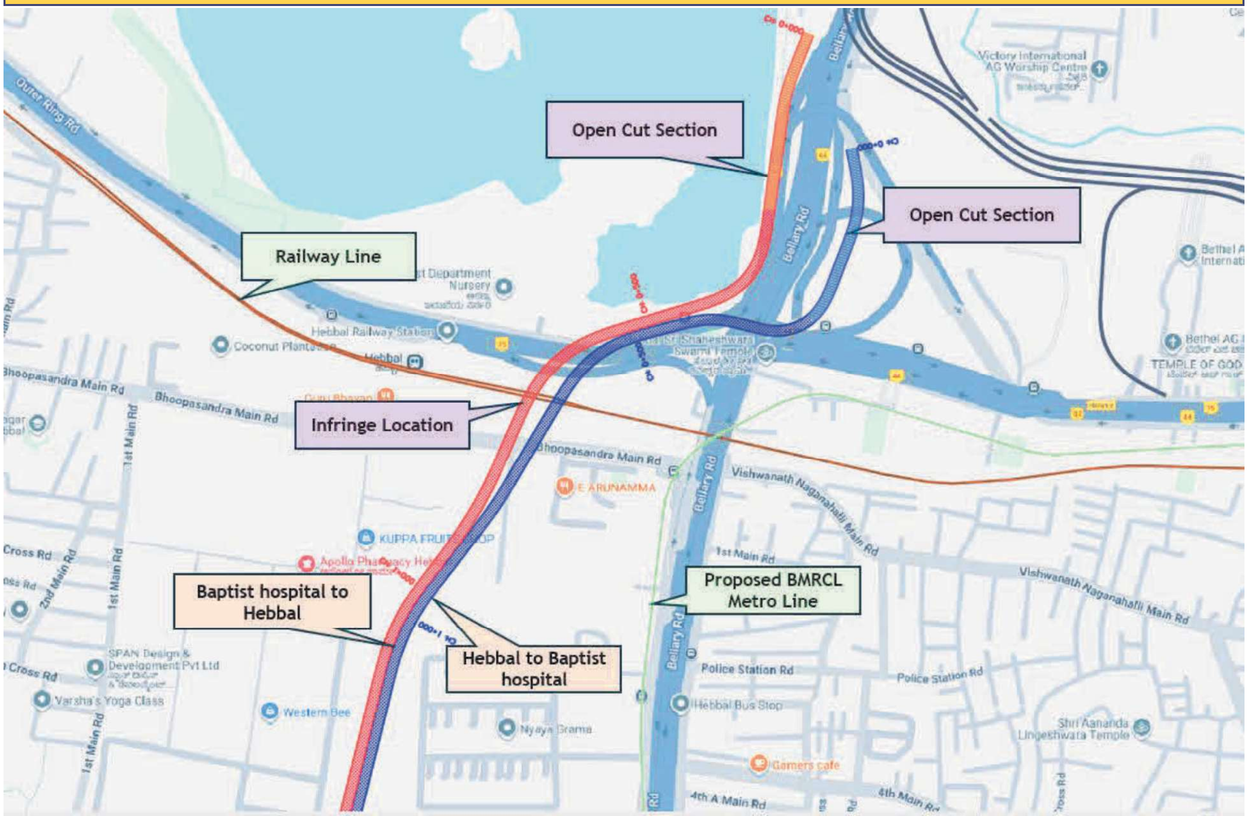


Figure 11: Infringe Location with Railway

- Alignment Infringement with Proposed BMRCL metro.
  The alignment passes through the alignment of proposed BMRCL metro line. The alignment is shown below.

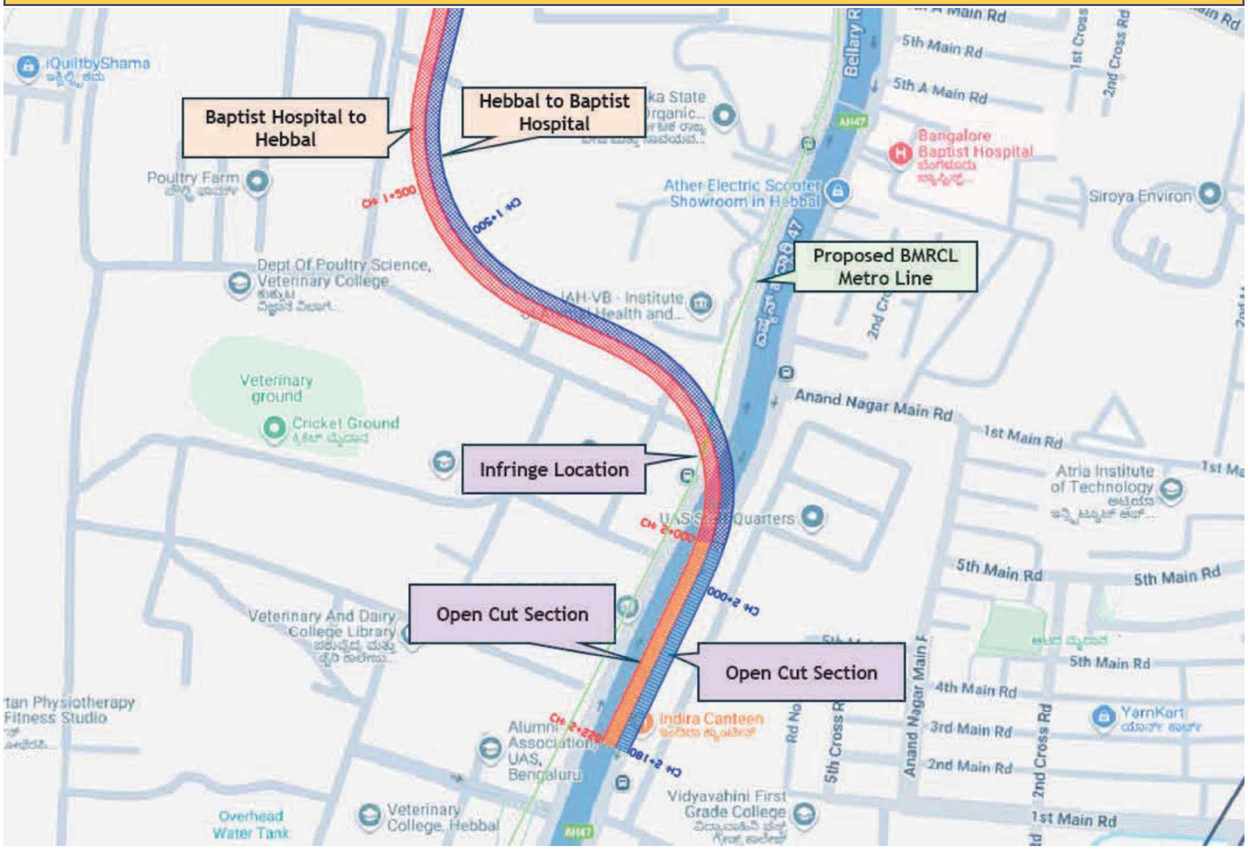


Figure 12: Infringe Location with Proposed BMRCL Metro Line

CHAPTER 4 :TRAFFIC STUDIES AND PROJECTION

4.1 Project Background

4.1.1 Project Initiation

Despite the growing population and vehicular density, Bengaluru has struggled to match its infrastructure supply with the increasing demand. This discrepancy has led to longer travel times, decreased patronage of public transport, and widespread traffic congestion. The Hebbal Interchange continues to serve as one of the most critical and persistent traffic bottlenecks in Bengaluru, particularly along NH-44/Airport Road. The existing road geometry—with six-lane approaches funnelling into a narrower flyover—creates significant congestion across all directions. This issue is further exacerbated by ongoing infrastructure works in and around the junction, intensifying delays, and operational inefficiencies.

During peak hours, typically between 8:00–10:00 AM and 5:00–7:00 PM, traffic movement slows drastically, with vehicles queuing for extended periods on the approach ramps. Commuters often report crawling traffic speeds of less than 10 km/h, contributing to increased fuel consumption and elevated emissions due to prolonged idling. Despite the implementation of various short- and medium-term interventions in the past, congestion and queuing remain consistent, rendering Hebbal one of the most gridlocked locations in the city. There have even been instances of air passengers missing flights due to delays at this interchange.

To address this, a new 700-meter loop flyover is currently under construction, connecting the Outer Ring Road (ORR) from Nagawara to Baptist Hospital towards Mekhri Circle. This infrastructure is expected to significantly streamline traffic flow from the K.R. Puram side towards central Bengaluru.

Travel Time Impacts

Travel times through Hebbal during peak periods are typically 20-40% longer than usual. For example, a journey that would normally take 30-40 minutes can extend to nearly an hour. Studies suggest that Bengaluru commuters lose over 240 hours annually due to traffic congestion, with Hebbal being a major contributor. In recent congestion rankings (e.g., TomTom Traffic Index 2024), Hebbal has been identified as one of the city's most severely impacted corridors.

Air Pollution and Health Impacts

While Hebbal is not the highest-ranked in terms of air pollution levels (with Silk Board and Whitefield being more severe), it remains within a high-traffic corridor where Air Quality Index (AQI) levels frequently range from 76 to 314, indicating a shift from moderate to severe pollution. Primary pollutants include PM2.5, PM10, nitrogen oxides (NO_x), and carbon monoxide, largely attributable to vehicular idling and stop-and-go movement. Such pollution has direct implications on public health, particularly respiratory and cardiovascular conditions, and contributes to reduced productivity among daily commuters exposed to these conditions.

4.1.2 Need for Comprehensive Solution

Given that prior short- and medium-term measures have not provided long-lasting relief, urban planners and mobility experts have emphasized the importance of expanding mass transit options such as the Metro. However, Metro and public transport alone may not be sufficient. A significant portion of the commuting population—including commercial vehicles, two-wheelers, and users who rely on private transport for last-mile connectivity—continues to depend on road-based mobility.

Recognizing the need for a holistic, multi-modal solution, B-Smile has proposed a two-tiered strategy:

For long-distance commuters: A 14-kilometre underground tunnel connecting Hebbal to Madiwala Junction, with four entry and exit points. This corridor aims to provide a seamless travel route from Kempegowda International Airport to Silk Board, bypassing surface-level congestion.

For immediate congestion relief at Hebbal: A short-span underpass is proposed between Baptist Hospital and the Airport-bound carriageway, enabling smoother directional flow and reducing load on the main flyover.

These initiatives aim to address not only current traffic bottlenecks but also provide scalable, inclusive mobility solutions for all user groups across the transport network.

4.1.3 Objectives of Study

The Traffic Impact Assessment Study shall aim at providing high and improved levels of mobility, accessibility, convenience and comfort for all the road users as well as the residents who will reside in the vicinity of the project site. The objective of the study would include:

- Assessment of the existing road infrastructure in the study area in terms of traffic congestions, connectivity, safety and convenience;
- Propose implementable interventions and come up with conceptual level drawings of the same for improving mobility along the corridors of influence to the project site.
- Impact Assessment for the proposed proposal at the project site.

4.1.4 Scope of Work

The study is aimed at proposing strategies or plans that can be implementable within a time frame, that could provide relief to commuters. The focus of these plans would be on reducing travel time for commuters by resolving conflicts at Hebbal Interchange and other bottleneck locations, with particular focus on increasing speeds of public buses, cars , two wheelers and other commercial vehicles on this stretch. The plans shall lay emphasis on improved accessibility to vehicles for seamless travel.

4.2 Study Area

4.2.1 Study Area Profile

The primary objective of the project is to formulate a comprehensive long-term traffic management strategy, along with an impact assessment study for the proposed interventions, to ensure seamless movement for short-distance commuters at the Hebbal interchange — with a specific focus on facilitating traffic flow between Bengaluru city and the airport corridor."

4.2.2 Integrated TIA for Hebbal Interchange

Major corridors which will have the impact of the new proposed infrastructure development are as listed below.

1. Airport Corridor - taking Bangalore city traffic and Airport traffic.

2. Major relief for feeder roads which are located within the radius of 3-4 kms which includes:

- Anand Nagar Main road
- CBI main road
- 5th Main Ganaganagar.
- Sanjay Nagar main road.
- Binny Mill road
- Tarabalau Main road
- Jayamahal road
- C.V. Raman road

Kempapura, Sahakarnagar, Byatarayanapura, Anand Nagar, Bhoopasandra, Kanakanagara, Dollars Colony, R.T.Nagar, Ganganagar, Gangenahalli,Sanjaynagar, J.C Nagar, Sadashivnagar, Yeshwanthapura, Malleshwaram, Benson Town, Jayamahal, MLA Layout etc.

The identified corridors are critical routes with heavy traffic flow, feeding into the Hebbal interchange and contributing to severe congestion along the Outer Ring Road. While a large volume of long-distance traffic enters from the airport side towards Bangalore city and vice-versa, a significant share of short-distance commuters within a 3–4 km radius faces prolonged delays. To address this, a comprehensive long-term solution is being proposed based on detailed traffic surveys and demand assessment. This strategy aims to enhance mobility for local commuters, reduce travel time, and improve quality of life. The plan includes thorough traffic analysis, forecasting, and appropriate mitigation measures to ensure smoother and more efficient movement."

4.2.3 Project Area as per Draft Revised Master Plan (RMP) 2031

As per the Draft Revised Master Plan 2031, the alignment of the Outer Ring Road and the Airport Road from Mekhri Circle to Hebbal .

The proposed underpass is located entirely within the Public and Semi-Public facilities zone. The alignment intersects a railway line, crosses the Outer Ring Road, and extends into the lake buffer area. It then merges with the service road and passes beneath the existing interchange towards the Airport, while connecting with the central carriageway on the Bangalore city side

4.3 Methodology for Traffic Survey

4.3.1 Approach

The increasing traffic volumes in Bengaluru, particularly around the Hebbal corridor, have led to severe congestion and deteriorating air quality. This situation demands a structured and multi-pronged approach to formulate mobility solutions that can address both present challenges and future demands.

The proposed Traffic Impact Assessment (TIA) Study for the Hebbal region, under the scope of the development by B-SMILE, aims to develop an optimized road transport plan that enhances mobility for all modes — including buses, cars, two-wheelers, and auto-rickshaws — while identifying short-, medium-, and long-term interventions to improve overall traffic efficiency in the study area.

As a first step, a comprehensive and systematic collection of data will be undertaken to gain insights into:

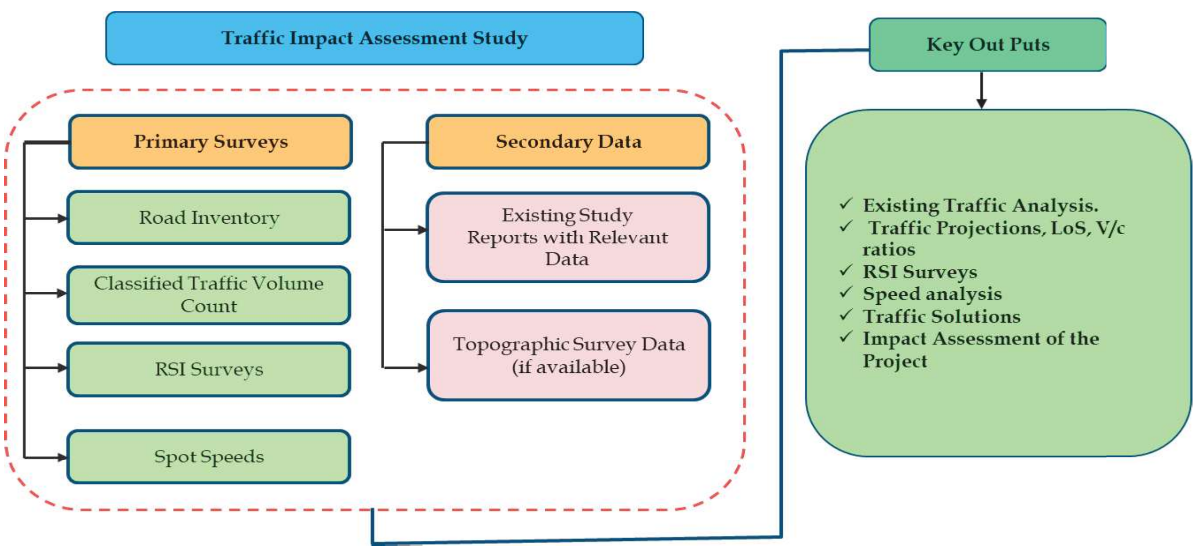
- Existing traffic volumes (peak and off-peak),

- Vehicular composition,
- Traffic flow patterns and turning movements,
- Congestion hotspots and bottlenecks,
- Road geometry

This base data will help assess the current traffic scenario in the vicinity of the proposed development and serve as the foundation for all further analysis.

4.3.2 Methodology Adopted

The objective of the study is to improve the average speeds on the corridors by easing out the congestion points. The proposed methodology is as illustrated below,



The study is further divided into tasks as mentioned below:

Task 1: Baseline Scenario

The consultant shall establish the baseline for current corridor characteristics influencing the project site by means of Site Visits and Reconnaissance Survey. Apart from this the consultant has also undertake;

- Photo Documentation of the Corridors/Routes and Stretches
- Interactions with the Officials and Stakeholders to identify gaps and challenges
- Review of previous documents pertaining to the locations along the corridors/routes/stretches if any.
- The consultant shall presented the major issues, opportunities and concerns observed and outline the broad strategies to guide the rest of the study.

Task 2: Primary Survey and Data Analysis

The consultant shall collect all relevant data by means of Surveys. The team will conduct the following surveys, as deemed necessary for the study;

- Road Network Inventory
- Spot Speeds.
- Classified Traffic Volume Counts (Video Recording) at critical locations as discussed with client.

Based on the data collected from the primary surveys and secondary sources, the team has done the data analysis for the following assessments

- Assessment of the Traffic Volumes as per IRC Guidelines or any other similar guidelines.
- Volume Delay Assessment
- Road Side Interviews to know the opinion of the commuters.

The various assessments undertaken as part of this task has identified the critical gaps and challenges along the corridor, which will be used as inputs for formulating the strategies and interventions for the Corridor Improvements within the study area.

Task 3: Corridor Improvement Solutions

Consultants shall identify all the appropriate implementable Interventions for Traffic Impact Assessment, considering equitable road spaces for all Modes of Transport .

- *Road Improvement Plan and Circulation Plans as deemed necessary; including*:
  - Junction Improvement
  - Turning movement controls
- *Road Safety measures like*
  - Traffic engineering measures – Geometric Design Corrections
- *Long term Solutions*
  - Underpasses / Flyovers
  - Tunnels

Task 4: Conceptual Drawings

All the critical proposals has been discussed with the stakeholders and conceptual drawings have been prepared by the Consultant.

4.4 Existing Traffic Scenario

4.4.1 Base Map of Hot Spots in the Study Area

As per the site reconnaissance survey conducted with in the vicinity of the study area certain hot spots were noted wherein the traffic congestions where happening and required immediate attention to address the issues as shown in the Figure below. Further the issue / hot spots are explained in detailed.

Figure 13 : Traffic Hotspots

01	Traffic from Airport entering the City via Through Flyover
02	At-grade traffic merges onto the flyover via a central ramp.
03	Merging and diverging point where traffic from the service road joins the flyover towards Tumkur and Airport.
04	Road stretch between HMT Bhavan and Air Force Gate, before Mekhri Circle.

4.4.2 Hot Spot 1 : Traffic from Airport entering the City via Through Flyover

Traffic congestion is observed at the entry point of the interchange. As a short-term measure, traffic management interventions were introduced to improve lane discipline and provide free access for vehicles arriving from the airport towards the city. This was achieved by installing precast medians along the carriageway to separate expressway traffic from service road traffic merging at the same point, which was a major cause of congestion. Subsequently, an additional road was constructed below the flyover and connected to the ramp, which in turn links to the top of the flyover. However, this intervention has not fully resolved the issue, as congestion now occurs on the flyover itself where the down ramp merges. To manage this situation, police personnel have been deployed to manually regulate traffic flow. In essence, the short-term correction has only shifted the congestion point from the base of the flyover to its upper section.

- Average travel delay of 13–15 minutes is experienced at this point during peak hours.
- New road users face confusion in selecting the correct route, adding to traffic disruptions.
- Merging and diverging conflicts are a major contributor to congestion.

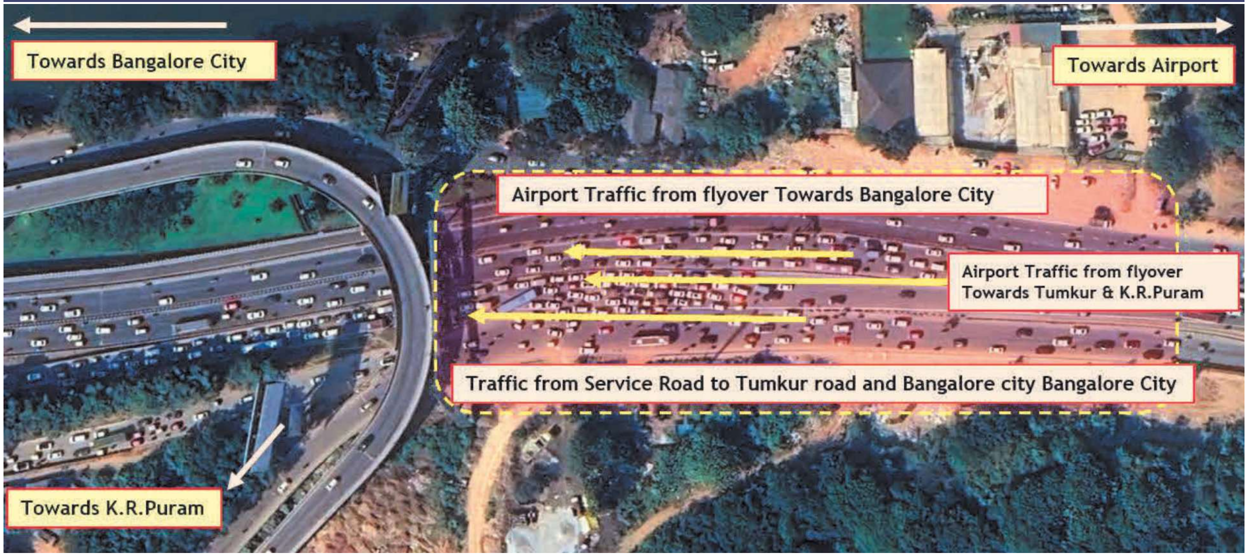
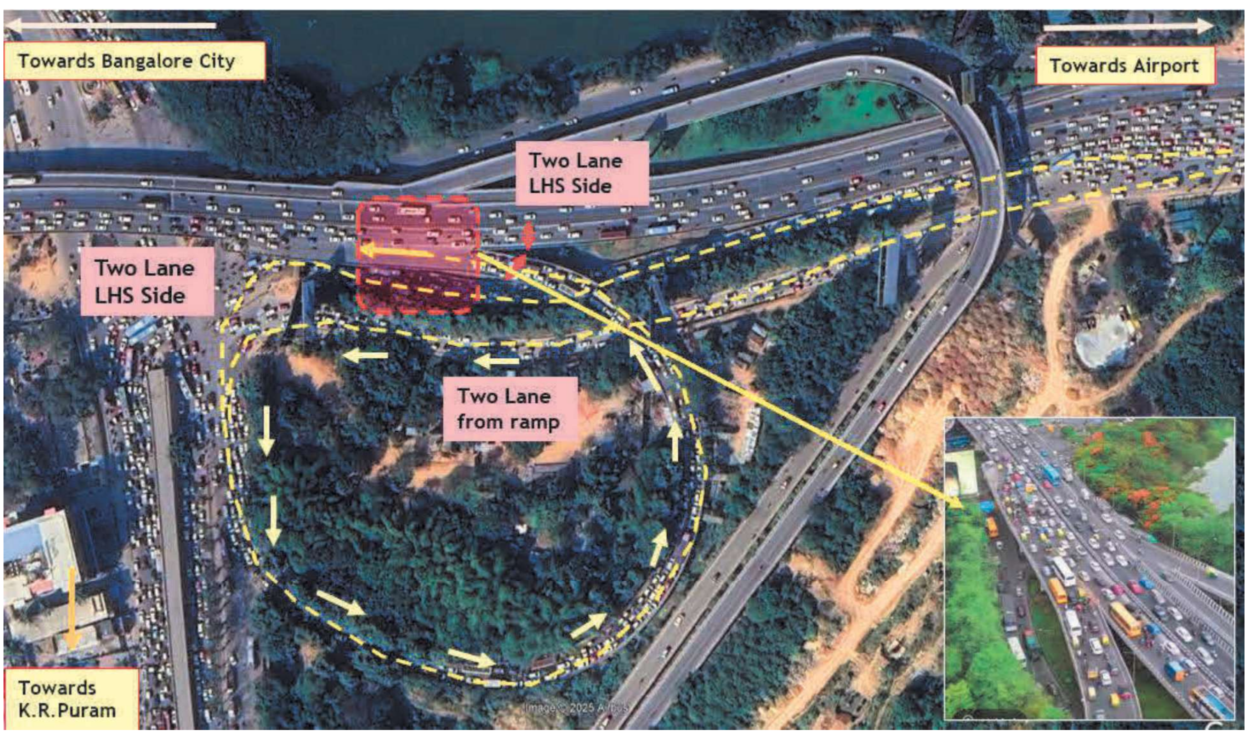


Figure 14: *Map showing Hot Spot 1 - Veerannapalya Junction*

4.4.3 Hot Spot 2 : At-grade traffic merges onto the flyover via a central ramp.

Traffic congestion is observed on the top of the flyover where the down ramp from the Outer Ring Road connects with the up ramp from the airport side, along with traffic merging from the Kempapura service road. At this merging point, the variation in lane widths requires police personnel to manually regulate and phase traffic movement.

Here, two lanes from the flyover and two lanes from the ramp converge into just two lanes, with only a small storage lane available. This lane reduction and merging conflict are the primary reasons for congestion at this location.



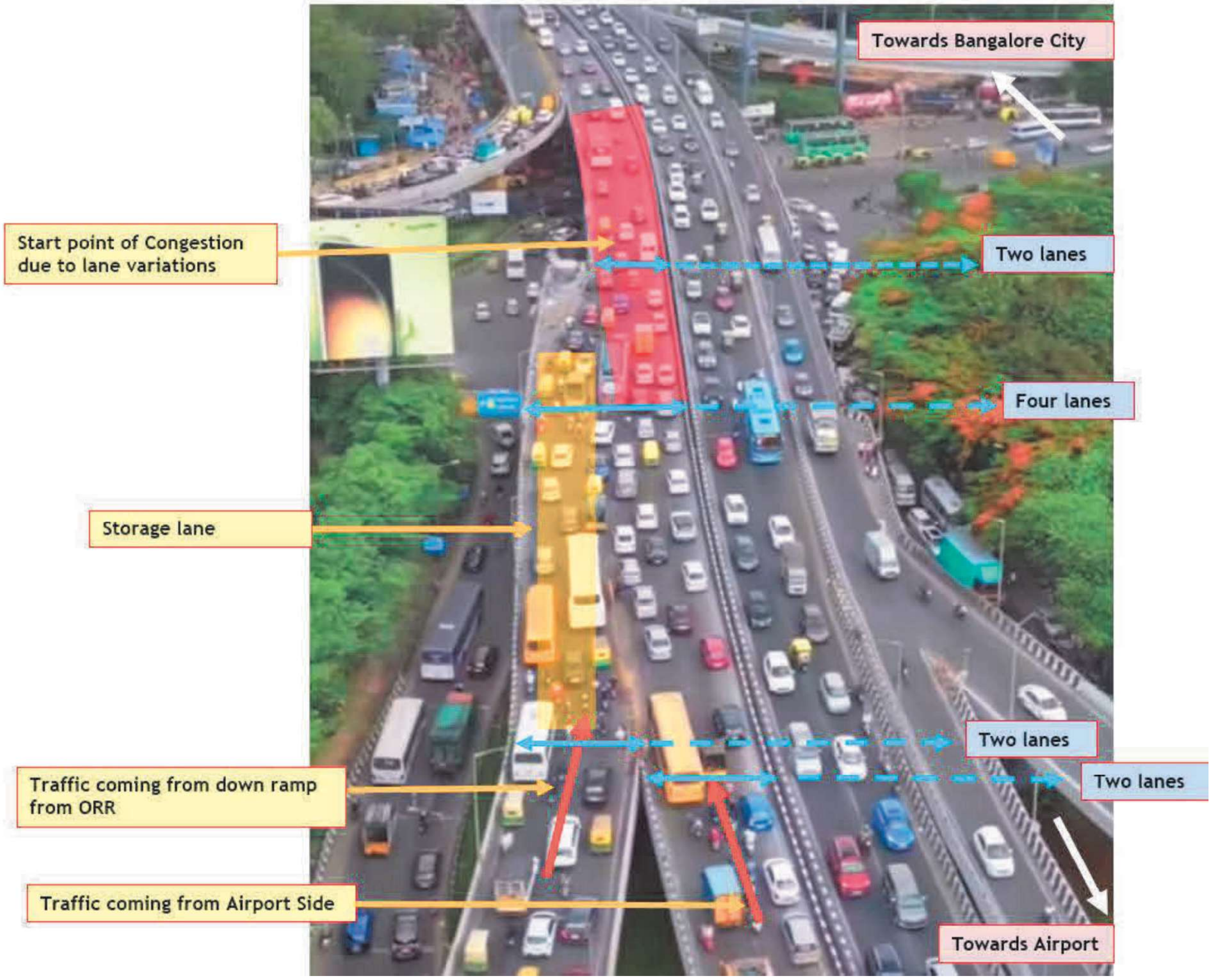


Figure 15 : Congestion

4.4.4 Hot Spot 3 : Merging and diverging point where traffic from the service road joins the flyover towards Tumkur and Airport.

Traffic congestion is occurring during the peak hour at the up ramp of the flyover towards Airport side as shown in the figure . This is mainly due to the traffic coming on to the service road from the nearby areas like Anand Nagar, R.T.Nagar, Sultanpalya, Dinnur, Rahmath Nagar, HMT layout etc. These short distance road users who tend to go towards the airport need to access the service road and then either merge to the main flyover or the single lane ramp which connects to Tumkur road , K.R Puram. And airport. At this point it is also observed that the traffic from the main carriageway diverges and merges at the same ramp to go towards Tumkur leading to extreme traffic congestions and queuing which extends up till CBI road during the peak hours which is about 1.5 kms. This is again due to two reasons:

1. Variation in lanes Wherein Three lanes merges into one lanes.
2. Diverging and merging at the same point.

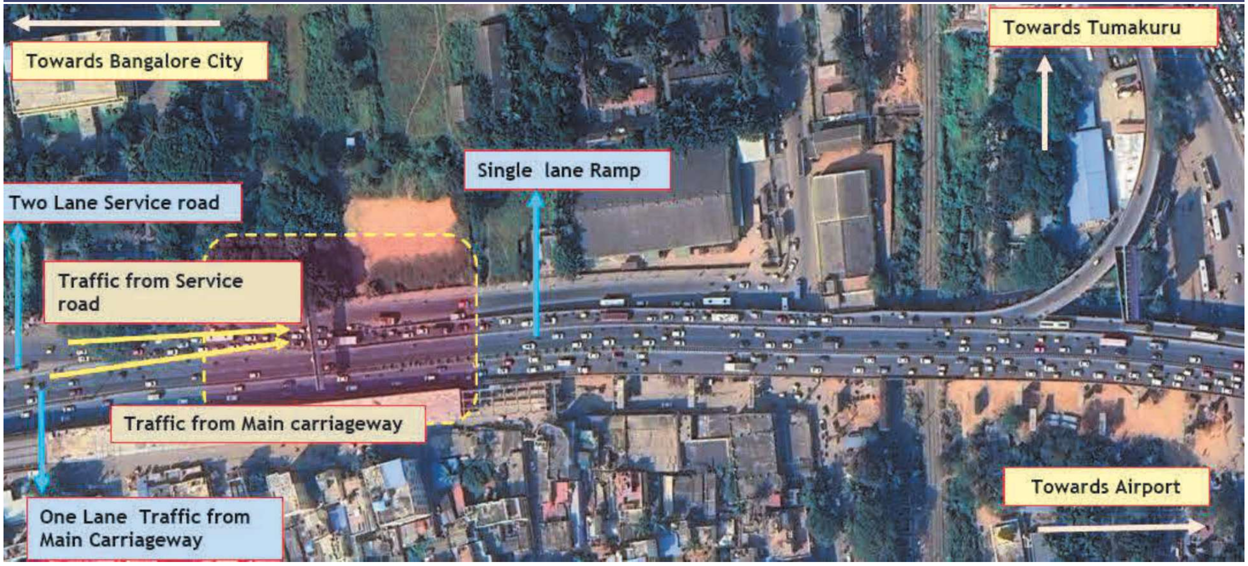
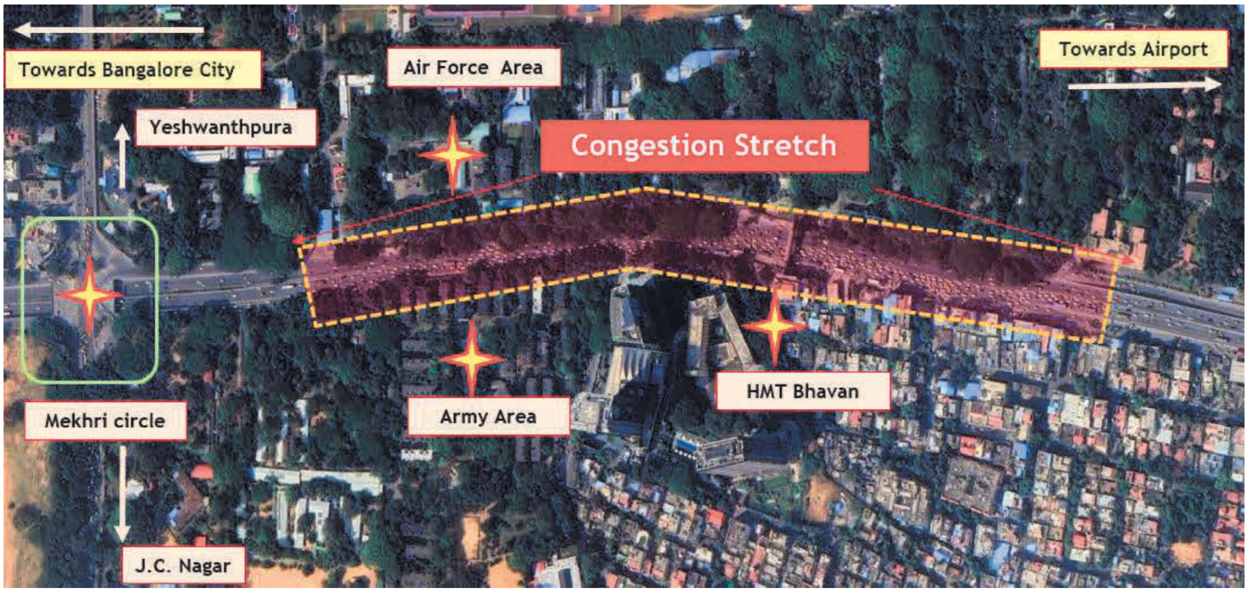


Figure 16 : V*iew of* Veerannapalya Junction Issue

4.4.5 Hot Spot 4 : Road stretch between HMT Bhavan and Air Force Gate, before Mekhri Circle.

Traffic Congestion Between Sanjay Nagar Overpass and Mekhri Circle Down Ramp Significant traffic congestion is consistently observed during peak hours along the stretch from the Sanjay Nagar overpass to the Mekhri Circle down ramp. The primary cause of this issue is the variation in the width of the main carriageway. At present, the roadway reduces abruptly from six lanes to four lanes in this section. This sudden narrowing of the carriageway forces merging movements, creating a bottleneck situation that severely affects the traffic flow. The challenge is further compounded by the presence of defense land on either side of the corridor, which restricts the possibility of roadway expansion and limits geometric improvements. Additionally, a bus bay located towards the airport side just before the Sanjay Nagar road contributes to traffic build-up. Public and private buses often stop either within or outside the designated bay, with some private buses halting directly on the main carriageway. These unregulated stops obstruct through traffic and aggravate congestion along this already critical stretch.



4.5 Primary Surveys and Data collection

4.5.1 Primary surveys

In any transport planning exercise, data collection is the cornerstone and the very foundation on which rests the super structure of planning. The data is used to analyse the existing transport and traffic situation in the study area. The activity is undertaken to understand traffic and travel characteristics along the corridor. The following surveys have been carried out for the Traffic Impact Assessment for the proposed underpass at Hebbal

4.5.1.1 Road inventory Surveys

A full-scale inventory survey was undertaken to create a road network database. Inventories of the following facilities were carried out as part of the task.

- Road Network
- Effective Road width
- Adjoining Land use and available Access control
- Intersection Facilities
- Pedestrian Facilities
- Traffic Control/management Measures like one -ways

Accordingly, road inventory survey was done for the entire corridor.

4.5.1.2 Intersection Turning Volume and Mid Block Traffic Counts along with traffic counts on the individual ramps

Survey Location: 24 hours traffic counts were done at critical junctions / entry and exit points of all the major roads in between Mekhri circle and Hebbal interchange along with individual ramps at Hebbal interchange on the same.

Objective: Surveys were conducted at the identified critical intersections entry and exit points in between Mekhri circle to Hebbal. The data will help in realizing the traffic flow pattern in between Mekhri circle to Hebbal and help in giving the right solution.

Conduct: Video graphic counts were carried out along the corridor. Volume counts were carried out on a typical working day for 24 hours covering both morning and evening peak periods.

Data Entry and Analysis: The traffic data collected from the field were scrutinized and processed. The Passenger Car Unit (PCU) values recommended by Indian Roads Congress (IRC) are used in the traffic volume analysis.

MITIGATION MEASURES:

- Peak Hour Volume at critical junctions (Veh./Hr. and PCU/Hr)
- Traffic by Vehicle type and hourly distribution of Traffic
- Identification of traffic related issues at the junction along the corridor.
- Traffic travel pattern along the project corridor.

4.5.1.3 Spot Speed Survey

Objective: The principle objective of the survey is to find out the spot speed at the defined location on the corridors within the study area.

Conduct:

Spot speed are measured using laser gun. Speeds of different vehicles are taken from two wheelers, cars, autos, LCV, HCV, buses etc

MITIGATION MEASURES:

- Speeds of individual vehicle is obtained during peak hour and off peak hour.

4.5.2 Intersection Turning Volume and Mid Block Traffic Counts along with traffic counts on the individual ramps

As stated earlier, traffic count surveys were carried out continuously for 24 hours at eight key locations along all major roads that connect the primary corridor between Mekhri Circle and Hebbal Interchange. In addition to these points, traffic counts were also conducted on all ramps at both the Hebbal Interchange and the Mekhri Circle underpass. To ensure consistency and to capture an accurate representation of traffic movement, all surveys were undertaken on the same day, enabling a comprehensive understanding of traffic patterns across the project corridor. The specific locations where the traffic surveys were conducted are illustrated in the figure below, accompanied by a detailed list.

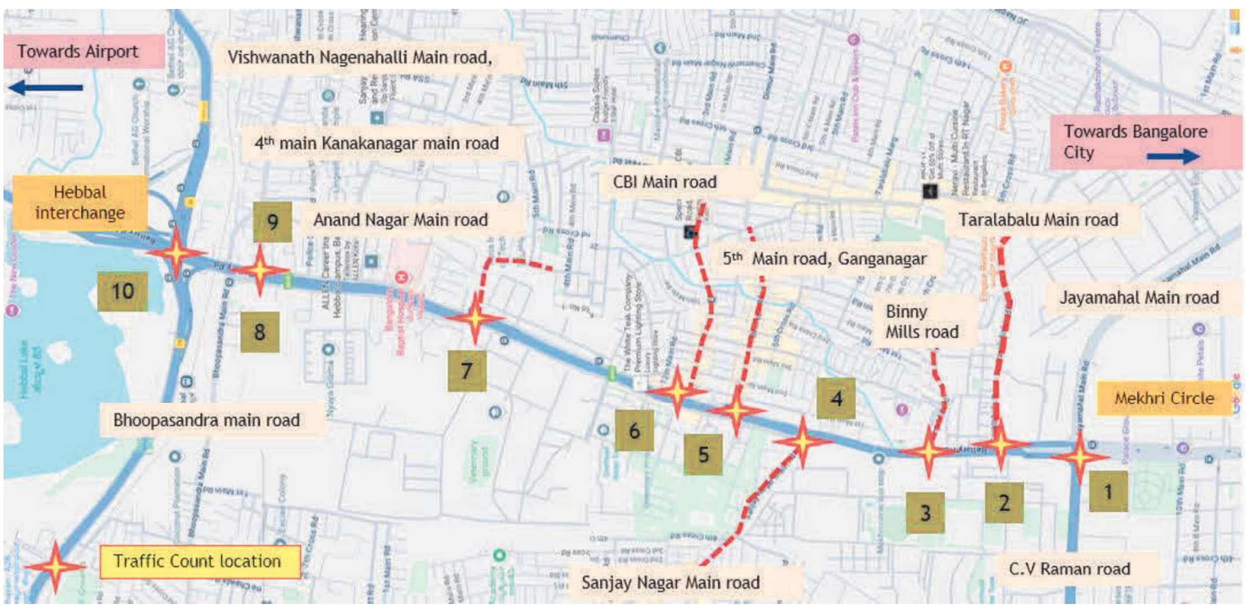


Figure 17 : Traffic Survey Locations

Sl No.	Location	Type
1	Mekhri Circle	At grade junction and underpass
2	Taralabalu Road	Entry & Exit
3	Binny Mills road	Entry & Exit
4	Sanjay nagar Main road	Entry & Exit
5	Ganganagar 5th main road	Entry & Exit
6	CBI road	Entry & Exit & Right Turn
7	Anand Nagar ain road	Entry & Exit & Right Turn
8	New Ramp from K.R.Puram	Newly inaugurated ramp
9	Bhoopasandra main road, Vishwanath Nagenahalli Main Road, 4^{th} main Kanakanagar main road	All combine traffic coming from Service Road
10	Hebbal Interchange	All the individual of the interchange and at grade outer ring road

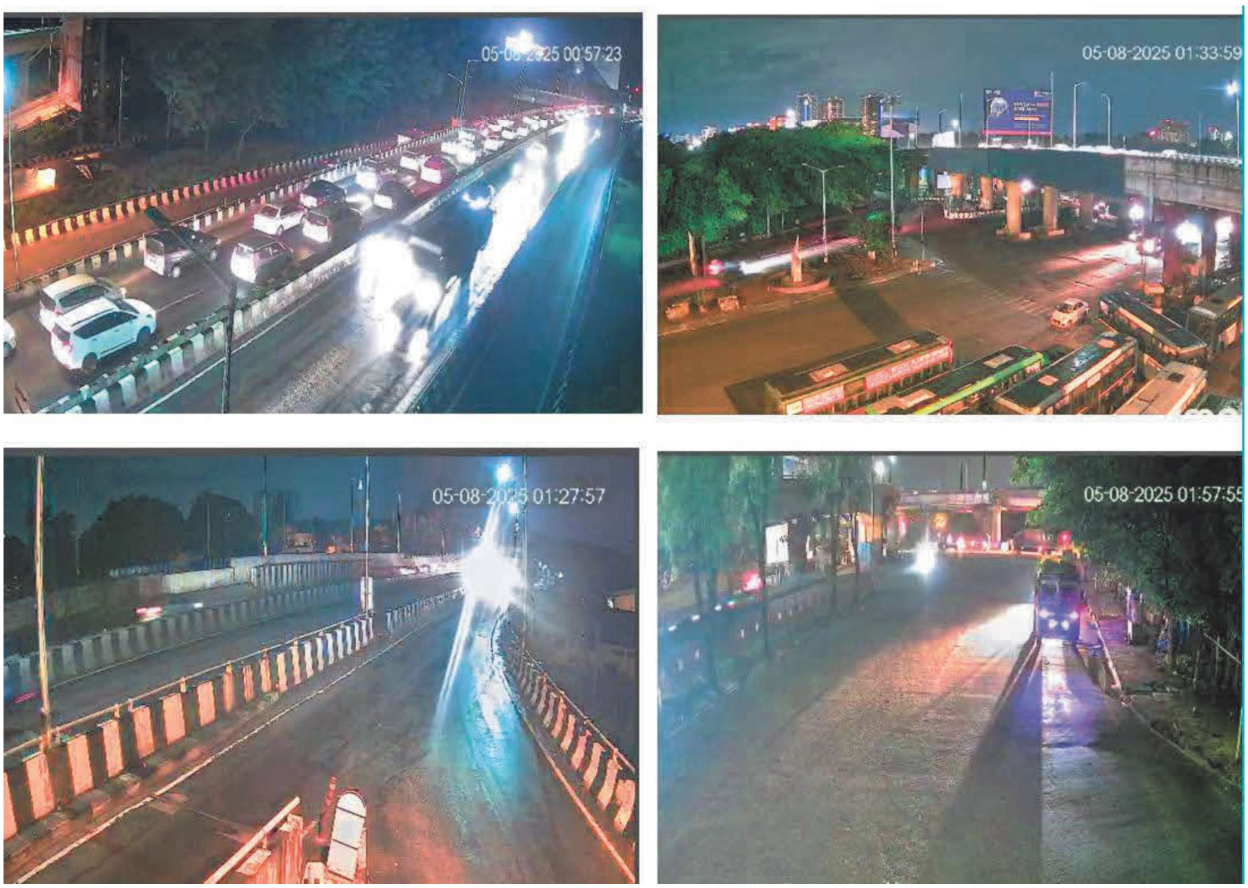


Figure 18 : Video Traffic Count

Figure 19 : Traffic Counting Using AI Software

4.5.3 Spot Speeds Survey roads in the Study Area

Spot speed surveys were conducted at four locations, as illustrated in Figure below. The surveys were carried out during weekday peak hours to assess vehicle speeds along the proposed development corridor. The results indicate that spot speeds tend to decrease significantly at identified congestion hotspots, as discussed in the earlier chapter, and subsequently increase once vehicles move away from these critical locations.

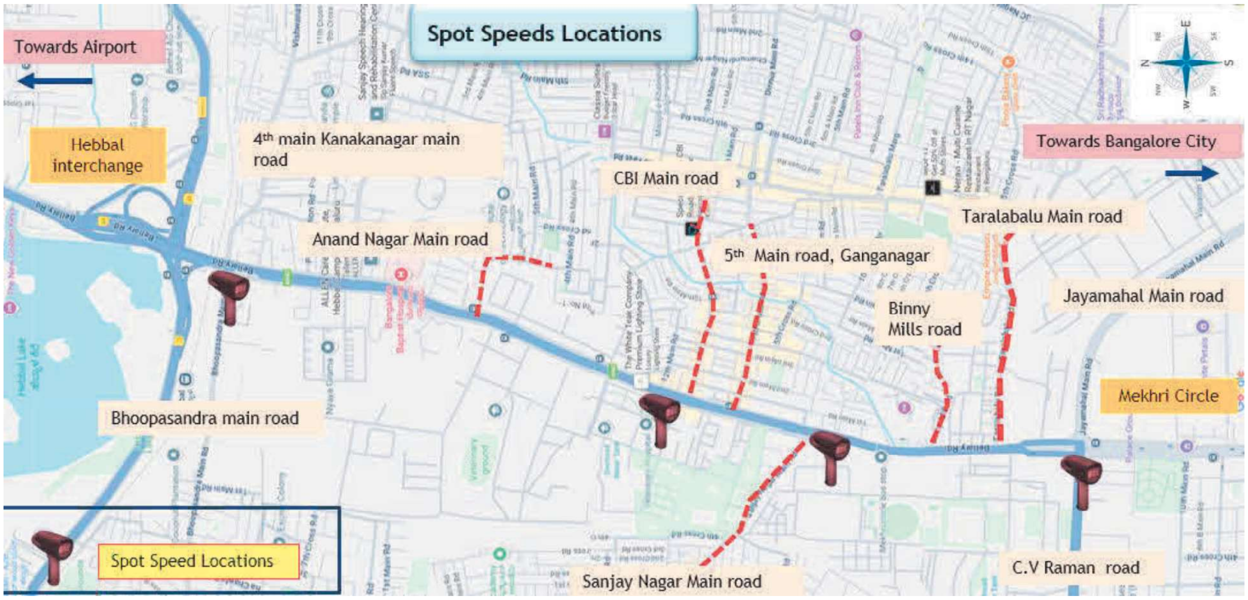


Figure 20 : Spot Speed Measure Locations

1	Near Baptist Hospital
2	Near Over pass , CBI road
3	Near HMT Bhavan
4	Near Mekhri circle Underpass

4.5.4 Speed and Delay Surveys

Speed and delay surveys were conducted along the project corridor from Hebbal to Mekhri circle as shown above. The surveys were carried out during weekday peak hours to assess vehicle speeds along the proposed development corridor. The results indicate that speeds tend to decrease significantly at identified congestion hotspots, as discussed in the earlier chapter, and subsequently increase once vehicles move away from these critical locations.

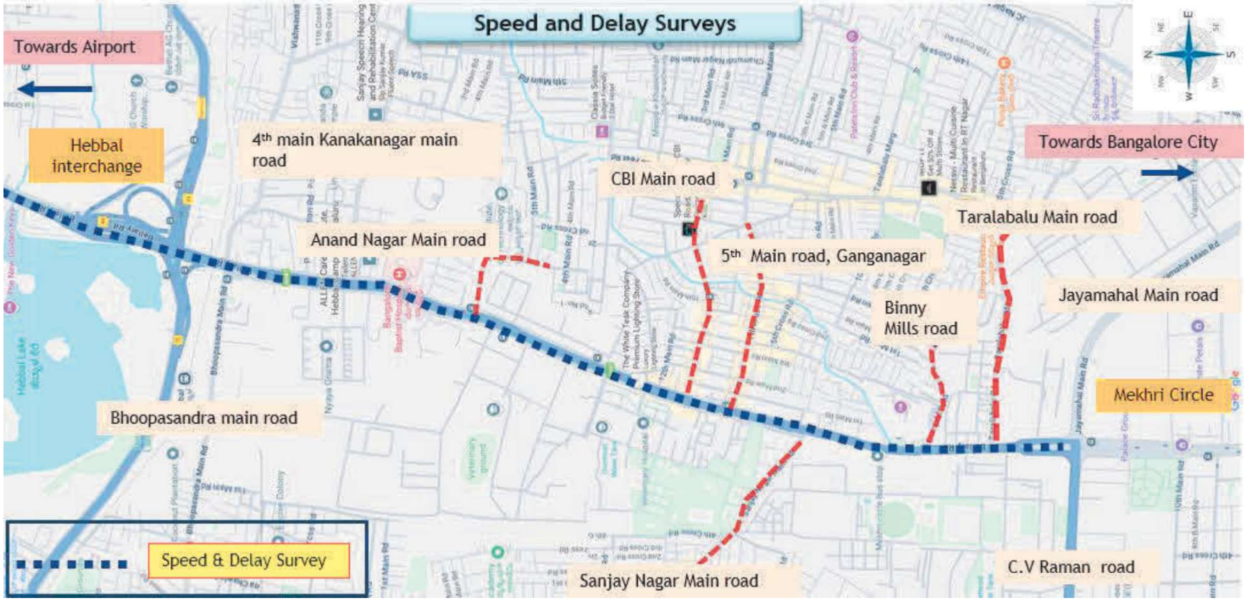


Figure 21 : Speed and Delay route

4.6 Traffic Analysis

4.6.1 Spot Speeds Survey roads in the Study Area

Spot speed surveys were conducted at four locations, as shown in Figure, during weekday peak hours to assess vehicle speeds along the proposed development corridor. The findings reveal that spot speeds decrease notably at identified congestion hotspots, as highlighted in the earlier chapter, and increase once vehicles pass beyond these critical sections. Along the stretch between Hebbal and Mekhri Circle, the speed variation ranges from 8 km/h to 60 km/h, with significant reductions at hotspot locations and higher speeds observed at mid-block sections between these points. The details of the spot speeds are given in the Table

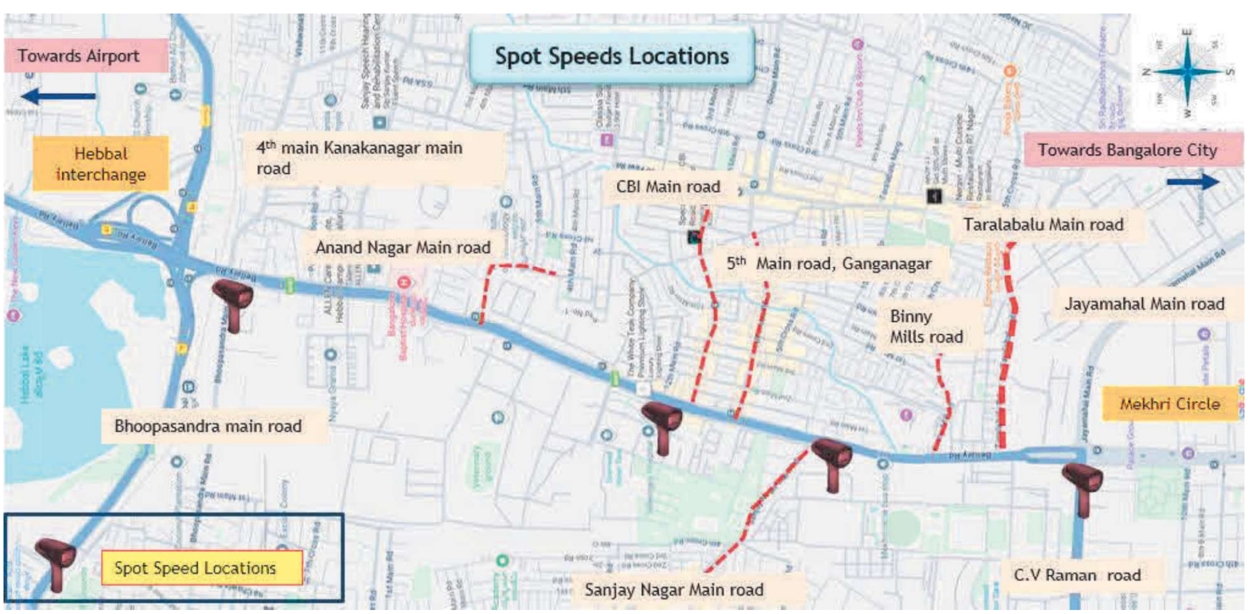


Figure 22 : Map ***showing Spot Speed Survey locations***

Table 5: Spot Speed Data

Name of the Location : Hebbal Flyover on Top				
Sl no.	Cars	Two Wheelers	LCV's	Auto
1	12	11	15	16
2	13	18	13	13
3	9	12	13	14
4	11	15	14	15
5	12	14	16	14
6	10	13	13	10
7	8	12	13	17
8	6	11	12	12
9	5	18	11	15
10	17	21	12	11
Total	103	145	132	137
Average	10.3	14.5	13.2	13.7

Name of the location : Near CBI				
Sl no.	Cars	Two Wheelers	LCV's	Auto
1	55	48	42	35
2	46	52	36	44
3	42	36	39	32
4	52	44	32	39
5	56	33	45	27
6	44	56	31	36
7	48	48	38	39
8	43	44	26	37
9	58	36	35	32
10	50	41	46	38
Total	494	438	370	359
Average	49.4	43.8	37	35.9

Name of the location: Near HMT Bhavan near to Mekhri Circle				
Sl no.	Cars	Two Wheelers	LCV's	Auto
1	11	17	16	12
2	12	15	12	13
3	9	12	11	14
4	10	13	11	15

5	13	16	15	11
6	14	18	12	10
7	7	10	9	17
8	12	11	10	12
9	6	18	8	15
10	12	17	12	13
Total	106	147	116	132
Average	10.6	14.7	11.6	13.2

Name of the location: Below the Mekhri Circle Underpass				
Sl no.	**Cars**	**Two Wheelers**	**LCV's**	**Auto**
1	36	25	28	33
2	38	28	33	44
3	29	33	27	38
4	41	38	28	28
5	37	41	26	31
6	43	29	22	28
7	33	30	29	32
8	25	29	26	30
9	38	38	34	32
10	20	18	22	28
Total	340	309	275	324
Average	34	30.9	27.5	32.4

4.6.2 Speed and Delay

Based on the Speed and Delay Survey conducted on the Main Carriageway, during a typical peak hour on a weekday along, it was observed that the travel time from Esteem mall to Hebbal down Ramp near Baptist hospital via the service road and the loop connecting the flyover which is about 1.36 km is approximately 38 minutes. This translates to an average vehicular speed of just 3.57 kmph, which is alarmingly low. Such conditions not only result in excessive fuel consumption but also contribute significantly to air pollution and cause considerable stress for commuters.

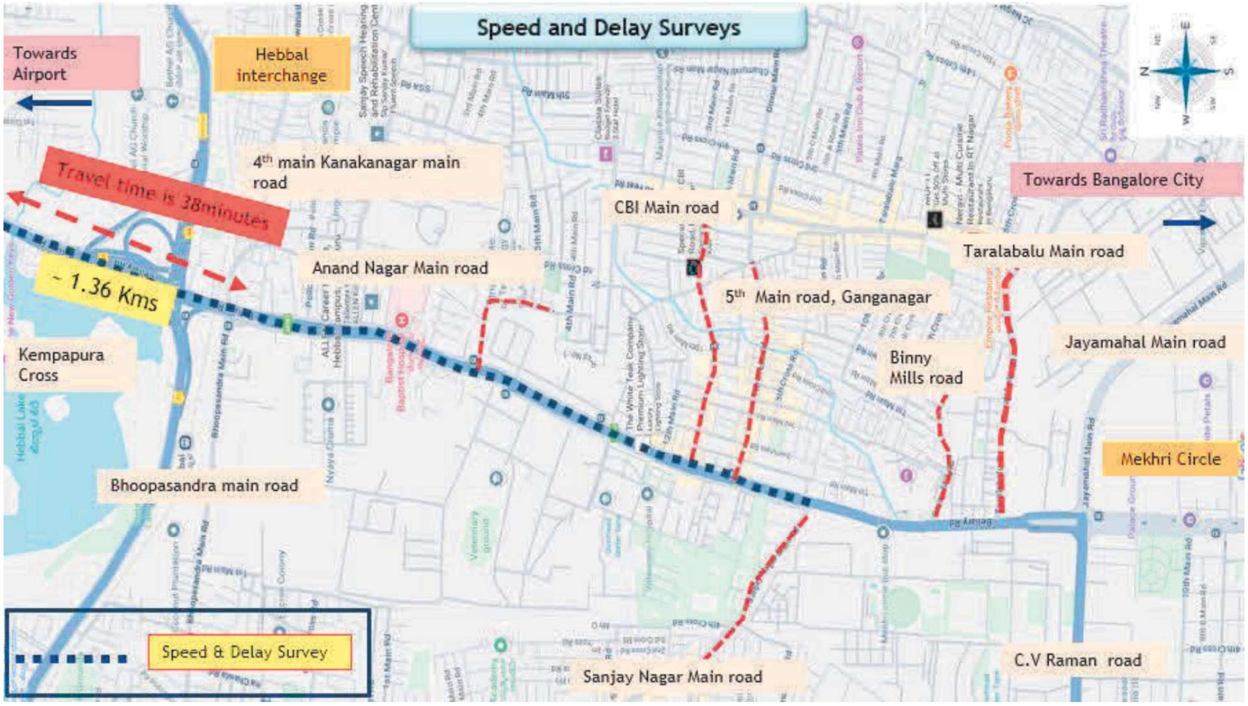


Figure 23 : *Speed and Delay survey details along the project corridor*

Based on the Speed and Delay Survey conducted on the service road, during a typical peak hour on a weekday along Anand Nagar Main Road near the DCP North Traffic Office, it was observed that the travel time for a stretch of 2 km is approximately 28 minutes. This translates to an average vehicular speed of just 4.29 kmph, which is alarmingly low. Such conditions not only result in excessive fuel consumption but also contribute significantly to air pollution and cause considerable stress for commuters.

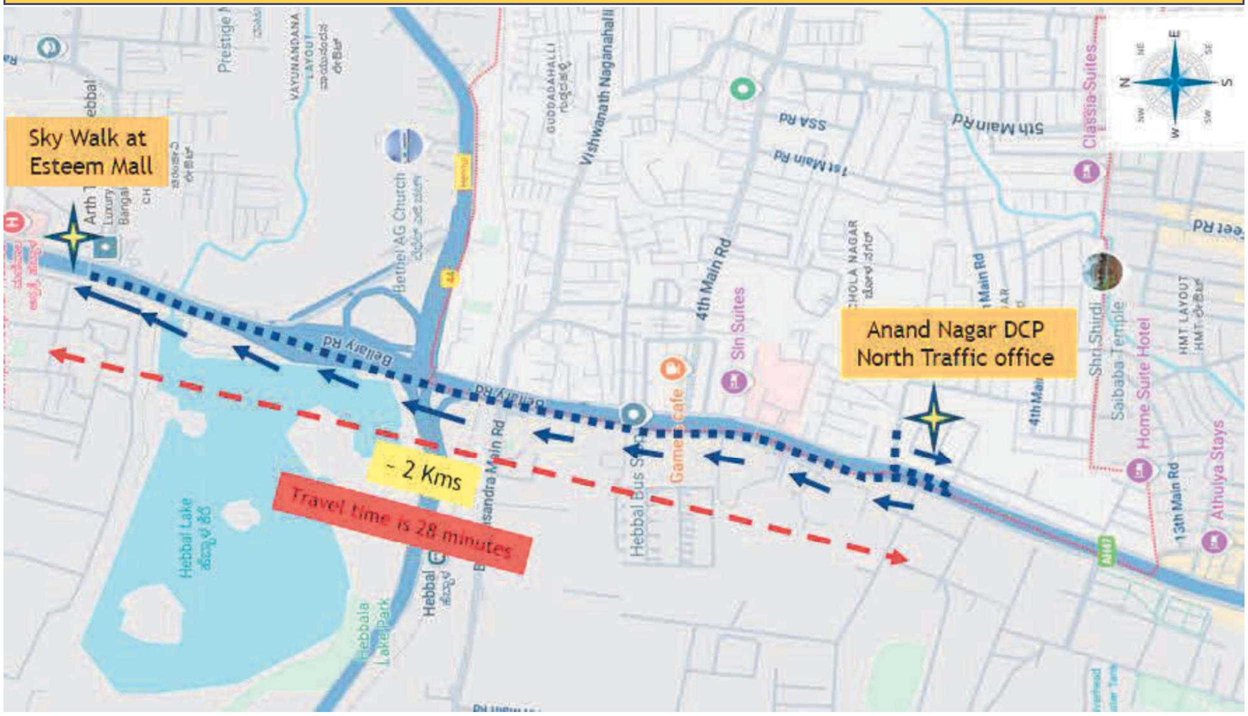
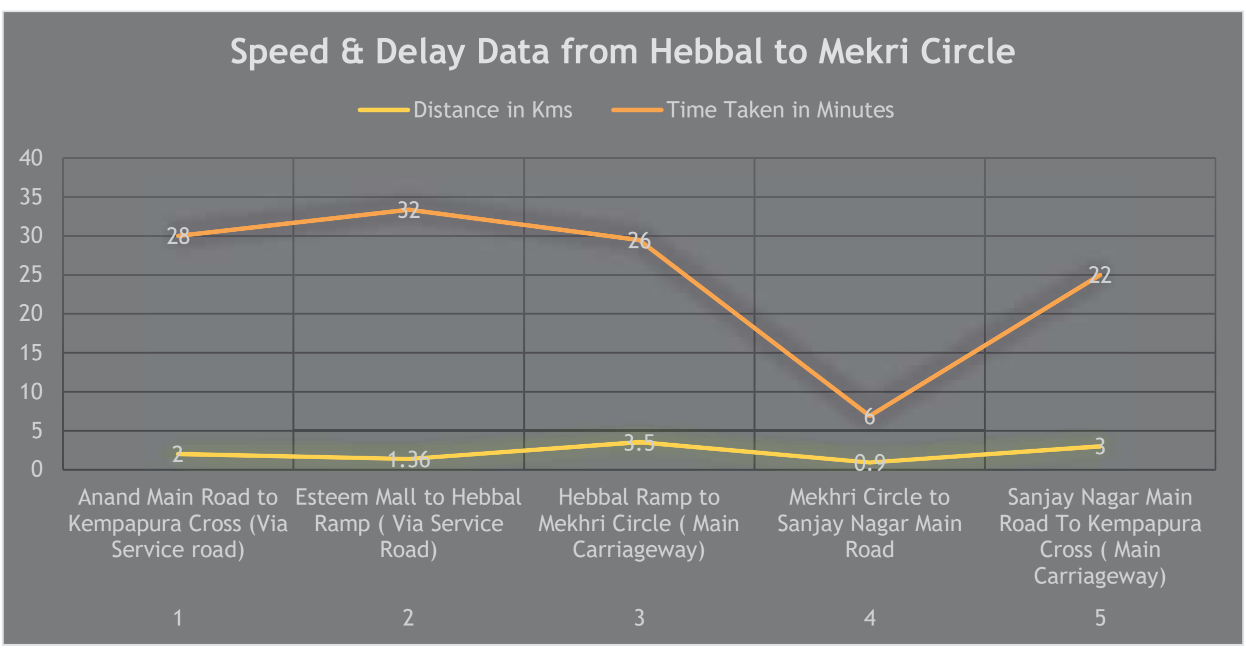


Figure 24 : *Speed and Delay survey details along the project corridor*

Sl no.	Location Stretch	Distance in Kms	Time Taken
1	Anand Main Road to Kempapura Cross (Via Service road)	2	28 Min-LHS
2	Esteem Mall to Hebbal Ramp (Via Service Road)	1.36	32 Min- RHS
3	Hebbal Ramp to Mekhri Circle (Main Carriageway)	3.5	26 Min-RHS
4	Mekhri Circle to Sanjay Nagar Main Road	0.9	6 Min-LHS
5	Sanjay Nagar Main Road To Kempapura Cross (Main Carriageway)	3	22 Min-LHS



4.6.3 Level of Service

The Volume to Capacity Ratio (V/C Ratio) is the ratio of peak-hour traffic flow rate to capacity, while the Level of Service (LOS) serves as a qualitative measure describing operational conditions within a traffic stream and their perception by drivers/passengers. LOS utilizes a lettering scheme ranging from A to F, where LOS 'A' represents the highest quality of service and LOS 'F' indicates heavily congested flow, where traffic demand exceeds capacity. Service measures defining LOS include density and volume-to-capacity ratio. Capacity values for V/C Ratio computation are based on road geometrics, conforming to site conditions as outlined in Table 3 of the Indo Highway Capacity Manual 2012-2017.

V/C	LOS	Performance
<=0.15	A	Excellent
0.15-0.45	B	Above Average
0.46-0.75	C	Average
0.76-0.85	D	Below Average
0.86-1.0	E	Poor
>1.0	F	Very Poor

The ratio of peak hour traffic flow rate to capacity (V/C Ratio) and the Level of Service (LOS) of the road sections within the influence area are presented.

Table 6: Capacity of Base Segments of Urban Roads

Typology of the Road	Capacity (PCUs/hr)	Lane Capacity (PCUs/hr)
Two-lane Undivided	2400	1200
Four-lane Divided	5400 (2700)	1350
Six-lane Divided	8400 (4200)	1400
Eight-lane Divided	13600 (6800)	1700
Ten-lane Divided	20000 (10000)	2000

Table 7: Capacity of Base Segments of Urban Roads

Typology of the Road	Capacity (PCUs/hr)	Lane Capacity (PCUs/hr)
Two-lane Undivided	2400	1200
Four-lane Divided	5400 (2700)	1350
Six-lane Divided	8400 (4200)	1400
Eight-lane Divided	13600 (6800)	1700
Ten-lane Divided	20000 (10000)	2000

The proposed underpass is Six Lane divided which provides signal-free, grade-separated facility and also facilitates seamless through-movement of traffic. Hence Capacity of urban expressways is considered as the capacity of the proposed Underpass (6900 PCUs/direction).

Sl No	Type of Expressway	Typology of Express way	Capacity (PCUs/hr/ direction)	Capacity per lane (PCUs/hr/lane)
1	Four Lane Divided	Interurban	5000	2500
2	Six Lane Divided	Interurban	7500	2500
3	Eight Lane Divided	Urban	9200	2300

Reference: Indian Highway Capacity Manual (Indo-HCM), sponsored by Council of Scientific and Industrial Research(CSIR), New Delhi. 2012-17 page no 4-7, Chapter-4

The expressways available in the country are limited and consequently, the capacity values have not been evolved covering the varying carriageway widths. In the event of capacity values are not available in the manual for the carriageway width under study for any typical urban or interurban expressway: it can be calculated from lane capacity. For example:

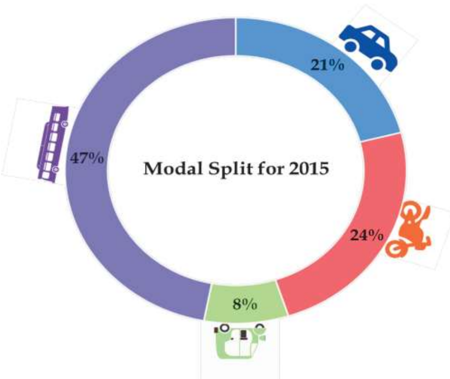
- If the analyst wants to determine adjusted capacity for eight-lane divided interurban express, which is not presented in Table above. It can be determined by multiplying the lane capacity of interurban expressway with 4. This implies that the capacity of eight -lane divided section becomes , 2500*4=10,000 PCU/Hour/direction.
- Similarly , if the analyst wants to determine adjusted capacity of six-lane divided or four lane divided urban expressway which are furnished in the Table above, it can be calculated by multiplying lane capacity of eight-lane divided urban expressway with 3 and 2 respectively. This implies that the capacity of six lane divided section becomes, 2300*3=6900 PCU/hour/direction and four lane divided section becomes 2300*2=4600 PCU/hour/direction.

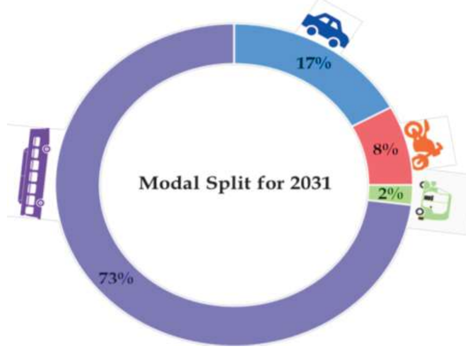
Table 8: PCU Conversation factors as per IRC 106-1990.

Sl NO	Mode	PCUs
1	Two Wheelers	0.75
2	Car/Jeeps/Van	1
3	Auto Rickshaw-3 seater	2
4	Mini Bus	1.5
5	Bus	3.7
6	Goods Auto	2
7	LCV	2
8	2-Axle Trucks	2.2
9	3-Axle Trucks	2.2
10	Multi-Axle Trucks	4
11	Agricultural Tractor Trailer	4
12	Cycles	0.4
13	Animal Drawn	2
14	Others	2

Table 9: **Modal Split as per Bangalore CMP 2019-20**

Sl NO	Mode	2015	2031
1	Car + Taxi	21%	17%
2	Two-Wheeler	24%	8%
3	Auto rickshaw	8%	2%
4	Public Transport	47%	73%





Reference for The Analysis,

1. *Indian Highway Capacity Manual (Indo-HCM), sponsored by Council of Scientific and Industrial Research(CSIR), New Delhi. 2012-17 page no 4-7, Chapter-4.*
2. *IRC 106-1990- Guidelines for Capacity of Urban Roads in Plain Areas.*
3. *Bangalore Comprehensive Mobility Plan 2019-20, Directorate of Urban Land Transport (DULT), in collaboration with the Bangalore Metro Rail Corporation Limited (BMRCL)*
4. *North-South Tunnel DPR , B-Smile*

4.6.4 Other Secondary Data available related to the project

Traffic survey Details

The traffic survey is crucial for grasping the current traffic dynamics within the corridors of the surrounding area and the immediate effects on intersections. Careful planning of the survey was undertaken, analyzing the study requirements, and senior team members conducted a thorough site visit to understand the existing conditions of the proposed underpass. Traffic volume counts were conducted at two intersections viz. Hebbal Junction and Mekhri Circle and 6 Entry Exit Points in between Mekri circle and Hebbal to gauge the existing traffic levels. These locations were identified following reconnaissance to facilitate the conduct of traffic volume count surveys.

Traffic counts were conducted for a continuous duration of 24 hours on a typical working day. All survey locations were covered on the same day to capture the exact traffic flow from all feeder roads, except the newly inaugurated ramp, which became operational a few days after the surveys were completed. The counts were carried out at designated locations using videography, with all turning movements recorded. Data was classified by vehicle category, following the prescribed IRC standards.

The survey outputs include:

- Peak-hour turning traffic
- Peak-hour traffic share.

A peak-hour traffic analysis was performed at all intersections to understand variations. The key findings are summarized below.

Table 10: Summary of Junction Counts

Sl. No.	Junction Name	Morning Peak Hour	Peak Hour Volume	
			Vehicles	PCUs
1	Hebbal Junction	09.00-10.00	32770	31758
2	Mekhri Circle	09.00-10.00	28493	27863

Hebbal Junction-Peak Traffic Count

Peak Hour	09.00-10.00
Peak Hour Volume (Nos.)	32770
Peak Volume (in PCUs)	31758

Towards Yelehanka

From Tumkur Road				
Two Wheelers	672	1885	38	8
Two Wheelers(Taxi)	0	0	0	0
Car/Jeep/Van	552	635	31	5
Autorickshaw - 3wh	92	182	11	0
City Bus (BMTC)	1	49	0	1
Mofussil Bus	0	0	0	0
Other Buses	4	4	0	0
Mini/Midi Bus	7	5	1	1
Goods Auto/LCV	54	86	0	0
Other Trucks	12	7	0	0
Agricultural Tractor/Trailer	1	0	0	0
Cycle	2	4	1	0
PBS	0	0	0	0
Others	0	0	0	0
Total Vehicles	**1397**	**2857**	**82**	**15**
Total PCUs	**1368**	**2674**	**83**	**15**
% PCU	**4%**	**8%**	**0%**	**0%**

From Yelehanka					Bellary Slip Rd to Bengaluru City
Two Wheelers	597	3513	568	7	2122
Two Wheelers(Taxi)	0	0	0	0	0
Car/Jeep/Van	483	2656	359	7	343
Autorickshaw - 3wh	111	354	42	1	299
City Bus (BMTC)	3	79	7	0	0
Mofussil Bus	0	32	0	0	0
Other Buses	3	22	12	0	0
Mini/Midi Bus	1	16	8	0	2
Goods Auto/LCV	19	25	21	0	45
Other Trucks	0	0	1	0	0
Agricultural Tractor/Trailer	0	0	2	0	1
Cycle	0	2	0	0	9
PBS	0	0	0	0	0
Others	1	0	2	0	0
Total Vehicles	**1218**	**6699**	**1022**	**15**	**2821**
Total PCUs	**1196**	**6351**	**965**	**14**	**2606**
% PCU	**4%**	**20%**	**3%**	**0%**	**8%**

Towards Tumkur Road

Towards KR Puram

From Bangalore City			
Two Wheelers	236	4043	1230
Two Wheelers(Taxi)	0	0	0
Car/Jeep/Van	80	2815	721
Autorickshaw - 3wh	51	634	199
City Bus (BMTC)	0	62	2
Mofussil Bus	0	18	0
Other Buses	0	22	0
Mini/Midi Bus	1	19	3
Goods Auto/LCV	4	183	46
Other Trucks	0	21	3
Agricultural Tractor/Trailer	0	7	2
Cycle	0	1	0
PBS	0	0	0
Others	0	0	0
Total Vehicles	**372**	**7825**	**2206**
Total PCUs	**366**	**7699**	**2129**
% PCU	**1%**	**24%**	**7%**

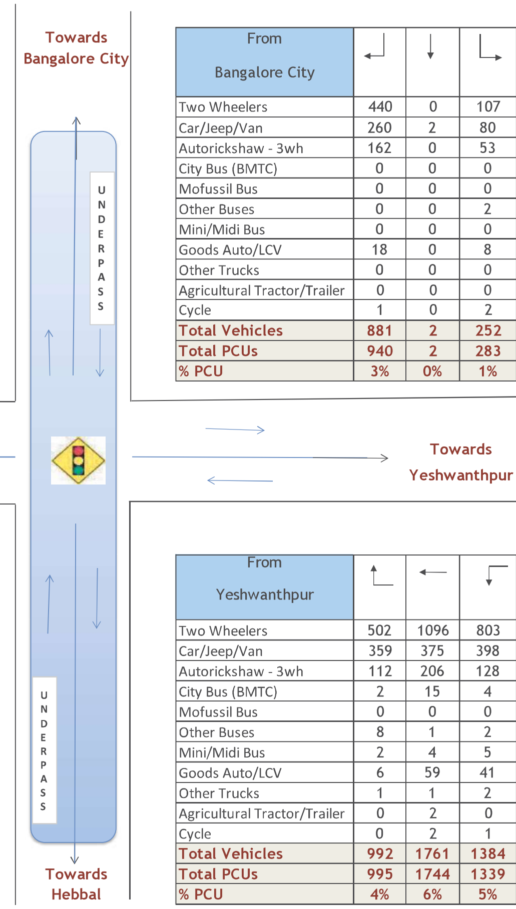
Towards Bangalore City

From KR Puram				
Two Wheelers	823	1517	718	17
Two Wheelers(Taxi)	0	0	0	0
Car/Jeep/Van	747	981	523	13
Autorickshaw - 3wh	149	245	136	6
City Bus (BMTC)	22	11	56	21
Mofussil Bus	0	0	1	0
Other Buses	12	6	4	0
Mini/Midi Bus	16	16	6	1
Goods Auto/LCV	28	111	27	2
Other Trucks	5	11	2	0
Agricultural Tractor/Trailer	0	3	2	0
Cycle	1	1	0	0
PBS	0	0	0	0
Others	0	0	1	0
Total Vehicles	**1803**	**2902**	**1476**	**60**
Total PCUs	**1812**	**2862**	**1528**	**88**
% PCU	**6%**	**9%**	**5%**	**0%**

Peak Hour	09.00-10.00
Peak Hour Volume (Nos.)	28493
Peak Volume (in PCUs)	27863

From Jayamahal	↰	→	↴
Two Wheelers	45	667	461
Car/Jeep/Van	6	221	265
Autorickshaw - 3wh	14	125	113
City Bus (BMTC)	0	6	5
Mofussil Bus	0	0	0
Other Buses	0	2	3
Mini/Midi Bus	1	1	3
Goods Auto/LCV	1	37	30
Other Trucks	0	0	0
Agricultural Tractor/Trailer	0	0	1
Cycle	0	1	2
Total Vehicles	67	1060	883
Total PCUs	71	1043	906
% PCU	0%	4%	3%

From Bangalore City	↲	↓	↳	U-turn	Bangalore City-Hebbal (Underpass Traffic)
Two Wheelers	440	0	107	139	3731
Car/Jeep/Van	260	2	80	226	2590
Autorickshaw - 3wh	162	0	53	32	700
City Bus (BMTC)	0	0	0	1	68
Mofussil Bus	0	0	0	0	18
Other Buses	0	0	2	1	14
Mini/Midi Bus	0	0	0	0	14
Goods Auto/LCV	18	0	8	4	180
Other Trucks	0	0	0	0	2
Agricultural Tractor/Trailer	0	0	0	0	5
Cycle	1	0	2	0	2
Total Vehicles	881	2	252	403	7324
Total PCUs	940	2	283	404	7306
% PCU	3%	0%	1%	1%	26%



From Hebbal	↰	↑	↱	U-turn	Hebbal-Bangalore City (Underpass Traffic)
Two Wheelers	1196	2	2002	71	4891
Car/Jeep/Van	442	1	620	120	2674
Autorickshaw - 3wh	164	0	298	63	614
City Bus (BMTC)	7	0	5	0	104
Mofussil Bus	0	0	0	0	13
Other Buses	10	0	4	1	22
Mini/Midi Bus	0	0	3	0	6
Goods Auto/LCV	14	0	47	2	35
Other Trucks	1	0	0	0	0
Agricultural Tractor/Trailer	1	0	1	0	1
Cycle	5	2	6	0	1
Total Vehicles	1840	5	2986	257	8361
Total PCUs	1732	3	2814	304	7938
% PCU	6%	0%	10%	1%	28%

From Yeshwanthpur	↑	←	↓	U-turn
Two Wheelers	502	1096	803	22
Car/Jeep/Van	359	375	398	4
Autorickshaw - 3wh	112	206	128	9
City Bus (BMTC)	2	15	4	0
Mofussil Bus	0	0	0	0
Other Buses	8	1	2	0
Mini/Midi Bus	2	4	5	0
Goods Auto/LCV	6	59	41	0
Other Trucks	1	1	2	0
Agricultural Tractor/Trailer	0	2	0	0
Cycle	0	2	1	0
Total Vehicles	992	1761	1384	35
Total PCUs	995	1744	1339	39
% PCU	4%	6%	5%	0%

4.6.5 Peak Hour Traffic Composition at Junction

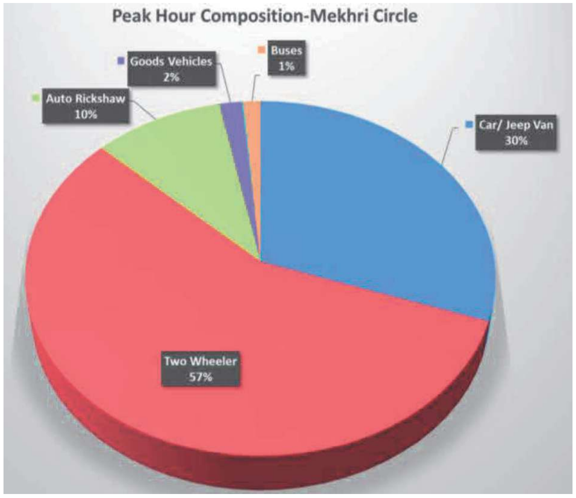
A large share of urban traffic comprises two-wheelers and cars, which together make up the majority of vehicles on the road. At both the surveyed locations along study corridor, two-wheelers alone constitute a substantial 55% to 57% of the total traffic volume. This dominance reflects the widespread use of two-wheelers for personal and short-distance travel, likely due to their cost-effectiveness, fuel efficiency, and ability to navigate through urban congestion. Cars, meanwhile, account for a significant portion which contributes about 30%-33% of the remaining traffic, emphasizing the combined influence of these vehicle types in defining mobility patterns within the study area.

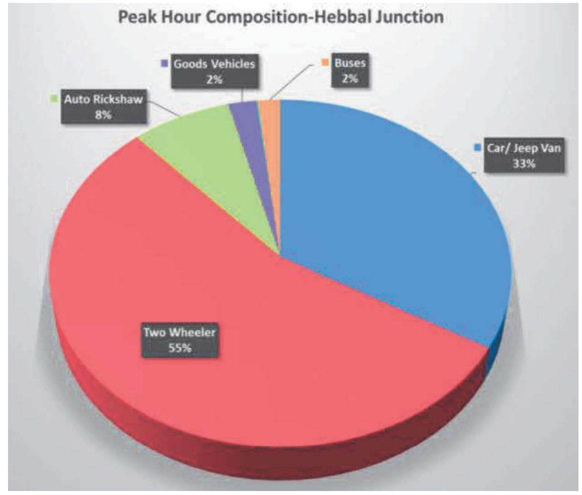
The Peak Hour Traffic Composition at both the intersections are presented.

Table 11: Peak Hour Traffic

Sl. No.	Junction Name	Car/ Jeep Van	Two Wheeler	Auto Rickshaw	Goods Vehicles	Slow Moving Vehicles	Buses
1	Mekhri Circle	30%	57%	10%	2%	0%	1%

2	Hebbal Junction	33%	55%	8%	2%	0%	2%





Volume to Capacity Ratio and Level of Service

Volume to Capacity Ratio (V/C Ratio) is defined as the ratio of peak hour traffic flow rate to capacity and Level of Service (LOS) is defined as the a qualitative measure, describing operational conditions within a traffic stream and their perception by the drivers/passengers.

Universally, LOS is lettering scheme ranging from A to F. LOS 'A' represents highest quality of service whereas LOS 'F' represents heavily congested flow where traffic demand exceeds capacity. The service measures used for defining LOS are density and volume-to-capacity ratio.

For computation of V/C Ratio the capacity values have been adopted based on the road geometrics by applying adjustment factors (as per **Indo Highway Capacity Manual 2012-2017**) conforming to the site conditions.

Table 12: Traffic Volume to Capacity ratio and Level of Service

Location	Direction	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service
Hebbal Flyover Ramp	Yelahanka To Bangalore City	2400	6351	**2.65**	**LOS F**
	Bangalore City To Yelahanka (Towards Airport)	3600	7699	**2.14**	**LOS F**

Figure 25 : Traffic at Hebbal Flyover

It is observed that the traffic volume approaching the Hebbal Flyover on both ramps has exceeded the available capacity, leading to significant delays and long queues.

The volume-to-capacity (V/C) ratio at both locations is greater than 1.0, and the Level of Service (LOS) is classified as 'F,' indicating severe congestion where traffic demand surpasses capacity.

At these locations, the V/C ratios of 2.65 and 2.14 suggest conditions worse than LOS F, with operating speeds dropping below 10 km/h.

Feeder Road Entry Exits-Peak Traffic Count

The main objective of conducting entry exit traffic counts aa major feeder roads along the corridor was to quantify vehicle movements at access points connecting local feeder roads to the main roadway network. Traffic counts were carried out for a duration of 24 hours, on a typical working day. These counts were conducted at identified locations using videography. At each designated location, traffic entering and existing at all the major feeder roads between Hebbal Flyover and Mekhri Circle were recorded, and data was collected based on vehicle category.

The analysis of peak hour traffic dispersal along the corridor shows significant interaction between the mainline and its feeder roads. The ratio of peak hour traffic flow rate to capacity (V/C Ratio) and the Level of Service (LOS) of the road sections of all the surveyed Feeder Roads along the study corridor are presented.

Peak Hour Entry and Exit traffic volumes from these feeder roads have been mapped and are illustrated below. It was observed that nearly **3512 PCUs** which accounts to nearly **39%** of the total traffic volume from Hebbal Flyover, is dispersed onto adjoining feeder roads during the peak period indicating the need for short length underpass.

Table 13: Traffic Volume to Capacity ratio and Level of Service of Feeder Roads

Sl.No.	Feeder Road	Capacity/ Direction	Entry			Exit		
			Peak Hour PCUs	V/C Ratio	LOS	Peak Hour PCUs	V/C Ratio	LOS
1	Sanjaynagar Main Road	1200	1666	1.39	LOS F	3977	3.31	LOS F
2	Anand Nagar Main Road	1200	655	0.55	LOS C	494	0.41	LOS B
3	C.B.I Road	1800	1240	0.69	LOS C	1683	0.94	LOS E
4	Ganganagar Road,5th Main Road	1200	800	0.67	LOS C	185	0.15	LOS B
5	Binny Mills Road	1200	380	0.32	LOS B	405	0.34	LOS B
6	Taralabalu Road	1200	151	0.13	LOS A	1909	1.59	LOS F

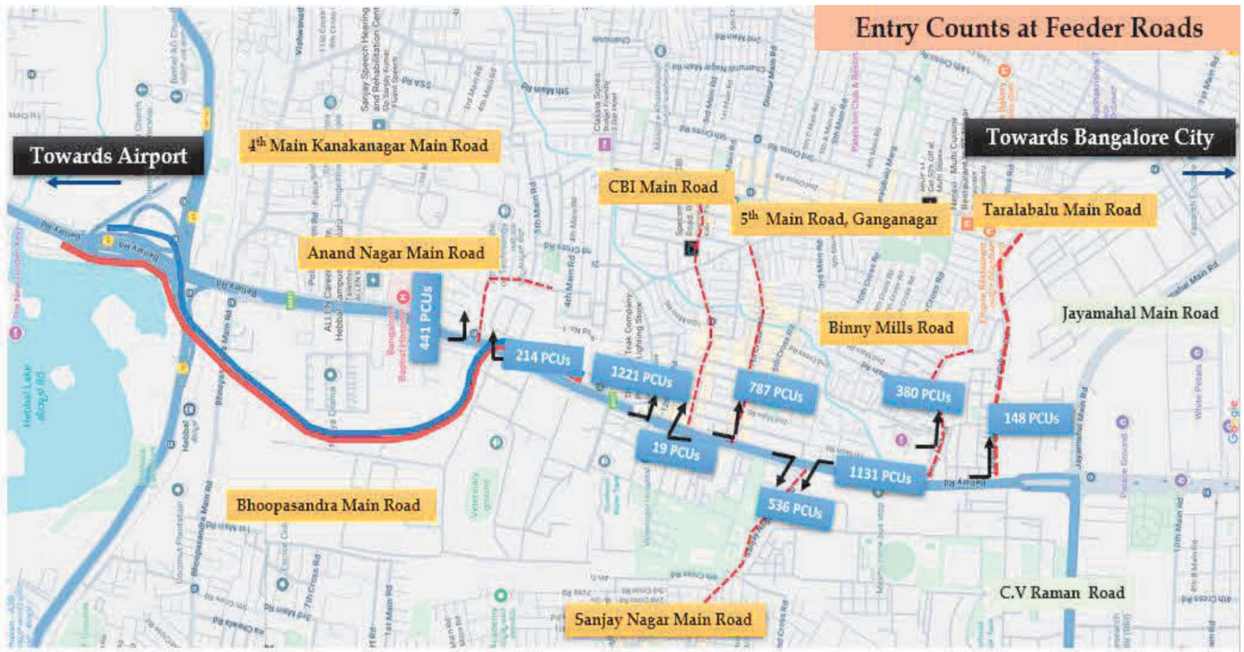


Figure 26 : Feeder Road Entry

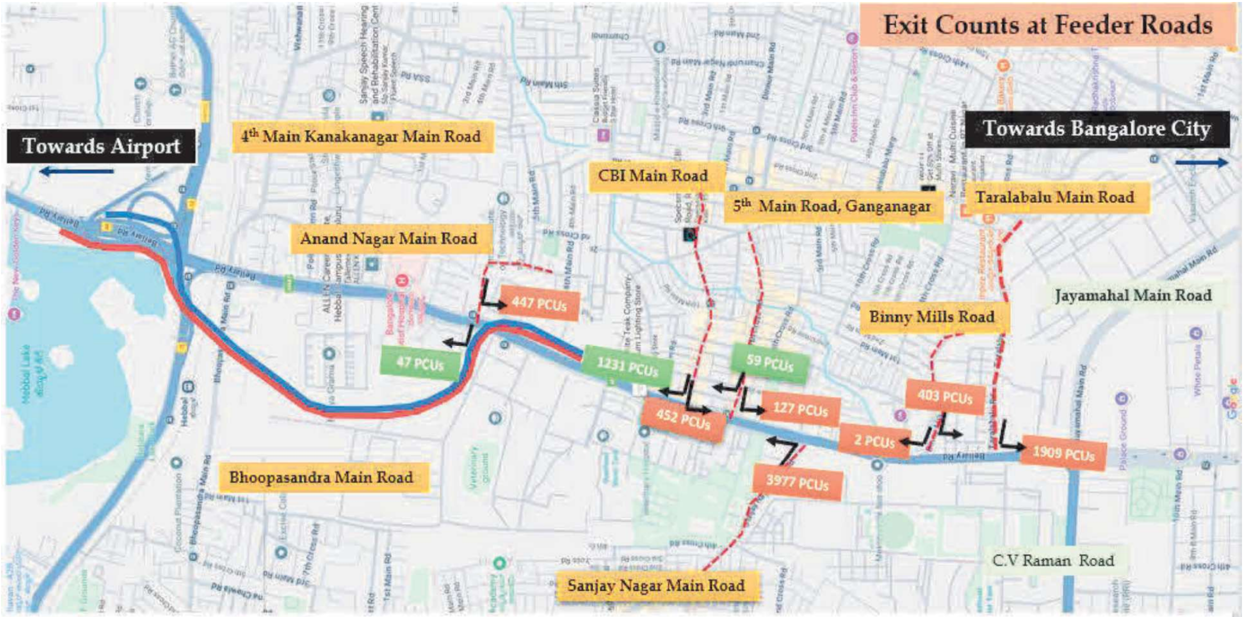


Figure 27 : Feeder Road Exit

4.7 Traffic Forecast

The project is anticipated to commence operations by 2027, with full operational status expected by 2028. A short-term Level of Service (LOS) analysis has been conducted to evaluate traffic conditions surrounding the project site. Future peak hour traffic volumes for the years 2027 and 2037 were forecasted using growth rates adopted in the Preparation of Detailed Project Report for the Underground Tunnel from Hebbal Esteem Mall Junction to Silk Board KSRP Junction . These growth rates were utilized to project future traffic volumes for both short-term (2027) and cumulative (2037) conditions, considering a span of 10 years.

To comprehend the impact of proposed Short Length Underpass on the existing Hebbal Flyover Ramps, traffic projections with and without development were assessed. Traffic redistribution is estimated under four scenarios: 80%, 70%, 60%, and 50% traffic diversion from the Hebbal Flyover to the underpass and estimated traffic figures is presented in the tables below.

Based on the peak traffic projections for the year 2027 with and without proposed underpass it is clear that with 80% traffic diversion there will be maximum relief to Hebbal Flyover ramps as Underpass carries majority of the load and Hebbal Flyover becomes there will be primarily through-traffic with smoother flows.

Table 14: Scenario 1 Peak Hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2027

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	6869	2.86	LOS F	15	1374	0.57	LOS C	30	6900	5495	0.80	LOS D	25
	Bangalore City To Yelahanka (Towards Airport)	3600	8327	2.31	LOS F	15	1665	0.46	LOS C	30	6900	6662	0.97	LOS E	25

Table 15: Scenario 1 Peak hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2031

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	8036	3.35	**LOS F**	**15**	1607	0.67	**LOS C**	**30**	6900	6429	0.93	**LOS E**	**25**

	Bangalore City To Yelahanka (Towards Airport)	3600	9742	2.71	**LOS F**	**15**	1948	0.54	**LOS C**	**30**	6900	7793	1.13	**LOS F**	**15**

Table 16: Scenario 1 Peak Hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2037

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	10168	4.24	LOS F	15	2034	0.85	LOS D	25	6900	8135	1.18	LOS F	15
	Bangalore City To Yelahanka (Towards Airport)	3600	12326	3.42	LOS F	15	2465	0.68	LOS C	30	6900	9861	1.43	LOS F	15

Table 17: Scenario 1 Peak Hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2047

Location	Direction	Capacity	Without Improvement	With Underpass-On Hebbal Flyover Ramps	Underpass

			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	13665	5.69	LOS F	15	2733	1.14	LOS F	15	6900	10932	1.58	LOS F	15
	Bangalore City To Yelahanka (Towards Airport)	3600	16565	4.60	LOS F	15	3313	0.92	LOS E	25	6900	13252	1.92	LOS F	15

Based on the peak traffic projections for the year 2037 and 2047 with and without proposed underpass it is clear that with 80% traffic diversion there will be significant relief to Hebbal Flyover ramps ,speeds rise to 30 km/h and Level of service improves to LOS C/D/E. Underpass gets over-saturated (LOS F), speeds ~15 km/h. Underpass alone will not be sufficient due to high traffic demand . If Underpass is implemented only as a standalone facility, it will not resolve congestion due to overwhelming traffic demand

Table 18: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2027

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)

NH-44 Bellary Road	Yelahanka To Bangalore City	2400	6869	2.86	LOS F	15	2061	0.86	LOS E	25	6900	4808	0.70	LOS C	30
	Bangalore City To Yelahanka (Towards Airport)	3600	8327	2.31	LOS F	15	2498	0.69	LOS C	30	6900	5829	0.84	LOS D	25

Based on the peak traffic projections for the year 2027 with and without proposed underpass it is clear that with 70% traffic diversion there will be balanced load sharing between flyover and underpass and noticeable congestion reduction on ramps, underpass still efficient.

Table 19: Scenario 2 Peak hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2031

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	8036	3.35	**LOS F**	**15**	2411	1.00	**LOS F**	**15**	6900	5625	0.82	**LOS D**	**25**

	Bangalore City To Yelahanka (Towards Airport)	3600	9742	2.71	**LOS F**	**15**	2922	0.81	**LOS D**	**25**	6900	6819	0.99	**LOS E**	**25**

Table 20: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2037

Location	**Direction**	**Capacity**	**Without Improvement**				**With Underpass-On Hebbal Flyover Ramps**				**Underpass**				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	10168	4.24	LOS F	15	3050	1.27	LOS F	15	6900	7118	1.03	LOS F	15
	Bangalore City To Yelahanka (Towards Airport)	3600	12326	3.42	LOS F	15	3698	1.03	LOS F	15	6900	8628	1.25	LOS F	15

Table 21: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2047

Location	**Direction**	**Capacity**	**Without Improvement**	**With Underpass-On Hebbal Flyover Ramps**	**Underpass**

			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	13665	5.69	LOS F	15	4100	1.71	LOS F	15	6900	9566	1.39	LOS F	15
	Bangalore City To Yelahanka (Towards Airport)	3600	16565	4.60	LOS F	15	4970	1.38	LOS F	15	6900	11596	1.68	LOS F	15

Based on the peak traffic projections for the year 2037 and 2047 with and without proposed underpass it is clear that with 70% traffic diversion without any improvement Hebbal Flyover ramps on both the directions will be extremely congested with Level of Service F and speeds only 15 km/h. The underpass brings marginal benefits (mainly speed improvements on ramps), but cannot eliminate congestion (LOS F still persists). To achieve sustainable improvements, the underpass must be integrated with larger-scale capacity enhancement.

Table 22: Scenario 3 Peak Hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2027

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)

NH-44 Bellary Road	Yelahanka To Bangalore City	2400	6869	2.86	LOS F	15	2748	1.14	LOS F	15	6900	4122	0.60	LOS C	30
	Bangalore City To Yelahanka (Towards Airport)	3600	8327	2.31	LOS F	15	3331	0.93	LOS E	25	6900	4996	0.72	LOS C	30

Based on the peak traffic projections for the year 2027 with and without proposed underpass it is clear that with 60% traffic diversion there will be mmoderate reduction at ramps. Underpass begins to function as an alternate rather than the main route. Some residual congestion at Hebbal ramps may persist.

Table 23: Scenario 3 Peak Hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2031

Location	**Direction**	**Capacity**	**Without Improvement**				**With Underpass-On Hebbal Flyover Ramps**				**Underpass**				
			Peak Hour PCUs	**Volume to Capacity Ratio**	**Level of Service**	**Anticipated Speed (KMPH)**	**Peak Hour PCUs**	**Volume to Capacity Ratio**	**Level of Service**	**Anticipated Speed (KMPH)**	**Capacity**	**Peak Hour PCUs**	**Volume to Capacity Ratio**	**Level of Service**	**Anticipated Speeds (KMPH)**
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	8036	3.35	**LOS F**	**15**	3214	1.34	**LOS F**	**15**	6900	4822	0.70	**LOS C**	**30**
	Bangalore City To Yelahanka	3600	9742	2.71	**LOS F**	**15**	3897	1.08	**LOS F**	**15**	6900	5845	0.85	**LOS D**	**25**

	(Towards Airport)													

Based on the peak traffic projections for the year 2027 with and without proposed underpass it is clear that with 60% traffic diversion there will be mmoderate reduction at ramps. Underpass begins to function as an alternate rather than the main route. Some residual congestion at Hebbal ramps may persist.

Table 24: Scenario 3 Peak Hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2037

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	10168	4.24	LOS F	15	4067	1.69	LOS F	15	6900	6101	0.88	LOS E	25
	Bangalore City To Yelahanka (Towards Airport)	3600	12326	3.42	LOS F	15	4931	1.37	LOS F	15	6900	7396	1.07	LOS F	15

Table 25: Scenario 3 Peak Hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2047

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	13665	5.69	LOS F	15	5466	2.28	LOS F	15	6900	8199	1.19	LOS F	15
	Bangalore City To Yelahanka (Towards Airport)	3600	16565	4.60	LOS F	15	6626	1.84	LOS F	15	6900	9939	1.44	LOS F	15

Based on the peak traffic projections for the year 2037 and 2047 with and without proposed underpass it is clear that with 60% traffic diversion without any improvement Hebbal Flyover ramps on both the directions will be Extremely over-saturated, very poor service levels (LOS F) and low speeds (15km/hr). The underpass provides partial relief, especially for traffic from Yelahanka To Bangalore City direction. However, congestion towards Yelahanka and Airport persists at LOS F It is clear that the Underpass alone cannot fully address capacity shortfalls

Table 26: Scenario 4 Peak Hour Traffic Forecast -50% Traffic Diversion to the Proposed Underpass-2027

Location	Direction	Capacity	Without Improvement	With Underpass-On Hebbal Flyover Ramps	Underpass

			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	6869	2.86	LOS F	15	3435	1.43	LOS F	15	6900	3435	0.50	LOS C	30
	Bangalore City To Yelahanka (Towards Airport)	3600	8327	2.31	LOS F	15	4164	1.16	LOS F	15	6900	4164	0.60	LOS C	30

Table 27: Scenario 4 Peak Hour Traffic Forecast -50% Traffic Diversion to the Proposed Underpass-2031

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	8036	3.35	LOS F	15	4018	1.67	LOS F	15	6900	4018	0.58	LOS C	30

	Bangalore City To Yelahanka (Towards Airport)	3600	9742	2.71	LOS F	15	4871	1.35	LOS F	15	6900	4871	0.71	LOS C	30

Table 28: Scenario 4 Peak Hour Traffic Forecast -50% Traffic Diversion to the Proposed Underpass-2037

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
NH-44 Bellary Road	Yelahanka To Bangalore City	2400	10168	4.24	LOS F	15	5084	2.12	LOS F	15	6900	5084	0.74	LOS C	30
	Bangalore City To Yelahanka (Towards Airport)	3600	12326	3.42	LOS F	15	6163	1.71	LOS F	15	6900	6163	0.89	LOS E	25

Table 29: Scenario 4 Peak Hour Traffic Forecast -50% Traffic Diversion to the Proposed Underpass-2047

Location	Direction	Capacity	Without Improvement				With Underpass-On Hebbal Flyover Ramps				Underpass				
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)

NH-44 Bellary Road	Yelahanka To Bangalore City	2400	13665	5.69	LOS F	15	6833	2.85	LOS F	15	6900	6833	0.99	LOS E	25
	Bangalore City To Yelahanka (Towards Airport)	3600	16565	4.60	LOS F	15	8283	2.30	LOS F	15	6900	8283	1.20	LOS F	15

Based on the peak traffic projections for the year 2031,2037 and 2047 with and without proposed underpass it is clear that with 50% traffic diversion without any improvement Hebbal Flyover ramps on both the directions will be Extremely congested; far beyond capacity; severe LOS F in both directions. With Underpass Traffic demand reduces compared to base case but still well over capacity; LOS remains F. Only slight speed improvement (towards Bangalore City). The underpass provides substantial relief in both directions, particularly for Yelahanka to Bangalore City traffic, turning severe congestion into manageable flow by reducing congestion levels from LOS F to LOS E and almost doubling average travel speeds.

4.8 Impact of Proposed Underpass on North-South Tunnel

Bruhat Bengaluru Mahanagara Palike (BBMP) intends to Construct an Underground Vehicular Tunnel for the North – South Corridor starting from Hebbal Esteem Mall junction to Silk Board KSRP Junction in order to to provide safe and efficient service levels to growing traffic movements and better connectivity between Silk board junction and Esteem mall junction. The project is anticipated to commence operations by 2031.

The proposed North-South Tunnel is envisioned as a long-distance, high-capacity corridor to facilitate through-traffic across Bengaluru. However, given the scale and complexity of construction, commissioning is expected to take nearly a decade. As an immediate relief measure, a Short Length Underpass connecting the Hebbal Flyover junction to Veterinary College on Bellary Road has been proposed. The underpass is intended to address the acute congestion at Hebbal Flyover ramps by diverting significant volumes of local and medium-distance traffic.

To evaluate the combined influence of the proposed North-South Tunnel and the Short Length Underpass (SLU) on the existing Hebbal Flyover ramps, traffic projections were analyzed under both with and without development scenarios. Traffic redistribution was modeled across four diversion assumptions: 80%, 70%, 60%, and 50% of ramp traffic shifting from the Hebbal Flyover to the underpass. In addition, the North-South Tunnel is projected to divert:

- 3038 PCUs, 3,624 PCUs in 2037 and 4,445 PCUs in 2047 → Bengaluru City to Yelahanka (Airport) direction, and
- 3,067 PCUs in 2031 ,3,772 PCUs and 4,759 PCUs in 2047 → Yelahanka to Bengaluru City direction.

These tunnel diversions were deducted from the estimated underpass volumes to reflect realistic demand conditions once both facilities are operational. The Peak Hour Traffic Forecast for Do-nothing Scenario, revised figures capturing the effect of tunnel-induced relief on the underpass, are presented in the subsequent tables.

Table 30: Peak Hour Traffic Forecast -Do-Nothing Scenario

Location	Direction	Capacity	2027			2037			2047		
			Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service
Hebbal Flyover Ramp	Yelahanka To Bangalore City	2400	6869	2.86	LOS F	10168	4.24	LOS F	13665	5.69	LOS F
	Bangalore City To Yelahanka (Towards Airport)	3600	8327	2.31	LOS F	16565	4.60	LOS F	16565	4.60	LOS F

Table 31: Scenario 1 Peak hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2031

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	1607	0.67	LOS C	25	6900	3067	0.44	LOS B	40	6900	3362	0.49	LOS C	30

Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	1948	0.54	LOS C	30	6900	3038	0.44	LOS B	40	6900	4755	0.69	LOS C	25

Table 32: Scenario 1 Peak hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2037

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	2034	0.85	LOS D	25	6900	3772	0.55	LOS C	30	6900	4363	0.63	LOS C	30
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	2465	0.68	LOS C	30	6900	3624	0.53	LOS C	30	6900	6237	0.90	**LOS E**	**25**

Table 33: Scenario 1 Peak hour Traffic Forecast -80% Traffic Diversion to the Proposed Underpass-2047

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	2733	1.14	LOS F	15	6900	4759	0.69	LOS C	30	6900	6173	0.89	LOS E	25
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	3313	0.92	LOS E	**15**	6900	4445	0.64	LOS C	30	6900	8807	1.28	LOS F	15

Table 34: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2031

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)

Dir-I: Yelahanka To Bangalore City	2400	2411	1.00	LOS F	15	6900	3067	0.44	LOS B	30	6900	2558	0.37	LOS B	40
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	2922	0.81	LOS D	15	6900	3038	0.44	LOS B	30	6900	3781	0.55	LOS C	30

Table 35: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2037

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	3050	1.27	LOS F	15	6900	3772	0.55	LOS C	30	6900	3346	0.48	LOS C	30

Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	3698	1.03	LOS F	15	6900	3664	0.53	LOS C	30	6900	5004	0.73	LOS C	30

Table 36: Scenario 2 Peak Hour Traffic Forecast -70% Traffic Diversion to the Proposed Underpass-2047

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)
Dir-I: Yelahanka To Bangalore City	**2400**	**4100**	**1.71**	**LOS F**	**15**	**6900**	**4759**	**0.69**	**LOS C**	**30**	**6900**	**4807**	**0.70**	**LOS C**	**30**
Dir-II: Bangalore City To Yelahanka (Towards Airport)	**3600**	**4970**	**1.38**	**LOS F**	**15**	**6900**	**4445**	**0.64**	**LOS C**	**30**	**6900**	**7151**	**1.04**	**LOS F**	**15**

Table 37: Scenario 3 Peak hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2031

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	3214	1.34	LOS F	15	6900	3067	0.44	LOS B	30	6900	1755	0.25	LOS B	40
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	3897	1.08	LOS F	15	6900	3038	0.44	LOS B	30	6900	2807	0.41	LOS B	40

Table 38: Scenario 3 Peak hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2037

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)

Dir-I: Yelahanka To Bangalore City	2400	4067	1.69	LOS F	15	6900	3772	0.55	LOS C	30	6900	2329	0.34	LOS B	40
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	4931	1.37	LOS F	15	6900	3664	0.53	LOS C	30	6900	3772	0.55	LOS C	**30**

Table 39: Scenario 3 Peak hour Traffic Forecast -60% Traffic Diversion to the Proposed Underpass-2047

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	5466	2.28	**LOS F**	**15**	6900	4759	0.69	**LOS C**	**30**	6900	3440	0.50	**LOS C**	**30**

Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	6626	1.84	**LOS F**	**15**	6900	4445	0.64	**LOS C**	**30**	6900	5494	0.80	**LOS D**	**25**

Table 40: Scenario 4 Peak hour Traffic Forecast - 50% Traffic Diversion to the Proposed Underpass-2031

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)
Dir-I: Yelahanka To Bangalore City	**2400**	**4067**	**1.69**	**LOS F**	**15**	**6900**	**3772**	**0.55**	**LOS C**	**30**	**6900**	**1312**	**0.19**	**LOS B**	**40**
Dir-II: Bangalore City To Yelahanka (Towards Airport)	**3600**	**4931**	**1.37**	**LOS F**	**15**	**6900**	**3664**	**0.53**	**LOS C**	**30**	**6900**	**2539**	**0.37**	**LOS B**	**40**

Table 41: Scenario 4 Peak hour Traffic Forecast - 50% Traffic Diversion to the Proposed Underpass-2037

Direction	With Underpass-On Hebbal Flyover Ramps	N-S Tunnel	Underpass

	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)
Dir-I: Yelahanka To Bangalore City	2400	4067	1.69	LOS F	15	6900	3772	0.55	LOS C	30	6900	1312	0.19	LOS B	40
Dir-II: Bangalore City To Yelahanka (Towards Airport)	3600	4931	1.37	LOS F	15	6900	3664	0.53	LOS C	30	6900	2539	0.37	LOS B	40

Table 42: Scenario 4 Peak hour Traffic Forecast - 50% Traffic Diversion to the Proposed Underpass-2047

Direction	With Underpass-On Hebbal Flyover Ramps					N-S Tunnel					Underpass				
	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speeds (KMPH)	Capacity	Peak Hour PCUs	Volume to Capacity Ratio	Level of Service	Anticipated Speed (KMPH)
Dir-I: Yelahanka To	2400	6833	2.85	LOS F	15	6900	4759	0.69	LOS C	30	6900	2074	0.30	LOS B	40

Bangalore City															
Dir-II: Bangalore City To Yelahanka (Towards Airport)	**3600**	**8283**	**2.30**	**LOS F**	**15**	**6900**	**4445**	**0.64**	**LOS C**	**30**	**6900**	**3838**	**0.56**	**LOS C**	**30**

Based on the peak traffic projections for the year 2031 and 2037 with and without proposed underpass and North South Tunnel it is clear that with 80% traffic diversion there will be maximum relief to Hebbal Flyover ramps as congestion drops from LOS F to LOS C/D/E, Travel speeds nearly double in the year 2037. Whereas the traffic projections for 2047 suggests that Underpass is slightly over capacity in both directions, with Level of Service E/F, indicating unstable flow and potential delays.

4.9 Mitigation Measures

As a long-term measure to address the growing traffic congestion in and around Hebbal, it is proposed to construct an underpass connecting Hebbal to Baptist Hospital. The primary objective of this facility is to cater to the local and short-distance traffic demand generated from areas within a radius of 1.5 to 2 kilometers. This underpass is expected to provide significant relief to commuters traveling from Bangalore city towards the airport and in the reverse direction. However, it may not yield substantial benefits for through traffic originating from K.R. Puram and Yeshwanthpur, which generally bypass the local movements.

Despite this limitation, the underpass will play a crucial role in reducing the traffic load at the Hebbal interchange by streamlining local traffic, thereby creating smoother flow conditions for all commuters.

Speed and delay studies further highlight the severity of the problem. For example, traffic moving from Anand Nagar towards Hebbal takes nearly 28 minutes to cover a mere 2 km stretch, resulting in an average speed of only 4.29 km/h. Such low speeds not only lead to excessive travel time but also cause higher fuel consumption and contribute to worsening air pollution levels in the area.

The proposed underpass aims to directly address this issue by providing a seamless passage for short-distance commuters who are otherwise forced to wait at the congested Hebbal interchange. By diverting and accommodating this localized traffic, the underpass will significantly reduce travel time, lower fuel consumption, and improve overall air quality in and around the Hebbal junction.

In conclusion, the underpass is a targeted infrastructure intervention designed to improve local accessibility, enhance traffic efficiency, and promote environmental sustainability in the Hebbal region.

Conclusions

- Traffic at the Hebbal Flyover exceeds the road's capacity, leading to significant delays and long queues. From Yelahanka to Bangalore City, the volume-to-capacity ratio is 2.65, and from Bangalore City to Yelahanka (towards Airport) it is 2.14—both rated as Level of Service F, indicating severe congestion.
- A speed and delay survey on Sanjay Nagar Main Road near HMT Bhavan found that during a typical weekday peak hour, vehicles take about 22 minutes to cover 3 km, resulting in an average speed of only 8.3 km/h, indicating severe traffic congestion. Similarly, the speeds are 3.57 kmph from Esteem mall to down ramp of Hebbal near Baptist hospital for a distance of 1.36 kms.
- It was observed that nearly 3512 PCUs which accounts to nearly 39% of the total traffic volume from Hebbal Flyover is dispersed onto adjoining feeder roads during the peak period indicating the need for short length underpass.

- In order to address the traffic issues, B-Smile has proposed a comprehensive two-tier strategy to address traffic congestion. For long-distance commuters, which constitutes 61%of traffic, a 14 km underground tunnel is planned between Hebbal and Madiwala Junction, with four entry/exit points, offering a direct route from Kempegowda International Airport to Silk Board while bypassing surface-level traffic.

- To tackle immediate congestion at Hebbal, a short underpass near Baptist Hospital is proposed to streamline airport-bound traffic. Together, these measures aim to ease both long-haul and local traffic pressures on the corridor. The project is anticipated to commence operations by 2027, with full operational status expected by 2028.

Impact of Proposed Underpass on the Current Hebbal Flyover

The impact of the proposed short underpass at Hebbal Flyover was evaluated by comparing traffic conditions with and without the project. Projections consider traffic diversion scenarios of 80%, 70%, 60%, and 50% from the flyover to the underpass, assessing how redistribution would ease congestion.

Scenario 1 - 80% Traffic Diversion to the Proposed Underpass

- With 80% Traffic Diversion to the Proposed Underpass in the year 2027 there will be significant improvement in traffic flow. Volume-to-capacity ratios drop below 0.6 and Level of Service improves to LOS C in both directions of Hebbal Ramps.

- Traffic Forecast for 2037 & 2047 suggests that Hebbal Flyover ramps experience significant relief, Level of Service (LOS) improves to C/D/E, Indicates moderate to acceptable traffic conditions whereas the proposed Underpass is over-saturated due to high demand, LOS drops to F (worst level), Fails to handle projected volumes alone.

Scenario 2 - 70% Traffic Diversion to the Proposed Underpass

- Based on the peak traffic projections for the year 2027 with and without proposed underpass it is clear that with 70% traffic diversion there will be balanced load sharing between flyover and underpass and noticeable congestion reduction on ramps, underpass still efficient.

- Traffic Forecast for 2037 & 2047 suggests that Hebbal Flyover ramps remain severely congested with Level of Service F, Speeds drop to 15 km/h. The underpass brings marginal benefits (mainly speed improvements on ramps), but cannot eliminate congestion (LOS F still persists). To achieve sustainable improvements, the underpass must be integrated with larger-scale capacity enhancement.

Scenario 3 - 60% Traffic Diversion to the Proposed Underpass

- With 60% Traffic Diversion to the Proposed Underpass in the year 2027 there will be moderate reduction at ramps with V/C Ratio 0.93, LOS E (Bangalore City To Yelahanka direction). Underpass begins to function as an alternate rather than the main route with LOS C and speed 30 Kmph. Some residual congestion at Hebbal ramps may persist.

- Traffic Forecast for 2037 & 2047 suggests that **Hebbal Flyover ramps** in both directions become **extremely over-saturated with LOS F, speeds 15kmph.** The underpass provides partial relief, especially for traffic from Yelahanka To Bangalore City direction. However, congestion towards Yelahanka and Airport persists at LOS F It is clear that the Underpass alone cannot fully address capacity shortfalls.

Scenario 4 - 50% Traffic Diversion to the Proposed Underpass

- With 50% Traffic Diversion to the Proposed Underpass in the year 2027 there will be will be Limited relief to the Hebbal Flyover ramps with LOS F on both the directions. Underpass adds redundancy, but overall network congestion remains significant.
- By 2037 and 2047, even with 50% traffic diversion, Hebbal Flyover ramps will face extreme congestion and severe service degradation (LOS F) without improvements. While the proposed underpass offers significant relief—especially for Yelahanka to Bangalore City traffic—reducing congestion from LOS F to LOS E and nearly doubling speeds, it still falls short of fully addressing capacity demands.

<u>Impact of Proposed Underpass on North-South Tunnel</u>

BBMP plans a major North-South Tunnel from Hebbal to Silk Board to ease long-distance traffic by 2037. As a quicker fix, a Short Length Underpass (SLU) is proposed to reduce congestion at Hebbal Flyover. As per the North-South Tunnel Traffic modeling shows the tunnel will divert over 3,664 PCUs in the Bengaluru City to Yelahanka (Airport) direction, and 3,772 PCUs in the Yelahanka to Bengaluru City direction easing pressure on the underpass. These tunnel diversions were deducted from the estimated underpass volumes to reflect realistic demand conditions once both facilities are operational. Traffic redistribution was modeled across four diversion assumptions: 80%, 70%, 60%, and 50% of ramp traffic shifting from the Hebbal Flyover to the underpass.

Scenario 1 - 80% Traffic Diversion to the Proposed Underpass

- Traffic forecasts for 2037 and 2047 show that with 80% diversion to the proposed underpass and North-South Tunnel, congestion at Hebbal Flyover ramps significantly improves. The level of service rises from LOS F to LOS C/D/E, and travel speeds nearly double.

Scenario 2 - 70% Traffic Diversion to the Proposed Underpass

- Traffic projections for 2037 and 2047 show that with 70% diversion, the proposed underpass and North-South Tunnel together offer effective high-capacity alternatives. This combination helps distribute traffic more evenly and reduces dependence on the congested Hebbal Flyover ramps

Scenario 3 - 60% Traffic Diversion to the Proposed Underpass

- With 60% traffic diversion, projections for 2037 and 2047 show that the underpass and North-South Tunnel effectively distribute traffic loads. Together, they support sustainable flow and help manage future demand across key corridors.

Scenario 4 - 50% Traffic Diversion to the Proposed Underpass

- With 50% traffic diversion, projections for 2037 and 2047 show that the proposed underpass effectively supports long-term traffic growth with LOS B in both the directions. It complements the North-South Tunnel by redistributing flows and reducing bottlenecks at key junctions.

The underpass alone can't solve the congestion problem. The North-South Tunnel is key to long-term traffic improvement, while the underpass provides relief for the short distance travelers.

CHAPTER 5: TOPOGRAPHY AND GEOTECHNICAL INVESTIGATIONS

5.1 TOPOGRAPHY OF HEBBAL (NORTH BENGALURU)

The Proposed short length transitory 3-lane Bi-directional Vehicular Underpass is located near Hebbal located in the northern sector of Bengaluru city. The proposed structure is cut and cover tunnel.

Hebbal, located in the northern sector of Bengaluru, lies within the Deccan Plateau and is characterized by a gently undulating relief with a prominent ridge-valley drainage framework. Elevations typically range from ~886 m in valley floors to ~929 m at local highs, with a mean around ~900–904 m above MSL. This topographic setting shapes surface runoff pathways into the Hebbal Valley and the impounded waterbody of Hebbal Lake, a key element in Bengaluru's historical lake-valley network.

5.1.1 Elevation Profile

The Hebbal area exhibits mild relief and subdued slopes typical of a high plateau surface. The following metrics are representative for the immediate Hebbal Lake vicinity:

- Average elevation: ~904 m.
- Minimum elevation: ~886 m (valley floor near Hebbal Lake).
- Maximum elevation: ~929 m (local high points)

5.1.2 Ridge-Valley Framework

Bengaluru's terrain is structured around a north-south trending water divide (ridge). Hebbal lies within one of the principal valleys draining this divide. Historically, valley bottlenecks were dammed with earthen bunds to create a chain of lakes; Hebbal Lake is an example, lying at a natural topographic low that captures local catchment runoff.

5.1.3 Terrain Characteristics

The Hebbal region is best described as a gently undulating plateau with shallow depressions. Slope gradients are mild, facilitating natural drainage without steep erosional features. Such terrain has historically been suitable for human settlement, agriculture (prior to urbanization), and later urban expansion. The presence of the Hebbal Lake further enhanced the suitability of the area as a water resource hub. The Hebbal Valley forms part of the interconnected lake-valley system in northern Bengaluru that facilitates stormwater conveyance, temporary storage, and groundwater recharge. Urbanisation has modified natural drainage, necessitating engineered augmentation (e.g., stormwater drains, detention basins). Protecting longitudinal valley corridors is critical for flood resilience.

5.2 GEOMORPHOLOGY OF HEBBAL

This section presents the geomorphology of the Hebbal region within a 5 km radius, highlighting physiographic setting, landforms, drainage, soils, and structural controls. High-resolution maps with local names are included to support spatial interpretation of terrain and drainage characteristics.

5.2.1 Physiographic Setting

Hebbal is located in the northern part of Bengaluru, Karnataka, forming part of the Mysore Plateau (Southern Deccan Plateau). The terrain is undulating, with elevations ranging from 880–940 m above mean sea level (MSL). It slopes gently eastward into the Koramangala-Challaghatta valley system. The physiography is dominated by pediplains interspersed with residual hills and localized valley fills.

5.2.2 Landforms

- Residual Hills: Formed of erosion-resistant Peninsular Gneiss, forming tors and knolls.
- Pediplains: Gently undulating surfaces representing long-term denudation.
- Valley Fills: Low-lying zones near Hebbal Lake and streams with depositional silty-clay soils.
- Water Bodies: Hebbal Lake and interconnected valley lakes representing geomorphic depressions.

5.2.3 Drainage and Surface Processes

Hebbal falls within the Koramangala–Challaghatta valley drainage system, which ultimately connects to the Arkavathi–Vrishabhavathi basins. The drainage pattern is dendritic to sub-dendritic, typical of crystalline basement rocks. Seasonal surface runoff is high due to impervious rocky substrata, resulting in flashy streams during monsoon periods.

5.2.4 Soils and Regolith

Soils across Hebbal vary with geomorphic unit: red loamy and lateritic soils dominate uplands, while deeper clayey alluvium is found in valley fills. Upland soils are shallow (20–50 cm), pediplains moderately deep (50–100 cm), and valley fills exceed 150 cm depth.

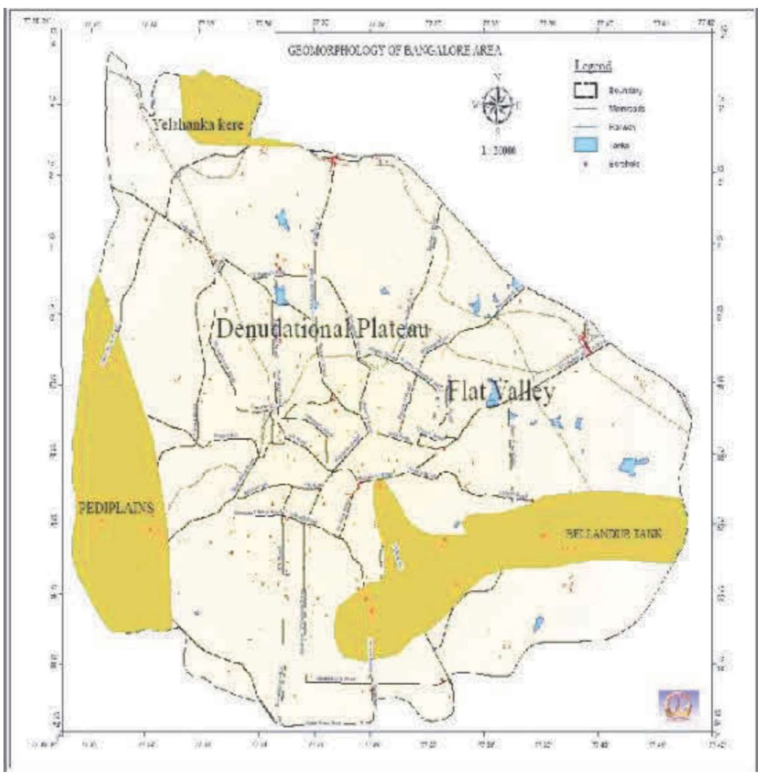


Figure 28: Geomorphology of Bangalore area showing pediplains, residual hills, and valleys

5.2.5 Structural and Lithological Influence

The geomorphology of Hebbal is controlled by the Peninsular Gneissic Complex (PGC). Jointing, fracturing, and weathering patterns govern drainage alignment and localized groundwater storage. Saprolite development is common in valley zones, up to 10-15 m thick.

5.2.6 Geomorphic Significance for Urban Development

The pediplains and valley fills have enabled urbanization and infrastructure development around Hebbal. However, valley zones are prone to flooding and waterlogging, especially near Hebbal Lake. Residual hills provide stable ground but pose excavation challenges for large projects. Urban planning and infrastructure design must integrate geomorphic considerations for sustainable development.

5.3 HYDROLOGY

Hydrology plays a critical role in the planning, design, and execution of cut-and-cover tunnel construction. The Hebbal region of Bengaluru is characterized by a network of natural drainage channels, urban stormwater systems, and proximity to the Hebbal Lake catchment. The interaction between groundwater, surface drainage, and rainfall patterns must be carefully assessed to ensure safe construction and long-term performance of the tunnel.

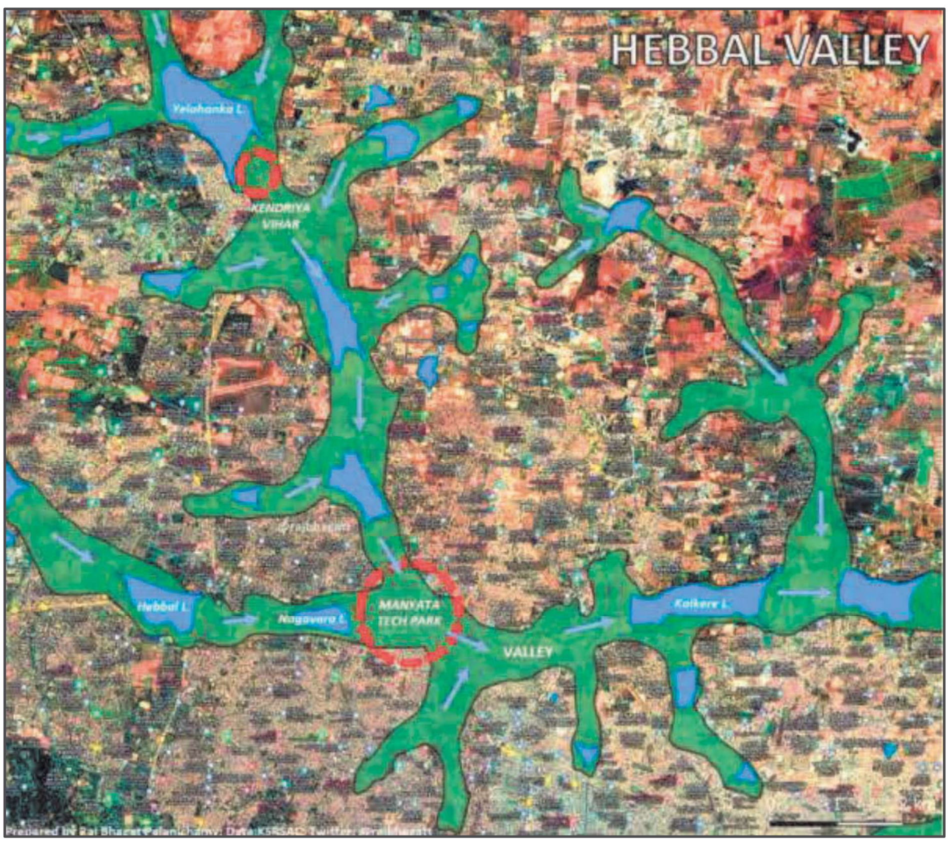


Figure 29:Regional Hydrology Map of Hebbal Valley

5.3.1 Regional Hydrological Setting

- **Catchment Area**: The Hebbal area lies within the **Koramangala-Challaghatta (K&C) Valley system**, draining northward into Hebbal Lake, which forms part of the larger interconnected lake chain in Bengaluru.
- **Surface Water Bodies**: Hebbal Lake (approx. 150 ha) is the dominant hydrological feature, receiving inflows from multiple stormwater drains.
- **Drainage Pattern**: The region exhibits a **dendritic drainage pattern**, with several secondary and tertiary drains feeding into the main valley channel.
- **Rainfall Characteristics**:
    - Average annual rainfall: ~970 mm (IMD Bengaluru data).
    - Monsoonal dominance: Southwest monsoon (June–September) contributes ~65% of rainfall.
    - High-intensity, short-duration storms often exceed 60–80 mm/hr, creating flash flooding.

5.3.2 Groundwater Regime

- **Aquifer Type**: Predominantly **weathered and fractured granite gneiss aquifers**, with shallow water table conditions (3–8 m bgl) in low-lying areas near Hebbal Lake.
- **Fluctuations**: Seasonal groundwater fluctuation of 1–3 m is common, with higher levels during monsoon.
- **Implications for Construction**:
    - Dewatering may be required for cut-and-cover excavation, particularly in monsoon season.
    - High water table increases hydrostatic pressure on tunnel walls and base slab.
    - Adequate waterproofing and drainage systems must be integrated into tunnel design.

5.3.3 Flood and Stormwater Considerations

- **Flood Hazard**: Hebbal junction and surrounding low-lying areas are prone to **urban flooding** due to inadequate stormwater capacity and backflow from Hebbal Lake.
- **Stormwater Drains**: Existing RCC and open drains are insufficient to carry peak monsoon discharge, leading to waterlogging.
- **Impact on C &C Tunnel Construction**:
    - Temporary diversion of drains may be required to avoid flooding of excavation pits.
    - Tunnel portals/openings should be designed with flood barriers and sump pumping systems.
    - Cut-and-cover excavation requires **cofferdam-type protection** during monsoon.

5.4 REGIONAL GEOLOGICAL STUDIES OF BANGALORE CITY

5.4.1 Regional Geological Framework

The Peninsular Indian shield is made up of a mosaic of Precambrian metamorphic terrains that exhibit low to high-grade metamorphic rocks (Figure 30).

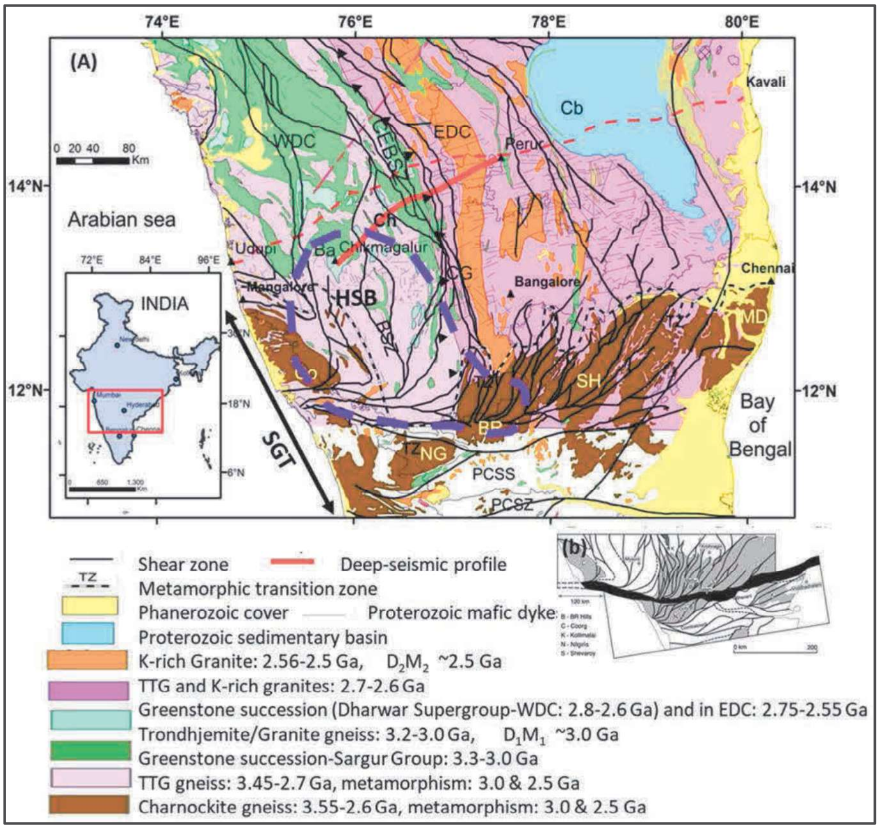


Figure 30: A simplified geological map of Dharwar craton, southern India showing major Archean tectonic blocks; WDC, EDC and northern part of the SGT (after Bhaskar Rao et al 2020).

{The EDC and WDC separated by Chitradurga Eastern Boundary Shear Zone (CEBSZ). The Paleo-Mesoarchean crustal domain surrounding the Holenarsipur Supracrustal Belt (HSB) is demarcated by an ovoid bold dash-line. Important greenstone belts in the WDC; Bababudan (Ba), Shimoga (Sh), and Chitradurga (Ch). Closepet Granite (CG). Major charnockite massifs in the Archean granulite gneiss crust include Coorg (Co), Bilirigi Rangan (BR), MalaiMahadeva – Shevaroy (SH),Nilgiri (NG) and Madras (MD). The dextral Palghat-Cauvery shear system (PCSS) and Palghat-Cauvery suture zone (PCSZ). Insert A is a reconstruction of the crustal blocks across shear systems in the northern part of the PCSS after correction for a 120 km dextral E-W shift and a 9° anticlockwise rotation of the southern block.}

These terrains that owe their origin to the repeated events of silicic/mafic magmatism, formations of ancient depositional basins, their burials at sub-crustal depths and subsequent exhumation at shallow crustal levels have witnessed the most eventful formational history during the Precambrian times. Since then, these terrains have attained tectonic stability for prolonged period. Such crustal segments with vibrant evolutionary history during Precambrian and a subsequent quiescent or a passive role in crustal evolution since then are designated as cratons. The major cratons in Indian shield are Dharwar in the south, Bastar and Singhbhum in the east, Bundelkhand in the center and Aravalli in the northwestern parts. The cratonic regions develop peripheral strips of intensely deformed and metamorphosed supracrustal rocks often referred to as mobile belts. The prominent mobile belts of the subcontinent are Southern Granulite belt fringing Dharwar Craton, Eastern Ghat Mobile Belt bordering Dharwar, Singhbhum and Bastar cratons and Aravalli-Delhi mobile belt stitched with Aravalli Craton. The Dharwar craton (Figure 30), the largest cratonic mass of the Indian shield is situated in Karnataka and parts of Andhra Pradesh and Tamil Nadu. Geologically, it is bound to the east and south with Proterozoic high-grade metamorphic terranes (the Eastern Ghats Granulite Terrane and the Madurai and Trivandrum blocks of the Southern Granulite Terrane). The northern margin of the craton is concealed by Proterozoic and Phanerozoic sedimentary cover and the Cretaceous Deccan lavas. A large part in the east is covered by Paleo- to Neoproterozoic Cuddapah sedimentary basin.

Bulk of the rocks in the state of Karnataka is grouped under two major tectono-metamorphic units. These are (i) granites and gneiss that are studied under a blanket term of Peninsular Gneissic Complex and (ii) the schistose supracrustal belts. The schistose supracrustal belts occur at three tectono-stratigraphic levels. These are (i) the smaller lenses and linear belts that occur as enclaves within the sea of migmatitic gneisses and referred to as Ancient Supracrustals (Sargur Schist complex) (ii) linear, auriferous schist belts (Kolar, Hutti, Ramagir) that occur in eastern parts of the craton and (iii) the younger schist belts (Bababudan, chitradurga schist belts). A striking feature in the geological map of Dharwar craton is the occurrence of a 300 km long N-S to NNW-SSE trending linear belt of granite referred to as Closepet Granite.

5.4.2 Lithostratigraphic sequence in Bangalore area

The city of Bangalore is located in central part of the Dharwar Craton. Balachandran (1978) has carried out systematic detailed geological mapping in about 500 sq km of the city on 1:20,000 and partly on 1:63360 scales. This study has helped in identifying and demarcating broadly five major lithostratigraphic units. These are: (i) Ancient supracrustals (ii) Peninsular Gneissic Complex (iii) younger granites, (iv) Younger mafic intrusives and (5) Laterites. The spatial distribution of the rock types in Bangalore area is shown in Figure-2.

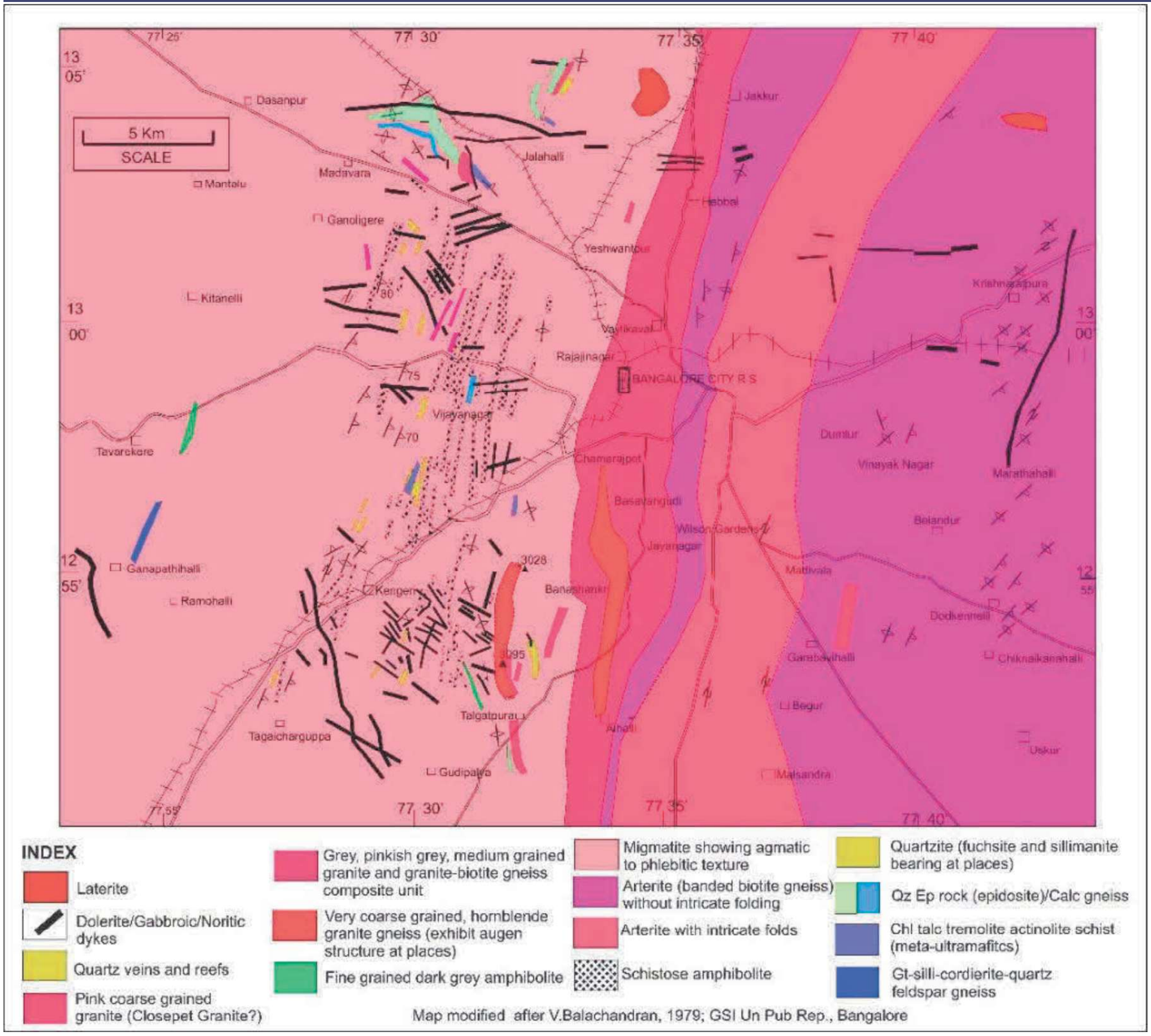


Figure 31: Geological map of the Bangalore City (after Balachandran, 1979)

The litho-stratigraphic order of the rocks is provided below.

Table 43: Litho-stratigraphic sequence of rocks in Bangalore City

Litho-stratigraphic Order	Rock types/Litho unit	Stratigraphic Unit
10	Laterite	Cap Rocks
9	Meta-dolerite/gabbro/noritic dykes trending WNW-ESE to EW	Younger Intrusives
8	Meta-dolerite/gabbro/noritic dykes trending NNE-SSW	
7	Pegmatites, aplites, quartz veins	Peninsular Gneissic Complex
6	Light grey, pinkish grey,pink, medium grained,schilieric, nebulitic to hamophanous biotite granite	
5	Schistose amphibolite, talc-serpentine rock and talc-tremolite-chloirte schist	

Litho-stratigraphic Order	Rock types/Litho unit	Stratigraphic Unit
4	Grey to dark grey, very course grained biotitic hornblende, augen gneissic granodiorite	
3	Migmatitic gneiss showing agmatiticato p lebitic structures	
2	Migmatitic banded biotite gneiss, folded and controted	
1	Quartzite, epidosite, calc-granulite, cordierite-sillimanite-garnet-quartz feldspar gneiss	Sargur Group (?)

5.4.3 Geological Description Of Rocks In Bangalore City

5.4.3.1 Ancient Supracrustal:

Enclaves of metasedimentary, metavolcanic and meta-ultramafite in nature ranging in size from a small outcrop scale (<1m) to those forming discontinuous bands exceeding 5 kms are recognized within the gneissic rocks. Geologically these represent oldest remnants of volcano-sedimentary rocks that are intruded and migmatised by several phases of igneous intrusions and generally referred to as Ancient Supracrustal. They are stratigraphically equivalent to the supracrustal rocks of Sargur area in southern Karnataka and clubbed under Sargur Group of rocks (Ramakrishna and Vishwanathan, 1978).

In Bangalore, these rocks occur exclusively in the western zone, being more particularly prominent in the north-western sector. Their disposition is conformable to the trend of foliation of the surrounding migmatitic gneiss and their contacts with the latter are gradational. Though the disposition of the enclaves is nearly in conformity with the foliation trend of the enclosing migmatitic gneiss, albeit a certain degree of disconformity is discernible at places that brings to the forth their antiquity vis-à-vis the surrounding gneisses. Balachandran (1978) has reported two instances where the contact relationship of ancient supracrutals and gneisses could be studied. At Mallsandra and Singapura in northwest sector it can be clearly observed that the quartzite and epidosite have been intruded by light grey homophonous granite. On the southern side of the Chickbanavar hill, at one place the gneissic trend is at the right angles to the near E-W trend of the quartzite, which forms the hill. But, as one proceeds westwards the gneissic foliation is seen trending parallel to that of the quartzite. They have invariably traversed by homophonous bioitite granite. Polyphase deformation in ancient supracrustal and the surrounding gneisses is evident in the form of (i) early fabric-forming event that resulted in the penetrative foliations which mimics the earliest deformation fabric in the gneisses (ii) the second deformation event folded the primary foliation into sub-isoclinal folds, with attendant metamorphism that produced a second phase of metamorphic mineral assemblages and (iii) a third deformation phase led to local shearing and retrogression of the mineral assemblages. The coarse porphyroblastic growth of high temperature mineral assemblages (garnet, cordierite, sillimanite, hypersthene) suggests that metamorphism have outlasted deformation.

Compositionally the metasedimentary enclaves include horizons of quartzite, epidosite, calc-granulite, garnet-cordierite bearing pelitic gneisses, banded quartz-magnetite, quartzites (fuchsite and sillimanite bearing, at places), and hypersthene-plagioclase bearing meta-psamitic rocks. The meta-volcanic enclaves are represented by (i) fine grained massive amphibolites (ii) medium to coarse grained schistose amphibolites. The meta-ultramafite enclaves are represented by chlorite-talc-tremolite-actinolite schist.

Quartzite, epidosite, calc-granulite:

Quartzite, epidosite (quart-epidote rock) and calc granulite occur together, except at Singapura, 1 km west of IAF Hospital Town and at west of the Bangalore University campus. The epidosite and calc-granulite occur as lenticular bands, clefts, patches and streaks and runs extending over 10m and being 1 to 2 m wide within the white or pinkish white quartzite. They are all profusely traversed by opalescent quartz veins predominantly along the bedding. The quartzite at Chickbanavar hill is the most extensive (3 km long and the 100 to 500m thick) quartzite band followed by the Singapura band, which is 1.5 km long and 100m wide and 1 km long, noticed in the high ground at 1.5 km NW of Kodegahalli and south of Bangalore-Magadi road between 16 and 17 km stones. Sporadic outcrops of calc-granulite met with at Srikantapura and north of it have been interpreted to be part of sinuously folded extensive band. All the calc-granulte bands occurring in the abovementioned locations as well as the minor bands found at 500m WE of Sunkadakatte, 1k m west of Karivebhnahalli, north of Nayandhalli railway station, and south of Talagathpura (16 km stone of Kanakapura road) exhibit ribbed weathering characteristic of this rock.

The quartzite is composed essentially of saccharoidal grains of quartz, minor proportions of bioitite, altered plagioclase and oxidised specks of iron ore, which gives a pitted appearance to the quartzite; it occasionally contains sillimanite and fuchsite. Usually we find epidote disseminated throughout it and near calc-granulite it contains diopside giving rise to epidote quartzite (epidosite) and diopside quartzite respectively. The calc-granulite is composed of granular mixture of pale green diopside (very often altering to amphibole), quartz, saussuritised plagioclase and minor proportions of epidote, calcite and a few specks of sphene.

The Chickbanavar hill (3105) is in the form of a ‘knee bend’ reflecting the geological structure. This hill is made up of steeplydipping quartzite associated with epidosite and calc-granulite, which have been folded in the form of an open antiform plunging NE. The surrounding migmatitic gneiss has also been folded along with it. At Malsandra, near its south-eastern extremity, the quartzite has been traversed by a stock of biotite granite. The quartzite on the eastern side of the Malsandra granite has been displaced northwards, which is probably the effect of faulting at the contact or the effect of granitic intrusion or both. It is interesting to note that adjacent to the granite the supracrustal assemblage is richer in diopside and epidote including zoisite and exhibit tight contortions.

At Singapura the quartzite occurs in the form of an arcuate band, extending over a length of 1.5 km. The quartzite here is well-bedded, the thickness of the individual beds being 30 cms and dips at 70 towards E or vertical. It is traversed by light grey biotite granite in its southern part. A pegmatite vein cuts the quartzite discordantly near the nala just north of Singapura. About 500m north of this band, there is a small occurrence of grey to white quartzite which contains sillimantie. Adjacent to it pinkish white fuchsite bearing quartzite is encountered; the same band grades westwards into epidote-quartz rock and then to green diopside-plagioclase-quartz rock. All these rock formations have been intruded by biotite granite and adjacent to granite they are richer in diopside and epidote including pink zoisite and have suffered plastic deformation.The rich development of diopside and epidote minerals and also plastic deformation noticed in the neighbourhood of granite bodies must be the direct result of contact metamorphism.

Amphibolites and meta-ultramafites:

Amphibolites: The most common older mafic rocks recorded in the migmatitic gneisses are amphibolites. They either as occur as 2 to 20m wide and 100m to over 5 km long bands or as rafts measuring 30 cm to 2m in width and 5 to 6m in length. The rock is generally schistose, the schisotisy being more apparent on weathered surfaces. These bands and rafts of amphibolite appear to be generally concordant to the gneissic foliations, but at many places they can be seen to be disposed slightly obliquely to the foliation trend of the gneiss. The amphibolites are usually traversed by quartz, pegmatite and granitic veins. It is not uncommon to see a selvedge of biotite developed at the contacts of the amphibolite with the gneisses. A transition from amphibolite into diroritic gneiss and then to granodioritic gneiss and finally into biotite granite with proportion of k-feldspar and biotite increasing away from the amphibolite band has been recorded. The banded gneiss, as earlier mentioned, is frequently contorted. The quartzo-feldspathic veins traversing the amphibolite can also be seen traversing the gneiss. In the wider amphibolite bands, it can be seen that the rock is finer grained at the margins than in the central portions. The field relationships clearly suggest that the amphibolites represent remnants of the older mafic intrusions. The amphibolite possesses mostly an equigranular texture and are composed of plagioclase and hornblende in equal proportions. Porphyroblastic texture and relict ophitic or sub-ophitic texture are not uncommon.

Ultramafties: Several bands of meta-ultramafite have been mapped in the northwest sector and west of Avalahalli in the southwest sector. The rock is schistose and composed of chlorite, talc, serpentine and/or tremolite-actinolite. These bands are 15 to 25m wide and can be traced for about 1 km.

5.4.3.2 Peninsular Gneissic Complex

The Peninsular Gneissic complex of the Bangalore region is highly variable in mineralogical composition and texture. They vary from granite through granodiorite to diorite. The dioritic variants are rare, seldom observable in close proximity of mafic enclaves. Gneisses of granodioritic composition are most predominant and the granitic ones are next in abundance. Three principal minerals viz quartz, K-feldspar and plagioclase vary in each of the variant. In a modal Q-A-P diagram, the gneisses of Bangalore plot in the fields of granite and granodiorite with a few samples straddling closer to the boundaries of qz-syenite and qzgabbros. Mineralogically, both the principal variants (granites and granodiorite) are mainly composed of quartz, k-feldspar (generally microcline), microperthite, sodic plagioclase and biotite. Whereas the volume percentage of quartz (25-35%) in both the varieties remain uniform, the relative proportion of potash-feldspar and the plagioclase classify them into granite and granodiorite. The proportion of biotite, a major mafic mineral, is also variable (1-5%) reflecting probably the original composition of the paleosome - the dioritic to granodioritic gneisses being richer in biotite.

The Peninsular Gneissic Complex of Bangalore area could be classified into three units namely (i) Migmatitic gneisses (ii) Arteritic Gneisses with and without folding, and (iii) Augen gneisses. All the above units have a well-defined structural fabric related to repeated events of deformation with attendant metamorphism and/or migmatisation. The rock units trend in approximate N-S direction and presumably shows a broad concordant relation, albeit, the inter-relationship and the relative antiquity of the rock units could be discerned with the detailed quarry maps that expose few, if not all variants of the felsic rocks.

Migmatite Gneisses:

The migmatite gneiss is the most dominant unit in Bangalore which is seen flanking the main granite body on the west. It shows macroscopic structural heterogeneity which appears to be related to the degree of polyphase re-melting over a prolonged history of migmatisation of the Peninsular Gneissic Complex. There are stringers and lenses of high melt proportion consist of more ductile-deformed gneiss with contorted banding and buckle folding. The paleosomes in this unit, represented by biotite granite gneiss, dark dioritic gneiss and relicts of amphibolitic enclaves (together with patches of restities), are traversed profusely by light grey granite and pegmatites (neosomes). It exhibits mafic schlieren, pods of nebulitic, agmatitic and phlebitic structures. The amphibolite relicts within the dark grey gneisses and dioritic gneisses are often broken and the fragments show every transition from amphibolites to diffuse, partly assimilated rock types. The minerals of the original amphibolite have become unstable and have been changed to minerals in equilibrium with those of the surrounding rocks i.e amphibole ± biotite.

The migmatite is conspicuous by the rarity of basic enclaves for a distance of 2 to 3 km from the main granite body. Small occasional dark patches and bands do occur, which on closer examination are revealed to contain a good deal of feldspar and biotite. But, as we proceed westwards the proportion of restites increases. In fact, in the hilly tract west of Chick Bettaalli Hill-Rajajinagar-Hosahalli-Hoskerehalli line, an 'interbanded' sequence of biotite granitic gneiss and schistose amphibolite, meta-ultramafites and high grade supracrustals are ubiquitous (Figure 31). These features suggest that migmatization and homogenization have proceeded to an advanced degree in the 2 to 3 km reach adjacent to the main granite, but beyond these limits the intensity of migmatization gradually has decreased westwards.

Arteritic migmatitic gneiss occurs adjacent to the mafic enclaves. They are built up of alternating dark and light "bands" of varying thickness, from a few centimetres up to 10s of centimetres. This variant of migmatitic gneiss displays several stages of progressive anatectic melting from incipient metatectic films parallel to gneissic bands, to arterites (injection gneisses produced by intrusion of late-phase felsic neosomes parallel to the foliations) with preponderance of neosome over paleosomes. These are dioritic or granodioritic in composition and it is often highly contorted, but the mafic enclaves themselves have remained undeformed. The well foliated, well banded migmatitic biotite gneiss is met with on the eastern side of the main granite body and occupies much the greater part of the eastern zone of the Bangalore. The folded and contorted variety occurs sandwiched between two wide zones of the non-folded variety. Both the types are made up of well-foliated biotite granite gneiss (paleosome) interlayered with 2 to 15 cm thick granite, pegmatitic or aplitic neosome. Discordant veins of granite, pegmatite and aplite are also seen traversing the banded gneisses. In fact, there are indications to show that they have been fragmented by subsequent granitic intrusion. The folded variety is very well seen in Hulimavu, Adogodi, Hennur quarries and near Ulsoor tank. There are concordant unaltered basic enclaves within this migmatite. Feldspathised and biotitised basic xenoliths are seen at Aduogodi, Hulimavu and Chikkanhaalli quarries, which are folded along with the enclosing migmatite.

Augen gneissic granodiorite: This rock is grey to dark grey, very coarse grained with an ill-defined foliation and consists of biotite, hornblende, quartz, K-feldspar (principally microcline), micro-perthite and sodic plagioclase with zircon, epidote and opaque ore minerals as accessories. The plagioclase is generally saussuritised. The proportion of sodic plagioclase is either nearly equal to that of K-feldspar or in excess of it. Some of the larger crystals of feldspar (usually sodic plagioclase) are stretched out in the form of éyes' giving rise to the augen structure. Balachandran (ibid) has mapped several augen gneissic granodiorite bands near Gavipuram temple, Mount Joy, Banashankri layout and further south to Allahalli. Another large linear body of this rock is encountered amidst the migmatitic gneiss the western part of the Uttarahalli Betta and the ridges south of it, including theTurahalli Betta (.3095). Xenolithc fragments and stringers of augen gneissic granodiorite are seen within granite at the quarries in the CPRI premises at Karithimanahalli, Geddalhalli and on the western side of Basavangudda (.940m). It is frequently traversed by light grey biotite granite veins as also by pegmatite and aplitic veins. At Mt. Joy Banashanari, Dayanada College premises, quite a number of these veins are seen to emanate from the main granite body.

5.4.3.3 Central Bangalore Granites and Biotite Gneiss (CBGG) Unit

A composite unit of granite and biotite gneiss occur in the central parts of the city. This linear unit, 2-6 km wide, running in N-S direction through the heart of the city and occupying a comparatively elevated geomorphic profile constitutes a midriff like structure on whose western and eastern flanks occur are the older migmatite-gneissic terrains of contrasting lithologies. The granite and biotite-gneiss body, referred here as Central Bangalore Granite Gneiss (CBGG) can be traced from Yelahanka in the north and to the south of Allahalli.

Biotite Gneiss:

Bulk of this unit is made up of alternating dark and light gneissic foliations of varying thickness, ranging from fraction of centimeter to a few centimeters. It is distinctly homophonous i.e a gneissic body showing the characteristics of a massive plutonic nature having derived from tonalitic felsic magmas. Nevertheless, this unit is also characterized by very ubiquitous presence of relict patches, zones and lenses of migmatites developed from sedimentary precursors. Among the migmatites two types were recorded. These are (i) diatexitic migmatites and schlieren migmatite. The diatexitic migmaties, essentially a mesocratic restite migmatites, are developed from partial melting of sedimentary precursors. The schlieren migmatites are meso- to melanocratic restite migmaties that have schlieren-structure or flame-like with narrow and longish blocks of mafic mineral aggregates. An individual schliere can be composed, in addition to biotite, of amphibole, pyroxene, sillimanite, and plagioclase. There appears to be seamless structural transition from pure schlieren migmatite towards vein- and layered- leucogranite migmatite and similarly towards nebulitic (random distribution of structure-less small melt lenses, connected with a shear band).

Granite:

Several small, un-mappable, discrete linear bodies of pink and grey coloured coarse grained granite occurs within the biotite gneiss. Such rocks could be observed near Mallasandra, Gottigere Betta, and east of Subramanya and at Mangammanapalya. There are granitic bodies immediate north of Mohammad Sahibpalya (Lat 13° 4' 56"; Long 77° 33'0") and one km north of Kodigehall (Lat 13 3'55: Long 77 34'54"). It is not clear whether the northwestern outcrop limits of the granite extend up to these two localities or this represents an isolated granite body located much westward to the main body. Relict oval to sub-rounded granite boulders (1-3m along longer axis) lodged in the soil are not uncommon. The contact between the younger granite and the older gneisses into which they have apparently intruded is nowhere sharp, the transition being almost always gradual.

The granite shows the typical hypidiomorphic equigranular texture. The mineral constituents in the rocks include quartz, microcline, minor proportion of sodic plagioclase (often saussuritised). Biotite zircon, apatite, sphene and epidote are the accessory minerals in the rock.

Besides homogenous granite, three important rock units within the granite are recognized. These are (i) rocks with incipient foliation in NNE-SSW directions at some places like Banashankari quarry, eastern part of Karithimmanahalli, at Basvangudda and at the premises of Bangalore Palace and (ii) well-foliated, elliptical masses of gneissic inclusions that grade into massive granite, as at Anebande in Jayanagar III Block and at Hebbal quarry and (iii) microgranular mafic enclaves (MME enclaves) and granodiorite enclaves.

The field relationships with the host gneisses, presence of enclaves of older gneisses and their physical and mineralogical features suggest that the granitic bodies within the biotite gneiss represent an outlier intrusion, contemporaneous to the Closepet granite (the main Closepet granite traverse at about 20 km west of CBGG). Though this granite bodies are much smaller in dimension and has restricted width, it still maintains two characteristic features of the main Closepet batholith that its margins are migmatitic in nature with an attendant transitional fabric akin to the enveloping gneisses and that the central portion of the granitic massif has more homogenous texture and uniform composition.

Amphibolites in CBGG:

The CBGG is characterized by lenses and bands of amphibolites and is also traversed by polyphase veins of pegmatite and aplite. Prominent among these are (i) a 30 m wide and 100m long amphibolite band about 1 km SE of Kathriguppe in the southwest sector and (ii) three amphibolite bands at the Kathreguppa quarry. The latter amphibolites are veined and fragmented by the intrusion of granitic material resulting in the formation of agmatitic structures. Near the basic enclaves banded gneiss and diorites have developed due to lit-par-lit injection of granitic material along the schistosity and subsequent partial assimilation of the basic rock.

5.4.3.4 Metamorphism

Cordierite Gneisses in Bangalore area and metamorphic conditions: Bangalore is located in close proximity of the Closepet granite (Figure 30). Lenticular enclaves and concordant bands of cordierite-bearing gneisses are recognized to the west and southwest of Bangalore (Figure 30) along both the eastern and western contacts of the Closept granite. These metapelitic gneisses have attracted the attention of many earlier workers as these rocks could get some good mineralogical and geochronological data that shed light on the tectono-metamorphic conditions of rocks of Bangalore region. Jayaram et al (1976) have provided field and petrographic details of the cordierite bearing rocks occurring on either side of the Closepet granite in Bangalore region. These rocks occur as linear bands and isolated stringers within the migmatitecomplex. The thickness varies from 15 to 100m and the strike length from a few metres to as much as 3 km, The more prominent of these occurrences are located NNE of Doddaladamarapalya (Lat. 12°54'35" : Long. 77°23'40"), South-East of Jeksandra (Lat. 12°38'50" : Long. 77°26'30") and NNW of ValagerehalJi (Lat.12°35'5" : Long. 77°15'30"). See Fig. 1. Balachandarn (1978) mapped largest of these (300m wide and 3 km long), within the PGC at Dodddaladamarapalya and the same rock type is with east of Tavarekere at 22 km stone on Bangalore-Magdi road.

These gneisses are intimately associated with quartz-magnetite granulites and strike North-South with an easterly dip at 45° - 60°. In some localities a poorly defined mineral lineation by sillimanite and garnet porphyroblasts is observed; while elsewhere they are traversed by aplite and pegmatite veins. The exposures in general, are highly crumpled. However, a conformable relationship between them and the enclosing gneisses could be seen in all the areas. Although the individual bands are separated from each other, the mineral assemblage is strikingly similar. The latter consists of cordierite, sillimanite, garnet, biotite, feldspar and quartz cordierite and biotite being the abundant constituents). In the field, the cordierite gneisses appear more deformed and disturbed as compared to the surrounding migmatitic gneisses. Paleosomes in the cordierite gneisses are inter-banded along granitic leucosomes. The latter is comparable in character to the surrounding gneisses. Near Harohalli and Doddaladamarapalya areas, discordant leucosomes are found. In the vicinity of R-ll (13th mile, Bangalore-Magadi Road), the cordierite gneisses are associated with tremolite and actinolite-bearing mafic rocks.

Harris and Jayram (1982) studied the metamorphic assemblages of the gneisses from Bangalore region. They identified two groups of cordierites bearing pelitic assemblages: (i) cordierite-garnet-biotite-quartz-plagioclase -sillimanite ± microcline and (ii) cordierite - hypersthene - biotite - quartz - plagioclase. It has been noted that the two assemblages may both be present in the same outcrop, but not in the same horizon. The pelitic gneisses straddle along a line marking the northern limit of charnockite exposures to the south of Bangalore (Figure 31). The narrow bands of charnockites are found inter-bedded with pelites in localities which lie south of this line. Their study implies that the metamorphic assemblages reflect peak metamorphic conditions during or possibly post-dating the main fabric-forming event.

5.4.3.5 Mafic Dyke swarm within Bangalore City

Several mafic dykes have intruded the migmatite gneiss and granites of Bangalore. Depending up on their trends these can be classified into two major categories those that trend (i) E-W to WNW-ESE and (ii) N-S (± 20°). Both the sets of dykes have highly variable dimensions. A majority of them are 5 m to 20 m wide and extend for lengths of a few tens of meters. There are some dykes that extend in their length up to about 15 km (E-W dykes north of Jalahalli and northeast of K R Puram; N-S dykes east of Tagaicharguppa and southeast of K R Puram). Among other major dykes include are (i) the IAF Hospital town westwards up to the Arkavati River, a distance of 10 km and (ii) the eastern side extending from north of Medhalli (on old Madras road) to Marathahalli on the HAL-Whitefield road for a distance of 8 km. The preponderance of dykes is more to the west parts of Bangalore (to the west of the Central Bangalore Granite) than the eastern parts. The relative antiquity of these two sets of dykes worked out in field suggests that the dykes trending E-W to WNW-ESE directions are the youngest of the sets of dykes and these are also the most predominant. A polyphase intrusions of dykes is recorded near Kengeri where a close network of dykes is met with; here some of the dykes are disposed in NW-SE direction, which intersect the dykes trending NNE-SSW direction and are intersected by the E-W dykes.

The nature of the dyke exposures is invariably bouldary. A few of the large boulders (up to 3 meters along longer axis) could be seen. The dykes are dark grey, greenish grey, melanocratic to hypermelanic in colour. Irrespective of their trends, almost all the dykes show a close mineralogical and textural similarity. Porphyritic varieties being rare, most of the dolerites are equigranular with the grain size of the constituent minerals ranging from very coarse to coarse grained gabbroic rocks to the medium to fine grained doleritic rocks. Under the microscope subhedral grains of pyroxene and feldspars are generally fresh, only occasionally showing alteration to either hornblende or chlorite. Augite is the main pyroxene mineral butdiopsidic augite and diopside are not uncommon.The pyroxene occurs in large-sized prisms ophitically inter-grown with plagioclase and is generally pale green to colourless. Plagioclase is labrodorite in composition and is always twinned. Feldspars are invariably saussuritized. Skeletal iron ore completely or partially enclosed in pyroxene is common. Sometimes it has a semi-circular habit. Sphene and ilmenite occur as accessory minerals. Olivine bearing dolerites have been reported in M.G Road to Shivajinagar sector during tunnelling for the metro rail.

5.4.4 Structure

5.4.4.1 Regional Structural studies in Dharwar Craton:

The Dharwar Craton represents a mosaic of Sargur and Dharwar supracrustal belts/schist belts referred to as ‘cover rocks’ enveloped in granite-gneiss-migmatite, referred to as ‘basement rocks’. The overall structural pattern in Dharwar Craton is one of subparallel, linear schist belts whose regional trend changes from N-S in the southern part to NW-SE in the north.

The rocks in the craton show three principal episodes of folding decipherable both in the basement gneisses and the schistose cover rocks. These are (i) the first phase structures (DF1) are the isoclinal folds with attendant axial planar schistosity in the Sargur and the Dharwar rocks; (ii) the second phase structures are represented by folds (DF2) that have a consistent sinisterly sense of vergence and they refold the DF1 folds; the axial planes of second generation folds make small angles with regional bedding (iii) ductile deformation style and polyphase migmatization, interspersed with the aforementioned two folding episodes, characterize the Peninsular Gneiss Complex; the polyphase deformation and migmatisation events presents a very complex and intriguing evolutionary history and pose sever constraints in unraveling it even in a smaller quarry outcrops;(iv) the youngest deformation features are manifested in large, open to tight folds; the E-W shear systems in the craton are also related to this phase of deformation; the late deformation phase has caused retrogression of the granulites and development of mylonites and augen gneisses. The regional Closepet Granite together with many other contemporaneous granite bodies in the craton, are emplaced parallel to the axial planes of late folds in the Peninsular Gneisses.

5.4.4.2 Structural Studies in Bangalore City:

Exclusive studies on the strucural aspects of Bangalore rock has not been carried out so far. However, observations made during a systematic 1:50,000 scale mapping within the Bangalore city, quarry mapping on a larger scales in the city’s outskirts, studies in indivdual outrcorps and together with many fresh rocks exposed during the excavation for the metro rail revealed that the area has undergone poly phase folding episodes with attendant planar and linear elements that confirms to the major conclusions made on the regional structural studies of Dharwar Craton. The salient structural features in the city rocks are: (a) the early fold structures (F1) and (F2) are present only on minor scale; (b) the F1 structures are isoclinals in nature with variable axial traces, often recorded in the form of floating hinges in the gneissic rocks; (c) F2 folds are co-axial to F1, tight to isoclinals in nature, invariably have an upright pattern with very low plunge (d) the third most prolific planar features recorded in Bangalore city, both in granite and migmatite are the sheet joint. These are wide spaced, E-W to ENE-WSW trending shallow dipping (~ 5°) joints and they are invariably open, permitting water seepage down to considerable depths. These sheet jointing, can be very persistent and preferred planes/zones for weathering induced weakening. Together with regular vertical / steep joints these sheets get dissected to regular blocks which with type smoothen around the edges to form typical boulder formation in granitic terrain, closer to ground surface. F3 folds are open type with E-W to ESE-WNW sub-vertical axial planes.

Balachandran (1978) noted varying foliation trends (S1) of the migmatite gneisses on either side of the major central granitic body in the Central Bangalore District. Towards west of the granite the penetrative foliation fabric trend is in NNE-SSW direction, in the southern part wich gradually changes to NNW-SSE direction, south of Tumkur road and then to WNW-ESE and finally swings back to NNE-SSW directions, north of the Chickbanavar hill. The foliation in the banded gneisses in the eastern zone change from N-S in the southern part to NE-SW and then to ENE-WSW as we proceed north and northeastwards. The differences in the foliation trends of the migmatite gneisses on the western and eastern sides of the major central granite body has been interpreted either due to the (i) diachronous nature of migmatites development, or (ii) due to the preponderance of older supracrustal in the west zone the post-supracrustal magmatic fluids may just mimicking the early foliations of the supracrustals. The foliation variations could also be due to emplacement of the central granite body along the axial zone of the second generation fold. Balachandran (ibid) also noted that the presence of intricately folded banded gneiss sandwiched between two wide zones of the non-folded variety. These intriguing deformational patterns could be due to plastic flow at the time of migmatization. Likewise, the contorted banded gneisses seen adjacent to the amphibolite bands could have been produced in viscous state.

5.4.4.3 Lineaments in Bangalore City:

Regional studies involving landsat images have identified two prominent sets of lineaments with one having ENE-WSW trend, and the other approximately NW-SE to NNW-SSE trends. The NW-SE to NNW-SSE trending lineaments are medium to large in scale that are seen to transect the ENE-WSW lineament. The ENE-WSW lineament traversing the northern limits of Bangalore is traced from the Mandya and Chanpatna town and accordingly referred to as Mandya-Chanpatna-Bangalore lineament (MCB Lineament, Figure 31). It is further seen to extend towards Kolar. The off-set that the N-S trending Kolar schist belt shows along an ENE-WSW fault could be related to this lineament. This mega-lineament that has been traced to about 100 km is reported to be seismically active. The deformations associated with these lineaments have manifested in the form of persistent fracture/joint system, local faults and shears, folding patterns in the rocks. These structures could influence ground and surface water movements, which in turn can be assumed to be instrumental for setting up the existing trend/ pattern in intensities of weathering grades (laterally and vertically changing) of rocks with residual soil occurring towards the top.

A careful analysis of the geomorphological features, suggests the existence of extensive fractures/shear zones, particularly in the E-W direction. The well-defined E-W valley in the north, in which lie the Dodbommasandra, Hebbal, Nagwara, Kalere and Ranpur tanks and also the equally well pronounced valley denoted by the Mavalli, Koramangala, Belandur and Vartur tanks are speculated to be the results of erosion along E-W fractures/shear zones. The near N-S linear zone of deep weathering indicated by the seismic survey in the southeast sector could be the result of localised weathering along a shear zone. Balachandran (ibid) also links the predominance of E-W doleritic dykes to theE-W fracture system in Bangalore. Studyof aerial photographs may help resolve this issue.

Some other smaller size, linear structural features in the form of faults and shear zones having compatible ENE-WSW trend of the lineament are noticed in the central parts of the city (for examples in Vayalekaval, City Market area). The tunnel segment between Chickpet and K R Market show presence of normal fault in a dolerite dyke. The gneissic rocks in which these dykes intrude show all stages of development of mylonite fabric from simple mylonite tomylonite breccia to totally crushed cataclastic rock. Since the features are noticed in the excavated tunnel segment,the kinematic analysis of the shear zones could not be attempted. Nevertheless, presence of faults and shear related fabric is ubiquitous in Central Bangalore District.

5.4.4.4 Weathering Of Granite-Gneiss Rocks Of Bangalore Area

Weathering is an irreversible rock alteration process, happens under the influence of chemical, physical and biological agents through which fresh rocks masses undergo insitu disintegration and/or decomposition that finally lead to the formation of the Regoliths - the covering layers of weathered materials on fresh rocks. The upper layers of regoliths are continually removed, exposing the fresher material beneath it for weathering. In sub-surface conditions weathering occurs along the rock discontinuities (joints, fractures and faults) where the weathering agents penetrate much deeper parts of the rock mass and accentuate widening of the discontinuity planes and finally dislodge the weathered blocks from the parent rock mass. Such dislodged rock masses are generally referred as boulders. The size of the boulders is directly related to the spacing of the discontinuity planes.

A six-fold classification of weathered rocks (ISRM 2015, IS 4464) from Grade-I being fresh rock to Grade-VI soil as the final product of weathering. The description of six weathering grades is exclusively dependent on visually identifying relative volume percentage of the constituent minerals that lose their pristine colour and show alteration stains of varying degrees. This description, normally made during borehole core logging of geotechnical investigations, is therefore considered as subjective and qualitative Table-2 list the classification of rocks based on weathering grades and its comparison with the Rock Quality Designation (RQD) and Core Recovery (CR).

Table 44: Classification of rocks based on weathering grades

Weathering class and grade	Description of rock material and rock Mass	Strength	Index Properties		Effective Porosity
			CR [%]	RQD [%]	
Fresh (I)	No visible sign of material weathering. Near Boundary with Grade II some slight discoloration on major defects	Very High	95-100	90-100	-
Slightly weathered (II)	Discoloration indicates weathering of rock material and defect surface. Discoloration ranges from defect surface only to completely stained	Very high to 50-60% of fresh rock strength	90-95	75-90	5% increase from fresh rock
Moderately weathered (III)	Less than 50 % material decomposed and disintegrated to intact soil. Rock core discoloured and weakened.	30% of fresh rock strength	60-90	40-75	7% increase
Highly weathered (IV)	More than 50 % material decomposed and disintegrated to intact soil. Rock core discoloured and weakened.	15% of fresh rock strength	30-60	10-40	10% increase
Completely weathered (V)	Intact friable soil which may be weakly cohesive. Soil has fabric of parent rock.	Extremely low	0-30	0-10	20% increase
Residual soil (VI)	Friable soil with original rock fabric completely destroyed	Extremely low	0	0	>20 %

5.4.4.5 Fresh Basement rocks in Bangalore:

In Bangalore, fresh surface exposures of granite-gneiss are sparse (example, migmatite-gneiss in Lal Bagh Botanical Garden. There is considerable variation in the thickness of overburden on the fresh basement rock. In most of the city area the depth to the fresh rock (depth of overburden above fresh rock) is between 5 and 10 m with only in some central parts of the city where the depth to the basement rock is in excess of 10m. The deepest overburden recorded in the city is about 25m.

5.4.4.6 Weathered rocks of Bangalore city:

A fresh un-weathered parent rock, classified under Grade-I rock, is essentially a high strength grey coloured, medium to coarse grained banded and foliated granite-gneiss. Gneissic banding is well-defined with different coloured minerals showing separate and distinct parallel disposition. The darker bands in the rock are composed of biotite, muscovite, and/or hornblende whereas the lighter bands consist of feldspar and quartz. Epidote, magnetite and zircon occurs as accessory minerals. Slightly weathered rock, classified as Grade-II rock show signs of incipient alterations, particularly along joint planes in the form of yellowish stains. The moderately weathered rock, representing Grade-III shows widespread alterations, especially feldspar being altered to sericite. The grey colour of the rock is lost to yellowish and brownish mass. The lighter-coloured foliations/bands are now represented by only Quartz. The Highly altered rock, representing Grade-IV shows complete transformation of feldspars to clay with cations Na, Ca and K going into solutions and the rest forming cloudy mass of clays like kaolinite (aluminum silicate) and smectites. Biotite and muscovite alter to illite and montmorillonite (K-Al silicates). Quartz remains unaltered but get disintegrated into finer size angular to sub-angular grains. Ferromagnesian minerals like hornblende, epidote, and magnetite weather to clay plus highly insoluble iron oxides, essentially varieties of limonite (rust). The latter stains the rock in hues of red, orange and dark brown. The completely altered rocks represents a completely decomposed mass of red, yellow, brownish colours with relict with relict patches and stringers of the parent rock and quartz grains. Generally, various weathering grades are seen co-existing with each other.

5.5 SEISMICITY IN BANGALORE REGION:

Notwithstanding the fact that the city of Bangalore is located on a stable continental block with Moho located at about 37.0 kms, the region has experienced mild to moderate seismic activity in recent years. Such frequent recurrences have broken the myth that Bangalore city is free from the earthquake prone hazards. These recurrences also resulted in upgradation of Bangalore region from Zone I to Zone II in the seismic zonation map of India (IS1893:2002).

Further, several geological studies have shown that in the Bangalore region the reactivated reverse/normal faults have a dominant strike-strip movement resulting in repeated rupturing at close intervals. This is also evident from rejuvenation of the transcurrent faults manifested in recurrent earthquakes (Valdiya, 1998). Ganesha Raj and Nijagunappa (2004). In addition, because of density of population, mushrooming of buildings of all kinds from mud buildings to RCC framed structures and steel construction, improper and low quality construction practice and irregular and heavy traffic conditions; Bangalore is vulnerable even against average earthquakes.

Reasons for the seismicity of Bangalore region: Salient points for the recurrences of seismic activity in the region is provided below (Dasgupta et al 2000):

- Subtle variations in the physical properties and recurrences of the seismicity in the region could be explained in terms of two seismotectonic sub-zones namely (i) Mysore - Bangalore subzone and (ii) Bangalore-Kolar-Tirupathur subzone. The city of Bangalore being almost at the centre of the two zones on either side appears to be less tectonically active compared to the two areas on either side of it.

- A major NW-SE trending Arkavati Fault traverse to the west of Bangalore.
- There are two major lineaments, one NNW-SSE trending lineament travesing towards east in close proximity of Bangalore and another NE-SW trending lineament traversing north of Tiraputhur. Both these lineament appears to be free from seismic activity.
- The most significant tectonic feature of the area is the presence of a significantly large number of ENE-WSW minor lineaments that appears to be tectonically active as a large number of earthquakes are recorded along these lineaments. In Mysore-Bangalore region, earthquakes have frequently occurred since historic period more proximal to the Mysore-Bangalore lineament.
- Two clusters of earthquakes, one, on either side of Kolar Schist Belt (along its margin with the gneissic rocks) and another near Tiraputhur are very significant. The latter are recorded proximal to the intersection of the minor and major lineament.
- The epicentres of the earthquakes and their proximity to the regional fracture system is shown in Figure- 3 (after Ambazaghan et al 2010)

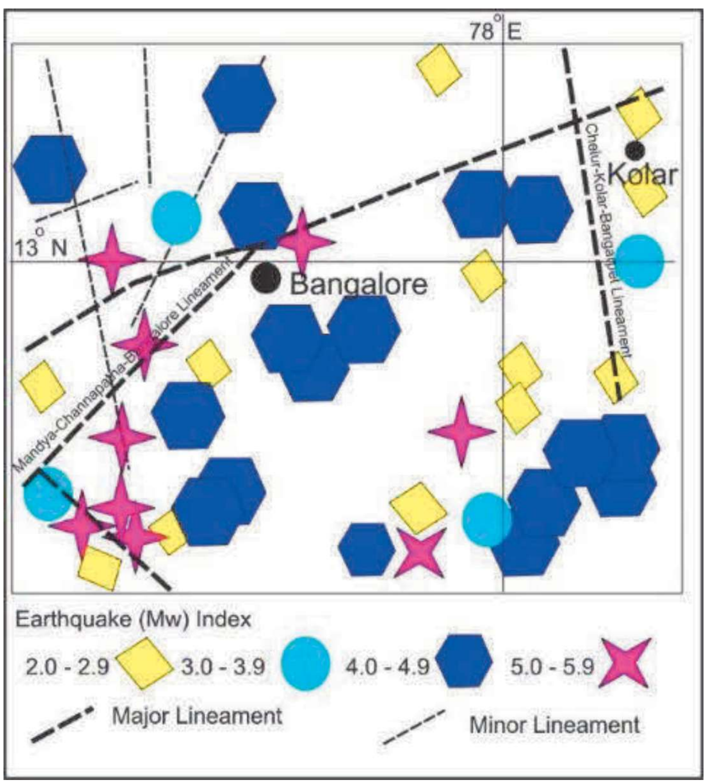


Figure 32: Earthquake epicenters in the city of Bangalore and their proximity with the major and minor lineaments.

The project area in the Bangalore city is part of the least seismically active and low risk , Seismic Zone II, with a Zone Factor Z of 0.10 as per IS1893, (Part 1) 2002. The final report on Development of Probabilistic Seismic Hazard Map of India (PSHMI) by National Disaster Authority (NDMA), places

Bangalore City under Zone 29 called Southern Craton, which has a maximum potential Earthquake of Magnitude up to 6.8Mw scale. According to PHSMI, Bangalore has a relative Seismic Hazard at 0.02,0.04,0.05 and 0.06 PGA(g) over 500,2500,5000 and 10000 years, time period.

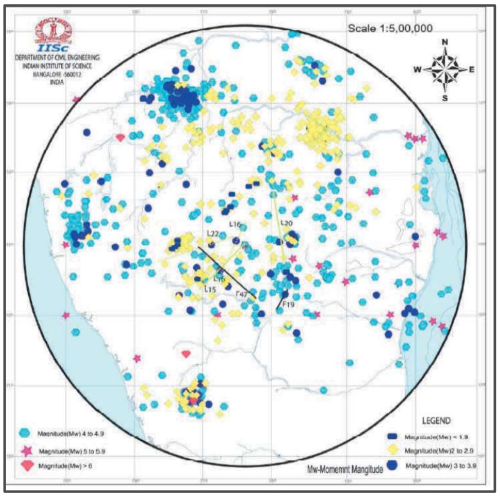


Figure 33: Seismotectonic Map of Bangalore area

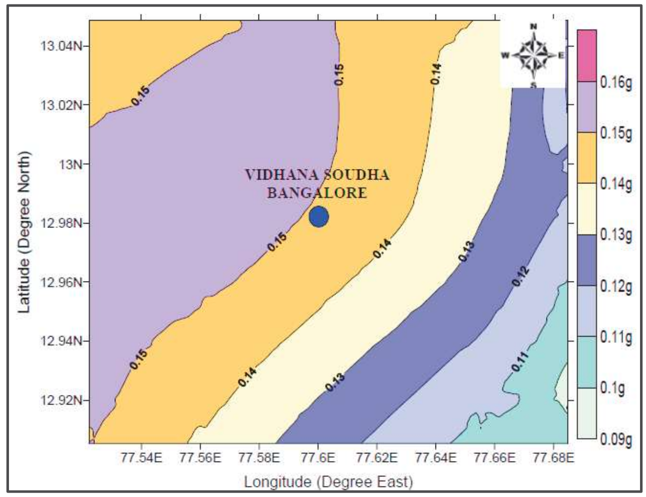


Figure 34 : Rock Level PGA map for Bangalore

Source: Seismic Microzonation of Banglore, TG Sitaram, IISC Banglore.

PROJECT GEOLOGY

5.5.1 General:

Hebbal, located in northern Bengaluru, lies within the **Peninsular Gneissic Complex (PGC)**—one of the oldest geological formations in India, comprising Archean granites and gneisses that are over 2.5-3.4 billion years old. The surface is covered by **lateritic red loamy to clayey soils**, formed through prolonged tropical weathering. The terrain is part of the central Bengaluru plateau, marked by **gently sloping pediments, shallow valleys, and isolated rock outcrops (inselbergs)**. Hebbal itself sits within a major valley system that naturally channels surface runoff into **Hebbal Lake**, a historic man-made reservoir dating back to the 16th century.

Subsurface conditions typically consist of a thin cover of silty sand and clayey soils underlain by weathered gneiss, transitioning into hard crystalline bedrock at depth. This geological setting influences **groundwater occurrence**, which is largely controlled by secondary porosity in weathered and fractured rock zones. The geology of Hebbal thus plays a critical role in shaping its land use, hydrology, and suitability for urban infrastructure development.

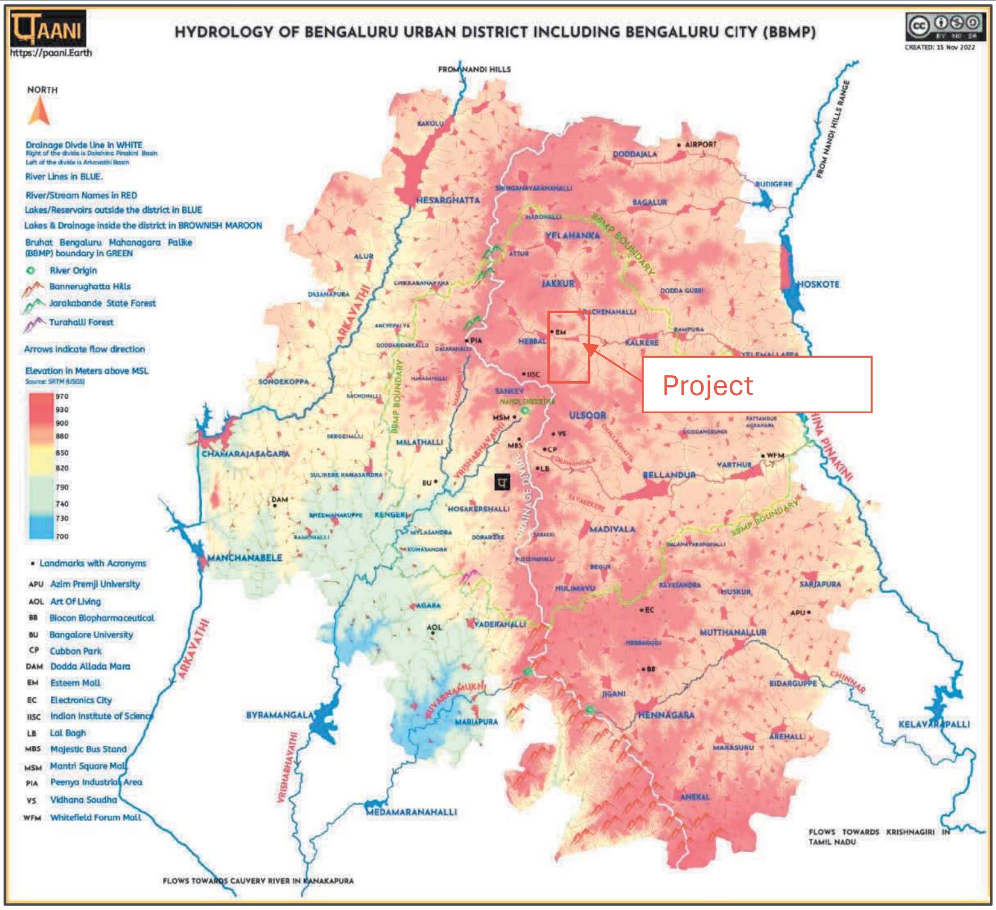


Figure 35: Hydrology of Bengaluru Urban District.

5.5.2 The soil-rock stratification:

The rock-soil stratification in the city that exists below existing ground level, is shown in the **table below** and description of each of the unit is provided below.

Table 45: Rock-soil Stratification of Bangalore City

Unit	Name	Description of the unit	Name adopted in the DPR	Weathering Grade	Remark
1	Filled up soil	Consist of transported sand-silt, organic matter, bitumen, concrete etc	Filled up soil		Over Burden
2	Soil	Residual soil with original rock fabric completely destroyed	Soil	Grade-6	
3	Completely Weathered rock	Intact friable soil, weakly cohesive, has fabric of parent rock.		Grade-5	
4	Highly Weathered rock	Rock with > 50 % decomposed and disintegrated to intact soil.	Soft Rock	Grade-4	Rock

		Discoloured and weakened rock.			
4	Moderately weathered rock	Rock with < 50 % decomposed and disintegrated to intact soil. Discoloured and weakened rock		Grade-3	
5	Slightly weathered rock	Slightly discoloured rock	Hard Rock	Grade-2	
6	Fresh Rock	Unweathered rock,/ fresh rock		Grade-1	

5.5.3 Thickness of over burden:

Extensive studies involving sub-surface drilling and geophysical exploration by Geological Survey of India (Balachandran, 1979), Indian Institute of Science (Anbazagan) and the recent drilling exploration by the BMRCL (unpublished data) has now provided a fairly good insight into the Bangalore substratum. The road tunnel alignment near hebbal is underlain by a variably thick overburden that rest over the basement rocks (Figure 36).

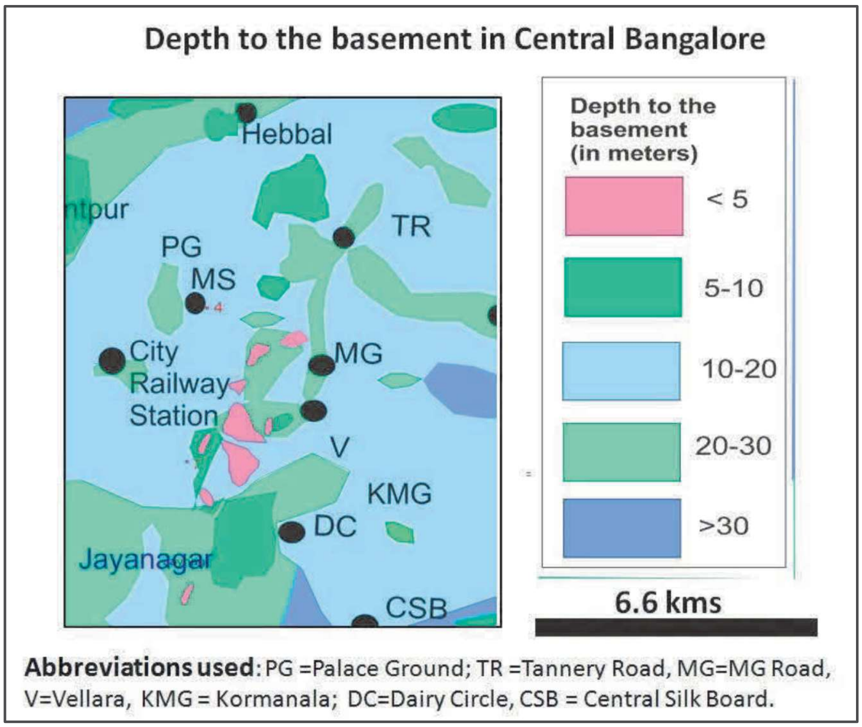


Figure 36: Depth to the basement in Bangalore area

The overburden comprises of filled-up soil and residual soil that rest over the rocks. Notwithstanding the local variations, which at times substantial, and dependent on the influence of local joint/fracture systems and the major drainage system, the overburden in Central Bangalore region recorded between 10-20m with sporadic lenses where basement lies between <5 m and up to 30m. Near Hebbal, the basement lies between 10-20m and for most parts along the alignment the basement is expected to be lying at this depth.

5.5.4 Description of Soil horizon:

Filled-up Soil: Very loose to loose, completely disturbed soil horizon at the surface is classified as 'Filled-up soil'. The layer comprises transported sand and sandy silt grains, organic materials and fragments of bitumen and concrete. Filled up material is very huge in places where reclaimed lands either from pre-existing lakes or abandoned stone quarries are converted for urban needs (housing, recreation etc). In cases where the pre-existing lakes are reclaimed, the top soil is dominated by silty-clay. On the other hand, where the reclaimed land represents a pre-existing quarry, the filled-up soil is largely represented by urban waste that was used as the land-fill. Proximal to the proposed road tunnel alignment, filled up soil largely found near southeast of Hebbal.

Soil Layer: Two units are considered to represent soil horizon in the area. These are (i) typical residual soil with original rock fabric completely destroyed, this represents soil Grade-6 of the weathering grades and (ii) intact friable soil, weakly cohesive, has fabric of parent rock, this represents completely weathered rock. The spatial distribution of soil in near Hebbal is shown in Figure 37.

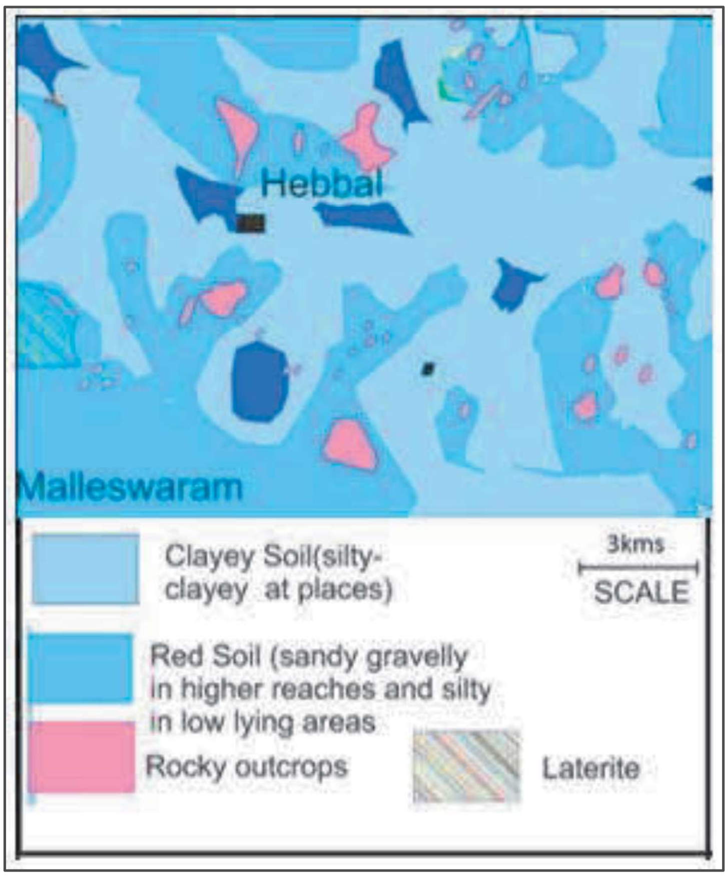


Figure 37: The spatial distribution of soil near Hebbal.

The typical residual soil layer along the tunnel alignment is dominated by the presence of two types of soils. These are (i) Grayish to brownish clayey soil to silty-clay soil and (ii) red soil which is sandy-gravelly in higher reaches and silty in low lying areas. The distribution of these two types of soil is very irregular, though the red-soil is seen to be more dominant where the rocky outcrops or boulders occur either on the surface or close to the surface and the clayey and silty clayey soil is more proximal to the areas of existing lakes Patches and lenses of loamy soil are not uncommon. The soil is formed with the complete in-place disintegration of parent bedrock material that has yielded the typical texture of the soil material.

The soil unit represented by completely weathered rock has the same soil composition and texture except that it is denser silty sand and gravelly sand and possess relict texture and fragments of the parent rock mass.

5.5.5 Description of Rock sequences:

As per the interpreted surface geological map, the north-south trending stretch of road alignment traverse through two major units. These are (i) from Hebbal to Lalbagh area, it transects mostly through a composite unit of granite and biotite-gneiss termed as Central Bangalore Granite-Gneiss (CBGG) unit, and (ii) from Lalbagh to Silk Board area the road tunnel traverses two variants of migmatites i.e (iia) arterite without intricate folds and (iib) arterite with intricate folds. Another smaller, albeit, important rock unit that the road tunnel traverse will be the ENE-WSW trending mafic dykes, mostly of dolerite/gabbroic composition. The N-S trending road alignment is likely to cross the dyke bodies in area to the south of Bangalore Palace.

5.5.5.1 Central Bangalore Granite-Gneiss unit

As the Road Tunnel Alignment is along the central ridge of Bangalore bulk, it traverses through the composite unite of granite and biotite-gneiss. The biotite-gneiss component of this unit possess intact foliations whereas the granitic units have very coarse grained equigranular, hypediomorphic granitic texture.

5.5.5.2 Arterite:

Arteritic migmatites have meso- to melano-cratic darker coloured rocks such as granodiorites/tonalities/diorite/amphibolites (paleosomes) injected by lighter quartzo-felspathic veins (aplite, granite and pegmatite; leucosomes). The two units display distinct banding. The latter being the product of intense degree of metamorphism and migmatisation. Two variants of arterites are reported. The arterite unit which is in contact with homophanous biotite gneiss is represented by dominantly homogeneous banded gneiss that seldom display any distinct zone of folding. The unit that occurs to the east of the latter display intricately folded structures. The folded variety is very well seen in Hulimavu, Adogodi and Silk board areas. These areas also possess concordant unaltered basic enclaves within this migmatite. Feldspathised and biotitised basic xenoliths are seen at Aduogodi, Hulimavu and Chikkanhaalli quarries, which are folded along with the enclosing migmatite.

5.5.5.3 Dolerite/gabbro dyke bodies

The ENE-WSW trending mafic dykes, that the road alignment is likely to cross are part of the ENE-WSW dyke swarm that has been mapped in west Central Bangalore. In other parts of the city, such dykes are seen at the surface as boulders of variable sizes.

5.5.5.4 Structures:

Three phases of structures, reported during regional studies, are likely to be present along the road tunnel. Sub-vertically dipping gneissic foliations recorded as axial planar to the early isoclinal folds (F1 parallel F2) are the most dominant structural fabric in the area. The other planar structures recorded in the area are the NE-SW to ENE-WSW trending fractures that are ubiquitous along the contact regions of different lithounits. The dyke rocks of the area are also seen to be compatible with these fracture systems.

Several lineaments have been mapped in Bangalore. Among these, the proposed c&c tunnel alignment cross ENE-WSW trending lineament; this is part of a regional lineament called Mandya-Chanpatna-Bangalore lineament; the road alignment will cross this lineament near Hebbal; it is likely that several subsidiary parallel lineaments related to this major lineament may also occur along the alignment.

5.6 TOPOGRAPHY SURVEY

5.6.1 Topographic Survey

5.6.1.1 Objective

The objective of the topographic survey is to generate a precise ground profile and capture existing features along the tunnel alignment corridor and its approaches, so that the design of the tunnel structure and associated works can be carried out accurately.

5.6.1.2 Survey Methodology:

The survey was carried out using a combination of Differential Global Positioning System (DGPS) and Total Station instruments.

Ground Control Points:

- Control points were established near Entry and Exit with the help of DGPS.
- Horizontal and vertical accuracy achieved was within ±10 mm.
- Coordinates were geo-referenced to WGS-84 datum and UTM projection.

5.6.1.3 Detailed Topographic Survey:

Detailed pick-up of ground features, road edges, utilities, trees, structures, and drainage features were done using Total Station/DGPS. Cross-sections were taken at 25 m intervals along straight sections and at 10 m intervals in curved or complex stretches. Spot levels were recorded at every 10 m in open terrain and closer spacing in uneven ground.

5.6.2 Survey Coverage:

The survey covered:

- Cut and Cover Tunnel alignment
- Approaches and ramps
- Utility corridors
- Adjacent structures, drains, and natural features.

5.6.3 Outputs:

- The contour map has been developed from the ground data collected during survey. These points were used in AutoCAD Civil 3d to create DEM surface and further contour at 1m interval has been created to prepare contour plan.

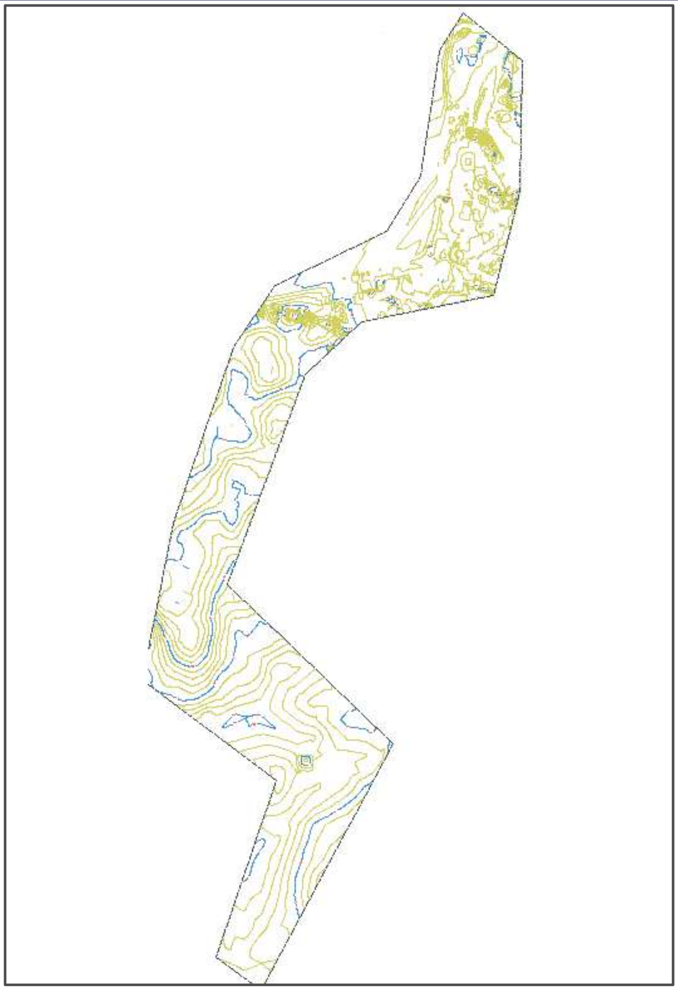


Figure 38: Snapshot of contour plan .

- Topographic map has been prepared from all features including buildings, road, electric poles, drains and all other available structure over surface within project corridor. These data has been further furnished in AutoCAD software in presentable form and accordingly topographic map has been developed.

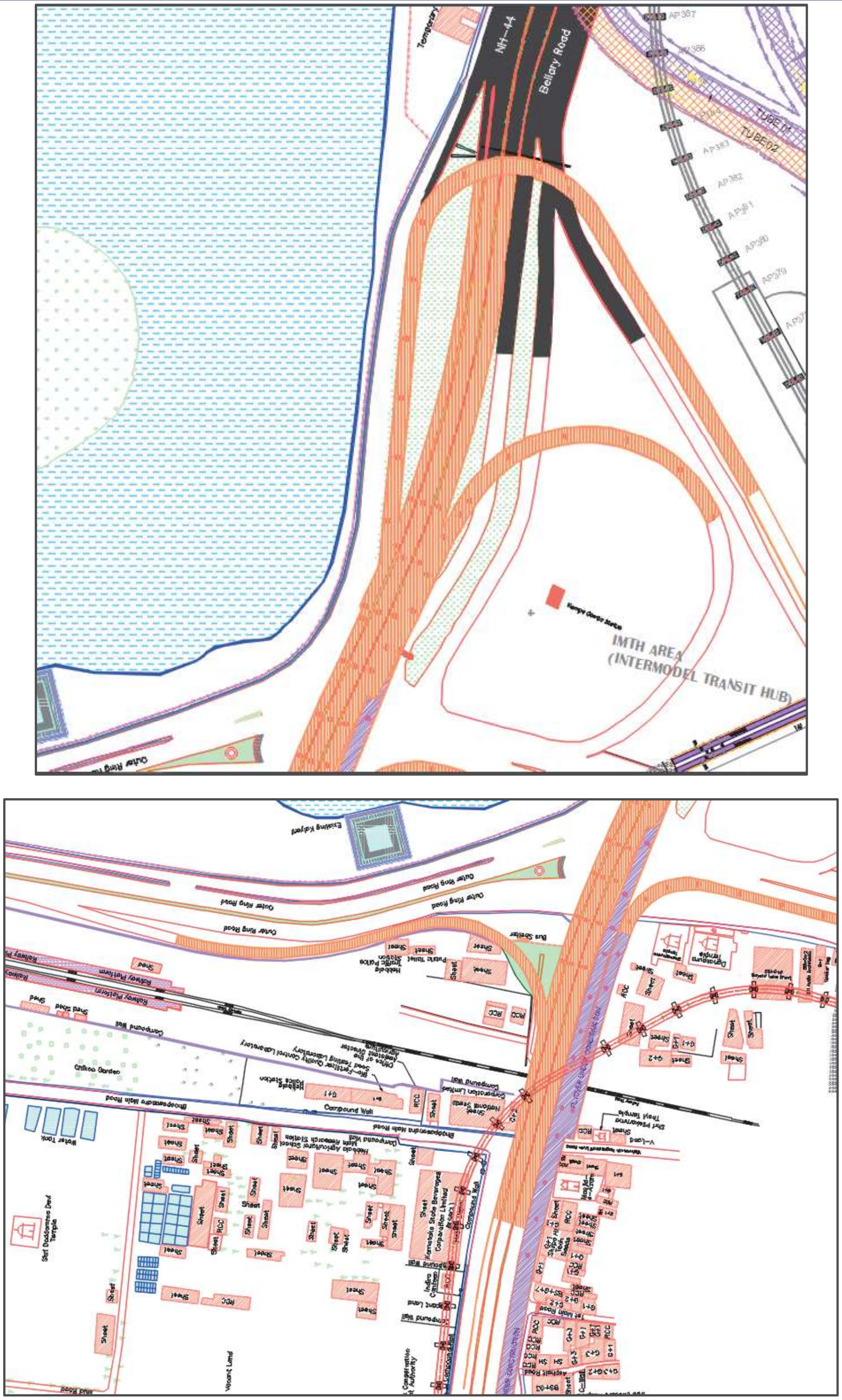


Figure 39: Snapshot of detailed topographic map .

5.7 GEOLOGICAL AND GEOTECHNICAL INVESTIGATION

Geotechnical Investigation are being carried out with the purpose to interpret subsurface ground conditions of the site and to present an evaluation and summary of the Rock and soil properties for design, awareness of the risks and to predict ground behaviour during construction.

The geological and geotechnical investigation of the project area has been planned and carried out in accordance with guidelines stipulated in the IRC: SP:91-2019 and IS:17883-2022 in addition to the collection of existing information/data.

The geological and geotechnical investigation carried out by DPR consultant are:

i. Collection and Study of Existing Information/ Data

ii. Geologic Foot Survey and Mapping

iii. Subsurface Investigations/ Exploratory Drilling and in-situ & laboratory testing of soil/rock samples.

The intrusive investigations by drilling boreholes are in process and expected to be completed shortly.

5.7.1 Collection and Study of the Existing Information/data

Several scientific papers along with geological maps of previous studies concerning different geological aspects (structural geology, litho-stratigraphy, geomorphology, slope instability, seismic hazard, etc.,) of the area, have been collected and critically reviewed. The geological data/information in these papers have been useful in understanding the general geological set up of the region, as well as geological assessment along the project corridor.

Some of the relevant references directly related to the project area have been list below:

- Anbazhagan, P., Thingbaijam K.K.S., Nat, S.K., Narendara Kumar, J.N, and Sitharam (2010) T. G Multi-criteria seismic hazard evaluation for Bangalore city, India. J. Asian Earth Sciences vol. 38, pp. 186-198.
- Balachandran,V (1978): Geological Mapping of Bangalore city. Unpub.Rep. GSI, Bangalore
- Bhaskar Rao, Y.J., T. Vijaya Kumar, B. Sreenivas, E.V.S.S.K. Babu(2020) A Review of Paleo- to Neoarchean crustal evolution in the Dharwar craton, Southern India and the transition towards a Plate Tectonic regime. Episodes Vol…, pages…
- Dasgupta, S., Pande, P., Ganguly, D., Iqbal, Z., Sanyal, K., Venaktraman, N.V., Dasgupta, S., Sural, B., Harendranath, L., Mazumadar, K., Sanyal, S., Roy, A., Das, L.K., Misra, P.S., Gupta, H., 2000. Seismotectonic Atlas of India and its Environs, Geological Survey of India, Calcutta, India.
- Ganesha Raj, K., Nijagunappa, R., 2004. Major lineaments of Karnataka State and their relation to seismicity: remote sensing based analysis. Journal of the Geological Society of India 63, 430–439.
- Harris, NBW and Jayram, S (1982): Metamorphism of Bangalore Cordierite Gneisses from Indian Archean.Lithos, vol 15, pp.89-98.

- Ramakrishnan, M., Viswanatha, M.N., and Swami Nath, J., (1976), Basement-cover relationships of Peninsular Gneisses with high grade schists and greenstone belts of southern Karnataka. Journal Geological Society of India, v. 17, pp. 97-111.
- Sitharam, T.G., Anbazhagan, P., 2007a. Seismic hazard analysis for Bangalore region. Natural Hazard 40, 261–278.Valdiya, K.S., 1998. Late quaternary movements and landscape rejuvenation in south-eastern Karnataka and adjoining Tamil Nadu in southern India shield. Journal of the Geological Society of India 51, 139–166.
- Detailed Project Report For Phase – 3a Of Bangalore Metro, Chapter 5: Civil Engineering And Alignment Details

5.7.2 Result of study of existing information/data

The desk analysis of available Literature/data allowed defining some basic aspects concerning geological configuration of the area that helped to prepare a first preliminary geological reference model (GRM) of the project area.

From the existing data/ investigations carried out by metro in the nearby area, following data has been utilized for preliminary analysis of sub-surface conditions along the project corridor:

S. No.	Bore hole no.	Location of Bore hole	Depth in soil (m)	Depth in rock (m)	Total depth of Bore hole (m)	Ground water table Position	Sub soil Strata Profile
1	1	Near by Kempe Gowda Statue and Hebbal Flyover	9	18.5	27.5	Nil	0-1.5-filledup soil 1.5-3-Soil 3-4.5-Completely disintegrated Weathered Rock 4.5-7.5 - Sample Not obtained 7.5-12- Soil 12-15 -Completely disintegrated Weathered Rock 15-16.5-Soft Rock 16.5-22.5 -Completely disintegrated Weathered Rock 22.5-24 -Soft Rock 24-27.5 - Hard Rock
2	2	Hebbal Flyover Service road	4.5	20.5	25	Nil	0-6 -Soil 6-21 -Completely disintegrated Weathered Rock 21-22 -Sample Not Obtained 22-25 -Hard Rock
3	3	Left side of IFAB (Floral Studio)	1.5	6	7.5	Nil	0-3 -Gravel 3-7.5- Hard Rock
4	4	Inside of Dairy Science College	3	5.1	8.1	Nil	1.5 -Gravel 1.5-4.5- Soil 4.5-8.1-Hard Rock
5	5	Inside Veterniary College	1.5	9	10.5	Nil	0-1.5 -Field up Soil 3-6 -Completely disintegrated Weathered Rock 6-10.5 Hard Rock
6	6	Indian Veterniary Research Center(Near Veterniary college station)	1.5	19.5	21	Nil	0-1.5-filledup soil 1.5-03-Soil 3-6-Completely disintegrated Weathered Rock 6-21 Soft Rock

Figure 40: List of existing boreholes nearby project alignment (*Source-BMRCL*) .

The information resulting from different literatures and documents gives only an “idea”, which was subsequently verified, analysed, rectified and detailed on the basis of the data collected during the geological foot survey & mapping and investigations.

However, collated basic information at this specific stage of the study proved to be useful to understand regional as well as local geological set up. It also helped to understand the litho-stratigraphic sequences prevailing in the project area. The information has been used in reconstruction of preliminary geological model of the project corridor. The preliminary model has been further used as reference during field mapping and has been rectified based on geologic data collected during field survey.

5.7.3 Geological Foot Survey and Mapping

The foot survey and mapping has been carried out by the team of expert geologists after preparation of preliminary GRM. The detailed geological survey has been carried out in the entire project corridor. Observations were noted during traverse for all rock outcrops, soils and overburden material. The geological traverse includes identification of rocks, Structural and weak features, soils/overburden, geomorphological setup prevailing in the project corridor.

The lithology dominating in the project corridor is granite biotite gneiss. Most of the stretch is covered with overburden/ soil with rock exposed at very few locations. The soil prevailing the project corridor are filled up soils and residual soil. The residual soil layer along the tunnel alignment is dominated by the presence of two types of soils. These are (i) Grayish to brownish clayey soil to silty-clay soil and (ii) red soil which is sandy-gravelly in higher reaches and silty in low lying areas. The thickness of overburden/soil varies significantly in the project corridor.

Based on the outcome of geological traverse, the GRM has been further updated. After getting inputs from the updated GRM, the alignment was optimized. After, finalizing the alignment, the sub-surface investigation in form of Geotechnical investigation/ core drilling commenced.

5.7.4 Subsurface Investigations/ Exploratory Drilling and in-situ & laboratory testing of soil/rock samples

The geotechnical investigation has been planned on the approved alignment. The Geotechnical investigations aim to validate the geotechnical interpretations made on the basis of above investigations and available data for the project alignment.

The information on following aspects are being captured by sub-surface investigation along the alignment.

- Stratification and sub surface profile
- Soil and intact Rock characteristics
- Rock mass condition (Blockiness, Weathering)
- Discontinuity Details (Type, orientation, infilling, spacing, persistence)
- Structural features like fold, faults etc.
- Ground water levels and ground permeabilities

In general, the GT investigations on the soil and rock samples carried out are as per relevant Codes as listed below:

Drilling Investigations:

- IS 5313 : 1980 Guide for core drilling observations
- IS 4464 : 1985 Code of practice for presentation of drilling information and core description information investigation
- IS 9143 : 1980 Code of practice for indexing and storage of cores
- IS 4078 : 1980 Code of practice for indexing and storage of drill cores
- IS 6935 : 1973 Method for determination of water level in a bore hole.
- BS 5930: Code of Practice for Site Investigations.

In-situ testing:

- IS 2131 : 1981 Method of Standard penetration test for soils
- IS 5529 : (Part 1) : 1985 In situ permeability testing in overburden
- IS 5529 : (Part 2) : 2006 In situ permeability testing in bed rock
- IS 15681 : Geological exploration by geophysical method (seismic refraction)

Laboratory testing:

- IS 2720: Part 1:1983 Preparation of dry soil samples for various tests.
- IS 2720: Part 2:1973 Determination of water content
- IS 2720: Part 3-1:1980 Determination of specific gravity, fine grained soils.
- IS 2720: Part 3-2: 1980 Determination of specific gravity, Fine, medium and coarse-grained soils.
- IS 2720: Part 4:1985 Grain size analysis.
- IS 2720: Part 5: 1986 Determination of Liquid and Plastic limit
- IS 2720: Part 10: 1991 Determination of unconfined compressive strength
- IS 2720 Part 11: 1993 Determination of the Shear Strength Parameters of a specimen tested in unconsolidated, undrained triaxial compression without the measurement of pore water pressure.
- IS 2720: Part 12: 1981 Determination of shear strength parameters of soil from consolidated undrained triaxial compression test with measurement of pore water pressure
- IS 2720: Part 13: 1986 Direct Shear Test
- IS 2720: Part 17: 1986 Laboratory Determination of Permeability
- IS 2720: Part 22: 1986 Determination of organic matter

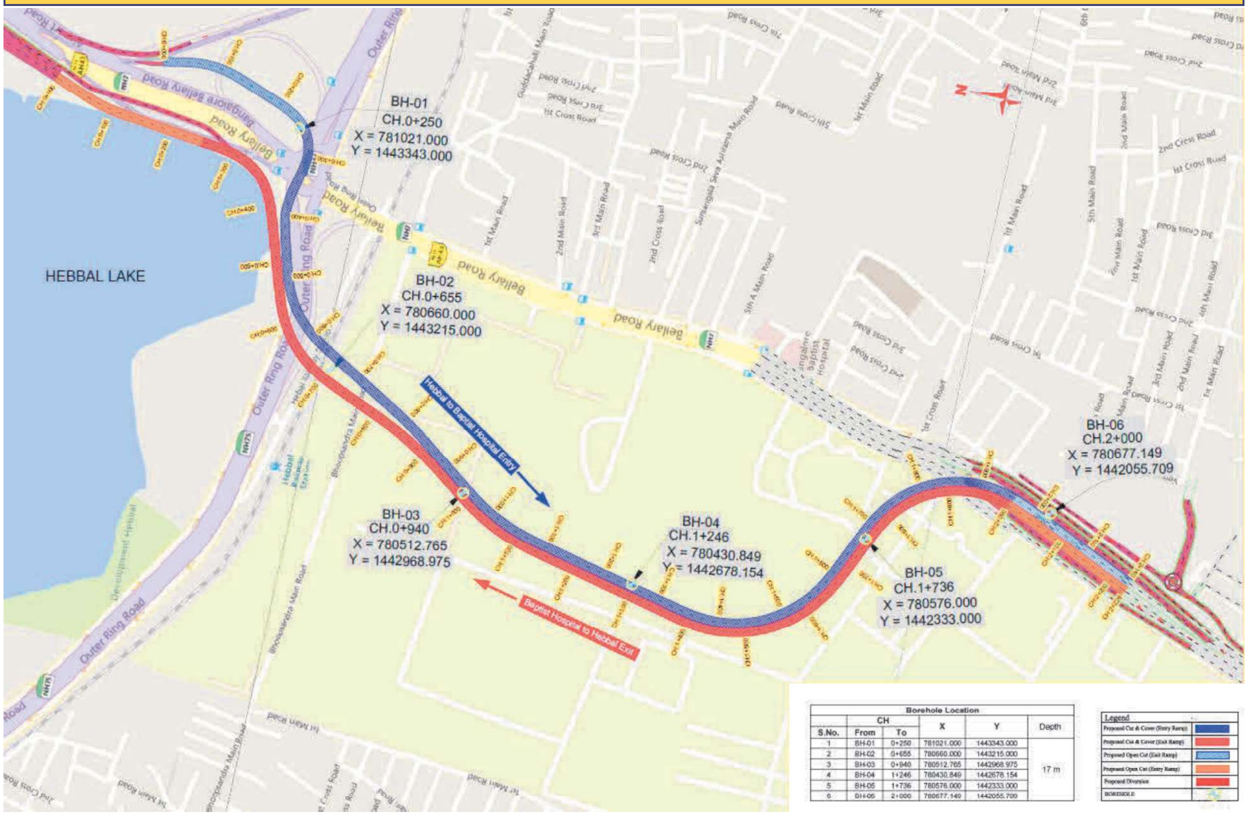
- IS: 1498-1970 Classification and identification of soils for general engineering purposes
- IS 3025: Part 32: Determination of Ph value
- IS 3025: Part 11: Determination of total soluble sulphate
- IS 3025: Part 24: Determination of chloride content
- IS 13030-1991: Bulk density & water absorption of rock
- IS 8764-1998: Point Load Strength of rock
- IS 9143: Unconfined compressive strength of rock.

5.7.4.1 List of Boreholes executed along road alignment

The details of borehole locations executed at site along the proposed alignment are as follows.

Table 46: Proposed Bore Hole Locations

Sl No	Borehole No	Chainages	Structure Name/ Location	Layer thickness of sub-soil stratification			Total Depth (m)
				Soil strata	Refusal strata	Rock with core recovery	
01	BH-01	0+250	3 Lane Twin Road	0.0-1.5 4.5-14.0	14.0-15.0	1.5-4.5	15.0
02	BH-02	0+600		2.0-15.0	-	0.0-2.0	15.0
03	BH-03	0+940		0.0-15.0	-	-	15.0
04	BH-04	1+246		0.0-13.5	13.5-15.0	-	15.0
05	BH-05	1+736		0.0-2.0	2.0-4.5	4.5-15.0	15.0
06	BH-06	2+050		0.0-8.0	8.0-15.0	-	15.0



Borehole Location

S.No.	CH From	CH To	X	Y	Depth
1	BH-01	0+250	781021.000	1443343.000	17 m
2	BH-02	0+655	780660.000	1443215.000	
3	BH-03	0+940	780512.765	1442968.975	
4	BH-04	1+246	780430.849	1442678.154	
5	BH-05	1+736	780576.000	1442333.000	
6	BH-06	2+000	780677.149	1442055.709	

Figure 41: Location map of proposed borehole along the proposed road alignment.

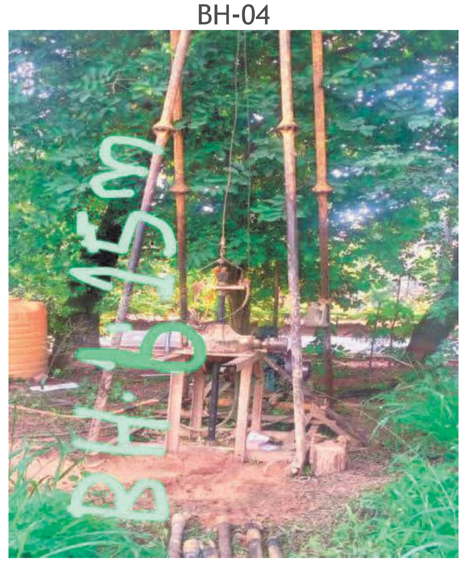
BH-01

BH-02

BH-03

BH-04

BH-05



BC-06

Figure 42: Photograph showing borehole location along proposed alignment

5.7.4.2 Status of Geotechnical Investigation

The geotechnical investigation along proposed road alignment have been completed. The summary of geotechnical investigation is as follows:

Table 47: Summary of Geotech Investigations

Sl No	Borehole No	Location of Borehole	Depth in Soil (m)	Depth in Rock/soft rock (m)	Total Depth of Borehole (m)	Ground Water Table Position from GL (m)	Sub-Soil Strata Profile
1	BH-01	0+250	11.0	4.0	15.0	8.0	0.0m to 1.5m- Soil 1.5m to 4.5m-

Sl No	Borehole No	Location of Borehole	Depth in Soil (m)	Depth in Rock/soft rock (m)	Total Depth of Borehole (m)	Ground Water Table Position from GL (m)	Sub-Soil Strata Profile
							Boulders 4.5m to 14.0m- Soil 14.0m to 15.0m- Soft Rock
2	BH-02	0+600	13.0	2.0	15.0	5.5	0.0m to 2.0m- Boulders 2.0m to 15.0m- Soil
3	BH-03	0+940	15.0	-	15.0	2.0	0.0m to 15m- Soil
4	BH-04	1+246	13.5	1.5	15.0	5.5	0.0m to 13.5m- Soil 13.5m-15.0m- soft rock
5	BH-05	1+736	2.0	13.0	15.0	9.0	0.0m to 2.0m- Soil 2.0m-4.5m- soft rock 4.5m-15.0-rock
6	BH-06	2+050	8.0	7.0	15.0	3.5	0.0m to 8.0m- Soil 8.0m to 15.0m- Soft Rock

Figure 43: Photograph showing soil/rock sample obtained from boreholes

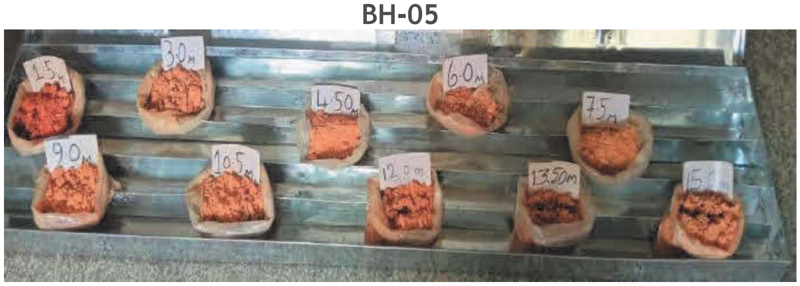
BH-01

BH-02

BH-03

BH-04

BH-05



BH-06

5.8 GEOTECHNICAL CONDITION ALONG THE PROPOSED ROUTE ALIGNMENT

On the basis of information available on the adjacent project and investigations carried out, geotechnical conditions have been interpreted as follows.

5.8.1 Soil Types:

The soil consists of red/brownish/grey sandy to silty soil mixed with boulders. The depth of soil strata varies from 2m to 15m from borehole to borehole.

Grain size analysis on samples from borehole depths up to 15 m from ground surface, suggested dominantly silty sand with patches/ layers of sandy lean clay towards Hebbal side. Occasional layers of sand/silt with gravel is also noticed at few places.

1) Index properties

Silty sand soil samples recorded low plasticity Index (<20%) whereas, the sandy clay samples recorded plasticity up to 40%

The median values of soil samples for their Atterberg limits and Weight properties are as below.

Table 48: The median values of soil samples for their Atterberg limits and Weight properties

Soil Type	LL%	PL%	PI%	Blk Dn. gm/cc	In situ Moisture content %	Sp. Gr.
Silty Sand	34	12	8	1.91	7.95	2.63
Sandy Fat Clay	59	19	40		9.56	2.61
Sandy Lean Clay	38	17	21	1.85	15.78	2.61

2) Field SPT

The SPT values appeared to vary and related to the depth of the bedrock.

Table 49: Table showing Field SPT Values against depth

Depth	SPT N- Value					
	BH-1	BH-2	BH-3	BH-4	BH-5	BH-6
1.5	20		7	7	25	35
3		21	10	12	Refusal	Refusal
4.5		16	16	16	Refusal	Refusal
6	15	21	24	22	Refusal	Refusal
7.5	24	22	26	29	Refusal	Refusal
9	31	28	35	23		
10.5	36	30	21	35		
12	44	31	27	Refusal		
13.5	Refusal	Refusal	38	Refusal		

From the SPT value recorded, the inference of soil strata can be done as follows:

- **Top 1.5-3 m**: Loose to medium soils in BH-2, 3, 4 (weak bearing capacity, high settlement risk).
- **Mid depths (~5-10 m)**: Medium dense layers in most boreholes (N ~15-25).

- **Below ~10 m**: Generally **dense strata (N ~30–40)** across all boreholes.
- **Rock/Refusal**: Present in **BH-6 from ~3 m** → possibility of highly dense strata/shallow rock profile locally.

5.8.2 Intact Rock

Intact rocks collected from boreholes were tested for their mechanical properties. The rocks along the alignment is generally identified as granite gneisses which is observed in BH-5. In all other boreholes, only completely weather to disintegrated rock with core recovery as nil and SPT N-value as refusal has been recorded.

The specific gravity of the rocks is found to be around 2.6. The rocks being of plutonic igneous origin, they are generally not porous in their fresh un-weathered state. With increase in weathering, they develop some porosity and also attract moisture content. The moisture content is observed to be between 0.15% to 0.27%.

The range of UCS values were observed to be approximately between 11.56 MPa to 22.45MPa which states the weathering condition of rock mass as highly weathered.

CHAPTER 6 : IMPROVEMENT PROPOSALS

6.1 Summar

This chapter describes the various improvement proposals proposed for this project. These improvement proposals are based on the findings of various engineering features carried out on the project roads such as Traffic Survey and Analysis, Inventory Data and Geotechnical Investigations.

The improvement proposals for proposed widening include the provisions for the following major items:

a. Project Geometry
b. Typical Cross Sections
c. Ventilation
d. Electrical and Lighting
e. Drainage

6.2 Geometric Design

Geometric design of a highway is the process whereby the layout of the road in specific terrain is designed to meet the needs of the road users keeping in view the road function, type and volume of traffic, potential traffic hazards and safety as well as convenience of the road users. The principal areas of control for fulfilment of this objective are- horizontal alignment, vertical alignment and the road cross-section.

The Consultants have referred to the latest IRC publications and MORT&H circulars regarding design standards for National Highways in India. After careful review of all available data and requirements of the project road the proposed Design Standards for adoption on the project road have been recommended.

6.2.1 Levels of Service (LOS)

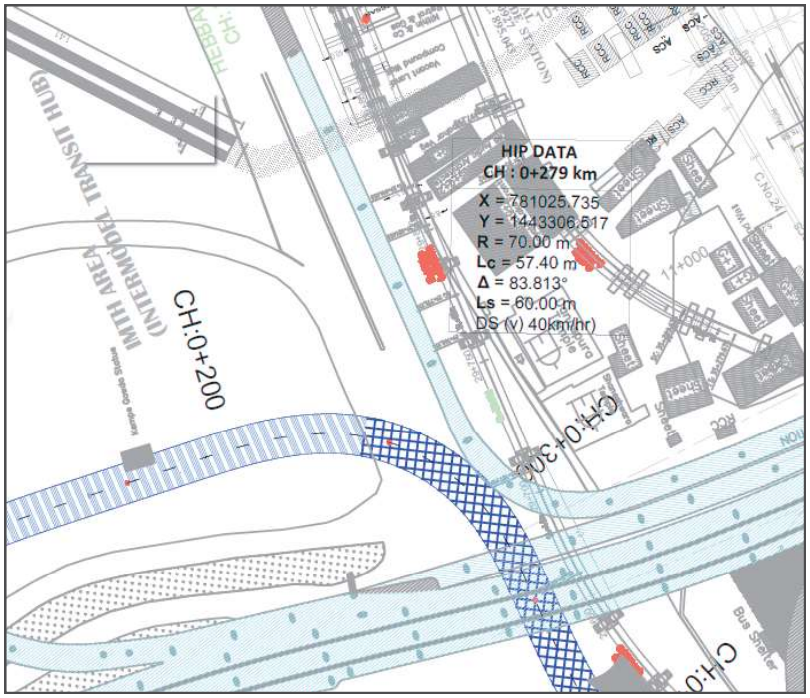
Considering the importance of the highway, presence of urban land use and volume of traffic a level of service up to LOS- 'C' may be acceptable as per IRC:106-1990/ Highway Capacity Manual (Indo-HCM)-2012-17 published by the CRRI.

6.2.2 Design Speed

The project road passes through plain terrain. For geometric design of the highway, design speed is used as an index which links road function, traffic flow and terrain. An appropriate design speed should correspond to general topography and adjacent land use. The speed selected for design should also cater to travel needs and behavior of the road users.

The design speed corresponding to the plain terrain and urban scenario as Per IRC 86-2018.

The project geometry has been designed to cater for a speed of 60 Kmph. At one location the speed is restricted to 40 kmph, due to unavailability of land/space and presence of existing major structures.



6.3 Typical Cross Section (TCS)

The project is proposed to be a 6 lane bi directions underpass in which major portion of project is to be constructed as a box structure (Cut & Cover Sections), while its approaches are proposed as open cut ramps.

The salient features of the cross-sectional elements are provided below

Table 50: Cross Sectional Details

Sr. No.	Description	Details
1	Design Speed	60 Kmph
2	Lane Configurations	3+3 Lanes
3	Carriageway Width for 3 Lanes	10.5 m
4	Kerb Shyness	500 mm
5	Crash barrier	500 mm
6	Single Lane width	3.5 m
7	Walkway	750 mm
8	Maximum Vertical Gradient Adopted	4.8 %
9	Maximum Superelevation	5%
10	Minimum Radius of Horizontal Curve Adopted	60 m

There are two sections in Open Cut

- 6-Lane combined Cross Sections i.e., TCS-4
- 3-lane Uni directional Section i.e., TCS-1, TCS-1A

Then, there is also 2 sections in Cut and Cover

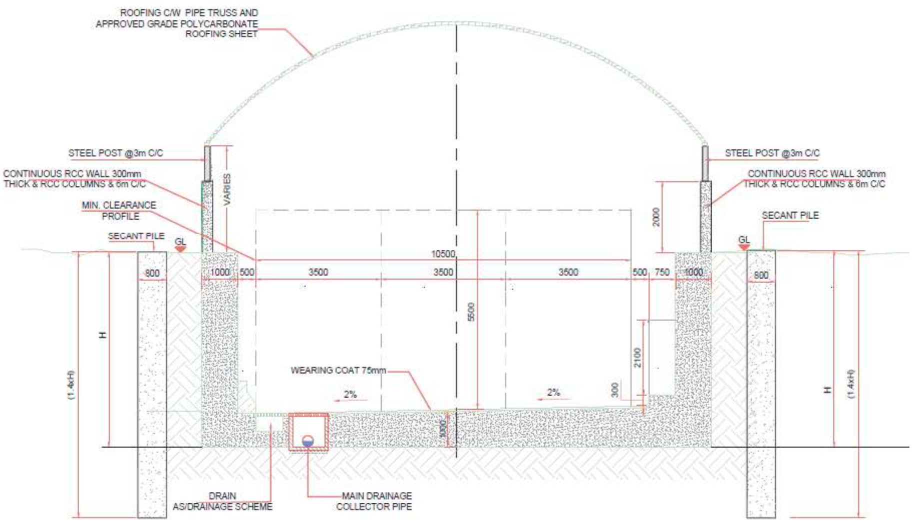
- 6-Lane combined Cross Sections i.e., TCS-3
- 3-lane Uni directional Section i.e., TCS-2, TCS-2A

The TCS Schedule of the projects is given below followed by their Typical Cross Sections

Table 51: TCS Schedules

Hebbal to Baptist Hospital Entry				
Sr. No.	**Form**	**To**	**Length (m)**	**TCS Type**
Hebbal to Baptist Hospital Entry				
1	00+000	00+250	250	TCS-1
2	00+250	00+627	377	TCS-2
3	00+627	00+647	20	**As per GAD**
4	00+647	00+950	303	TCS-2
5	00+950	01+950	1000	TCS-3
6	01+950	02+180	230	TCS-4
	Total Length		**2180**	

Baptist Hospital to Hebbal Exit				
Sr. No.	**Form**	**To**	**Length (m)**	**TCS Type**
1	00+000	00+250	250	TCS-1A
2	00+250	00+565	315	TCS-2A
3	00+565	00+686	121	TCS-2
4	00+686	00+706	20	**As per GAD**
5	00+706	01+000	294	TCS-2
6	01+000	02+000	1000	TCS-3
7	02+000	02+228	228	TCS-4
	Total Length		**2228**	



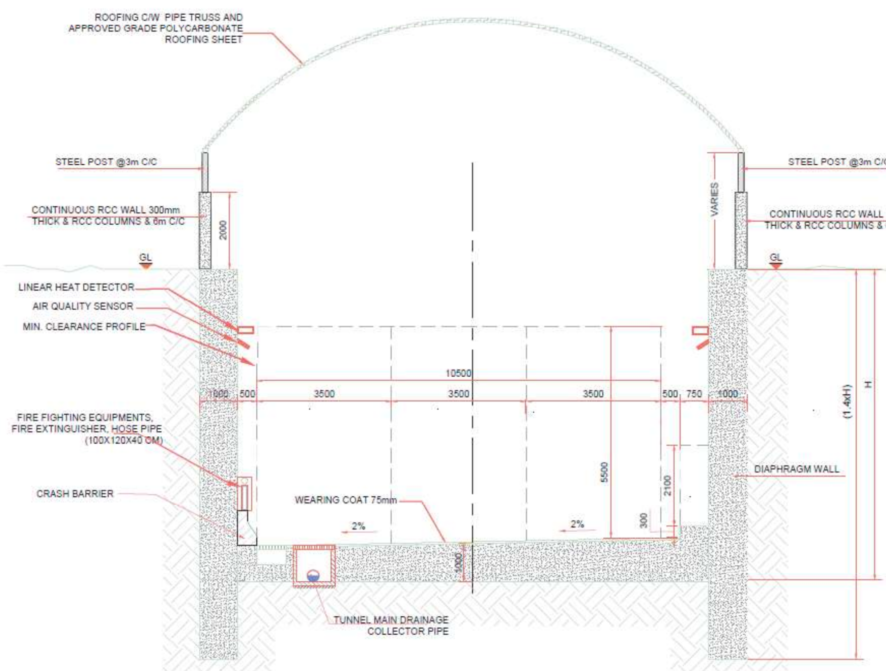
TYPICAL CROSS SECTION-01
OPEN RAMP (3 LANES)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:

GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D



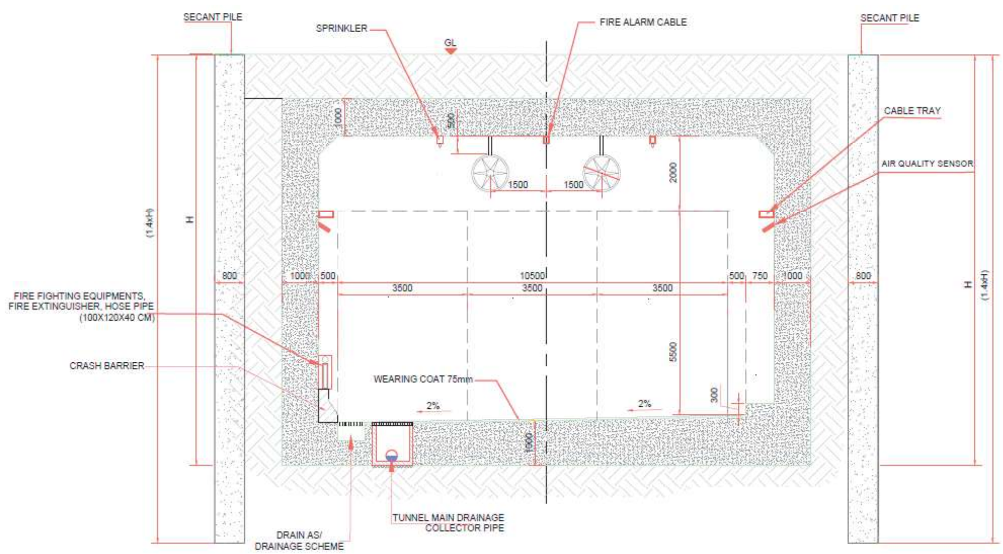
TYPICAL CROSS SECTION-01A
OPEN RAMP (3 LANE) WITH D WALL
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:

GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D



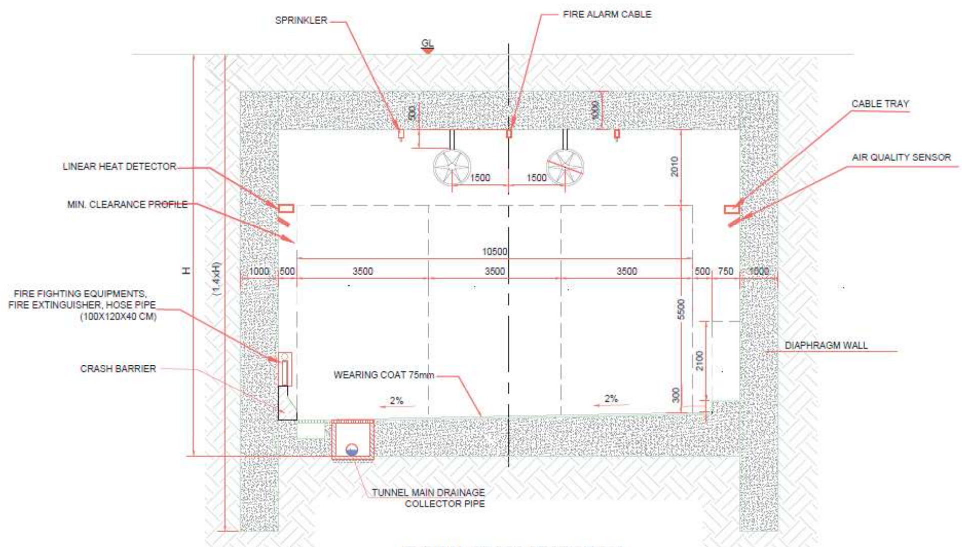
TYPICAL CROSS SECTION -02
CUT/COVER SECTION (3 LANES)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN. DETAILED DESIGN OF LINING SHALL BE DONE BY CONTRACTOR.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:

GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D

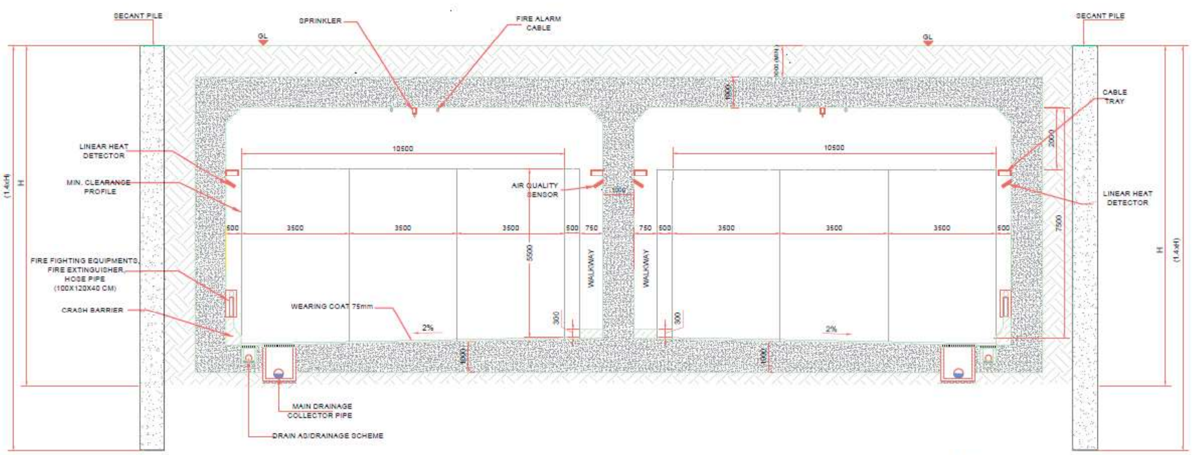


TYPICAL CROSS SECTION-02A
CUT/COVER SECTION (3LANE) WITH D WALL
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTORS DETAILED DESIGN. DETAILED DESIGN OF LINING SHALL BE DONE BY CONTRACTOR.
3. SIZING AND DETAILS OF CRASH BARRIER, DRAINAGE , UTILITY PIPE TRENCH ETC . MAY CHANGE AS PER CONTRACTORS DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWING SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS:
GRADE OF CONCRETE - M35
GRADE OF STEEL Fe550D



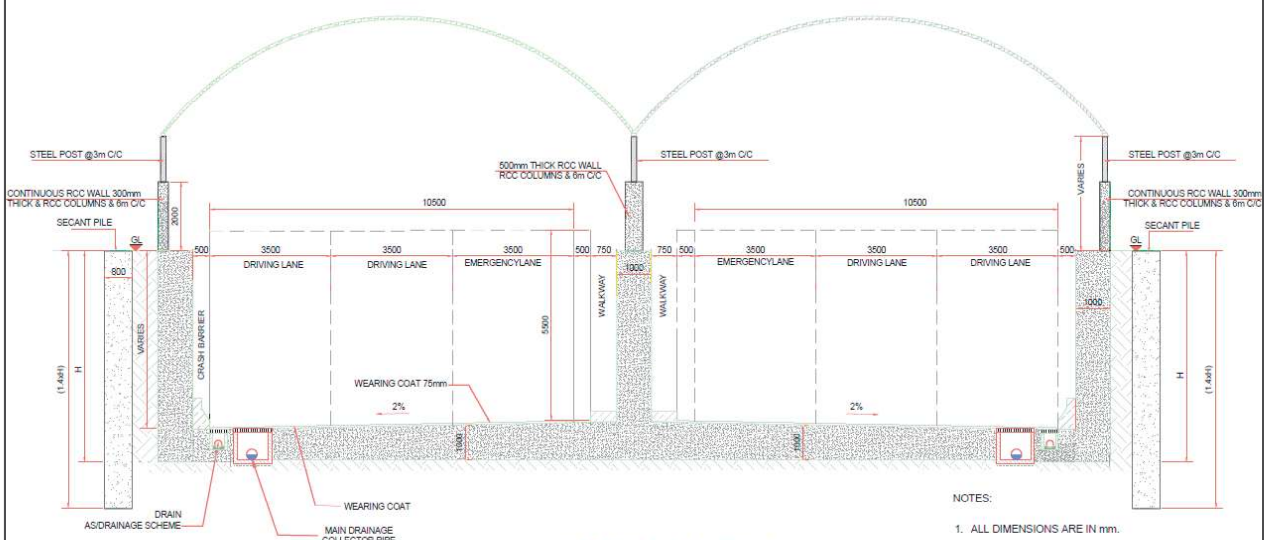
TYPICAL CROSS SECTION-03
CUT AND COVER (3 LANE+MEDIAN WALL+ 3 LANE)
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
3. SIZING AND DETAILS OF TYPICAL DETAILS OF CRASH BARRIER , UTILITY PIPE TRENCH , MAIN DRAINAGE ETC. MAY CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN .
5. DRAWINGS SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS: -

GRADE OF CONCRETE -M35 ,
STEEL GRADE Fe550D



TYPICAL CROSS SECTION -04
OPEN RAMP SECTION 3LANE+MEDIAN WALL+3LANE
SCALE 1:50

NOTES:

1. ALL DIMENSIONS ARE IN mm.
2. THE STRUCTURAL DIMENSIONS SHOWN ARE INDICATIVE AND SUBJECTED TO CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
3. SIZING AND DETAILS OF TYPICAL DETAILS OF CRASH BARRIER, UTILITY PIPE TRENCH, MAIN DRAINAGE ETC. MAY CHANGE AS PER CONTRACTOR'S DETAILED DESIGN.
4. WALKWAY CAN BE PLANNED ON EITHER SIDE OF THE ROAD AS PER DETAILED DESIGN.
5. DRAWINGS SHALL BE READ IN CONJUNCTION WITH THE PROJECT SPECIFICATIONS AND CONTRACT PROVISIONS.

MATERIALS: -
GRADE OF CONCRETE -M35, STEEL GRADE Fe550D

6.4 Ventilation

There are mainly two types of ventilation systems exist:

1. Natural ventilation:
2. Mechanical ventilation

The guidelines provided in "IRC_SP 91-2019" section 5.2 suggests that the mechanical ventilation system is required for the tunnel lengths/section lengths more than 500 m. The length of the tunnel tube of the proposed tunnel is larger than 500 m. Therefore, the mechanical ventilation system will be considered for the design. This ventilation systems mainly are of two types:

1) Longitudinal: This is the simplest tunnel ventilation system, and the most used nowadays, and it consist mainly in developing an air flow inside the tunnel by means of jet-fans or Saccardo nozzles, so that fresh air comes in at one side and polluted air / smoke goes out through the other end of the tunnel. According to IRC_SP91-2019 section 5.2, this system is suitable to use for the tunnel lengths of 500 m to 4000 m with light traffic density. However, this system needs to be provided with intermediate shafts for massing exchange of exhaust with fresh air.
2) Transverse:
    - Fully transverse: A fully transverse system consists in 2 different ducted ventilation systems, one for fresh air injection (preferable at floor level) and another for exhaust (at the ceiling), evenly distributed along the tunnel. This system is the best for contaminants control. Its main disadvantage is the high cost involved due to the complex and large civil infrastructures needed (shafts, ventilation buildings, ducts). However, practically there is no limit to the tunnel length to use this system. For the longer tunnel lengths with heavy traffic, this system is suitable.
    - Semi transverse: In this case there is only a ventilation duct along the tunnel that can work either injecting fresh air for contamination control or exhausting smoke in a similar way as a transverse system. This system needs to be provided with intermediate shafts for massing exchange of exhaust with fresh air more frequent than fully transverse system. As per IRC_SP-91, 2019 section 5.2, the semi-transverse systems are required to have shafts installed at every 3 km.

Based on the project requirements both tunnel tubes are proposed to have longitudinal ventilation systems. In these sections, the air flow under normal operating conditions will be in the direction of traffic

It is important to note that, the consideration of the transverse and semi-transverse ventilation system for the main tube sections is rules out due to tube lengths. (Since Cut and cover section length is 1700 m and 1750 m in Tube 1 and Tube 2)

The main tunnel tubes will be connected through cross passage doors at an interval of 500 m for air flow as well as people escape in a fire event (Item 8 in Annexure B of IRC-SP91, 2019; Note 2 in Section 2.8.2.5 of IRC-SP91, 2010).

The design calculations to estimate the fresh air flow requirement and the number of fans for both normal operation and for fire scenario for these sections are discussed hereafter in Ventilation Chapter.

6.5 Electrical, Lightning, SCADA and others

The details of Electrical System, Lighting system, SCADA, CCTV Systems is explained in later parts of the report.

6.6 WATERPROFING AND DRAINAGE SYSTEM

6.6.1 Waterproofing System

Considering the urban environment, the c &c tunnels in this project shall be designed as watertight (tanked system) that means ground water is not allowed to drain. Different approaches for waterproofing can be proposed during detailed design by contractor. However, depending on the construction type the following options would remain viable

a. Cut & Cover and Ramps – All C&C tunnels and Ramps are proposed to have cast in situ box/ U structure. Water tightness of structure can be achieved by application of waterproofing membrane on the external boundary of structure and/or with addition of waterproofing admixture. All construction joints to be treated with water stop bars.

Project specifications shall be followed for minimum requirement for various waterproofing system.

6.6.2 C &C Tunnels Drainage System

The c&c tunnel drainage system shall cover all sorts of water which may reach the tunnels such as road surface spillage, cleaning water, ground water seepage, firefighting or rainwater etc. It is important to control the spills at source level, however, tunnels cannot be assumed dry at all times. Therefore, continuous drainage shall be provided to collect those water and channelize it to the designated sumps from where it can be mechanically discharged to nearest municipal drains through the project shaft. A typical arrangement for drainage system has been included in the DPR however Contractor shall carry out the detailed design to estimate the amount of water for which drainage system shall be designed and sizing of each component shall be elaborated.

The tunnel drainage scheme has following features

1. **Drain and sumps in Open Ramp zone**: the entry of surface ground water shall be restricted by appropriate measures in at grade highway design so that it does not reach the falling grade of ramp area and unnecessarily increase the drainage efforts of tunnel. Also, the canopy roof structure shall be installed to minimize the entry of rainwater. Still some amount of rain water and ground water seepage can find access to ramp area and same shall be collected in the side drain of ramp. A central drain in case required, may also be constructed. A sump of suitable size shall be constructed at the interface of ramp and cut & cover section and water from this sump can directed to nearest municipal drain by pumping.

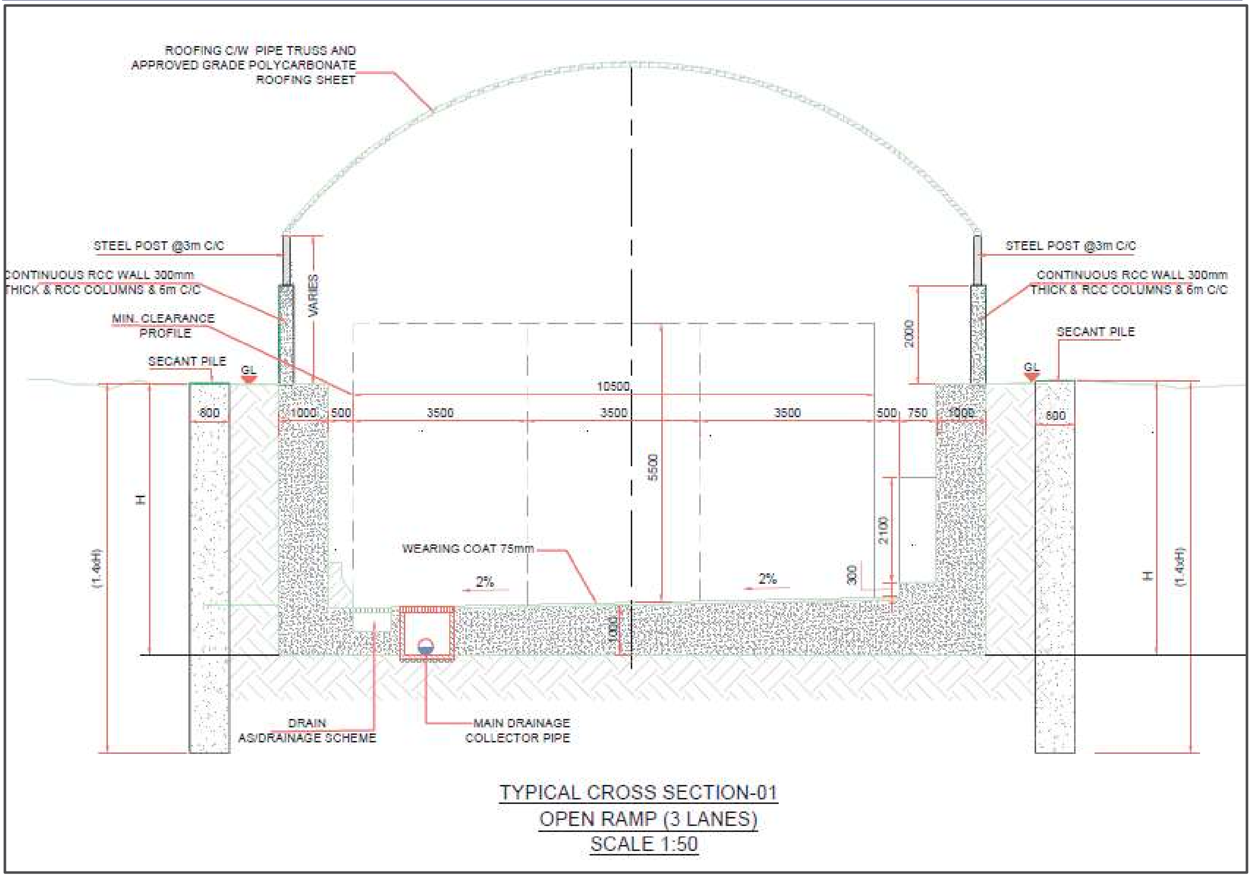


Figure 44: Typical drainage arrangement of Ramp area

The main drainage pipes shall remain buried in the base slab of ramp section. However, for maintenance purposes manholes at the spacing between 50 to 75m should be planned, the manhole opening size of minimum 400mm x 400mm or as designed by the contractor can be utilized. All ramp sections of main tunnels and entry/ exits proposed to have drainage arrangements of similar kind.

2. **Drainage in Cut & Cover tunnels:** The cut & cover section can expect ground water seepage and road spillage from cleaning, running vehicles or firefighting. The side drainage shall run along the Cut & cover tunnels to collect the water. A central drain connecting the surface drain to carry water along the C&C stretch is proposed. The central drain shall be a covered drain which will have connection to sump situated at lowest points along the c & c tunnel. Sump shall be equipped with riser pipe and pump to drain the accumulated water to the surface. The water from sump shall be drained to nearest municipal drain through the shafts.

   The pipe and manhole arrangement will remain similar to ramp section that means the manhole spacing between 50 to 75m with a size of minimum 400mm x 400mm. The side drain should be connected with central drain at every manhole point.

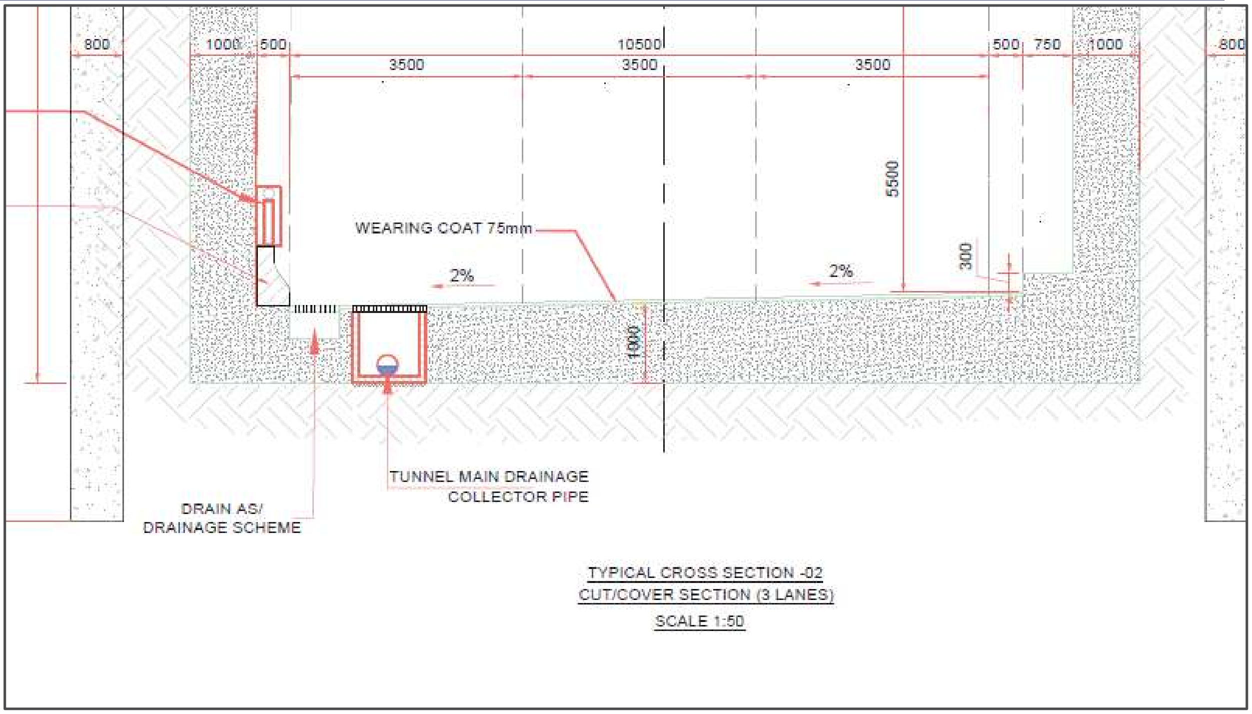
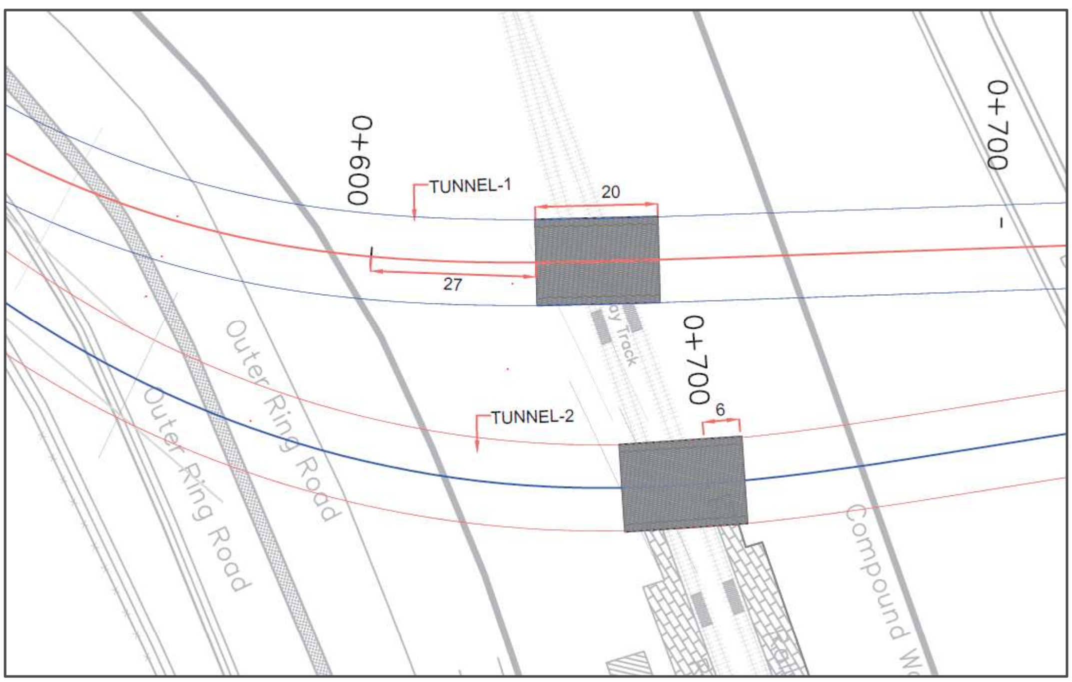
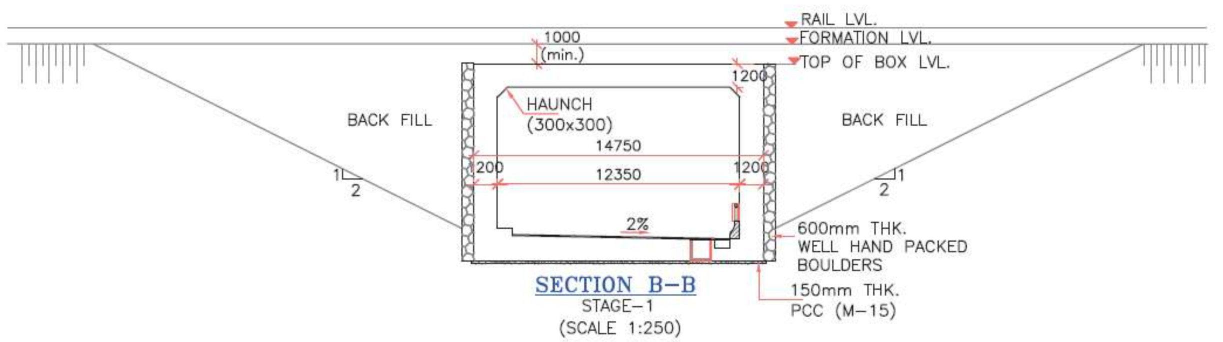


Figure 45: Typical drainage arrangement of C&C tunnels

6.7 Methodology for Box Pushing at Railway Line

The construction of RUB will be done in 2 Stages by box Pushing method. The first stage will be done in Tunnel-1 after that the second stage will be done in Tunne-2. A brief description of methodology is detailed below.



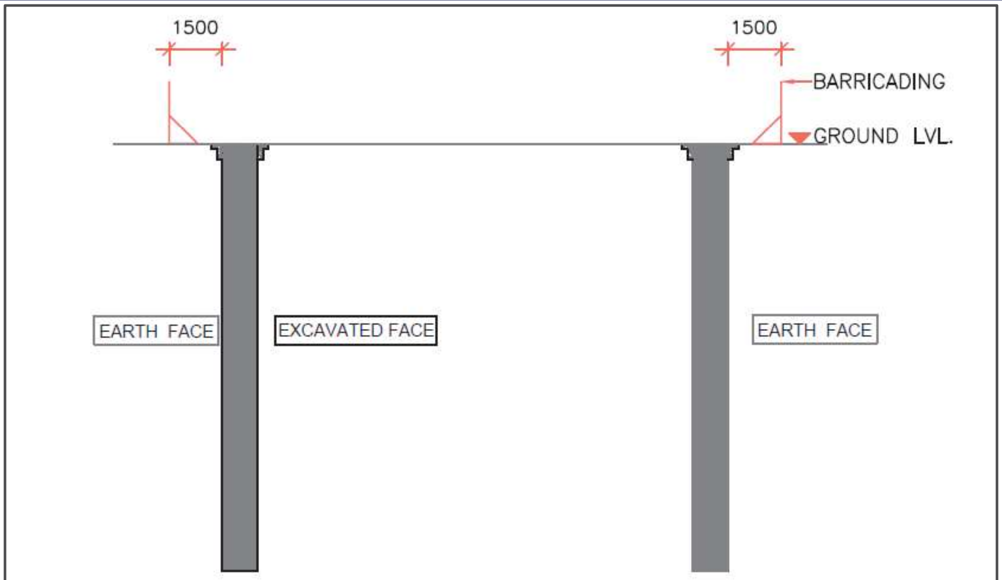


STAGE-1

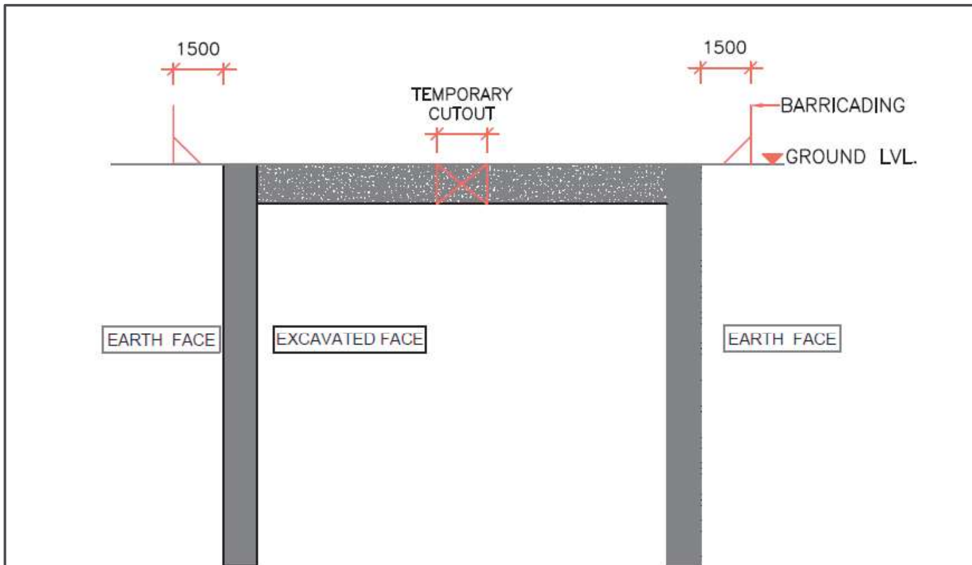
1. EXCAVATION ADJACENT TO THE TRACK
   (I) EXCAVATION EDGES DONE UP TO THE FOUNDATION LEVEL OF THE BOX TACKING SUFFICIENT CARE FOR SAFETY OF RUNNING TRACK.
2. PREPARATION OF CASTING BED
   (I) CASTING BED SHOULD BE PREPARED WITH SKID CONCRETE LAYER ON TOP WHICH HELPS IN THE PUSHING OPERATION OF THE BOX.
3. CASTING OF THE CONCRETE BOX
   (I) THE CONCRETE BOX SHOULD BE CAST IN–SITU ON THE CASTING BED.
4. FIXING TEMPORARY GIRDERS
   (I) TEMPORARY GIRDERS SHOULD BE FIXED UNDER THE RAILWAY TRACK AFTER TAKING SUITABLE DURATION BLOCK.
   (II) OPERATION OF TRAINS CONTINUES OVER THESE TEMPORARY GIRDERS.
5. PUSHING OF THE PRECAST CONCRETE BOX
   (I) SOIL UNDER THE RAILWAY LINE SHOULD BE CAREFULLY EXCAVATED SO THAT TEMPORARY GIRDERS REMAIN INTACT FOR A SUITABLE DURATION AND THE TRACK BLOCK IS CLEARED.
   (II) THE PRECAST CONCRETE BOX SHOULD BE PUSHED UNDER THE RAILWAY TRACK USING HYDRAULIC JACKS AND CRANES.
6. REMOVAL OF TEMPORARY GIRDERS
   (I) AFTER THE BOX IS SUITABLY POSITIONED, THE TEMPORARY GIRDERS SHOULD BE REMOVED, AND THE SAME TRACK PANELS SHOULD BE RE–LAID OVER THE BOX IN THE SAME BLOCK.

6.8 Methodology for Diaphragm Wall Construction

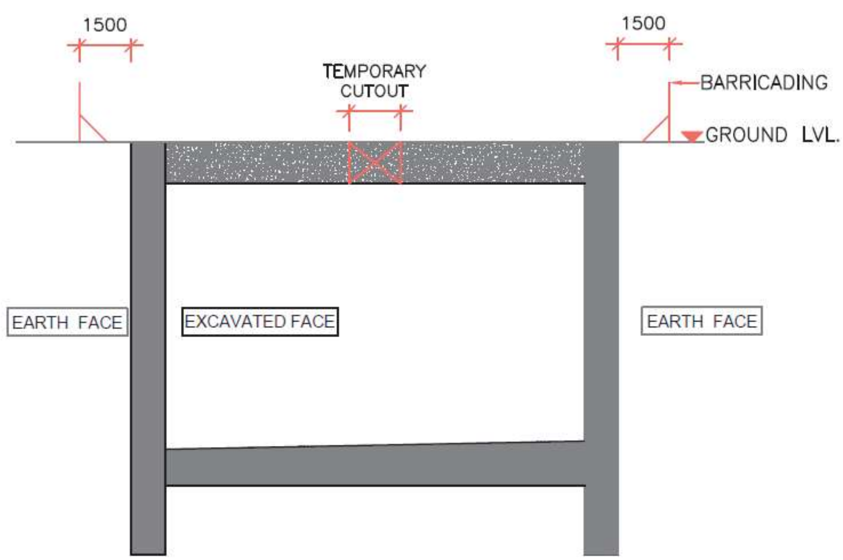
The box structure near the Hebbal lake will be constructed using the Diaphragm wall to stop the water ingress during construction. The brief methodology is elaborated below .



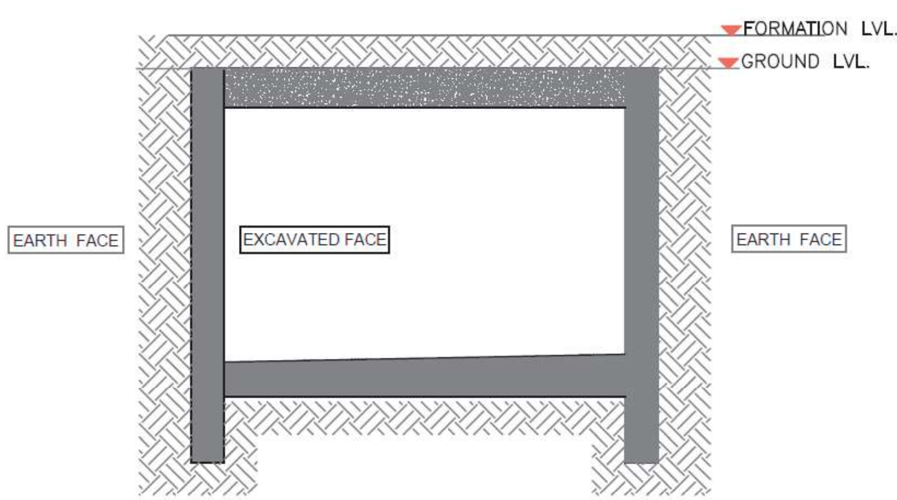
STAGE (1)
D-WALL
1.1) DIVERT THE TRAFFIC AS PER PROPOSED TRAFFIC DIVERSION PLAN.
1.2) BARRICADE FULL WIDTH OF CROSS OVER AREA.
1.3) RE-LOCATE UTILITIES (IF ANY) IN THE VICINITY.
1.4) INSTALL GUIDE WALL AS PER D-WALL LAYOUT.
1.5) CONSTRUCT D-WALL UP TO GROUND LEVEL.



STAGE (2)
2.1) AFTER D-WALL ATTAINS SUFFICIENT STRENGTH EXCAVATE IN SOIL UP TO SOFFIT OF ROOF SLAB.
2.2) LAY PCC AT SOFFIT OF ROOF SLAB
2.3) CAST ROOF SLAB BY LEAVING CUT-OUT AT DESIRED LOCATION AND LEAVE COUPLER IN SLAB TEMPORARY CUT-OUTS.



STAGE (3)
3.1) EXCAVATE UPTO SOFFIT OF BASE SLAB.
3.2) LAY PCC BELOW BASE SLAB, WITH WATER PROOFING MEMBRANE AS PER SPECIFICATION.
3.3) CAST BASE SLAB.



STAGE (4)
4.1) CAST TEMPORARY AND MUCK CUTOUT AT ROOF SLAB.
4.2) PLACE WATER PROOFING MEMBRANE AS PER SPECIFICATION ABOVE ROOF SLAB..
4.3) PLACE BACK FILL MATERIAL (AS PER OCS) UP TO THE GROUND LEVEL.
4.4) REMOVE BARRICADE.
4.5) REINSTATE THE GROUND LEVEL AS PER ARCHITECTURAL REINSTATEMENT DRAWING..

CHAPTER 7: Structural Design

7.1 Introduction

The report covers the preliminary structural design calculations for Cut & Cover, Ramp Portion including temporary secant pile & steel waler for C&C and ramp.

7.2 References

1. IS 456: 2000 Plain and reinforced concrete – Code of practice (Fourth Revision)
2. IS 800 (2007): General Construction In Steel - Code of Practice (Third Revision)
3. IS 4326:1993, Earthquake resistant design and construction of buildings -code of practice
4. IS 1893 (Part-1): 2016 Criteria for earthquake resistant design of structures
5. IS 2062: 2011: Hot Rolled Medium and High Tensile Structural Steel -Specification.
6. DIN 1045 – Concrete reinforced and pressurized concrete structures.
7. EN 1990: Euro code: Basis of structural design
8. EN 1991, Euro code 1: Actions on structures
9. EN 1992, Euro code 2: Design of concrete structures, Part 1-1: General rules and rules for buildings
10. ACI 358.1R-92 (The American Concrete Institute technical design standard, Analysis and Design of Reinforced and Prestressed Concrete Guideway Structures)
11. ACI 343.1R-12: Guide for the Analysis and Design of Reinforced and Prestressed Concrete Guideway Structures
12. ACI 544.7R16–Design and Construction of Fiber Reinforced Precast Concrete Tunnel Segments
13. International Tunnel Association (ITA), Volume 3, 1988: Guideline for Design of Tunnels
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15. International Tunnel Association (ITA): Seismic Design and Analysis of Underground Structures
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17. Seismic design and analysis of underground structures" by YMA Hashish, JJ Hook, Birger Schmidt and John I-Chiang Yao, Tunnelling and Underground Space Technology 16 (2001) 247 – 293 (ITA-AITES Accredited Material)
18. Muir-Wood, A.M. (1975) – The circular tunnel in elastic ground, Geotechnique 25, No. 1, 115-127.
19. Curtis D.J. (1976) – Discussion on the Circular tunnel in Elastic Ground, Geotechnique 26, No.1, 231-237
20. Wang.J., "Seismic Design of Tunnels"
21. Feder G. Felsbau und Bodenmechanik Veröffentlichungen – Collected and puplished by the Institute of Rock Mechanics and Tunneling University of Graz
22. Feder G. Rock mechanics Aspects of the "New Austrian Tunneling Method" (NATM), Arlberg Seminar 1980 of the American Engineering society
23. Austrian Standard Oenorm B2203 Part 1, Underground Works – Conventional Excavation, 2001
24. Duddeck H. and Erdmann J.: Structural design models for tunnels

25. Guidelines For Tunnel Lining Design -LTA Civil Design Division
26. Austrian Society for Geomechanics: Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation, 2010.
27. "Seismic Microzonation Manual", Ministry of Earth Science, Government of India
28. Williams, O. (1982). Department Of The Army, U.S Army Corps Of Engineers, Em 1110-2-2901.
29. Face stability Condition with Earth-Pressure-Balance Shield by G. Anagnostou & K K Vari, Tunnelling and Underground Space Technology, Vol. 11, No. 2. Pp. 165-173, 1996.

7.3 Software

1. RS2 (Version 10) – Rocscience Software, Finite Element Analysis for Excavations and Slopes
2. STAAD.Pro-Structural Analysis Software
3. In-house Spreadsheets

7.4 CUT & COVER

7.4.1 Geometry

The following Cross Sections of C&C Structures (C&C section of 3 lane & 3 lane + median wall + 3 lane) will be used as described below. For both type of structures, C&C Structures will have side walls, Bottom Slab and top slab with Reinforced Concrete Structure in which Bottom Slab of 1.0m thick will casted over 0.2 m thick PCC and Side wall of 1.0m thick and top slab with 1.0m thickness.

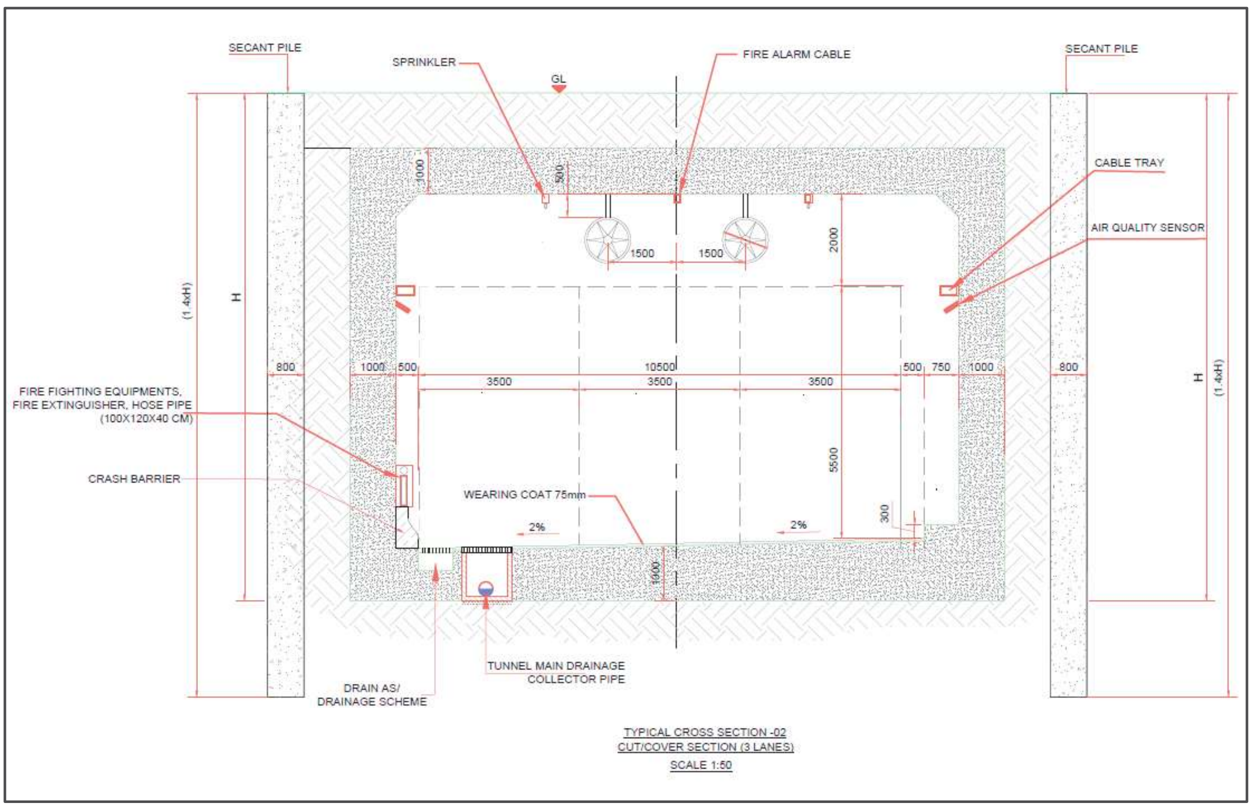


Figure 46: Typical Cross Section C&C Structure (3 LANE)

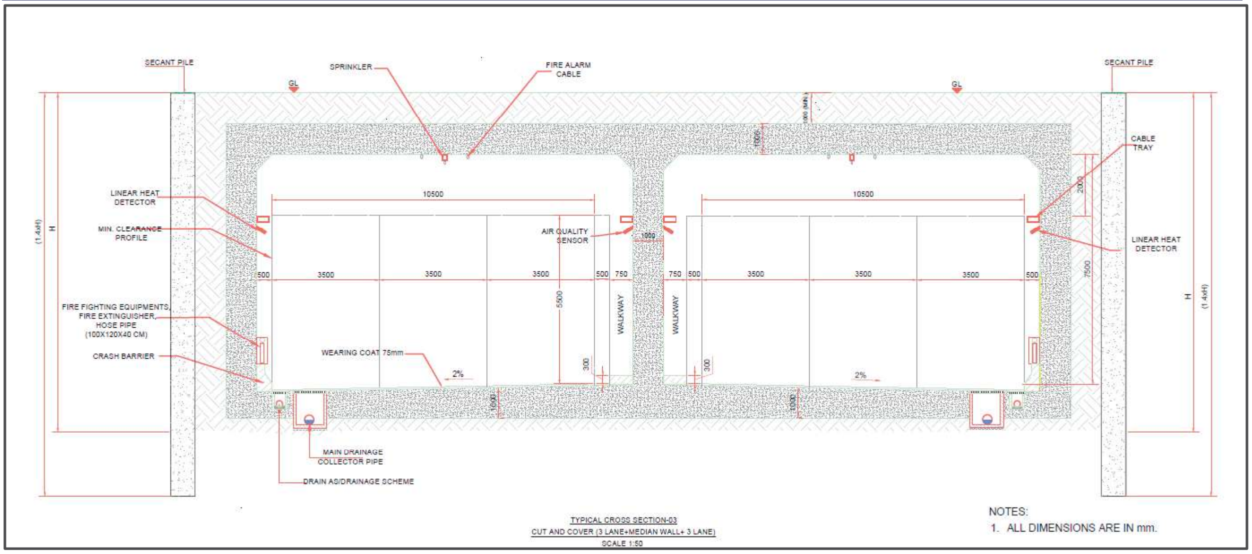


Figure 47: Typical Cross Section C&C Structure (3+3 LANE)

7.4.2 Materials

The relevant building materials, which are concrete and reinforcement steel, confirm the specifications given below.

7.4.2.1 Cast in Place Concrete

a) Bottom Slab & Wall

- Specified characteristic compressive strength fck = 35 N/mm2 (Concrete Grade M35 according to IS 456:2000)
- Young's modulus: E = 29580 MPa
- Poisson's ratio: v = 0.2
- Unit weight: ϒ = 25 kN/m3

7.4.2.2 Reinforcement Steel

Only thermo-mechanically treated reinforcement bars of grade Fe500D (yield stress of 500 MPa) with minimum total elongation of 16% conforming to IS 1786 - 2008 shall be adopted. For flexural design, material properties of Fe 500 shall be used but for design of shear stirrups, strength parameters of Fe415 shall be considered.

Young's modulus E=200 GPa

Yield strength fyk=500 MPa

7.4.3 Concrete Cover

For Underground structural elements in contact with non- aggressive soil

Sl. No.	Structural Components	Nominal Cover (mm)
1.	Base Slab (Earth face)	75
2.	Base Slab (inside face)	50
3.	Side wall (Earth face)	75
4.	Side wall (inside face)	50
5.	Top Slab (Earth face)	75
6.	Top Slab (Inside face)	50

Cover means – clear cover to outermost reinforcement.

7.4.4 Fire Resistance Design Requirements

For underground structures 4 hours of fire resistance criteria shall be adopted. Refer to table 16A IS 456, note that the cover adopted for slab satisfies the provided concrete cover.

7.4.5 Crack Width

All structural concrete elements shall be designed to prevent excessive cracking due to flexure. The maximum crack widths shall be as specified below.

Flexural crack width for different structural components is to be checked for all the load combinations at service stage except for instantaneous loading like seismic, winds.

For side wall and bottom slab: -

- 0.2mm for soil face
- 0.3mm for inner face

7.4.6 Load & Load Combinations

The relevant building materials, which are concrete and reinforcement steel, confirm the specifications given below.

7.4.6.1 General

Unless specified otherwise the design of concrete elements shall conform to IS 456.

7.4.6.2 Nominal Loads

For the purpose of computing stresses and deformations, the following minimum load types and consequential effects shall be considered as applicable.

Dead load (Self Weight)	DL
Superimposed Dead loads	SIDL
Live loads	LL
Seismic Loads	EQ
Earth Pressure	EP
Surcharge	SR
Hydrostatic	WP

7.4.6.3 Load Factors

The following load factors will be considered in the Design of RAMP Structures:

i. Ultimate Limit State

The Ultimate Load of the structures must be analyzed considering all relevant loads (Dead Loads as well as Imposed Loads) with an appropriate load factor.

ii. Serviceability Limit State

The Serviceability of the structures will be analyzed considering all relevant loads. Main serviceability related aspects include deflections limitation and crack widths limitation.

7.4.6.4 Load Combinations

i. Applied Load Cases

The applied load cases are listed in the following:

- G1 Self weight

- G2 Earth pressure (submerged)
- G3 Water pressure
- G4 Earth pressure (dry)
- G5 Surcharge Loads (Symmetrical)

The general format for combinations of actions for the ultimate and serviceability limit states are as stated below.

ii. Ultimate Limit State (ULS)

Calculations of ultimate limit state consider the following load combinations:

I =1.5×G1
II =1.50×G1+1.50×G2
III =1.50×G1+1.50×G2+1.5×G3
IV =1.50×G1+1.50×G2+1.5×G3+1.50×G5
V =1.50×G1+1.50×G4+1.50×G5

iii. Serviceability Limit State (SLS)

Calculations of serviceability limit state consider the following load combinations:

I =1.0×G1
II =1.0×G1+1.0×G2
III =1.0×G1+1.0×G2+1.0×G3
IV =1.0×G1+1.0×G2+1.0×G3+1.0×G5
V =1.0×G1+1.0×G4+1.0×G5

7.4.6.5 Design Summary

The reinforcement summary of two different sections has been given below. Design calculations are given in Annexure 1 Structure Design.

Table 52: Summary of Steel Reinforcement C&C Structure (3 lane)

Component of C&C Structure	Reinforcement (Soil Face)	Reinforcement (Inside Face)	Shear Reinforcement
Base Slab (1000mm thk) Main Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from support & 1-20 mm Dia bar at 100mm c/c at span	25 mm Dia bar at 100 mm c/c at mid till 2m from support and 20 mm Dia bar at 100 mm c/c at span	10 mm Dia link @ 100mm c/c
Base Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	
Top Slab (1000mm thk) Main Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from support & 1-25 mm Dia bar at 100mm c/c at span	25 mm Dia bar at 100 mm c/c at mid till 2m from supports and 25 mm Dia bar at 100 mm c/c at span	10 mm Dia link @ 100mm c/c
Top Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	
Side Wall 1000 mm thick Vertical Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from wall edge and 1-25 mm dia bar at 100 mm c/c at span	16 mm Dia @ 100 mm c/c	10 mm Dia link @ 200 mm c/c both ways

Component of C&C Structure	Reinforcement (Soil Face)	Reinforcement (Inside Face)	Shear Reinforcement
Side Wall 1200 mm thick Horizontal Reinforcement	20 mm Dia bar @ 100 mm c/c	12 mm Dia bar @ 100 mm c/c	

Table 53: Summary of Steel Reinforcement C&C Structure (3 lane + median wall + 3 lane)

Component of C&C Structure	Reinforcement (Soil Face)	Reinforcement (Inside Face)	Shear Reinforcement
Base Slab (1200mm thk) Main Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from support & 1-20 mm Dia bar at 100mm c/c at span	25 mm Dia bar at 100 mm c/c at mid till 2m from support and 20 mm Dia bar at 100 mm c/c at span	10 mm Dia link @ 100mm c/c
Base Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	
Top Slab (1200mm thk) Main Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from support & 1-25 mm Dia bar at 100mm c/c at span	25 mm Dia bar at 100 mm c/c at mid till 2m from supports and 25 mm Dia bar at 100 mm c/c at span	10 mm Dia link @ 100mm c/c
Top Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	
Side Wall 1200 mm thick Vertical Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from wall edge and 1-25 mm dia bar at 100 mm c/c at span	16 mm Dia @ 100 mm c/c	10 mm Dia link @ 100 mm c/c both ways
Side Wall 1200 mm thick Horizontal Reinforcement	20 mm Dia bar @ 100 mm c/c	12 mm Dia bar @ 100 mm c/c	
Median Wall 1000 mm thick Vertical Reinforcement	1-Layers - 25mm Dia bar at 100 mm at span	25 mm Dia @ 100 mm c/c	10 mm Dia link @ 100 mm c/c both ways
Median Wall 1000 mm thick Horizontal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	

7.5 Ramp Structure

7.5.1 Materials

The following Cross Sections of RAMP Structures (Ramp section of 3 lane, 3 lane + median wall + 3 lane) will be used as described in **Figure 48**, **& Figure 49** . RAMP Structures will have side walls and Bottom Slab with Reinforced Concrete Structure in which Bottom Slab of 1 m thick will casted over 0.2 m thick PCC and Side wall of 1m with roofing C/W pipe truss and approved grade polycarbonate roofing sheets. For Ramp wall height more than 6.5m, a beam 0.6m X 0.6m Beam at 6m spacing has been proposed.

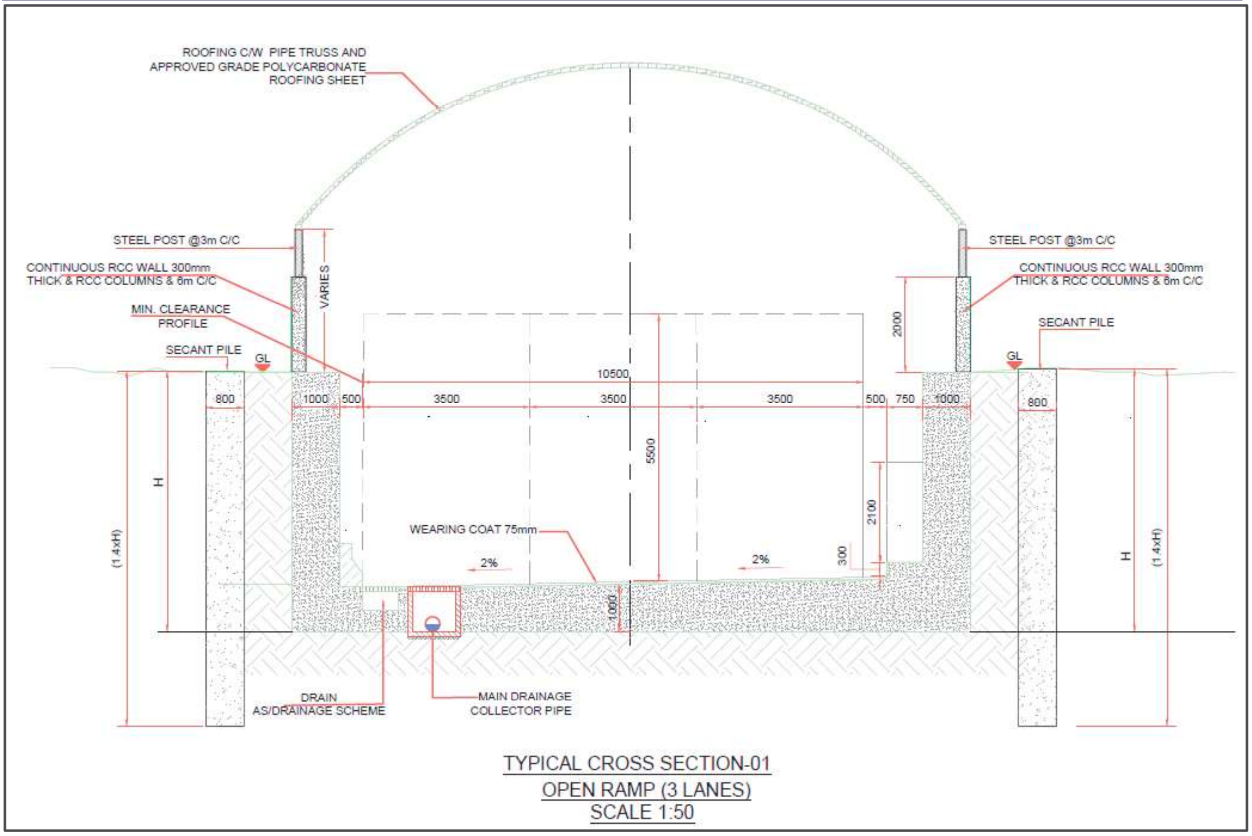


Figure 48: Typical Cross Section RAMP Structure (3 LANE)

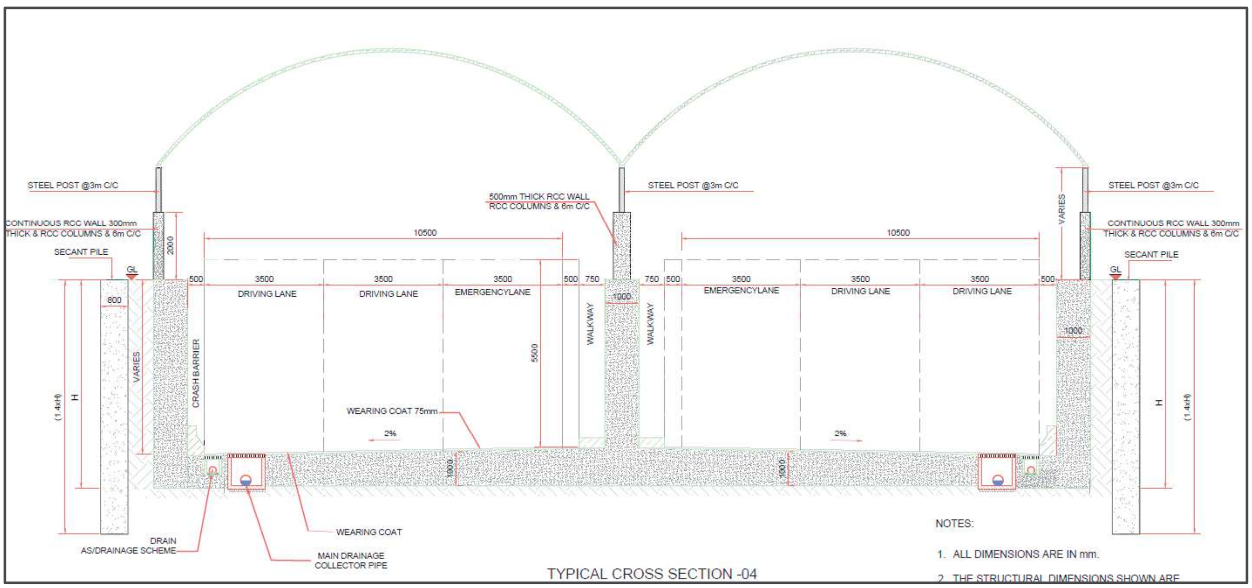


Figure 49: Typical Cross Section RAMP Structure (3 lane + median wall + 3 lane)

7.5.2 Materials

The relevant building materials, which are concrete and reinforcement steel, confirm the specifications given below.

7.5.2.1 Cast in Place Concrete

a) Bottom Slab & Wall

- Specified characteristic compressive strength fck = 35 N/mm2 (Concrete Grade M35 according to IS 456:2000)
- Young's modulus: E = 29580 MPa
- Poisson's ratio: v = 0.2
- Unit weight: Y = 25 kN/m3

7.5.2.2 Reinforcement Steel

Only thermo-mechanically treated reinforcement bars of grade Fe500D (yield stress of 500 MPa) with minimum total elongation of 16% conforming to IS 1786 - 2008 shall be adopted. For flexural design, material properties of Fe 500 shall be used but for design of shear stirrups, strength parameters of Fe415 shall be considered.

Young's modulus E=200 GPa

Yield strength fyk=500 MPa

7.5.3 Concrete Cover

For Underground structural elements in contact with non- aggressive soil

Sl. No.	Structural Components	Nominal Cover (mm)
1.	Base Slab (Earth face)	75
2.	Base Slab (inside face)	50
3.	Side wall (Earth face)	75
4.	Side wall (inside face)	50

Cover means – clear cover to outermost reinforcement.

7.5.4 Fire Resistance Design Requirements

For underground structures 4 hours of fire resistance criteria shall be adopted. Refer to table 16A IS 456, note that the cover adopted for slab satisfies the provided concrete cover.

7.5.5 Crack Width

All structural concrete elements shall be designed to prevent excessive cracking due to flexure. The maximum crack widths shall be as specified below.

Flexural crack width for different structural components is to be checked for all the load combinations at service stage except for instantaneous loading like seismic, winds.

For side wall and bottom slab: -

- 0.2mm for soil face
- 0.3mm for inner face

7.5.6 Load & Load Combinations

The relevant building materials, which are concrete and reinforcement steel, confirm the specifications given below.

7.5.6.1 General

Unless specified otherwise the design of concrete elements shall conform to IS 456.

7.5.6.1.1 Nominal Loads

For the purpose of computing stresses and deformations, the following minimum load types and consequential effects shall be considered as applicable.

Dead load (Self Weight)	DL
Superimposed Dead loads	SIDL
Live loads	LL
Seismic Loads	EQ
Earth Pressure	EP
Surcharge	SR
Hydrostatic	WP

Load and stiffness calculations are given in **Annexure 2 of Structure Design.**

7.5.7 Load Factors

The following load factors will be considered in the Design of RAMP Structures:

i. Ultimate Limit State

The Ultimate Load of the structures must be analysed considering all relevant loads (Dead Loads as well as Imposed Loads) with an appropriate load factor.

ii. Serviceability Limit State

The Serviceability of the structures will be analysed considering all relevant loads. Main serviceability related aspects include deflections limitation and crack widths limitation.

7.5.8 Load Combinations

i. Applied Load Cases

The applied load cases are listed in the following:

- G1 Self weight
- G2 Earth pressure (submerged)
- G3 Water pressure
- G4 Earth pressure (dry)
- G5 Surcharge Loads (Symmetrical)

The general format for combinations of actions for the ultimate and serviceability limit states are as stated below.

ii. Ultimate Limit State (ULS)

Calculations of ultimate limit state consider the following load combinations:

I =1.5×G1
II =1.50×G1+1.50×G2
III =1.50×G1+1.50×G2+1.5×G3
IV =1.50×G1+1.50×G2+1.5×G3+1.50×G5
V =1.50×G1+1.50×G4+1.50×G5

iii. Serviceability Limit State (SLS)

Calculations of serviceability limit state consider the following load combinations:

I =1.0×G1
II =1.0×G1+1.0×G2
III =1.0×G1+1.0×G2+1.0×G3
IV =1.0×G1+1.0×G2+1.0×G3+1.0×G5
V =1.0×G1+1.0×G4+1.0×G5

7.5.9 Design Summary

The reinforcement summary of 3 lane and 3 lane + median wall + 3 lane has been provided as per the critical forces in below table. The design calculations have given in **Annexure 2 of Structure Design.**

Table 54: Summary of Steel Reinforcement RAMP Structure (3 lane)

Component of C&C Structure	Reinforcement (Soil Face)	Reinforcement (Inside Face)	Shear Reinforcement
Base Slab (1000mm thk) Main Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from support & 1-20 mm Dia bar at 100mm c/c at span	25 mm Dia bar at 100 mm c/c at mid till 2m from support and 20 mm Dia bar at 100 mm c/c at span	10 mm Dia link @ 100mm c/c
Base Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	
Side Wall 1000 mm thick Vertical Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from wall edge and 1-25 mm dia bar at 100 mm c/c at span	16 mm Dia @ 100 mm c/c	10 mm Dia link @ 200 mm c/c both ways
Side Wall 1200 mm thick Horizontal Reinforcement	20 mm Dia bar @ 100 mm c/c	12 mm Dia bar @ 100 mm c/c	

Table 55: Summary of Steel Reinforcement RAMP Structure (3 lane + median wall + 3 lane)

Component of C&C Structure	Reinforcement (Soil Face)	Reinforcement (Inside Face)	Shear Reinforcement
Base Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	10 mm Dia link @ 100mm c/c
Side Wall 1200 mm thick Vertical Reinforcement	2-25 mm Dia bar at 100 mm c/c till 2m from wall edge and 1-25 mm dia bar at 100 mm c/c at span	16 mm Dia @ 100 mm c/c	
Side Wall 1200 mm thick Horizontal Reinforcement	20 mm Dia bar @ 100 mm c/c	12 mm Dia bar @ 100 mm c/c	10 mm Dia link @ 100 mm c/c both ways
Median Wall 1000 mm thick Vertical Reinforcement	1-Layers - 25mm Dia bar at 100 mm at span	25 mm Dia @ 100 mm c/c	
Median Wall 1000 mm thick Horizontal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	10 mm Dia link @ 100 mm c/c both ways
Base Slab Longitudinal Reinforcement	16 mm Dia bar @ 100 mm c/c	16 mm Dia bar @ 100 mm c/c	

7.6 LIST OF ANNEXURES

ANNEXURE - 1 – Structural Design Cut and Cover Sections

ANNEXURE - 2 - Structural Design of Open Cut Sections

CHAPTER 8: GEOTECHNICAL DESIGN OF DEEP EXCAVATION FOR C&C TUNNEL

8.1 Scope of this section

The chapter covers the stability analysis for the deep excavation of Cut and Cover Portion and structural Design of Cut & cover Box.

8.1.1 References

1) IS 456: 2000 Plain and reinforced concrete – Code of practice (Fourth Revision)
2) IS 14448-1979: Code of Practice for Reinforcement of Rock Slopes with Plane Wedge Failure
3) BS 8081:2015 – Code of practice for grouted anchors
4) EN 1992-1-1 (2004) (English): Eurocode 2: Design of Concrete Structures – Part-1-1: General rules and rules for buildings
5) FHWA-IF-99-015 (1999): Ground Anchors and Anchored Systems
6) FHWA-NHI-14-007 (2015): Soil Nail Walls Reference Manual
7) IS 10270-1982: Guidelines for Design and Construction of Prestressed Rock Anchors
8) IS 1556-1982: Specification for Hard-Drawn Steel Wire Fabric for Concrete Reinforcement
9) IS: 15026 (2002) – Tunnelling Methods in Rock Masses-Guidelines.
10) Duddeck H. and Erdmann J.: Structural design models for tunnels
11) Duddeck Duddeck H. and Erdmann J.: Vergleich ebener und Entwicklung räumlicherBerechnungsverfahren für Tunnel
12) Austrian Society for Rock Mechanics: Geotechnical Underground Structures Design (Tunneling in Rock)
13) Austrian Standard ONORM B2203 Part 1, Underground Works – Conventional Excavation, 2001
14) Austrian Society for Concrete and Construction technology: Guideline Sprayed concrete, 2013
15) Practical Rock Engineering by Evert Hoek
16) Soil Mechanics & Engineering in Practice by Karl Terzaghi and Ralph B. Peck
17) Foundation Analysis and Design by Joseph E Bowles.

8.1.2 Software

1) RS2 (Version 10) – Rocscience Software, Finite Element Analysis for Excavations and Slopes

8.2 GEOTECHNICAL DESIGN PARAMETERS

The Following parameters have been considered based on the available information.

Table 56 : Geotechnical Parameters for Soil

*Depth from	Strata Descriptio	Bulk Unit	Cohesio n (c')	Friction Angle(Ø')	(E')	Ko	Poisson's Ratio (v)	Permeabili ty (k)

Surface	n	Weight						
		[kN/m3]	[kPa]	[o]	[MPa]		[-]	[m/sec]
0-2 (7.5)m	Fill Material	16	0	25	5	0.58	0.3	5x10-5
2-4(12)m	Silty Sand/ Sandy silts with Clayey Sand	18	0-3	27-29	EXP(Z+2.85)/ 3.15	0.52	0.3	1x10-5
4-8m	Residual Soil	19	3-5	27-30	**100**	0.52	0.3	1x10-6

- The depths of soil and its types from ground surface to bedrock contact is variable. A tentative stratification interpreted is shown in the Geological L-Section developed from the available borehole data. Depending on the local topography/Geomorphological setup, the thickness of soil layers can increase beyond the general thickness anticipated (given in brackets)

Table 57 : Geotechnical Parameters for Rock

Overburden (m)		**Design Parameters for Rock Mass**			**(General Case) D=0**								
		Strata	**Grade**	**γb**	**GSI**	**σci**	**(MR)**	**Ko**	**Em**	**νm**	**(c)**	**(Ø')**	**(k)**
				[kN/m3]	[-]	[MPa]			[MPa]	[-]	[MPa]	[o]	[m/sec]
<30	Laterite	**CW -HW**	V-IV	23	15	25	400	0.42	300	0.30	0.6	22	1x10-5
		MW*	III	25	40	35	465	0.35	1600	0.26	1.8	30	1x10-6
	>30	**MW**	III	25	40	45	500	0.35	3600	0.26	2.7	37	1x10-7
		SW	II	26	70	55	500	0.27	15000	0.22	5.0	45	1x10-8
		FR	I	26	80	75	525	0.25	35000	0.20	8.0	50	1x10-8

A Case for segregating the Design Parameters for rock mass based on Overburden thickness (wrt Formation Level) has been interpreted, to consider for the marginally lower competence in the Moderately weathered rock masses (MW) under influence of deeper influence of weathering, applicable for portal areas, drain/ nalla sections, Shafts etc. The valuations are evaluated for the General case, as per RocLab.

For the analysis of deep excavation and from the data available the nearest geological data near to the deep cut section is considered, which is the conservative due to higher thickness of soil layer and the parameters considered for the design are tabulated below.

Table 58 : Geotechnical Design Parameters for Soil -Deep Excavation

		Undrained Parameters				Drained Parameters				
Depth below GL	Strata	ɣ	c	φ	E	c'	φ’	E'	Ko	k
[m]		[kN/m3]	[kPa]	[o]	[MPa]	[kPa]	[o]	[MPa]		[m/sec]
0.0-7.5	Fill Material	16	0	30	6	0	25	5+1.5Z	0.58	5x10^{-7}
7.5-12	Silty Sand/ Clayey Sand	18	0	30	30	2	25	25	0.58	1x10^{-7}

Table 59 : Geotechnical Design Parameters for Rock -Deep Excavation

										Slope		
Depth below GL	Strata	Grade of Rock	ɣ	GSI	UCS	Ei	K_o	Em	v	c'	φ’	k
[m]			[kN/m^3]	[-]	[MPa]	[GPa]		[GPa]	[-]	[MPa]	[^{o}]	[m/sec]
12-22	Completely to Highly Weathered	V-IV	22	25	25	10	0.43	0.3	0.3	0.12	39	1x10^{-6}
22-30	Moderately Weathered rock	III	25	45	35	16.65	0.33	1.3	0.25	0.25	52	1x10^{-7}
>30	Slightly Weathered to Fresh Rock	II-I	26	80	55	30.2	0.25	14.4	0.2	1.3	65	1x10^{-8}

8.3 LAYOUT OF CUT & COVER TUNNEL

Cut and cover tunnel involves deep excavation with depth varies up to 18.5m (max.). The excavation support consists of a combination of secant pile wall with steel waler beam and ground anchors, and the details of the secant pile is mentioned below.

8.3.1 General Section detail for secant pile

Th secant pile wall would be used to support the excavation of Cut and Cover. Secant pile walls consist of an alternate series of unreinforced soft piles (M15 grade) and reinforced hard piles (M35 grade). Initially, a 1.0m / 0.8m diameter soft pile will be installed in the ground, once the soft pile is constructed, 1.0m diameter of the hard pile will be installed in the ground with overlap of 200 mm/150mm between the hard and soft pile. The general details of the secant pile arrangement is show in the figure below

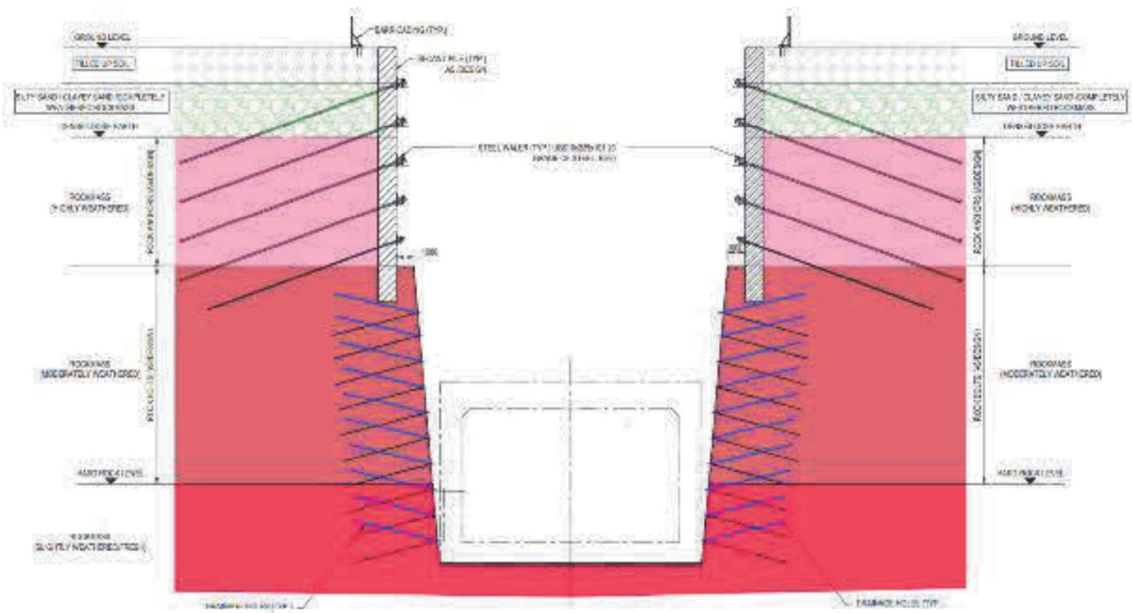


Figure 50: Typical Section Detail of Deep Excavation for Shaft & Cut and Cover Zone

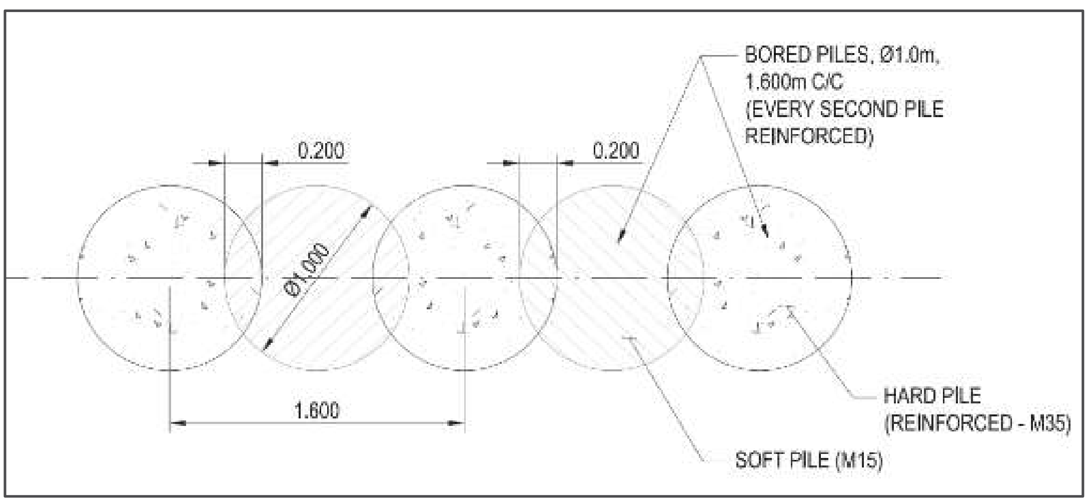


Figure 51: General details of Secant piles of 1.0m Diameter

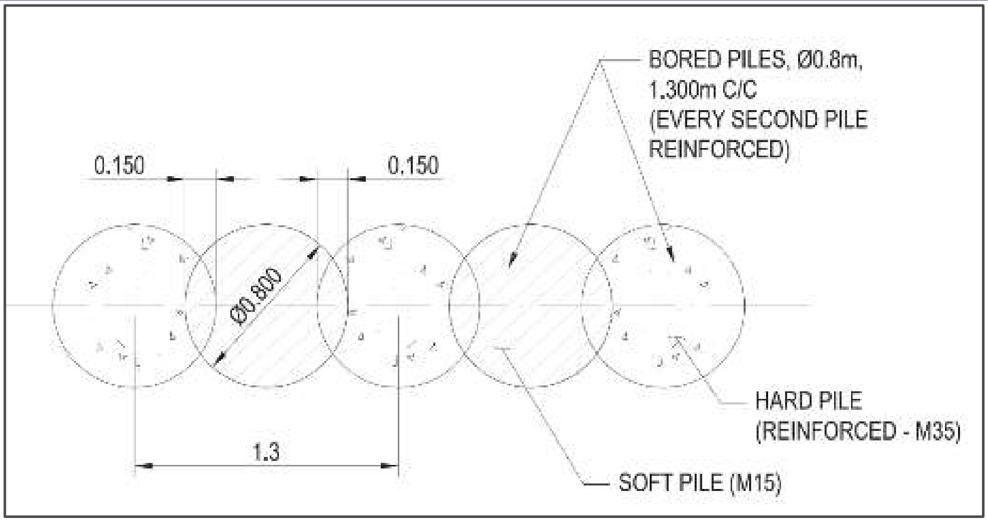


Figure 52: General details of Secant piles of 0.8m Diameter

8.3.2 Overlapping

The unreinforced soft pile will be installed in the ground 1.0m/0.8m diameter. Once the soft pile (M15) has been constructed, 1.0m/0.8 diameter of the hard pile (M35) will be installed in the ground with an overlap of 200mm/150mm between the soft and hard pile.

The maximum vertical tolerance of the finished secant pile is 1 in 200. For 12m height of pile the maximum deviation is 60mm at soffit of a pile. In a worst case scenario two adjacent piles having deviation in opposite directions would remain within the proposed overlap.

8.4 MATERIAL PROPERTIES

The material properties values provided in this section refer only to design values. The requirements of the Technical Specification ref Table, still apply and need to be achieved and verified in the field.

8.4.1 Concrete

The hard pile is proposed with a minimum M35 grade of concrete according to IS 456:2000. The following properties of the concrete are stated in Table 60.

Table 60 : Properties of M35 grade concrete for Hard Pile.

Parameter	Unit	Value
Pile Diameter	M	0.8
Grade of Concrete	-	M35
Characteristic Compressive Strength (28 days)	MPa	35
Young's modulus $(E_{conc})_{35}$	MPa	29580
Spacing	m	1.3
Unit weight	kN/m^3	25
Poisson's ratio	-	0.2
Soft Pile to hard pile overlap	[m]	0.15

8.4.2 Rock Bolts

Rock bolt support measures will consist of fully grouted steel rebar rock bolts.

Table 61 : Rock bolt support measures

Parameter	Unit	Value
Grade of Steel	-	Fe 500D
Type	-	Fully Grouted (SN)
Design Strength	kN	350 / 213
Diameter	mm	32 / 25

8.4.3 Pre-stressed soil anchors in secant pile (Tie Back)

Table 62 : Pre-stressed soil anchors in secant pile

Parameter	Unit	Value
Type	-	PT Anchor
Design Capacity	kN	As per design
Anchor Length	m	Varies
Bond Length	m	5
Pretension Force	kN	Varies
Bond strength*	kN/m2	500 As per IS 14448
Hole Dia	mm	150
Pullout Capacity*	kN/m	π x hole dia x bond strength = 235

*To be confirmed at site

8.5 LOADS & LOAD COMBINATION

8.5.1 Loads

For the purpose of computing stresses and deformations, the following minimum load types and consequential effects shall be considered as applicable.

Table 63 : Minimum Load Types and Consequential Effects

Loads	Symbol
Dead loads	DL
Earth Pressure	EP
Surcharge	SR
Hydrostatic	WP

i. **Dead Loads**

The design will consider all dead loads that will act on the structure, including the self-weight of the structure. The unit weight of the reinforced concrete will be considered as 25 kN/m^3 and for plain concrete it will be 24 kN/m^3.

ii. **Earth Pressure**

The effective lateral earth pressure is equal to the product of load due to the weight of overburden and coefficient of lateral earth pressure K_0.

iii. **Water Pressure**

As no level has been reported in BH, the water level from the adjacent lakes is considered. For the derivation of hydrostatic pressure, the maximum groundwater level considered at 5m bgl for design purpose as per the available information.

iv. **Earthquake Load**

The proposed structures are temporary in Nature; no seismic analysis shall be considered for the design.

v. **Surcharge Loads**

The design shall also consider loads from surrounding structures for a value of 60 kN/m^2

8.5.2 Load Factors

The following load factors will be considered in the design of the Secant pile with waler:

i. **Partial Factors of Safety for Materials**

The design strengths are obtained by dividing the characteristic strength by the material factors defined below:

Table 64: Partial Factors of Safety for Materials

Material	Ultimate (ULS)	Serviceability (SLS)
Concrete	1.5	1.0
Reinforcement	1.15	1.0

ii. **Factor of Safety**

The Factor of safety for slope stability based on temporary support system shall be 1.3 for static case.

8.6 MODELLING & ANALYSIS

The numerical analysis for complete excavation of Cut and Cover portion has been carried out with support system as secant pile walls, ground anchors, rock bolts & Sprayed Concrete is carried out in the FEM software RS2. The pile depth will vary as per geological conditions along the Cut and Cover or open ramp portion. Analysis has been carried out for 3 cases with 20 m deep excavation for CNC, 12m deep excavation for CNC & Open Ramp portion and 5m deep excavation for Open Ramp portion. The different design cases (excavation depth) are representative of major change in excavation and supports.

8.6.1 Numerical Analysis

The software used for the numerical analysis is the two-dimensional finite element software RS2. RS2 is a powerful and user-friendly finite-element (FE) package for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics. It is used in geotechnical challenges ranging from excavations, embankments, onshore or offshore foundations to tunnelling, mining, and reservoir geomechanics.

RS2 employ various constitutive models ranging from simple linear to advanced highly nonlinear models that allow accurate simulation of most soil and rock types. The material behaviour of the ground is simulated according to material model by Mohr-Coulomb considering drained condition.

The 2D plane strain analysis is used to simulate the deep excavation and support sequences. The half model representing the symmetrical model is considered with Graded 6node triangular element with mesh type. External boundaries of the model are considered far from excavation so that they are not influenced by the excavation impact. The external boundaries of the model are fixed in the horizontal direction on each side, which means that vertical movement is allowed, and the bottom part of the boundary is pinned, so both vertical and horizontal movements are fixed. The top surface of the model represents the ground surface, and it is free in both directions.

In RS2 secant pile and sprayed concrete lining is modelled as plate element with, properties are elastic and isotropic in nature. Secant pile wall is supported with PT anchors at different levels along with rock bolts to resist the movement of pile for stable excavation.

The representative cross section consist of encountered stratification is considered for numerical analysis. Figures below shows a typical FEM analysis cross section considered for 20m, 12m and 5m deep excavation case to simulate the excavation and support system.

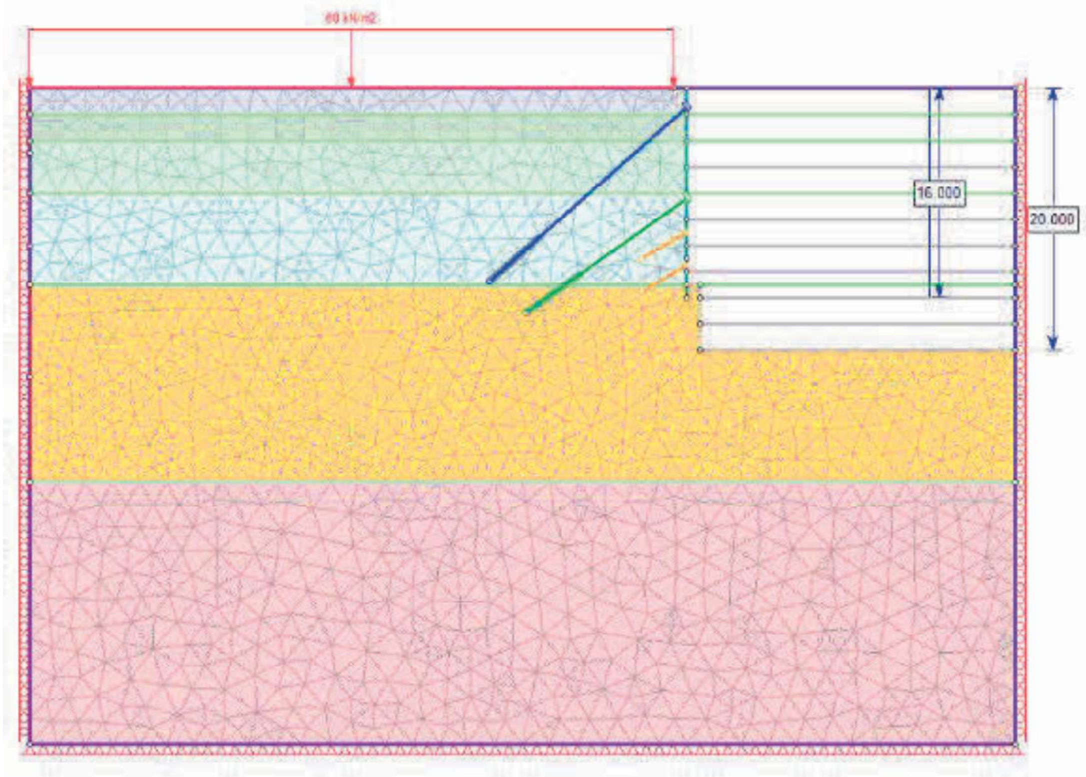


Figure 53: Typical FEM cross section for 20m Deep Excavation

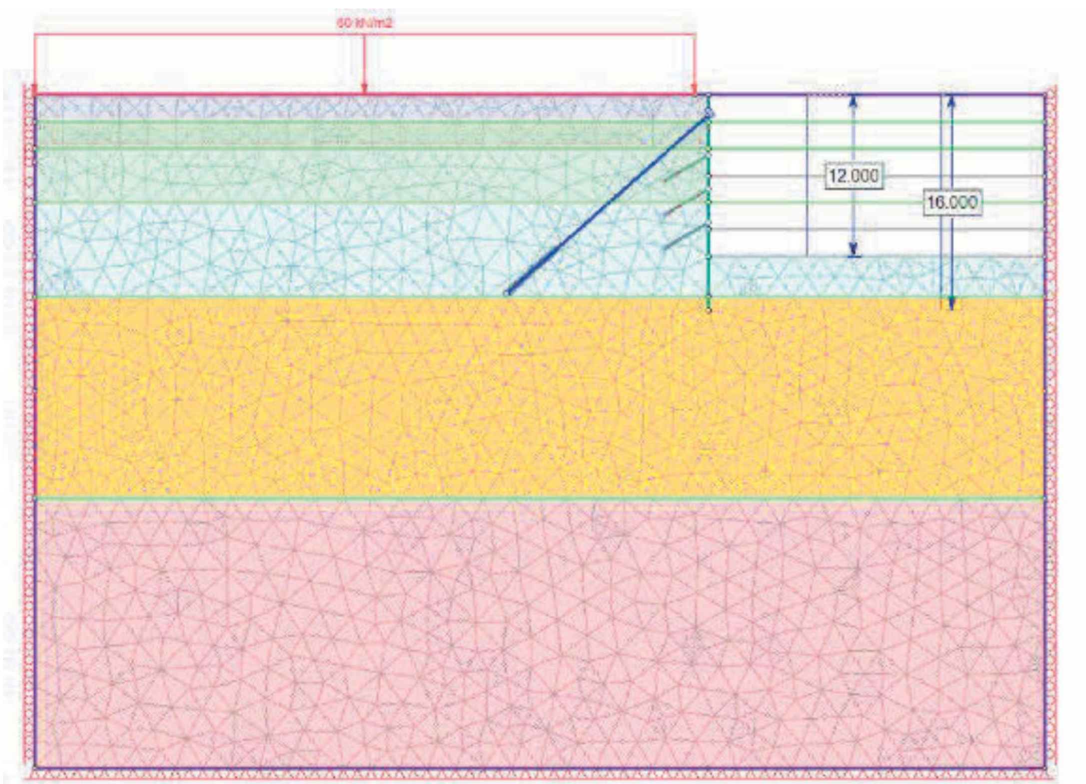


Figure 54: Typical FEM cross section for 12m Deep Excavation

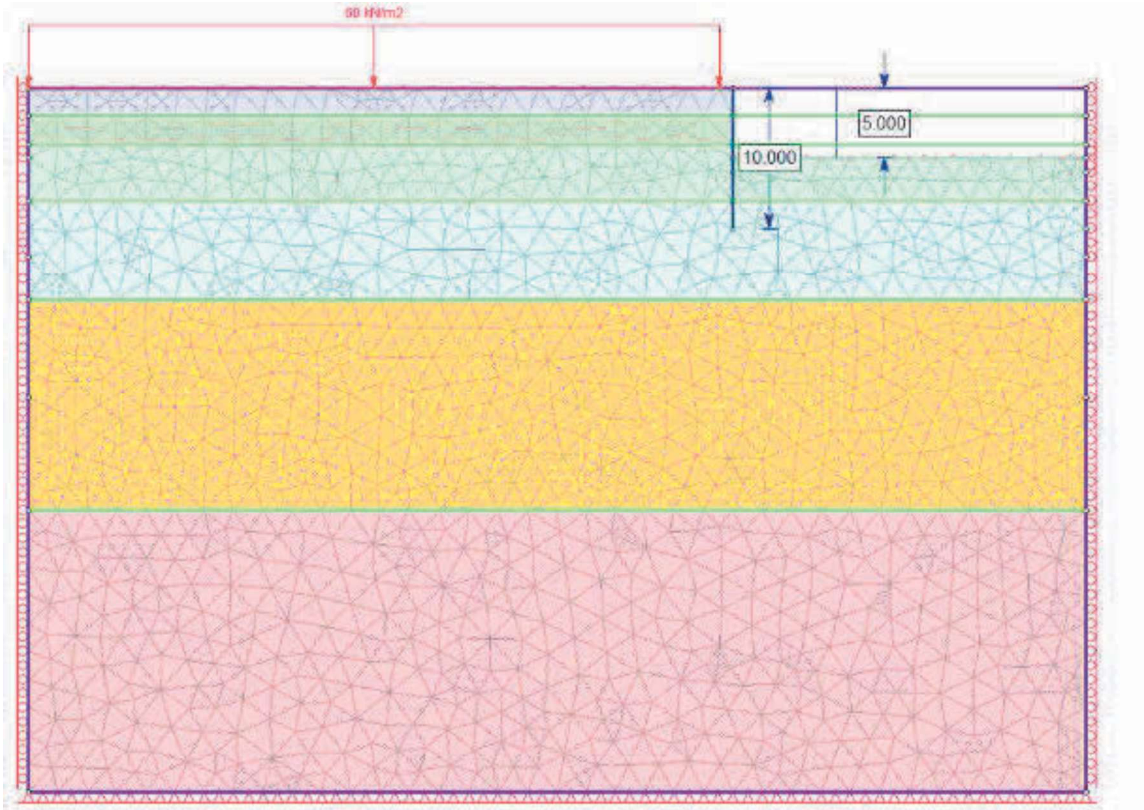


Figure 55: Typical FEM cross section for 5m Deep Excavation

8.6.2 FEM Modelling Stages

The excavation and behaviour of deep excavation for shafts / Cut and Cover and Ramp portion is simulated as per step-by-step process through numerical analysis. The table below show the steps involved in performing FEM analysis for 3 cases (20m,12m & 5m Deep).

Table 65: FEM modelling stages to simulate 20m Deep excavation (C&C)

Construction Stage Number	Description of calculation stages
1	Grid setup and initial stress field, reset displacement to zero and set design water table of 5.0m BGL
2	Activation of surcharge load of 60 kPa, reset displacement to zero
3	Installation of secant pile of 1m dia, Reset displacement to zero
4	Excavate in soil up to 2m from ground level
5	Installation of 1st level of Support-Anchor @ 1.5m BGL
6	Excavate further 2.0m in soil i.e., upto 4.0m BGL
7	Excavate further 2.0m in soil i.e., upto 6.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 7.0 m BGL
8	Excavate further 2.0m in soil i.e., upto 8.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 9.0 m

Construction Stage Number	Description of calculation stages
	BGL
9	Excavate further 2.0m i.e., upto 10.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 11 m BGL
10	Installation of 2nd level of Support- Anchor @ 8.5m BGL
11	Excavate further 2.0m i.e., upto 12.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 13 m BGL
12	Installation of 3rd level of Rock bolt @ 11m BGL
13	Excavate further 2.0m i.e., upto 14.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 15 m BGL
14	Installation of 3rd level of Rock bolt @ 13.5m BGL
15	Excavate further 2.0m i.e., upto 16.0m BGL and Maintain zero groundwater pressure at rock excavation boundary
16	Excavate further 2.0m i.e., upto 18.0m BGL and Maintain zero groundwater pressure at rock excavation boundary
17	Excavate further 2.0m i.e., upto 20.0m BGL and Maintain zero groundwater pressure at rock excavation boundary

Table 66: FEM modelling stages to simulate 12m Deep excavation (C&C & Ramp Portion)

Construction Stage Number	Description of calculation stages
1	Grid setup and initial stress field, reset displacement to zero and set design water table of 5.0m BGL
2	Activation of surcharge load of 60 kPa, reset displacement to zero
3	Installation of secant pile of 0.8m dia, Reset displacement to zero
4	Excavate in soil up to 2m from ground level
5	Installation of 1st level of Support-Anchor @ 1.5m BGL
6	Excavate further 2.0m in soil i.e., upto 4.0m BGL
7	Excavate further 2.0m in soil i.e., upto 6.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 7.0 m BGL
8	Installation of 2nd level of Support- Rock Bolt @ 4.5m BGL
9	Excavate further 2.0m in soil i.e., upto 8.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 9.0 m BGL
10	Installation of 3rd level of Support- Rock Bolt @ 7.0m BGL
11	Excavate further 2.0m in soil i.e., upto 10.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 11 m

Construction Stage Number	Description of calculation stages
	BGL
12	Installation of 4th level of Support- Rock Bolt @ 9.5m BGL
13	Excavate further 2.0m in soil i.e., upto 12.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 13 m BGL

Table 67: FEM modelling stages to simulate 5m Deep excavation (Ramp Portion)

Construction Stage Number	Description of calculation stages
1	Grid setup and initial stress field, reset displacement to zero and set design water table of 5.0m BGL
2	Activation of surcharge load of 60 kPa, reset displacement to zero
3	Installation of secant pile of 0.8m dia, Reset displacement to zero
4	Excavate in soil up to 2m from ground level
5	Excavate further 2.0m i.e., upto 4m BGL
6	Excavate further 1.0m i.e., upto 5.0m BGL and lowering the water table on excavation side up to 1m from excavation level i.e., 6 m BGL

Annexure 1 for RS2 Input and Output results.

8.7 RESULTS SUMMARY -DEEP EXCAVATION

8.7.1 Analysis Results

The below shows the numerical analysis results for the three cases of 20m, 12m and 5m deep excavation.

Table 68: FEM analysis results (Maximum Unfactored forces) for 20m, 12m & 5m Excavation depth

Excavation Depth	Axial Force (KN/m)	Bending Moment (kN-m/m)	Shear Force (kN/m)	Horizontal Dis. (mm)
20m	591	327	96	7
12m	435	217	66	6
5m	103	42	30	3

8.7.2 Global Stability

Strength reduction factor (SRF) tool of RS2 is adopted to get the factor of safety for slope stability analysis. The Factor of Safety is estimated at end of excavation stages. The shear strength reduction option performs a finite element slope stability analysis and computes a critical strength reduction factor for the model. The critical strength reduction factor is equivalent to the “safety factor” of the slope. The FoS is compared to the minimum desired value of 1.4 for temporary works at the end of excavation stages.

Table 69: Global Stability Check for 32m and 12m Excavation depth

Excavation Depth	FOS-Static
20m	5.68
12m	5.25
5m	3.63

Table 70: Summary of Anchor/ Bolt Forces -FEM Analysis

Pile Depth	Support	Level (m)	Load Case	Anchor/ Bolt Forces (kN)
20m	Anchor-1	1.5m bgl	60 KPa	352
	Anchor-2	8.5m bgl		354
	Rock Bolt-1	13m bgl		28
	Rock Bolt-2	15.5m bgl		28
12m	Anchor-1	1.5m bgl		354
	Rock Bolt-1	4.5m bgl		86
	Rock Bolt-2	7.0m bgl		125
	Rock Bolt-3	9.5m bgl		111
5m	NA	NA	-	NA

8.7.3 Support Summary

The following table shows the recommended support system.

Table 71: Support Summary for Secant Pile wall

Excavation Depth	Support Measure					
	Anchor			Rock Bolts		
	Anchor Length (m)	Hor. Spacing (m)	Inclination (Deg)	Bolt Length(m)	Spacing (m)	Inclination (Deg)
20m	20	1.6 (H)	40	4	3.0 (H)	30
	15	1.6 (H)	35	-	-	-
12m	20	2.6 (H)	40	4	3.2 (H)	30
5m	NA	NA	NA	NA	NA	-

8.7.4 Deep Excavation support summary

8.7.4.1 Local Stability

The Kinematic analysis is to be performed based on face mapping data during construction stage. For DPR stage, the slope support design for rock face has been carried out using stress analysis in FEM and found to be safe with the provided support.

Table shows the complete summary of support elements in rock proposed in deep excavation design.

Table 72: Support Summary - Deep Excavation

Excavation Support Recommendations

Sprayed Concrete	M30, 100mm thick
Wire mesh	150/150/6.0 mm (1 layer)
Rock Bolts	**Excavation in Rock (Rock Support)** Rock grade III • Fully grouted, 4m long, 25mm dia SN bolt, 213kN • spacing 2.0m (H) x 3.0m(V) Staggered Rock grade I/II • Fully grouted, 4m long, 25mm dia SN bolt, 213kN • spacing 3mx3m Staggered Spot Bolting (If required)
Drainage holes	50mm dia, 6m long @6x6 spacing

8.7.5 Pile Bearing Capacity Check

The secant pile load carrying capacity is derived in accordance with IRC 78, considering only the end bearing in grade III (MW) rockmass for 20m deep excavation and in end bearing in grade IV-V (CW-HW) rockmass for 12m/5m deep excavation.

The total axial on the secant pile wall is taken from the pile tip from the analysis output for all the pile cases, which is verified against the pile bearing capacity check. Refer Annexure-2 for bearing capacity calculation of secant pile walls.

8.7.6 Toe Stability Check

A toe stability check is performed for the determination of suitable embedment depth of secant pile wall for 20m, 12m and 5m excavation depth with water table at 5.0m BGL using the widely accepted method suggested in Euro code- EC7.

In toe stability check minimum required toe embedment is calculated by ensuring FOS=1.4. Failure of retaining structure can happen in case pile embedment is not sufficient ensuring the FOS in weak ground. For rock socketed pile this phenomenon is however not dominating.

Refer Annexure - 3 for Toe Stability check

8.7.7 Structural Reinforcement Detail Design for secant pile wall

The structural design is carried out in accordance with IS 456 with load. As a general construction practice, a crack width check is not done for temporary structures, hence no check for cracks will be carried out.

All components of the secant pile and associated elements have been checked for Ultimate Limit State only.

8.8 CONSTRUCTION IMAPACT ASSESSMENT APPROACH

In order to carry out a building impact assessment, buildings adjacent to the proposed alignment to be classified in terms of the potential risk of damage based on categories proposed by Burland et al. (1977). Boscardin and Cording (1989) showed that these categories of damage are related to the magnitude of the maximum tensile strain induced on the structure.

The damage classification is presented in **Table 73** below shall be used as per widely accepted practice for urban tunneling.

Table 73: Building Damage Classification (After Burland et al, 1977 and Boscardin and Cording, 1989)

Risk Category	Description of Degree of Damage	Description of Typical Damage and Likely Form of Repair for Typical Masonry Buildings	Approx. Crack Width (mm)	Max Tensile Strain%
B-0	Negligible	Hairline cracks.	Less than 0.1 mm	Less than 0.05
B-1	Very Slight	Fine cracks easily treated during normal redecoration. Damage generally restricted to internal wall finishes. Perhaps isolated slight fracture in buildings. Cracks in exterior brickwork visible upon close inspection.	0.1 to1mm	0.05 to 0.075
B-2	Slight	Cracks easily filled. Redecoration probably required, Several slight fractures inside building, Exterior cracks visible, some repainting may be required for weather tightness. Doors and windows may stick slightly.	1 to 5 mm	0.075 to 0.15
B-3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Tack pointing and possibly replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility Services may be interrupted. Weather tightness often impaired.	5 to 15mm or a number of cracks greater than 3mm	0.15 to 0.3
B-4	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and door frames distorted. Floor slopes noticeably, Walls lean or bulge noticeably. Some loss of bearing in beams.	15 to 25 but also depends on number of cracks	Greater than 0.3

Risk Category	Description of Degree of Damage	Description of Typical Damage and Likely Form of Repair for Typical Masonry Buildings	Approx. Crack Width (mm)	Max Tensile Strain%
B-5	Very Severe	Major repairs required involving partial or complete reconstruction. Beams, load bearing, walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	Usually greater than 25mm but depends on number of cracks	Greater than 0.3

8.8.1 Assessment of Risks for Building Damage

A staged approach shall be adopted to assess the degree of damage to the buildings due to ground movements from the excavation of the tunnel. The various stages of assessment based on domestic and international reference are explained as under:

8.8.1.1 Stage 1 Assessment

This stage includes the settlement analysis and preparation of settlement contours along the alignment. An empirical approach is used to carry out the analysis. Any structure where the predicted settlement is less than 10mm, and the predicted ground slope is less than 1/500 need not be subject to further assessment. All other structures within the zone of influence are subjected to a Stage 2 assessment. For critical/sensitive structures a more stringent slope and settlement criteria shall be adopted.

8.8.1.2 Stage 2 Assessment

The EBS identified to be having a potential risk as a result of Stage 1 assessment are individually assessed using a limiting tensile strain approach. This method of assessment takes into account the tensile strains in the ground and uses a simple idealized model of the building.

In stage 2, the settlement calculated for "greenfield" conditions is imposed on buildings, i.e. it is assumed that buildings behave completely flexibly and their own stiffness has no influence on the settlement behavior (E/G ratio is 2.6 for masonry and 12.5 for Framed structure). Conservatively, E/G ratio is taken as 2.6 in the analysis. In addition, the deformation due to horizontal ground movement is also taken into account. This is a conservative assumption as, in reality, a building's structure and foundations will modify the settlement effects and limit the development of horizontal strain, reducing the potential for damage.

All buildings (settlement >10mm) as identified within the influence zone and from stage 1 analysis are considered for stage 2 assessment. The assessment is based on the limiting tensile strain approach by Mair et al. (1996), wherein damage risk would then be carried out with reference to the classification of Burland et al. (1977) and Boscardin and Cording (1989). Movement and distortion shall be limited such that no individual EBS shall suffer damage greater than "Slight" Buildings as per damage classification table. Further structural assessment would not be required in case of damage category with slight or better. In the Stage 2 assessment, the Greenfield surface ground movement estimated in the stage 1 assessment above is used to compute the damage risk to the building due to the proposed construction.

Movement and distortion to critical/sensitive structures such as hospitals, bridges, flyovers, underpasses/sub-ways, viaducts, heritage structures and protected structures etc. shall be limited to “Negligible” as defined in damage classification table. The existing condition of buildings as determined based on the BCS survey is included in the assessment.

8.8.1.3 Stage 3 Assessment

All structures which are placed in Category 3 or above in the "Damage Classification" during the second stage assessment, and also all critical/sensitive structures for which a more stringent damage classification is required to be adopted, shall be subjected to a further settlement/distortion assessment. A detailed structural survey shall be undertaken to determine the structural form and condition of all such buildings/structures, followed by an analysis of how individual elements of the building/structure would be affected by the predicted settlement/distortion.

As a result of the Stage 3 analysis, the requirement for any protective works shall be established and the details of any protective works, including designs and method of working, determined.

8.8.2 Methodology

According to Burland and Wroth (1974), a building can be idealized as a deep beam with span ‘L’ and height ‘H’ deforming under a central point load to give a maximum deflection, Δ. The height H is taken as the height from foundation level to the eaves. The roof of the building is usually ignored.

Buildings, when affected by a settlement trough, are assumed to follow the deformed ground at the foundation level. The settlement trough (Gaussian distribution curve) consists of a sagging and a hogging zone, which are delimited by the point of inflection of the trough curve. A building can be considered separately at each side of a point of inflexion. Therefore, the assessment of building tensile strains can be carried out separately for the area of the building within the sagging and the hogging zone respectively.

For the portion of the building in the hogging zone, it is assumed that the restraining effect of the foundation will lower down the neutral axis, which can therefore be taken to coincide with the lower extreme fibre of the beam. Then, all strains due to bending are tensile.

For the portion of the building in the sagging zone, however, it is reasonable to assume that the neutral axis is located in the middle of the beam. In this case, bending will generate both tensile and compressive strains

Maximum bending and diagonal strains are calculated based on the arrangements presented in data above. The average horizontal strains for a respective sub-span (sagging or hogging) can be calculated by determining the horizontal movements at either end of a building span under consideration and the difference between these divided by the span length. The horizontal strains can be added directly to the bending strains.

When assessing building damage in the sagging and hogging zones, Lsz (length of the building within the sagging zone) and Lhz (length of the building within the hogging zone) should be used respectively. The length of the building does not need to be considered beyond the limit of the settlement trough, (assumed as 2.5*i for tunnels).

Structures on piled foundations will not follow the same settlements as the surrounding green field and are therefore less prone to differential settlements. Since buildings on piled foundations involve also pile caps, transfer beams etc., it is expected that buildings on piled foundations will behave stiffer at basement levels than buildings sitting only on shallow foundations.

Classification of building damage based on the Burland and Wroth approach is used to estimate potential building damage condition.

8.8.3 Flowchart for Building Damage Assessment

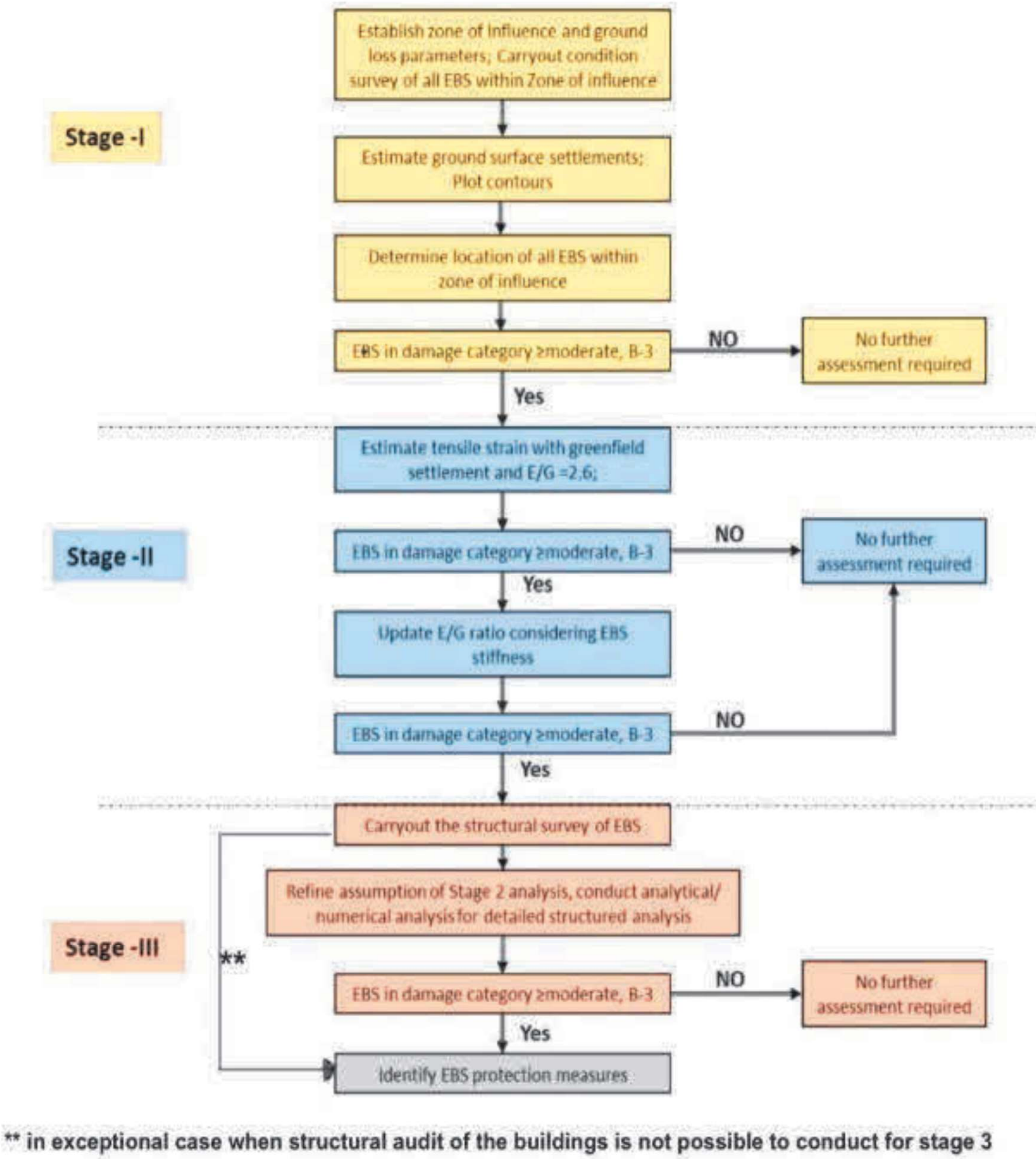


Figure 56: Flowchart for Building Damage Assessment

In order to carry out a building impact assessment, buildings adjacent to the proposed alignment to be classified in terms of the potential risk of damage based on categories proposed by Burland et al. (1977). Boscardin and Cording (1989) showed that these categories of damage are related to the magnitude of the maximum tensile strain induced on the structure.

The damage classification is presented in **Table 73** below shall be used as per widely accepted practice for urban tunneling/ excavation.

8.9 WATERPROFING AND DRAINAGE SYSTEM

8.9.1 Waterproofing System

Considering the urban environment, the c &c tunnels in this project shall be designed as watertight (tanked system) that means ground water is not allowed to drain. Different approaches for waterproofing can be proposed during detailed design by contractor. However, depending on the construction type the following options would remain viable

b. Cut & Cover and Ramps – All C&C tunnels and Ramps are proposed to have cast in situ box/ U structure. Water tightness of structure can be achieved by application of waterproofing membrane on the external boundary of structure and/or with addition of waterproofing admixture. All construction joints to be treated with water stop bars.

Project specifications shall be followed for minimum requirement for various waterproofing system.

8.9.2 C &C Tunnels Drainage System

The c&c tunnel drainage system shall cover all sorts of water which may reach the tunnels such as road surface spillage, cleaning water, ground water seepage, firefighting or rainwater etc. It is important to control the spills at source level, however, tunnels cannot be assumed dry at all times. Therefore, continuous drainage shall be provided to collect those water and channelize it to the designated sumps from where it can be mechanically discharged to nearest municipal drains through the project shaft. A typical arrangement for drainage system has been included in the DPR however Contractor shall carry out the detailed design to estimate the amount of water for which drainage system shall be designed and sizing of each component shall be elaborated.

The tunnel drainage scheme has following features

3. **Drain and sumps in Open Ramp zone**: the entry of surface ground water shall be restricted by appropriate measures in at grade highway design so that it does not reach the falling grade of ramp area and unnecessarily increase the drainage efforts of tunnel. Also, the canopy roof structure shall be installed to minimize the entry of rainwater. Still some amount of rain water and ground water seepage can find access to ramp area and same shall be collected in the side drain of ramp. A central drain in case required, may also be constructed. A sump of suitable size shall be constructed at the interface of ramp and cut & cover section and water from this sump can directed to nearest municipal drain by pumping.

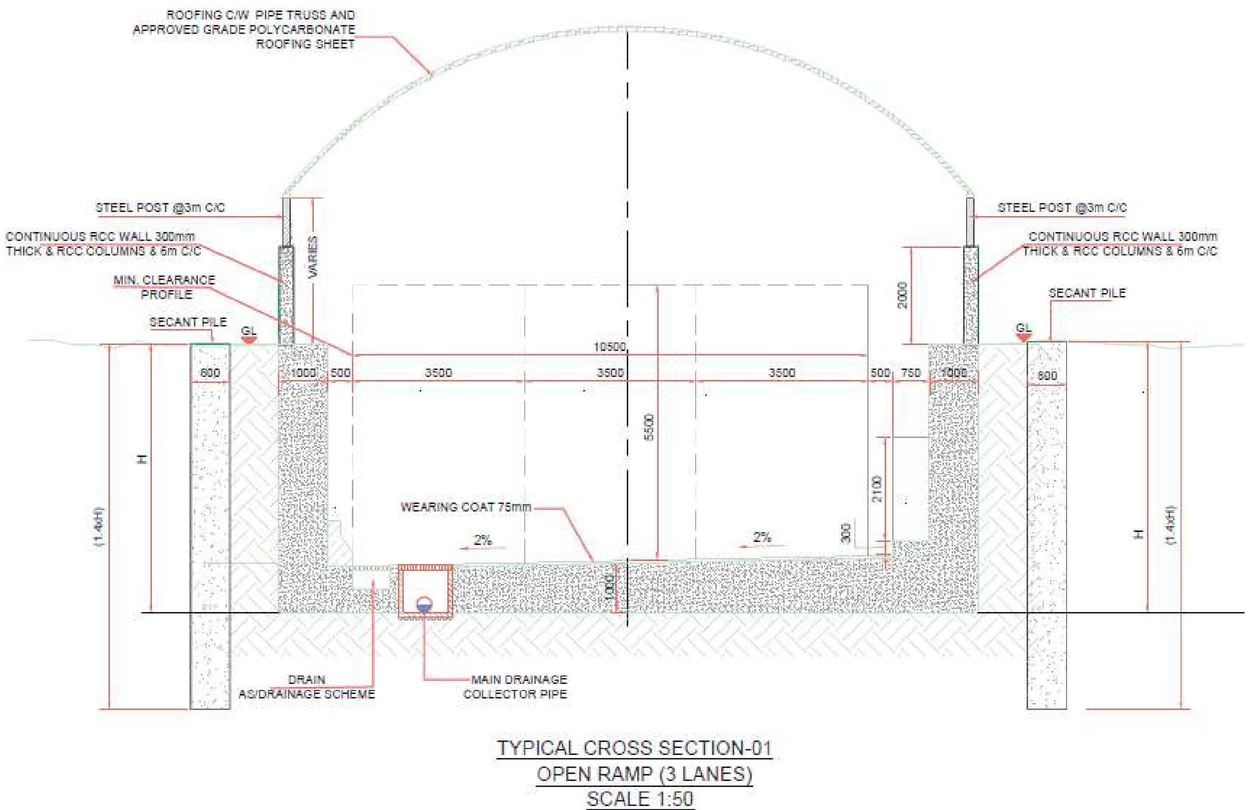


Figure 57: Typical drainage arrangement of Ramp area

The main drainage pipes shall remain buried in the base slab of ramp section. However, for maintenance purposes manholes at the spacing between 50 to 75m should be planned, the manhole opening size of minimum 400mm x 400mm or as designed by the contractor can be utilized. All ramp sections of main tunnels and entry/ exits proposed to have drainage arrangements of similar kind.

4. **Drainage in Cut & Cover tunnels:** The cut & cover section can expect ground water seepage and road spillage from cleaning, running vehicles or firefighting. The side drainage shall run along the Cut & cover tunnels to collect the water. A central drain connecting the surface drain to carry water along the C&C stretch is proposed. The central drain shall be a covered drain which will have connection to sump situated at lowest points along the c & c tunnel. Sump shall be equipped with riser pipe and pump to drain the accumulated water to the surface. The water from sump shall be drained to nearest municipal drain through the shafts.

   The pipe and manhole arrangement will remain similar to ramp section that means the manhole spacing between 50 to 75m with a size of minimum 400mm x 400mm. The side drain should be connected with central drain at every manhole point.

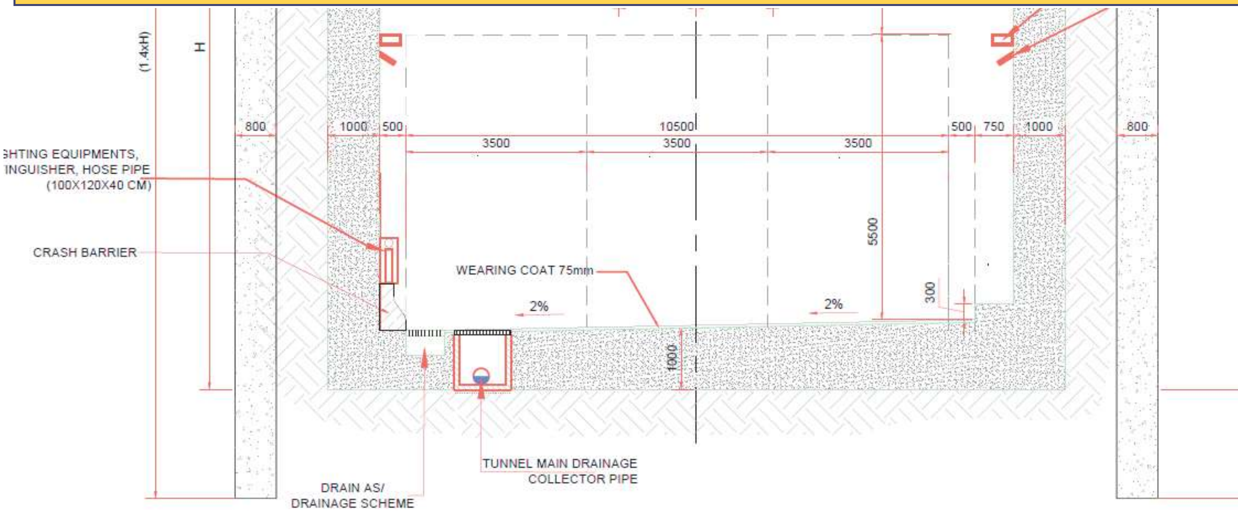


Figure 58: Typical drainage arrangement of C&C tunnels

8.10 LIST OF ANNEXURES

ANNEXURE - 1 - RS2 FEM OUTPUT

ANNEXURE - 2 - PILE BEARING CAPACITY CHECK

ANNEXURE - 3 - TOE STABILITY CHECK

CHAPTER 9 : ELECTRICAL AND LIGHTING PROPOSAL

9.1 Electrical System

9.1.1 Terms of Reference:

- IRC SP91-2019
- NFPA 502- 2017
- PIARC 2019R02EN
- IE Rules-1956, as amended till date
- CIE 88:2004 “Guide for the lighting of road tunnels and underpasses
- IS/IEC standards.
- Conditions of Supply of Electricity of Distribution Licensees in The State of Karnataka (KERC)

9.1.2 Power Supply

The preliminary load assessment based on emergency scenario for the Cut and Cover Tunnel from Hebbal to Baptist Hospital is estimated to approximately 2.6 MW or 2.9 MVA. For this electrical power requirement KERC has classified the voltage as HT supply ,3-phase, 50 c/s at 33KV. The excerpt of the guideline is appended below:

> **(c) H T SUPPLY, 3 PHASE, 50 C/S, 11/13.2KV AVAILABLE IN THE LOCALITY**
> All installations with a Contract Demand of 50 KW / 59 KVA and above up to and inclusive of 2,000 KVA.
> **Note:** - In case the power supply is given at13.2 KV, the transformer provided by the Consumer shall be designed for change over to11 KV, when the Licensee's supply line is converted to 11 KV.
>
> **(d) H T SUPPLY, 3PHASE, 50 C/S, 33KV**
> All installations with a contract demand above 2,000 KVA and upto and inclusive of 7,500 KVA

However, as the tunnel is being proposed to be fed from both ends, the electrical power of the twin tube tunnels will be divided and will fall below 2000 kVA, Therefore, instead of seeking 33KV supply at single point, two separate connections one each at Hebbal and Baptist side respectively be sought from KERC at 11KV. The power supply shall be provided from two independent power sources i.e. two independent HV supply lines brought to each end of the tunnel system from two grid networks.

The supply at each end of the portal will terminate into Distribution company's (KERC) Ring Main Unit (2 no. Load break switch as incomers + 1 no. VCB as outgoing) which will further connect to their metering cubicle.

Based on the load assessment in Annexure-I of this report, the total load envisaged for the project in both normal and emergency scenario is:

Load of both Tunnels in kW (In Normal Scenario)	1703.86 KW
Load of both Tunnels in kW (In Emergency Scenario)	2633.26 KW

9.1.3 11 kV System

The supply from the KERC metering cubicle will feed into the HV RMU placed in the portal substation, where in the LV switchgear and distribution facilities for ventilation and lighting loads are located.

11 KV RMU (at Hebbal and Baptist end) will have the following feeders:

- 1 no. incomers from KERC metering cubicle through 11 KV XLPE cable.
- 2 no. outgoings each feeding to Distribution transformers.

The cables shall be 3 phase, 11kV, FRLS, XLPE, armoured, Aluminium conductor of the capacity according to the system fault MVA.

9.1.4 Distribution Substation

The substations will comprise of a high voltage room, two transformer rooms and LT Panel Room. The Two transformers in each substation will guarantee power supply in case of a failure of one transformer or during maintenance works. Each transformer will be capable of supplying the whole substation and all systems which are supplied by the substation.

The Main equipments within the substation will generally comprise of the following:

Sl No	Description of item	Unit	Qty
1	3 way-11 kV Ring Main Unit (1 no VCB incomer + 2 no. VCB outgoing for Transformer feeder)	each	1
2	11/0.433 kV Distribution Transformer (Dry Type) w/o OLTC	each	2
3	MDB Panel	each	1
4	Lighting Panel	each	1
5	Ventilation Panel	each	4
6	APFCR Panel	each	1
7	UPS	each	2
8	UPS Incoming Panel	each	1
9	UPS Outgoing Panel	each	1
10	Fire fighting Panel	each	1

Based on the load assessment in Annexure-1, the possible distribution transformer configurations at the proposed locations have been described below

Table 74: Substation Capacity

Substation Capacity					
Sl. No	Description	Qty (in Nos.)	Load (in watt)	Substation Location	
				Hebbal Side	Baptist Side
1	**Jet fans**				
	Hebbal End	32	32000	1024	
	Baptist End	32	32000		1024
2	**Ventilation sensors**				
	Hebbal End(Lot)	1	50000	50	
	Baptist End(Lot)	1	50000		50
3	**Lighting Load**				

Substation Capacity					
Sl. No	Description	Qty (in Nos.)	Load (in watt)	Substation Location	
				Hebbal Side	Baptist Side
a	Threshold zone				
	300W	30	300	9	
	240W	14	240	3.36	
	180W	4	180	0.72	
	300W	24	300		7.2
	240W	16	240		3.84
	180W	4	180		0.72
b	Transition Zone				
	180W	12	180	2.16	
	80W	24	80	1.92	
	180W	12	180		2.16
	80W	20	80		1.6
c	Interior Zone-1				
	80W	42	80	3.36	
	80W	42	80		3.36
d	Interior zone-2				
	80W(Night/Normal)	223	80	17.84	
	80W(Night/Normal)	223	80		17.84
e	Exit Zone				
	180W	10	180	1.8	
	80W	2	80	0.16	
	180W	10	180		1.8
	80W	2	80		0.16
4	**Low Voltage Systems**				
a	Traffic Management System, CCTV/Surveillance System.			13.18	13.18
b	SOS/ECB System, PA System			1.45	1.45
c	SCADA System			4.50	4.50
d	Miscellaneous Loads			1.00	1.00
5	**Other Loads**				
a	Substation Lighting Loads			10	10
b	Maintenance Socket Outlets			3.00	3.00

Substation Capacity					
Sl. No	Description	Qty (in Nos.)	Load (in watt)	Substation Location	
				Hebbal Side	Baptist Side
c	DG Fuel Tank Filling			10	10
d	Fire doors			0	0
e	External Lighting			10	10
5	**Fire Fighting Loads**				300
	Total Connected Load in KW			**1167.5**	**1465.8**
	Power factor@0.90 in KVA			1297.2	1628.7
	Loading@80% in KVA			1621.5	2035.8
	Transformer Size in KVA			**2000**	**2000**
	No.s(1W+1SB)			**2**	**2**

The Distribution transformer will have the minimum parameters as enumerated below:

Voltage (primary side):	11 kV
Voltage (secondary side):	0.433 kV
Nominal frequency:	50 Hz
Cooling:	ANAN
Tapping range:	+5 %, +2.5 %, ± 0 %, -2.5 %, -5 %
Vector Group:	Dyn11
Enclosure:	IP 33
Location:	At Portal Sub-station
Primary connection:	Totally insulated plug-in connector
Secondary connection:	Connection safe to touch with connecting lug and insulating cover

9.1.5 LT power supply system

The general power supply of the 415 / 230 Volt-level to the different equipment inside the tunnel occurs from the main power supply (Portal Substation) to the E & M Niches in the tunnel wall preferably located at LHS of the driver direction/ as applicable and then further to the ultimate equipments.

All power and control units shall be installed into distribution panels, all different voltages (e.g., main power, UPS power, safety extra-low voltages, different control units and so on) shall be placed in separate or compartmentalised distribution panels.

Grounding and protection cables shall be coloured yellow green as per standards compliance.

The inlet of the cables into the distributors generally shall be made from bottom up (raised floor) with a degree of protection of IP 54 in EM Niches/Main Tunnel tube and IP 42 in the Service Buildings / control room.

The Niches also shall have cable inlets on top. This is necessary to lead the cables from the Niche to the cable tray along the tunnel wall.

Switches, push buttons, pilot lamps and measuring instruments shall be installed into the distribution panels' front doors.

All electrical equipment, inside distribution panels / boards shall be labelled. Also, the distribution panels themselves shall be labelled with a combination of letters and numbers, which shall be engraved into an aluminium-plate. Equipment inside the tunnel, measuring instruments, etc. shall be labelled with stainless steel-boards.

Each distribution panel shall be provided with a pocket for the drawings, this pocket shall be fixed on the inside of the distribution panels' door (fixed with screws or rivets, the use of glue is not allowed). All distribution panels shall be grounded.

Distribution panels shall have surge arrestors to protect all facilities from voltages higher than 415 V. All distribution panels, situated in the main tunnel tube, as well as in the Accesses (tunnel and shaft) shall be equipped with anti-condensation heating.

Circuit breakers and fuses shall be discriminating to each other facilities (discriminating ratio) in direction of the power / current flow.

The Main LV boards shall be modular, extendable and shall have maintenance friendly construction. It shall be of metal clad sheet steel enclosed cubicle, fully compartmentalized, floor mounting type suitable for indoor installations.

A capacitor bank of suitable capacity for maintaining the power factor of 0.95 at the 415 V bus shall be provided.

9.1.5.1 LT Cables

Following cables will be used:

- Cabling for jet fans, tunnel lighting and safety equipment will be Fire resistant cables capable of withstanding 950 deg C for 3 hours (CWZ specification).
- All other cables entering the open space of the tunnel will be Low Smoke Zero Halogen (LSZH) withstanding 250 deg C for 3 hours.
- Cables, which are laid outside the tunnel as well as running inside cable trenches, are of FRLS Cross Linked Polyethylene (FRLS-XLPE).

Each electrical circuit will have a separate cable.

Only cables with the same voltage will be installed within one conduit/duct.

Accessibility of the cables is given by cable pits and recesses.

9.1.5.2 Cables outside the tunnels

Outside the tunnel, extreme geological movement may be experienced between the Portals and the facilities building. Therefore, all cables shall be laid in Pre-cast concrete troughs/trenches conforming to the standards of the supply authority.

The troughs shall be composed of reinforced cement mortar.

The trench system shall consist of precast glass reinforced concrete, one piece channel sections, and removable cover sections assembled to form a completely enclosed trench on a 200mm sand bed. The trench shall be 800mm deep overall (including cover), with an interior clear width cross 600 mm. its design shall be such that the channel is self-supporting and can be set above grade if required.

The one-piece channel designed trench system shall be furnished in standard 1500mm or 2000mm lengths.

The precast trench covers shall be furnished in sections of the same material as the trough, and each shall have slots or internal lugs for lifting tools.

Provision shall be made to allow for the inclusion of 11kV SWA cables and segregation suitable for inclusion of both copper and optic control and communications cables within the same trough.

All cable covers will bear on both sides the inscription "DANGER - ELECTRIC CABLES".

9.1.5.3 Cables inside the tunnels

In the Main Tunnel the LT Power, Control and ELV (Extra Low voltage) cables shall be laid on cable trays mounted on both sides of the tunnel wall. The LT cables from substations will be carried in ducts/trenches under the tunnel walkway. Cable pull pits shall be provided at regular intervals in the tunnel pathways.

The technical parameters of 1.1kV XLPE cables shall be as follows:

Sr. No.	Item	Details
i.	Cable Type	A2XFY/ 2XFY
ii.	No. of Cores	3/3.5/4
iii.	Voltage Level	1.1kV
iv.	System Grounding	Solidly Grounded
v.	Nominal System voltage	400V ±10%
vi.	Nominal System Frequency	50Hz ±3%
vii.	Maximum conductor temperature at rated current	90°C
viii.	Maximum conductor temperature at Short-circuit	250°C
ix.	Conductor	
	Conductor Material	Electrolytic grade Copper, Purity > 99.97%
	Conductor type	Stranded with number of strands as per IS 8130 (Part-I) 1984
x.	Insulating material	Cross-Linked-Polyethylene (XLPE) Compound
xi.	Core Identification Strips	Red, Yellow, Blue & Black (for neutral)
xii.	Material of Inner Sheath	FRLS, PVC ST-2 Compound
xiii.	Armour	Single layer of Galvanized Steel Round Wire according to IS-3975
xiv.	Outer Sheath	FRLS, PVC ST-2 Compound according to IS-5831

9.1.6 DG Set

DG sets shall be sufficiently sized to cater for the tunnel load during emergency conditions and/or loss of external supply from the authority.

The DG set shall be based on the following parameters:

- Prime Rating
- 100% backup.
- Radiator cooled.
- Terminal voltage at 415V.
- Fuel Tank to be sized based on 8 hours of fuel capacity available at full loads.
- Located adjacent to technical rooms with fuel tank at portals

The DG set shall be complete with cooling system, fuel system, lubricating system, air intake system, exhaust system, governing system, standby system, engine protection safety system with microprocessor-based power control command generator set monitoring, metering, protection, and control system to meet demands of engine driven generator sets.

The alternator shall be of rated voltage 0.415 kV, power factor 0.8, with voltage regulation ± 0.5% for all loads between no load to full load conditions of insulation with soundproof enclosure, weatherproof enclosure Prime Power Rating (PRP) conforming to ISO 8528 part - I as per environment noise level norms 75 Db (decibels) as at one meter.

The alternator shall be self-excited, self-regulator, self-ventilated in brushless design processed with suitable AVR and shall conform to BS: 2613 or BS:5000 and shall give rated output at NTP conditions.

To ascertain the capacity of the 0.415 kV DG sets a tentative load assessment (refer Annexure-I) along with fuel consumption has been carried out below.

Table 75: DG Set Sizing

Sl No.	Description	Hebbal Side		Baptist Side	
		In Normal Scenario Load (in KW)	In Worst Case Scenario Load (in kW)	In Normal Scenario Load (in KW)	In Worst Case Scenario Load (in kW)
	DG Set Sizing and Fuel Requirement (Considering 0.415 kV Generation)				
a)	Load of half of twin tube length in kW-Hebbal side	852	1317		
b)	Load of balance half of twin tube length in kW-Baptist Side			852	1317
c)	Total kVA pf @ 0.8	1064.9	1645.8	1064.9	1645.8
d)	Considering 80%ge loading	1331.1	2057.2	1331.1	2057.2

Sl No.	Description	Hebbal Side		Baptist Side	
		In Normal Scenario Load (in KW)	In Worst Case Scenario Load (in kW)	In Normal Scenario Load (in KW)	In Worst Case Scenario Load (in kW)
e)	**DG set size considered in kVA**	**1010.0**	**1010.0**	**1010.0**	**1010.0**
f)	No of 415 V DG sets required	1.318	2.037	1.318	2.037
g)	**Approx nos.**	**2**	**2**	**2**	**2**
h)	Fuel @ 100% loading in ltrs/hr/DG	203.8	203.8	203.8	203.8
i)	Assumed Hours of operation	8	8	8	8
j)	Fuel @ 100% loading in 8 hrs continuous running (litres)/DG	1630.4	1630.4	1630.4	1630.4
k)	1st fill in day tank/DG	990	990	990	990
l)	Total litres of fuel/day/DG	2620.4	2620.4	2620.4	2620.4
m)	Total litres of fuel/day in litres	5240.8	5240.8	5240.8	5240.8
n)	**Considering a minimum of 1 day storage for catering to Normal scenario (in Litres)**	**5240.8**		**5240.8**	
o)	**Bulk fuel storage tank considered**	**1 x 5 kL**		**1 x 5 kL**	

Based on the analysis the recommended configuration of DG sets for the Tunnel are as follows:

Hebbal side

2 x 1010 kVA which will operate under both normal and emergency conditions.

Baptist Side

2 x 1010 kVA which will operate under both normal and emergency conditions.

The installation of Generator sets shall be inside soundproof enclosure to be installed in the open area.

To run DG sets at full capacity, adequate capacity of fuel storage shall be required. The capacity of fuel storage is computed based on the following conditions:

- No Grid supply.
- Emergency condition for 8 hours continuously.
- 2 days storage

For Exhaust stack, as per the notification by CPCB, DG sets with rating 1000 kVA and above will be installed to stand at 30m above the ground.

9.1.7 UPS system

Uninterrupted Power Supply system shall maintain uninterrupted power to equipment continuously and during power failure. UPS shall be provided to supply the following equipment:

- Emergency tunnel lighting, exit signages, strobe lights.
- Critical loads comprising of:

i. All Computer systems
ii. SCADA System including remote control units, sensors etc
iii. CCTV/surveillance systems
iv. Public Address Systems
v. Motorist Emergency Telephones
vi. Radio rebroadcast System
vii. Traffic lights, Variable Message signs
viii. Fire detection and Alarms systems.
ix. Access control

The UPS shall ensure uninterrupted power for a minimum period of 90 mins using sealed maintenance free VRLA battery.

UPS shall be installed at portal substations.

The rating of the different UPS shall be sufficient to supply the connected loads for the specified back-up period. The UPS system shall consist of a single UPS module, or the appropriate number of UPS modules connected in parallel for operation in capacity or in N+n redundancy mode.

The UPS system will be complete with inverter battery bank, rectifier charging unit, inverter units, protective devices, filter circuits, system static transfer switches/bypass switches, auxiliary equipments etc. All the characteristics of UPS (like THD, overload, etc.) shall be as per IEC/EN 62040.

The UPS will be fed from the main power supply (415/ 230 V, 50 Hz) and shall supply the connected equipment via rectifier, battery, and inverter.

In the event of a main power supply failure the equipment will be fed from the battery and inverter system without any interruption.

The UPS shall be equipped inclusive of bypass switch and an interface for Telecontrol System/ SCADA.

To ascertain the capacity of the UPS a tentative load assessment based on Annexure-I has been carried out below:

Table 76: UPS Sizing

UPS SIZING (90 mins)		
Sl No	Description	Load (in KW)
		Substation Location

		Hebbal side	Baptist Side
a)	Considering interior zone lighting on UPS	18.08	17.6
b)	Low Voltage Systems comprised of Traffic Mgmt. System, CCTV, SOS, PA, SCADA etc.	20.13	20.13
c)	Total kVA pf @ 0.8	47.8	47.2
d)	Considering 80%ge loading	59.7	59.0
e)	UPS size considered in kVA	60.0	60.0
f)	No of UPS sets required	1.000	1.000
g)	No of UPS in N+n mode	1+1	1+1

9.1.8 Lightning Protection

The lightning protection for the equipment buildings outside the tunnel shall be designed in accordance with the recommendations of BS: 6651, IE rules and other applicable standards in force. The lightning protection system shall convey lightning discharges to ground without electrification of structure. The air- termination system shall be connected to down conductors. The down conductors shall be bonded to a number of dedicated earth electrodes which do not make contact with any part of the structures or building. A bond should be mechanically and electrically effective and protected from corrosion in and erosion by the operating environment. The system shall have specific test links for periodic testing of continuity resistance. The whole of earth termination network should have a combined resistance to earth not exceeding the designed value in ohms without taking account of any bonding to other services.

All low voltages & communication cables metallic cables entering the services building, electrical rooms or control centre shall be protected against over voltage with special surge arrestor banks for control cables.

9.1.9 Earthing

A suitable size of earth conductor/ wire will run throughout the tunnel. All the electrical equipment like panels, distributions boards, lighting DB, power DB, Jet fans etc. will be connected to the earth conductor. The earth conductor will connect the earth grid provided at the portal areas.

The whole installation shall be grounded efficiently, that is the resistance from the ground to any point does not exceed the value specified by the operative codes of practice, which is less than 1 Ohm of its main protective ground system and less than 10 Ohm for all the lightning protection system. The whole installation shall be efficiently bonded.

9.2 Lighting System

Normal and emergency lighting system has been considered as per serial no 6.0, Vol-2C of Technical Schedule and as per CIE88-2004 guidelines.

The lighting system consists basically of:

- Tunnel lighting (entrance lighting, interior lighting)
- Emergency lighting.
- Night Time lighting

- Parting zone lighting
- Building lighting in the Service Buildings and in the niches

The tunnel lighting will be fully controlled automatically by the SCADA system according to measurements of the light sensors situated outside and inside the tunnel. A manual control of the entire lighting system will remain possible at any time.

Refer Relux simulation of the tunnel enclosed as Appendix-1 and Appendix-2 of the report

9.2.1 Tunnel Lighting

9.2.1.1 Zones in tunnel

It is practical to distinguish different zones in the tunnel in order to determine the longitudinal lighting level at daytime lighting: the access zone, the threshold zone, the transition zone, the interior zone and the exit zone.

9.2.1.2 Access zone

In access zone the number of light fixtures is calculated according to the required luminance level and design accordingly. It is the part of the open road immediately outside (in front of) the tunnel portal, covering the distance over which an approaching driver must be able to see into the tunnel. The access zone begins at the stopping distance point ahead of the portal and it ends at the portal.

9.2.1.3 Threshold zone and Transition zone

Threshold and transition zone lighting fixtures of the tunnel accommodation sections are situated on the roof of the tunnel tube in a line passing over the middle of an access traffic lane, the quantity and capacity of the light fitting will be designed as per the detailed luminous calculation.

- Lighting fixture specifications.
- Nominal power of light sources;
- Execution of the tunnel tube;
- Elevation and lateral location of lighting fixtures inside the tunnel tube;
- Spacing of lighting fixtures;
- Over switching regulation of lighting fixtures.

9.2.1.4 Interior zone

Very long tunnel's interior zone consists of two different sub zones.

The first sub zone corresponds to the length which is covered in 30 seconds and should be illuminated with the "long tunnel " levels. The second sub zone corresponds to the remaining length and should be illuminated with the "Very long tunnels" levels.

Lighting fixtures are situated in the centre line of the tunnel tube on the roof the quantity and capacity of the light fitting will be designed as per the detailed luminous calculation.

Luminance values in cd/m^2 in the interior zone (long tunnels)

Stopping Distance (m)	LONG TUNNELS Traffic flow [vehicles/hour/lane]	
	Low	Heavy
160 m	6	10
60 m	3	6

Luminance values in cd/m² in the interior zone (very long tunnels)

Stopping Distance (m)	VERY LONG TUNNELS Traffic flow [vehicles/hour/lane]	
	Low	Heavy
160 m	2,5	4,5
60 m	1	2

9.2.1.5 Exit zone

The exit zone lighting provides the visual contact for the driver still in the tunnel with the open road beyond the tunnel the quantity and capacity of the light fitting will be designed as per the detailed luminous calculation. In exit zone the Lighting is gradually increased to 5 times the interior lux.

9.2.2 Emergency Lighting

The emergency lighting is important part of road tunnel technical accessories. It consists of an emergency lighting of unprotected escape ways (for lay-bays, emergency exits, SOS boxes, FF niches and tunnel sidewalks) and an emergency lighting of escape ways in the tunnel complex (for escape tunnel, escape ways in technology buildings and rooms). Power supply of all the emergency lighting fixtures must be executed by on-line uninterruptible power sources (UPS).

According to CIE 88:2004 for emergency lighting the illuminance values must not fall below 10 lux.

9.2.3 Night-Time Lighting

If the tunnel is on a section of an illuminated road, the quality of the lighting inside the tunnel should be at least equal to the level, uniformities and glare of the access road. The uniformity at night of tunnels shall fulfil the same requirements as the daytime lighting.

9.2.4 Parting zone lighting

Parting Zone is first part of the open road directly after the exit portal of a tunnel. In case the tunnel is part of an unlit road and the speed of driving is higher than 50 km/h, night-time lighting of the parting zone is recommended:

- if the night-time lighting level in the tunnel is more than 1 cd/m²;

- if different weather conditions are likely to appear at the entrance and at the exit of the tunnel.

Road lighting in the parting zone shall be provided over the length of two stopping distances with road luminance not lower than 1/3 of the night-time luminance in the interior zone of the tunnel.

9.2.5 Building Lighting System

Conventional lighting according to local standards will be provided in the Service Buildings, electrical rooms, emergency call recesses and the Control Centre(s).

The illumination (in lux) for following rooms is:

1. Control room: 500 lux
2. Corridor: 100 lux
3. Distributing room (like server, LV, HV etc.): 150 lux
4. Office room: 400 lux
5. Common room (like kitchen, toilets, etc.): 100 lux
6. Workshop: 150 lux

9.3 CCTV System

9.3.1 CCTV Network

All the cameras monitoring one traffic direction will be oriented in the same direction. The cameras will be mounted on a height of approximately 5 m on one face of the tunnel wall at a spacing of approximately 80m.

Every access door to the cross passage will be monitored by a separate camera, which will be installed on the opposite tunnel wall. Also, cameras will be installed in the cross-passage.

The tunnel video camera network will be completed with pole mounted video cameras located outside of the tunnel. These cameras will monitor the traffic on the tunnel access road and tunnel access ramps. They will be equipped with pan/ tilt and zoom devices.

All the video pictures from the video cameras will be transmitted in real time to the Tunnel Control Centre and continuously recorded on HDD digital recording system.

The video pictures will be transmitted from the video camera to electrical substations via single optical fibre and then to the control centre via the main tunnel optical fiber network. The main tunnel optical fibre network is designed as a ring for redundancy.

The CCTV network will be connected to the Control Centre, by which the pictures can be seen, or cameras can be controlled.

9.3.2 Video Automatic Incident Detection

The tunnel CCTV system will be associated with an Automatic Incident Detection system.

The Automatic Incident Detection system will be able to detect and transmit alarms concerning:

- Stopped and/or slow vehicles.
- Vehicles travelling in the wrong direction (contra flow)
- Pedestrians in the tunnels
- Traffic congestion and queues

After an alarm is generated by the system, the system will be able to isolate the corresponding event on the HDD digital recording system for analyses.

The Video Automatic Incident Detection is connected to the Control Centre, by which the pictures can be seen, or cameras can be controlled.

9.4 Public Address System

Public address (PA) system shall enable the operator to broadcast evacuation tones and give directions to motorists and maintenance staff in the event that the tunnel needs to be evacuated. Loudspeakers shall be deployed along the tunnel and in the most critical area or technical room, in order to supply information to those who have alighted from their vehicles. It shall be mounted on the side walls in the main tunnel at maximum spacing of 50m.

Zone control switches shall be built into the operator's workstation so that the PA announcements can be confined to a selected zone.

The system shall deliver voices clear and audible enough to overcome environmental and emergency conditions within the tunnel. PA system shall be designed to withstand rough tunnel conditions and cleaning techniques used to clean contents of the tunnel.

The distribution amplifiers shall provide and maintain the necessary signal levels for optimum performance. All categories of amplifiers must be dual directional in the frequency bands.

The loudspeaker circuits shall be interleaved and overlapped so that alternate loudspeakers are supplied from separate amplifiers located in two different equipment racks.

A digital signal processing-based audio management system shall be provided to assist with audio quality. PA system shall store messages that can be automatically triggered from the operator’s workstation.

9.4.1 Emergency Call Network

An emergency call telephone will be installed at every 100m as per IRC SP 91 2019.

A dedicated workstation (Emergency Roadside Telephone Workstation) will be in the Tunnel Control Centre to allow the operator full control of the system. The architecture of the communication network of the emergency roadside telephones will consist in an optical fibre loop controlled from an emergency roadside telephone network interface located in the tunnel technical room. All of the emergency roadside telephone in tube-1 will be connected to one branch and all of the emergency roadside telephones in the tube-2 will be connected to the other branch. For redundancy, an emergency roadside telephone network interface is located at the portal-1 and another at the portal-2.

Service Telephone System

A telephone network will be installed for the entire tunnel project. The telephone network will consist of telephone sets in:

- Tunnel Control Centres

Control Rooms and Technical Rooms

- Service Buildings

At least one telephone

- ESS in tunnel

In the Technical Rooms

9.5 Tunnel Radio System

The system will perform the radio transmission for the road traffic areas, the access platform areas at Portal P1 and Portal P2 and the cross passages in the tunnel.

The radio system will be used by

- Fire brigade
- Traffic police
- Ambulance service
- Maintenance staff
- Operation

Every service gets its own channel (one channel for reserve).

The radio transmission will be performed through radio leaky cable mounted below the intermediate ceiling of the tunnel.

9.6 SCADA System and Data Processing and Transmission

The data processing and data transmission will be realized by using a fibre optic cable ring (over both tunnel tubes) where the local PLCs at Portal Substation will be connected to the fibre optic cable ring by using optical link modules. The use of a ring structure gives additional security, due to the fact that in case of a failure or cable break on one side of the ring, the data transmission will be done over the other side of the ring. The control of the tunnel will be designed in such a way, that the tunnel will operate fully automatic with the possibility of manual intervention if needed. In the control centre the supervision and manual control of the tunnel's electrical and safety installation can be managed (automatic/remote/local mode, supervision interface, SCADA-workstations, etc.).

The complete architecture of the data processing and data transmission as well as the SCADA system is designed redundant - so the power supply units, the data transmission rings (two rings are designed), etc. are designed in such a way, that the breakdown of a PLC, tunnel ring, etc. does not result in a breakdown of a part of the system resp. the complete system.

Control Centre (main CC and back-up CC)

The main Control Centre will be situated at the Hebbal side.

The back-up Control Centre will be situated at the Baptist side.

The control centre will include the control rooms for tunnels traffic operation all the necessary technical rooms, the operation and maintenance buildings and the administrative facilities.

The Tunnel Control Centre is an essential part of the tunnel safety system. It controls the traffic flow in the tunnel and co-ordinates the initial interventions in the event of an incident or emergency in the tunnel. The necessary rescue equipment and vehicles must be in the immediate vicinity of the tunnel portals.

The tunnel control centre will be associated with the following functions:

- Monitoring the traffic conditions in the tunnel and its accesses
- Monitoring the emergency call systems
- Receiving any alarms and alerts associated with the tunnel equipment systems
- Receiving and displaying the images transmitted from the CCTV cameras
- Supervising the operation of the tunnel ventilation, traffic control and lighting systems and other safety equipment

The equipment of the Control Centres includes the supervisor workstation, two traffic controller workstations, CCTV monitors, emergency call control equipment, tunnel radio control equipment, PA control equipment, etc.

The control room will contain:

- The supervisor's workstation
- The two traffic controller's workstations
- The tunnel CCTV monitors and control boards
- The main synoptic panel display
- The emergency telephone control station
- The radio communication
- All other equipment necessary for the tunnel operation

The Technical Specifications and Annexures are provided in sperate volume.

Load Assessment

Sl No.	Description	Qty	Load of each Item (Watt)	Total Load in kW	Normal Scenario Div	Normal Scenario Load (in kW)	Emergency Scenario Div	Emergency Scenario Load (in kW)	Qty	Load of each Item (Watt)	Total Load in kW	Normal Scenario Div	Normal Scenario Load (in kW)	Emergency Scenario Div	Emergency Scenario Load (in kW)
		Hebbal (South Side) L=1800 m							Baptist Side (North Side) L=1800 m						
A)	**Lighting Loads**														
1	LED-300W	30	300	9	100%	9	100%	9	24	300	7.2	100%	7.2	100%	7.2
2	LED-240W	14	240	3.36	100%	3.36	100%	3.36	16	240	3.84	100%	3.84	100%	3.84
3	LED-180W	26	180	4.68	100%	4.68	100%	4.68	26	180	4.68	100%	4.68	100%	4.68
4	LED-80W	68	80	5.44	100%	5.44	100%	5.44	64	80	5.12	100%	5.12	100%	5.12
5	LED-80W (Nightlight)	226	80	18.08	100%	18.08	100%	18.08	220	80	17.6	100%	17.6	100%	17.6
B)	**Ventilation Load**														
1	Jet fans	32	32000	1024	70%	716.8	100%	1024	32	32000	1024	70%	716.8	100%	1024
2	Ventilation sensors (1 lot)	1	50000	50	70%	35	100%	50	1	50000	50	70%	35	100%	50
C)	**Fire Fighting**				5%	0	100%	0			300	5%	15	100%	300
D)	**Low Voltage Systems**														
1	Traffic Management System, CCTV/Surveillance System.			13.18	100%	13.18	100%	13.18			13.18	100%	13.18	100%	13.18
2	SOS/ECB System, PA System			1.45	100%	1.45	100%	1.45			1.45	100%	1.45	100%	1.45
3	SCADA System			4.5	100%	4.5	100%	4.5			4.5	100%	4.5	100%	4.5
4	Miscellaneous Loads			1	100%	1	100%	1			1	100%	1	100%	1
E)	**Other Loads**														

Load Assessment																
Sl No.	Description	Qty	Load of each Item (Watt)	Total Load in kW	Normal Scenario		Emergency Scenario		Qty	Load of each Item (Watt)	Total Load in kW	Normal Scenario		Emergency Scenario		
					Div	Load (in kW)	Div	Load (in kW)				Div	Load (in kW)	Div	Load (in kW)	
		Hebbal (South Side) L=1800 m							Baptist Side (North Side) L=1800 m							
1	Maintenance Outlets															
a)	3 phase socket 32A	3	3000	9	20%	1.8	20%	1.8	3	3000	9	20%	1.8	20%	1.8	
b)	1 phase socket 16A	6	1000	6	20%	1.2	20%	1.2	6	1000	6	20%	1.2	20%	1.2	

CHAPTER 10: VENTILATION SYSTEM

10.1 Introduction

Tunnel ventilation systems should provide adequate in-tunnel air quality during normal and congested traffic operations and support the self-evacuation and rescue efforts during emergency incidents. Separately, the tunnel ventilation capacity requirements for emergency ventilation (typically for the control of smoke and hot gases during fire) must also be assessed and the system designed accordingly. This document presents the design of the ventilation system for the proposed “Underground Vehicular Tunnel from Hebbal to Baptist hospital”. Two ventilation scenarios will be considered:

i) Ventilation during normal operation of the tunnel, and

ii) Ventilation for a fire inside the tunnel.

The ventilation system is designed to provide:

1. The minimum air required to ensure adequate in-tunnel air quality and visibility thresholds during normal operation
2. A tunnel environment as safe as possible for the users and rescue services during a fire incident.

Following general factors are considered in the design:

1. Length of the tunnels (main tunnel and the entry and exit tunnels)
2. Cross section (width and height) of the tunnels.
3. Type of traffic
4. Fire safety
    a. Presence of emergency exits
    b. Change in the direction of fans
5. Cost and Environmental issues
    a. Energy consumption
    b. Localized and concentrated emission of polluted air from portals and stacks.

10.2 Design Process

Overall design process is as follows:

1. Divide the tunnel into different sections considering entry-exit ramps and sections between the ventilation stations.
2. For each section for normal operation of the tunnel:
    a. Estimate the pollutant emission rate for congestion (maximum ventilation capacity). This is done by considering different speeds of 0 – 50 km/h.
    b. Estimate the tunnel air flow rates and velocities for pollutant removal. Air flow rates for diluting CO, NOx and PM are separately calculated and the maximum of the three flow rates is considered for further design of the ventilation system.
    c. Estimate the tunnel pressure drop.
    d. Calculate the number of fans and the distance between fans based on the pressure drop.

3. For each section for fire scenario:
    a. Choose the fire curve and heat release rate
    b. Estimate the tunnel air flow required for efficient smoke removal.
    c. Check if the maximum capacity and the arrangement of the fans chosen based on pollutant dilution (normal operation) are sufficient to provide the air flow rate and pattern required for the smoke removal. If yes, choose between the two systems based on other constraints such as construction procedure, energy consumption and cost. If not, upgrade the fan power, number, positions and control to satisfy the smoke removal requirement.
    d. Decide the exhaust and intake locations and directions to avoid mixing of both the air streams in the nearby ambient.
    e. Decide the firefighting systems required.
        i. Sensors
        ii. Sprinklers
        iii. Fire extinguishers
        iv. Fire hoses
4. Prepare the list of items required and estimate the material and installation cost.
5. Prepare the guidelines for operation and maintenance: evacuation strategy, automatic control of fan power and directions, closing and opening of dampers, remote monitoring etc.
6. Do 3D simulations of selected regions to verify the ventilation system design both for normal and emergency (fire) scenarios.

10.3 Layout of the Proposed Tunnel

Proposed underground vehicular tunnel has two separate unidirectional tubes throughout between Hebbal to Baptist hospital. Each tunnel has an inside diameter of 10.82 m. The layout of the tunnel is shown in following figure

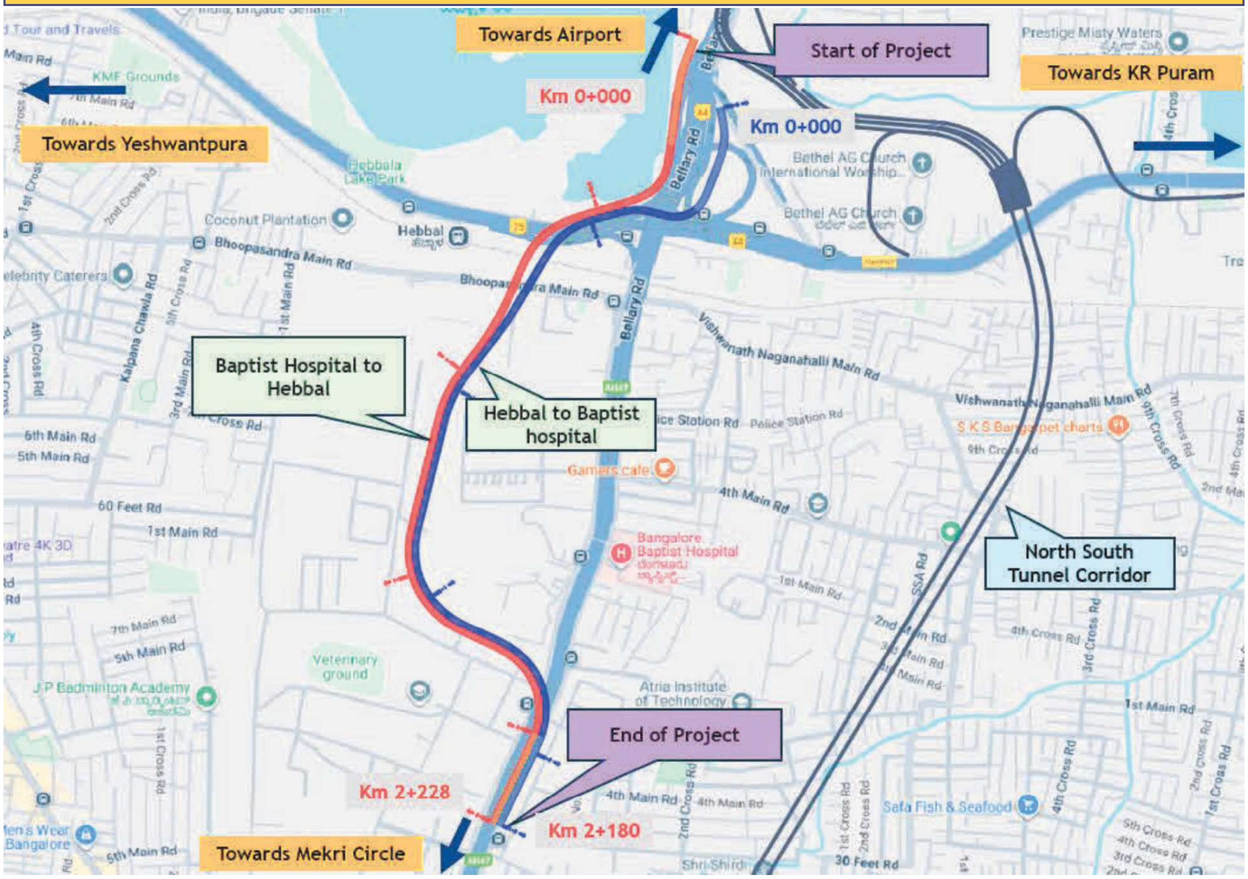


Figure 59: Layout of the proposed underground vehicular tunnel

There are no entry and exit ramps. The tunnel tubes have one entry and one exit separated by distance 1.750 km

10.4 Tunnel Cross Section

Figure 2 shows the tunnel cross-section of the two tubes. Inside diameter is 10.82 m. Vehicle clearance is 5.5 m. Free space available is 2 m, out of which 0.5 m is required for sign boards. The pavement is 1 m below the centre. Each lane is 3.5 m. The cross-section area is 91.875 m^2.

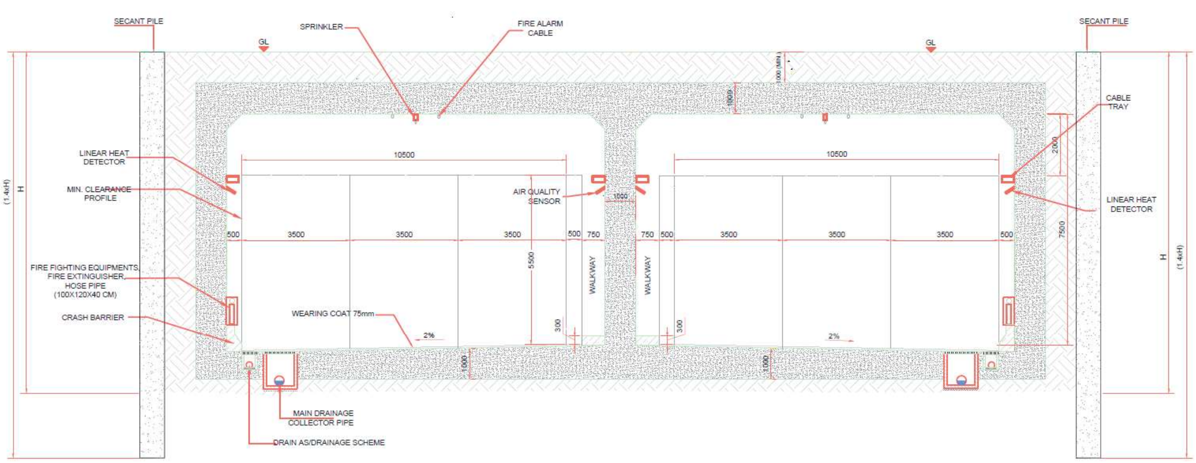


Figure 60: Underpasss cross-section

10.5 Design of a Ventilation System

The design of ventilation system is discussed with respected to two main elements, the type of ventilation and dimensioning and positioning of ventilation system type selected

10.5.1 Ventilation System type

There are mainly two types of ventilation systems exist:

3. Natural ventilation:
4. Mechanical ventilation

The guidelines provided in "IRC_SP 91-2019" section 5.2 suggests that the mechanical ventilation system is required for the tunnel lengths/section lengths more than 500 m. The length of the tunnel tube of the proposed tunnel is larger than 500 m. Therefore, the mechanical ventilation system will be considered for the design. This ventilation systems mainly are of two types (Figure 6):

3) Longitudinal: This is the simplest tunnel ventilation system, and the most used nowadays, and it consist mainly in developing an air flow inside the tunnel by means of jet-fans or Saccardo nozzles, so that fresh air comes in at one side and polluted air / smoke goes out through the other end of the tunnel. According to IRC_SP91-2019 section 5.2, this system is suitable to use for the tunnel lengths of 500 m to 4000 m with light traffic density. However, this system needs to be provided with intermediate shafts for massing exchange of exhaust with fresh air.

4) Transverse:

   - Fully transverse: A fully transverse system consists in 2 different ducted ventilation systems, one for fresh air injection (preferable at floor level) and another for exhaust (at the ceiling), evenly distributed along the tunnel. This system is the best for contaminants control. Its main disadvantage is the high cost involved due to the complex and large civil infrastructures needed (shafts, ventilation buildings, ducts). However, practically there is no limit to the tunnel length to use this system. For the longer tunnel lengths with heavy traffic, this system is suitable.
   - Semi transverse: In this case there is only a ventilation duct along the tunnel that can work either injecting fresh air for contamination control or exhausting smoke in a similar way as a transverse system. This system needs to be provided with intermediate shafts for massing exchange of exhaust with fresh air more frequent than fully transverse system. As per IRC_SP-91, 2019 section 5.2, the semi-transverse systems are required to have shafts installed at every 3 km.

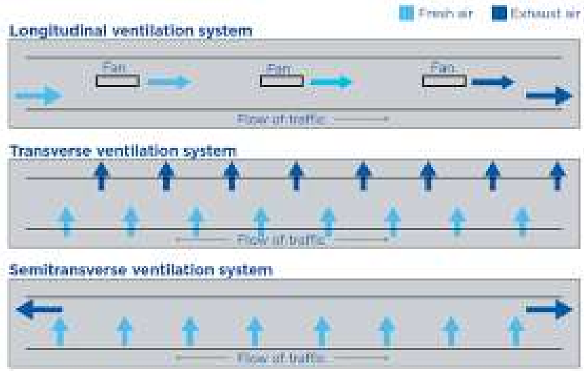


Figure 61: Schematic of different types of ventilation systems

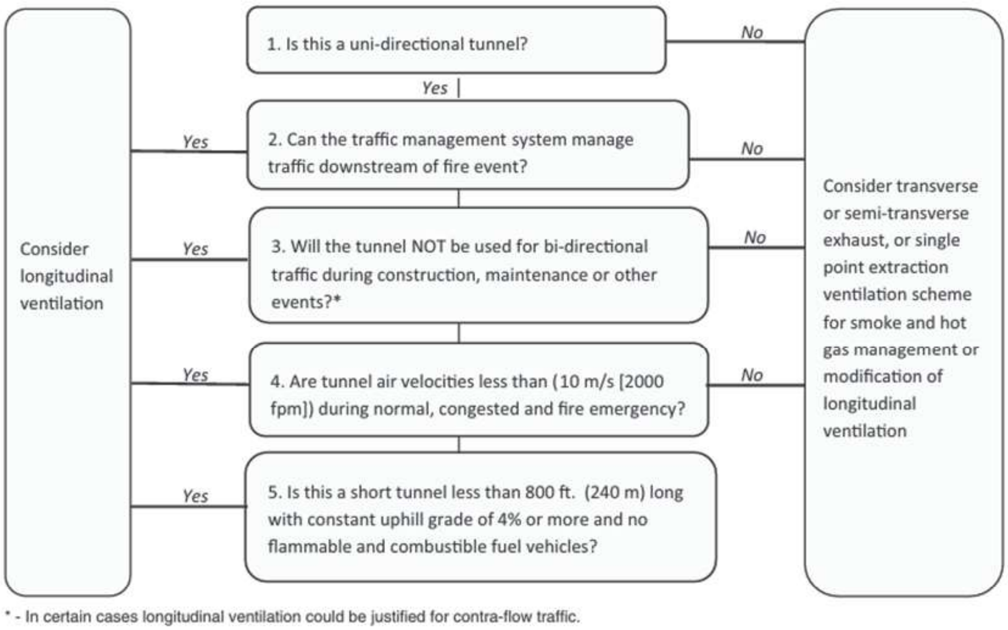


Figure 62: An example of ventilation system selection process (Maevski, 2017)

These ventilation types include three main types of fans, namely axial, propeller and centrifugal. The selection of the types of ventilation system and its equipment's will be decided based on the fresh air demand and the lengths of each section.

10.6 Choice of the Ventilation System

Table 1 contains the general characteristics of the proposed tunnel in order to select the suitable type of the ventilation system

Table 77 : Tunnel General Characteristics

Factor	Remarks
Length of the tunnel	Each tube has length 1.750 km
Possibility of congestion	Yes, Heavy traffic expected in main tubes
Traffic type (bidirectional or unidirectional)	Two unidirectional tubes interconnected through cross passages
Type of vehicles	PCU, LCV,HGV

Possibility of fire	Yes

Based on the details given table above and as per the guidelines provided in previous section, both tunnel tubes are proposed to have longitudinal ventilation systems. In these sections, the air flow under normal operating conditions will be in the direction of traffic.

The main tunnel tubes will be connected through cross passage doors at an interval of 500 m for air flow as well as people escape in a fire event (Item 8 in Annexure B of IRC-SP91, 2019; Note 2 in Section 2.8.2.5 of IRC-SP91, 2010).

These details are given in following table.

Table 78 : Choice of ventilation system for the proposed vehicular tunnel

Sections	Type of ventilation system
Both tunnel tubes	Longitudinal

It is important to note that, the consideration of the transverse and semi-transverse ventilation system for the main tube sections is rules out due to tube lengths.

The design calculations to estimate the fresh air flow requirement and the number of fans for both normal operation and for fire scenario for these sections are discussed hereafter in next sections.

10.7 Ventilation during normal operation of the tunnel

The proposed methodology for ventilation system design during normal operation of the tunnel consists of the following four steps.

1) Estimation of pollutant load
2) Estimation of fresh air requirement
3) Design of Ventilation system
4) Computational analysis to verify the designed system

10.7.1 Estimation of Pollutant Load

As per PIARC guidelines, the emissions in terms of CO, NOx (sum of NO and NO2) and particulate matters (PM) are considered as the pollutant load resulting from the IC engine driven vehicles for road tunnel ventilation system design. The calculation of the quantity of toxic pollutants produced in the tunnel according to a specific traffic scenario is based on reference emission rates multiplied by influencing factors and the number of vehicles, as described in this section. The resulting 'total emission rate' is then used to determine the fresh-air demand

The estimation of total emission rate or pollutant load inside the underground tunnel will be based on following considerations:

1) Analysis of alignment to decide sections
2) Analysis of traffic flux: vehicle categories and number of vehicles

10.7.2 Analysis of Alignment to Decide Sections

At first, the underground road topology will be surveyed based on the geographic data, cross sections of the tunnel at different locations, vertical profiles (road gradients).

Then as per the guidelines provided in the section 5 of the PIARC Report: "Road Tunnels: Vehicle Emissions and Air Demand for Ventilation", 2019, the complete length of the tunnel is divided into different sections based on constant cross section and gradient, altitude, traffic density, entry and exit portals and anticipated restrictions on exhaust emission locations.

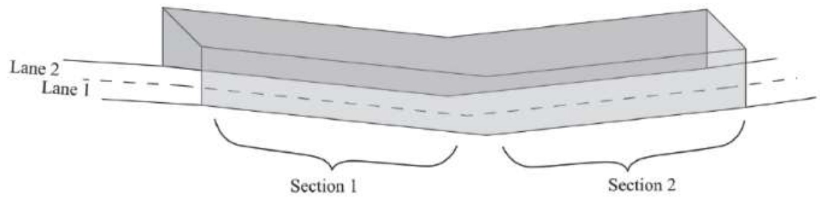


Figure 63: Schematic of sections selected based on constant slope/gradient

Individual sections are selected based on the ventilation station location details given in Section 0.

10.7.3 Analysis of Traffic Flux: Vehicle Categories and Number of Vehicles

As per the PIARC guidelines, the road vehicles are categorised in terms of their function and size as follows:

- Passenger car (PCU)
- Light commercial vehicle (LCV)
- Heavy goods vehicle (HGV)

The HGV category consists of the vehicles which are having size over 3.5 tons. These include trucks, articulated lorries, buses and coaches.

These vehicle categories can be sub-categorized by fuel, e.g. gasoline (petrol) or diesel such as:

- PC Gasoline
- PC Diesel
- LCV Gasoline
- LCV Diesel
- HGV Diesel

The emission data corresponding to these vehicle types for the year 2018 is available in the PIARC which will be used as a base emission data. HGV emissions are also highly dependent on vehicle mass and a mass factor will be applied to account for this as per PIARC guidelines. For the estimation of emission rate from each vehicle type, the information about the number of vehicles of each type in traffic flux is required to be known.

Summarizing the details discussed in the two parts of this section, the following input parameters will be considered for the estimation of pollutant load in terms of emission rates for each section of the tunnel:

- Length of the tunnel/section
- Road gradient or slope
- Tunnel altitude
- No. of different types of vehicles passing through the tunnel per hour. The vehicles mainly include, passenger car units (PCU), light commercial vehicle (LCV), heavy commercial vehicle (HCV), heavy goods vehicle (HGV), electric vehicles (EV)

- Speed of the vehicles. The speed of the vehicles will be different for different traffic conditions, normal and congested ones.
- Parameter influencing the power needed to propel the vehicle such as average mas of the HGV vehicle
- Pollutant concentration in fresh air/ fresh air quality separate estimations will be provided for the CO and NOx and to the particulate matter by appropriately taking into account the reduction factors provided in the reference documents to bridge the gap between available data and future years estimation requirements. Figure 6 shows a sample emission rate for petrol passenger cars as a function of speed and gradient (Ref: Vehicle Emissions and Air Demand for Ventilation, PIARC Report 2019R02EN)

PC Gasoline CO [g/h] 2018							
v [km/h]	Gradient [%]						
	-6	-4	-2	0	2	4	6
0	5.4	5.4	5.4	5.4	5.4	5.4	5.4
10	7.7	8.8	9.7	11.0	12.0	14.1	16.6
20	8.4	10.2	12.6	15.5	22.7	35.4	50.2
30	7.7	9.3	11.1	13.7	17.3	22.8	31.1
40	8.3	10.3	12.9	16.4	22.3	33.2	48.9
50	8.9	11.8	14.0	18.2	23.8	33.1	46.7
60	8.5	11.4	13.3	18.2	25.3	37.8	59.2
70	9.9	13.3	17.9	25.6	36.4	60.4	109.0
80	12.5	16.2	21.1	31.0	49.8	89.1	166.2
90	11.7	15.7	22.7	35.6	67.5	146.1	264.3
100	15.5	20.9	31.6	50.4	85.9	209.4	415.7
110	26.7	33.2	47.4	78.1	148.6	326.2	791.2
120	47.2	54.9	74.1	130.7	259.8	604.4	1506.2
130	85.3	106.2	142.2	236.6	504.3	1318.7	2568.7

Figure 64: Typical CO emission rate data, PCU

LCV Diesel CO [g/h] 2018							
	Gradient [%]						
v [km/h]	-6	-4	-2	0	2	4	6
0	0.4	0.4	0.4	0.4	0.4	0.4	0.4
10	0.9	1.0	1.2	1.5	1.6	1.8	2.1
20	1.0	1.2	1.5	1.8	1.9	2.1	2.3
30	1.0	1.3	1.6	2.0	2.2	2.4	2.6
40	1.1	1.3	1.7	2.0	2.3	2.5	2.9
50	1.1	1.4	1.7	2.1	2.5	2.8	3.0
60	1.0	1.4	1.7	2.1	2.7	3.0	3.4
70	1.1	1.6	1.8	2.3	3.0	3.3	3.8
80	1.4	1.7	1.9	2.5	3.3	3.6	4.2
90	1.7	2.0	2.1	2.6	3.5	3.9	5.1
100	2.0	2.3	2.2	2.8	3.9	4.6	5.7
110	2.4	2.6	2.5	3.0	4.4	5.4	6.2
120	2.8	3.0	3.4	4.2	5.4	6.0	6.6
130	2.9	3.6	4.2	5.1	6.0	6.4	6.8

Figure 65: Typical CO emission rate data, LCV

HGV Diesel CO [g/h] 2018							
	Gradient [%]						
v [km/h]	-6	-4	-2	0	2	4	6
0	3.8	3.8	3.8	3.8	3.8	3.8	3.8
10	11.7	14.1	17.3	21.0	24.3	28.0	31.3
20	10.0	11.4	17.8	22.3	26.2	30.6	35.2
30	8.7	10.1	18.3	23.9	30.6	37.8	42.3
40	5.8	8.7	18.8	26.9	37.3	48.1	55.1
50	4.1	6.2	19.3	29.4	43.2	56.8	64.8
60	3.5	6.1	19.8	34.9	53.3	62.3	67.7
70	3.6	6.1	20.3	40.3	63.1	67.8	70.6
80	3.6	6.1	20.7	45.8	73.3	77.2	76.6
90	3.6	6.1	22.2	47.0	75.7	83.1	82.4
100	3.6	6.1	22.3	49.6	78.1	88.6	88.0

Figure 66: Typical CO emission rate data, HGV

For the present design, following traffic composition is considered which is the daily traffic directed towards the city.

Table 79 : Daily number of vehicles

Car+Taxi	53257
Pvt. Bus	501
Govt. Bus	2171
LCV	3167
Truck	644

For the design calculation purposes, the Cars and taxis are considered as PCU. Buses and trucks are considered as diesel HGV and LCV are considered as diesel LCV

based on the information received from the traffic analysis, the vehicular composition is given in following table.

Table 80 : Vehicular composition

PCU	89.14%
HGV	5.56%
LCV	5.3%

The emission data in figures 6 to 8 represent the estimations corresponding to year 2018 and time factors are used to relate to year 2025 (which are used in the calculation). These are based on the base emission rates provided in the PIARC report, Road Tunnels Vehicle Emissions and Air Demand for Ventilation_2019, section 6.1.

10.7.4 Estimation of Pollutant Emission Rates

The pollutants considered are CO, NOx and PM. The emission rates are considered for the two congestion scenarios:

1. Tunnel filled with stationary vehicles
2. Vehicles moving at speeds from 10 km/h to 50 km/h.

The number of vehicles decreases as speed increases. Therefore, considering the figures 6 to 8, the maximum emission rates are obtained at 20 km/h for the above-mentioned scenarios and are selected for further airflow rate requirement calculations. It is important to note that, the present design calculations are done for 0 % road gradient condition.

Table 5 gives the emission rates estimated for full tunnel tube length. These emissions are estimated for the given vehicular composition and based on the 20 km/h. This covers the maximum possible emission and associated traffic influx.

Table 81 : Emission rates (g/h and m^2/h) in tunnel sections between Hebbal to Baptist hospital

Tunnel section/tube length (m)	Highest emission rate from different speeds		
	CO (g/h)	NOx (g/h)	PM (m^2/h)
1750 m	8065	2254	384

10.7.5 Estimation of Fresh Air Requirement

The fresh air requirement is estimated in reference to design and operational pollutant values, therefore this section is sub divided into two:

1) Design (threshold) and operational pollutant values

2) Fresh air requirement estimation

10.7.5.1 Design (threshold) and Operational Pollutant values

Design values provide a basis for the determination of the required capacity of the tunnel ventilation system. Operational values provide the limit levels for the different operating states such as normal operations, maintenance operations and closure conditions. PIARC 2019R02EN provided these values for different pollutants which will be considered are same are given as follows

- Design values for CO emission:

Table 82 : Design values for CO emissions, (IRC SP 91:2019, PIARC 2019R02EN)

Traffic situation	Design value	Operation condition	Operation limits
Free flowing peak traffic, 50 – 100 km/h	70 ppm	Normal operation	< 100 ppm
Daily congested traffic, stopped on all lanes	70 ppm	Planned maintenance work in a tunnel under traffic	20 ppm
Exceptional congested traffic, stopped on all lanes	90 ppm (100 ppm for IRC SP 91:2019)	Threshold value for tunnel closure	200 ppm

- Design values for NOx:

NO by itself is not considered a harmful pollutant at commonly encountered levels. On the other hand, NO2 is noxious and can irritate the lungs and lower the resistance to respiratory infections such as influenza. PIARC proposed to permit an average in-tunnel concentration of 1.0 ppm NO2 along the length of the tunnel at any one time as the design value.

- Design values for particulate matter (PM):

The presence of particulates leads to reduced visibility inside the tunnel. Therefore, visibility criteria are intended to support the ability of a driver to stop safely. The tunnel ventilation system must provide visibility levels that exceed the minimum vehicle stopping distance at the design speed.

There are two primary sources of PM in a tunnel, exhaust emissions and non-exhaust emissions. Exhaust emissions consist of PM emanating from the tailpipe as a result of fuel combustion. Non- exhaust PM consists of tyre and brake wear, road surface abrasion and re-suspended dust.

Table 83 : Design values for visibility based on PM emissions, PIARC 2019R02EN

Visibility condition	Extinction coefficient K	Length of light beam L with $\frac{I}{I_0}e^{(-KL)}$ = 20%
Slightly hazy	0.003 m-1	536 m
Hazy	0.007 m-1	230 m
Foggy	0.009 m-1	179 m

Visibility condition	Extinction coefficient K	Length of light beam L with $\frac{I}{I_0} e^{(-KL)} = 20\%$
Uncomfortable	0.012 m-1	134 m

10.7.5.2 Fresh Air Estimation

Once the pollutant load is estimated the fresh air requirement is estimated for the section considered based on the comparison of quality of polluted air to the admissible quality of air inside the tunnel (discussed in previous section) (IRC SP 91-2019, PIARC 2019R02EN).

The separate estimation of fresh air requirement (m^3/h) will be provided based on estimated CO, NOx and PM loads in tables above. The following input parameters will be considered in the calculations

- Total emissions from the vehicles (CO or NOx) in g/h, PM in 1/m
- Admissible pollutant level inside the tunnel (either CO or NOx) in g/m^3, PM in 1/m
- Atmospheric air quality (either CO or NOx) in g/m^3, PM in 1/m

The maximum of the air flow rate values obtained related to CO, NOx or PM emissions, will be considered in the design.

10.7.5.3 Tunnel air quality and visibility measurement system: recommendations

1. The operational ventilation inside the tunnel shall be managed by monitoring the tunnel air quality. This shall be managed through the tunnel measurement system which consists of measurement of visibility affected by dusty environment, measurement of CO and NOx emissions, flow velocity and direction measurement and temperature measurement etc.
2. The visibility sensors shall comprise of transmitter (TX) and receiver (RX) which work on the principle of a single pass light transmission system also known as optical measurement principle. The TX emits a visible (green) optical beam which is received by the RX. Any dust or smoke particles present will attenuate the light beam and cause the intensity of the light received by the RX to fall. This reduction in light intensity is used to determine visibility in the tunnel. The visibility criterion is mentioned in the normal operations above.
3. The tunnel air quality shall be monitored through the electrochemical cell technology to determine CO, NO & NO2 concentrations.
4. The ultrasonic airflow measurement technology shall be used in tunnels to measure the air flow velocity and direction. With no moving parts, the system requires minimal servicing and can be fully sealed from the tunnel's harsh environment. Measurements are independent of temperature, pressure and composition of the tunnel atmosphere. Other than a regular clean and check, it can be considered a 'fit and forget' solution. The two transducers shall be installed on the both walls of the tunnel in an angle of 45^0 to driving direction and shall work as sender and receiver alternately to determine the air flow speed and direction.
5. These sensors shall be positioned on the tunnel walls in equal distances to each other. The distance between air quality and visibility sensors shall be two times than the distance between the two air quality sensors and three times for air velocity and direction measurement sensors.
6. This system shall be connected to SCADA system through PLC and sensor measurements shall be provided through UPS.

7. 2 units of meteorological detection system shall be provided at the main entries of the two tunnel tubes which as per our understanding is sufficient.

10.7.6 Fresh Air Rate Requirements

Based on the pollutant emission rate obtained for parameters given in Table 5, the fresh air rate required for each pollutant is calculated according to PIARC (2019R02EN) guidelines. These values are given below.

Table 84 : Fresh air rates (m^3/s) required to dilute the pollutants

Tunnel tube/Section length (m)	Fresh air demand: highest airflow rate (m^3/s)		
	CO	NOx	PM
1750	23	333	21

Based on table, the maximum fresh air rate of 333 m^3/s is required for NOx. So, this is chosen to estimate the pressure drop in the tunnel and decide the number of fans for longitudinal ventilation system. The tunnel air velocity corresponding to this rate is 4 m/s in main tube sections, which is much less than the admissible longitudinal velocity of 10 m/s (PIARC, 1995) for long tunnels and more than the minimum air velocity range of 1-1.5 m/s recommended by IRC (Section 5.7 in IRC, 2019).

10.7.7 Ventilation System Fan Requirement for longitudinal ventilation system

Table 11 shows the input parameters used in the calculation of number of fans, minimum distance between them, and total power requirement for longest section. Table 12 gives the design values arrived at using the highest air flow requirement per tube and the estimation of the number of fans for longitudinal system (Ref: PIARC, 1995).

Table 85 : Design values for a longitudinal system for the longest section, 3.82 km

Parameter	Value	Remarks
Tunnel cross section area, m^2	92	
Area available for air flow, m^2	82	Subtracting the vehicle cross section area
Fresh air rate, m^3/s	333	For NOx
Pressure drop in Tunnel, Pa	110	
Fan flow rate, m^3/h	80000	
Fan area, m^2	0.79	
Pressure rise by fan, Pa	5	For the tunnel cross-section area
Total number of fans	30	
Distance between fans, m	120	Assuming two fans at one section
Type of fan	Traditional jet fan	
Power, kW	22.3	Per fan (minimum - estimated)

The pressure drop is calculated based on PIARC report 05-02-B.

Table 86 : Longitudinal System calculations for fan Requirements

Tunnel tube/Section Distance (m)	Total NOx Emission (g/h)	Air Flow Rate (m^3/s)	Pressure Drop in tunnel, pa	No. of Fans	Total Power (kw)	Distance b/w Fans (m)

1800	2254	333	110	30	669	120

Two additional fans are considered at the entrance of each tunnel tube. Hence, the number of fans required for each tunnel tube are 32 and total for both the tunnel tube are 64.

10.8 Ventilation during fire inside the tunnel

This section gives the designing the ventilation system during fire inside the tunnel. This involves following steps:

1. Choice of maximum heat load and design fire curve.
2. Selection of ventilation system
3. Design and dimensioning of the system
4. Design of firefighting systems.

10.8.1 Heat Release Rate and Fire Curve

The heat release rate and the design fire curve depend on the probable sources of fire. According to IRC-SP91-2019 (Section 5.9.1) the range of maximum heat release rate is 1.5–300 MW with a duration of this fire is 10 min. to 6+ days. For this heat release rate, the range of smoke release rate is 20–300 m3/s (Section 5.9.1, IRC-SP91-2019). The traffic mainly consists of passenger cars. For this type of vehicles, the range of heat release rate is 5–10 MW (Item 2 in Annexure F, IRC-SP91-2019). Along with this the buses and trucks are also allowed to enter and considering the possible allowance to other types of vehicles (LCV, HGV etc) a heat release rate of 50 MW for a duration 10 (to 60) minutes is chosen for the design. Assuming a linear correlation between the heat and smoke release rates a smoke release rate of 65 m^3/s at the maximum gas temperature of 1350°C is taken.

10.8.2 Selection of Appropriate Ventilation System

In addition to the requirement of supplying fresh air in the normal operating conditions the ventilation system should consider the following aspects to handle fires in tunnels:

1. Proper stratification of the smoke such that sufficient time is available for people to reach safety.
2. Change of ventilation air directions to remove the smoke in the direction of lower number of people and vehicles.
3. The equipment such as jet fans should be selected such that they work at least for at least 2 hours with hot air (250°C) and smoke.
4. Enough number of fans to maintain at higher power to account for loss of some fans due to fire. The 10 % additional cost is recommended to be reserved for the same.

In the present case the traffic will be taken to be unidirectional and a “stop” condition in case of the kind of fire mentioned in the section on heat release rate.

10.8.3 Design and Dimensioning of Ventilation System for Fire Scenario

The design of the ventilation system to handle fire and smoke involves the following steps:

1. Estimation of the smoke release rate due to the fire (Section III.4 of PIARC Report 05.05 1999).
2. Verify whether the air flow rate required for the normal operation is sufficient to remove the smoke at an acceptable rate. If not, the systems will be re-designed either by enhancing the capacity or by adding a possibility of reversing the flow (Section III.4

of PIARC Report 05.05 1999).

3. Calculate the power of additional (possibly bi-directional) ventilation systems to be placed in the cross-passages and similar escape routes.

The required tunnel air flow rate and velocity are decided based on the following objectives:

1. Velocity should be more than the critical velocity required to avoid the back layering (flow of smoke upstream of the fire). Equation 5.7.1 in PIARC (1999) and PIARC (2017).
2. Flow rate should be sufficient to dilute the smoke to acceptable limits within the distance of extraction.
3. Flow rate should be sufficient to cool the stratified smoke to levels such that the radiation intensity on escaping people below that is safe. This is verified using 3D CFD calculations and suggested a safe distance.

The airflow rate requirement leads to a tunnel air velocity of about 4 m/s, which is more than the critical velocity (2.5 m/s) to prevent the back-layering.

The longitudinal system designed for the pollutant dilution with added close to 20% air flow rate (IRC_SP-91 2019, section 5.9.1) and 40% increase in power should be used as the power requirement is proportional to the square of the flowrate (section 4.2.2, PIARC, report 05.05.B).

10.9 Design of Fire Fighting Systems

According to the latest guidelines for Road Tunnels published by the Indian Roads Congress (IRC), the firefighting system of the tunnels must be equipped with:

- Fire detection systems
- Hand – Operated Fire Extinguishers
- Fire Hydrants
- Water Reservoir
- Fire – Hose Coil with Supply

The firefighting equipment and their placement remains the same for both the tubes.

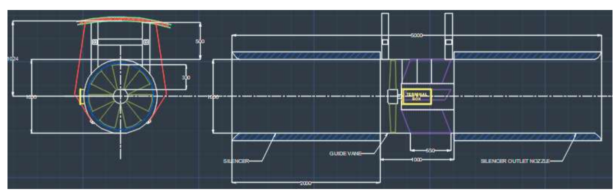
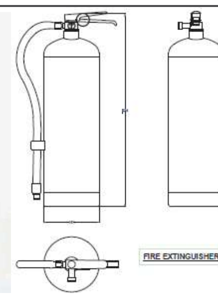
Following recommendations are given in IRC_SP-91 (2019), PIARC 05.05.B (1999) an NFPA 502:

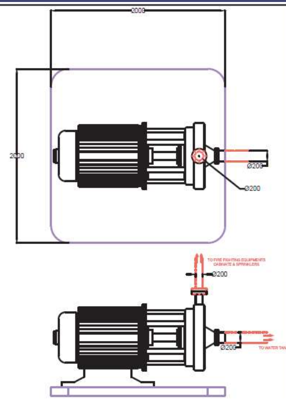
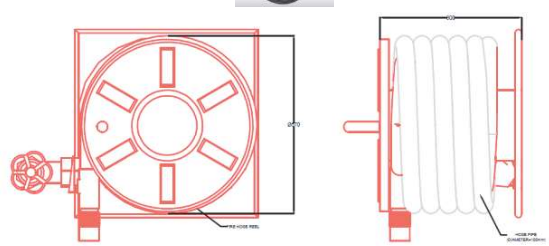
- Fire detection systems include detectors of heat (temperature and rate of rise), smoke, and flame. In addition, there are spot and linear heat detectors. LHD will be used in the tunnel and spot detectors shall be used inside the duct too. Automatic fire detection systems shall be capable of identifying the location of the fire within 15 m (50 ft). Automatic fire detection systems shall be able to detect a tunnel fire incident of 5 MW or less within 90 seconds or better in a testing environment of 3 m/sec (590 fpm) air velocity. Fire alarms are recommended to be placed at every 20 m which are inline with other firefighting equipment, while the fire alarm sensor at every 20 m as per section 7.4.6.6.4 of NFPA502. This meets the requirements of both the standards and permits some redundancies.
- The fire extinguishers should have a minimum content of 6 kg. They should be rated for liquid, grease and electrical equipment fires. The maximum distance between fire extinguishers recommended to be of 90 meters as per section 7.9 of NFPA502.

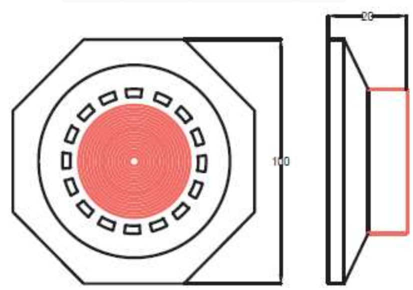
- It is recommended that all road tunnels of sufficient length (200 to 1000 m according to the case) be provided with a water supply standpipe installed through the length of the tunnel. This standpipe should have a minimum capacity of 1000 l/min at 0.5 MPa (PIARC, report 05.05.B, 1999, section 6.3.3.3). The standpipes are wet type. Hydrants should be placed at a spacing of 45 m. The fire main and hydrants shall be placed in such way that the walkway width remains clear of this.
- The total capacity of the water tank shall be sufficient to provide water supply for 60 minutes of operation. The tanks shall be placed closed to the pump room.

Firefighting systems also include the jet fans and pumping system. The specifications of the same along with other firefighting equipment are given in next section.

10.9.1 Firefighting equipment and specifications

Equipment	Technical Specification	Physical representation with sketches
Jet fan	• Flow rate: 80000 m3/hr • Reversible with 2D silencers at both ends. • Static pressure: 500 Pa • Thrust: 750N. • Operating voltage: 415V (3-phase 50Hz) • Fire rating: 250℃, 2 hr temperature rating.	 
Fire extinguishers	• 6Kg ABC Dry Powder (Stored Pressure) type • Pressurized with dry nitrogen gas at 15 bar.	 
Pumping unit	Electric Pump: • Axial suction, radial impulsion • Stainless steel shaft • 4660 lt/min, head of 350 m rated 2900 rpm • 2 poles three-phase asynchronous motor (415 V, 50 Hz) • Protection: IP55	

	• Power: 150 kW • Pressure range 3.5 kg/cm^2 at the farthest sprinkler/hydrant point Diesel Pump: • Horizontal centrifugal end suction type • 4660 lt/min, head of 350 m rated 2900 rpm • CI casing, CI impeller. Auxiliary Jockey Pump: • Vertical Multi in line type fire pump • 2900 RPM capable of delivering 460 lts/min against a head of 350 m. • 415V, 3phase, 50Hz • Bronze impeller • Power: 1.5 kW • Protection: IP55 • Shaft isolation with mechanical closure	
Fire Hydrant and hose connection	Fire hydrant • Type C (according to EN 14384 standard) with anti-icing system, helical spring closure • Nominal pressure: 16 bar Hose pipes • 100 mm diameter • 23 kgf/cm2 pressure	 

LHD	• Fixed temperature set point or Rate of rise temp setting with Programmable alarm • Operating temp (-20 ^{0}C to 70 ^{0}C) with alarms for open circuit and short circuit • Standard fixtures as required and duly approved by LPCB / EN54	
Fire alarms	• EN54 approved fire alarm control panel • Panel: expandable, networkable, having option to interface to BMS with optional interface of LON Works, BAC net & MOD Bus, with a battery backup of 24hrs in normal condition and 30min in alarm condition. • Multi sensor with optical smoke element and thermal element. • Detector: facility to mount in different comprehensive places as required and duly approved by LPCB / EN54.	 

It is important to note that the VFD panels are used to start, stop and control the speed of the motor of the fan, which is important to manage both the normal and emergency operations. Any additional flow requirement can be managed. However, the soft starters are used to start and stop the motors and only efficient with fixed defined speeds. VFD panels are also energy efficient and increases the equipment lifespan. Hence VFD panels are recommended.

10.10 Emergency and evacuation

The strategic planning of safety and evacuation during fire, accident and during vehicle breakdown inside tunnel is important in tunnel designing process. As a first step, in the event of an incident in the tunnel, the alarm can be raised by video surveillance or by more specific means such as (IRC: SP-91-2019):

- Emergency telephones (call stations)
- Notification of door opening (cross-passages) or removal of a fire extinguisher from its hook,
- Alarm push buttons (manual call points),
- Automatic incident detection (by analysing CCTV images),
- Fire detection systems.

In any case, it is important to evacuate early and fast. Therefore, in addition to providing an emergency route to a safe place, measures are required to make sure people react quickly and evacuate early through the emergency exits.

During the emergency scenario, the ventilation system aims to create and maintain a tenable environment for the evacuation of tunnel users. Specifically, this environment consists of acceptable visibility and air quality levels. In general during emergency operation, the most important thing is to evacuate quickly on foot, following the designated exit signs, driving out of the tunnel if possible, and never stopping your vehicle unless absolutely necessary; if it has to be stopped, one must proceed on foot to the nearest exit, always prioritizing the safety over belongings (PIARC Ref.: 2012R25EN).

10.10.1 Fire in the tunnel

If there is a fire within the tube, detected hot smoke will be extracted towards the tunnel ends. In this scenario, the air fans will be operated at their maximal power in order to get the maximum available extraction output. The jet fans are operated so that it is possible to avoid an expansion of the hot smoke gases in the tunnel on the one hand and on the other hand to ensure an equal afflux of the fresh air upwind of the fire location to the extraction point.

The cross-passage doors will be used as emergency exit which connect main tunnel tubes. These are located at every 500 m connecting the road tunnel with the other side tunnel. In case of a fire the people can leave the hazard zone via this evacuation route. In order to keep this emergency and rescue path free from smoke, a shear wall with an emergency door is proposed for each cross passage. These emergency doors or the main doors have to be equipped with an assisted electrical or mechanical opening system to ensure moderate opening forces of the emergency doors. It is also recommended to have the centralized control to the emergency openings. Doors also to be Fire rated for a minimum of 90 minutes.

During this kind of emergency, all the entries to the main tunnels will be closed. The passengers within the range of 100 m to the fire location, need to get out of the vehicles and walk towards the nearest cross-passage door in the opposite direction to smoke.

In tunnels with two tubes operating with unidirectional traffic, the ventilation typically supports smoke propagation in the driving direction (the initial direction of smoke propagation due to traffic-induced airflow). The smoke gradually affects the empty part of the tube in front of the incident. People that are stuck in traffic behind the incident can be evacuated to the other tube and are normally not affected by the smoke. The second tube will normally be closed to traffic and can be considered a safe zone to evacuate to.

In case of accidents, the entry to the corresponding tube is closed and the traffic upstream to the accidental location is either stopped or diverted to the upstream exit location. The injured people are rescued or the passage to the ambulances are provided from the nearest possible entries. One lane is made available for the same. The traffic downstream to accidental location is allowed to go out of the tunnel. The typical schematic of the fire and evacuation inside the main tunnel section is shown in the figure 13 below.

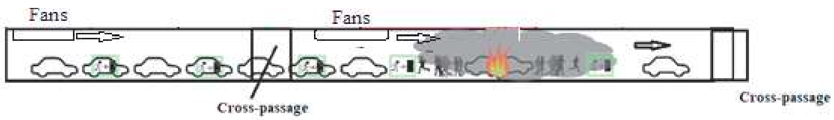


Figure 67: Schematic of fire inside the main tunnel

10.11 Recommendation for the whole tunnel ventilation system

Considering both the normal and emergency operations discussed in previous sections, it is recommended to use the longitudinal ventilation system in each of the tunnel tube. This is tabulated in following table

Table 87 : Proposed ventilation systems for entire vehicular passage of underground tunnel

Sections/tubes	Ventilation system	Flow exchange points
Both tunnel tubes	Longitudinal	Entry and exit locations

The maximum flowrate for the fans has to be increased by 20 % and the power by 40 % keeping the distance between them same as required in normal operation

Table 88 : Total fan requirements for whole tunnel ventilation system

Property	Value
Number of fans	64
Flow rate, m^3/h	80000
Fan area (dia.), m^2 (m)	0.79 (1)
Pressure, Pa	110
Power per fan, kW	31.2
Distance between fans, m	120 (with two fans at one place)

Total minimum estimated power requirement for operating fans is 2 MW considering the fire scenario. Typical power requirement to run the pumps is 0.3 MW. The power requirement for running air quality equipment's and fire-fighting equipment's is 0.2 MW. Therefore, the total ventilation system power requirement is 2.5 MW.

The cross-sectional view of the one tunnel tube with ventilation system and fire-fighting equipment's is shown in following figure

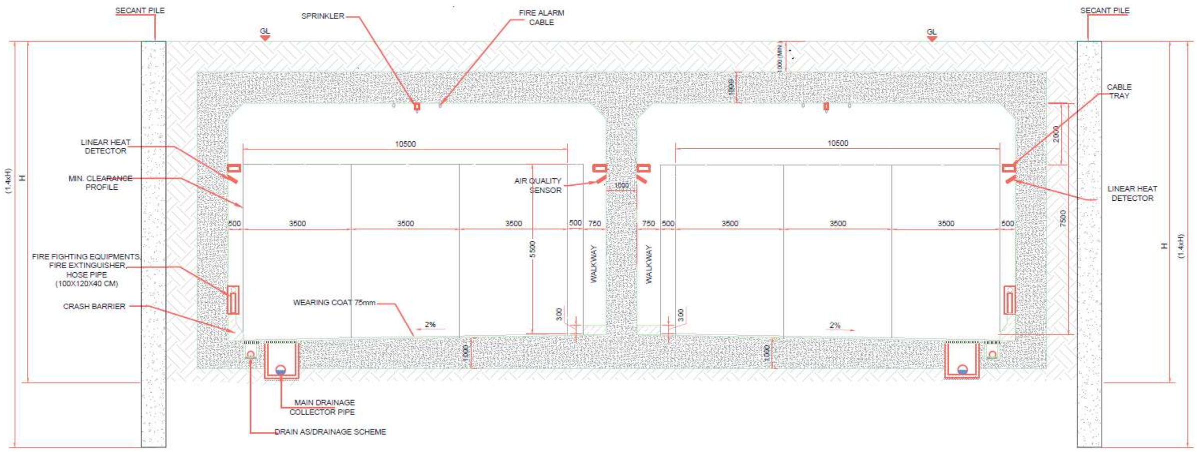


Figure 68: Typical cross section with ventilation system and fire-fighting equipment's

10.12 Computational Analysis to Verify the Designed Ventilation System

The ventilation system is designed in terms of dimensioning and positioning of the system equipment's, same design is verified for both the normal and emergency operations (fire) using the computational analysis. This includes the simulation and estimation of following parameters for a particular traffic condition:

5. Vehicle emissions
6. Tunnel air flow
7. Fan flow
8. Ventilated air flow distribution and quality assessment
9. Fire simulation and smoke extraction

These parameters are analysed for a entire tube to verify the designed ventilation system for its dimensioning and positioning of equipment. Computational analysis is performed with very well validated commercial software. The detailed report is given in the Section 2.

10.13 References

1. BBMP, Request for Proposal for the "Consultancy services for preparation of DPR for the work of Construction of Underground Vehicular Tunnel from Hebbal Esteem mall junction to Silk Board KSRP junction", 2024.
2. IRC, Guidelines for Road Tunnels, IRC: SP-91-2019, 2019.
3. IRC, Guidelines for Road Tunnels, IRC: SP-91-2010, 2010.
4. Maevski, I, Guidelines for Emergency Ventilation Smoke Control in Roadway Tunnels, NCHRP Research Report 836, 2017.
5. PIARC, Design Fire Characteristics for Road Tunnels, Report 2017R01EN, 2017.
6. PIARC, Fire and Smoke Control in Road Tunnels, Report 05.05.B, 1999.
7. PIARC, Road Tunnels: Vehicle Emissions and Air Demand for Ventilation, 2019R02EN, 2019.
8. PIARC, Vehicle Emissions, Air Demand, Environment, Longitudinal Ventilation, Report 05-02-B, 1995.

9. PIARC, Best practice for road tunnel emergency exercises, Report 2012R25EN

10. NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways

11. Tao Deng, Stuart Norris, Mingnian Wang, Li Yu, Zhiguo Yan, Rajnish N. Sharma, “Performance of water-based fixed firefighting systems in road tunnels: A review”, 2025

CHAPTER 11: PRELIMINARY COST

11.1 General

Cost estimation is a critical component of project planning, providing essential financial insights for project execution.

Hebbal to Baptist Hospital Tunnel Corridor being a complex underground urban tunnel project which has several uncertainties. Some of the components are not being captured in any of the similar estimates for tenders explicitly. The actual cost of such projects is largely market driven.

The Completion Period of the project has been estimated to be around 18 months considering the urban built environment, mobilization of heavy construction and transportation machinery, transportation delays and traffic diversions.

As discussed with the Authority, the Project shall be executed through EPC tendering.

11.2 Methodology:

11.2.1 Cut & Cover Sections

Considering the alignment, above ground structures, ground water condition and geotechnical data, excavation in soil/rock is proposed using Secant Piles/ Diaphragm Wall supported with walers and anchors, wherever required. The cost of cut-and-cover sections is determined based on bottom-up/top-down methods as per cross-sections & plans considering both the temporary support and permanent work.

11.2.2 Ramps

The locations where cut and cover method is not feasible due to less cover over the tunnel; the open ramps are proposed. Considering the alignment, above ground structures, ground water condition and geotechnical data, excavation in soil/rock is proposed using secant piles supported with walers and anchors. The cost of cut-and-cover sections is determined based on bottom-up/top-down methods as per cross-sections & plans considering both the temporary support and permanent work. The roofing of ramps shall be steel trusses and polycarbonate sheets.

11.2.3 Road wearing coat and pavement

75 mm thick RCC wearing coat with 2% camber is considered over the structural base slab, in cut and cover tunnel and open ramps. The existing roads shall be restored with flexible pavement as per existing specifications.

11.2.4 Traffic Signs & Road Appurtenances

Quantities for traffic signs, markings, and other project-related facilities (such as road accessories) are calculated from the plan drawings, and costs are determined accordingly..

11.2.5 Electromechanical System

Highway tunnels require various Mechanical, electrical and plumbing installations to ensure the safety of commuters in the underground environment. The MEP services include main power supply system, power backup system, UPS system, Lighting system, Surveillance system, Incident Detection System, Public address (PA) system, Tunnel radio, Emergency Call Network, Supervisory Control and Data Acquisition (SCADA) system etc.

11.2.6 Tunnel Ventilation System and Fire Fighting system

As per IRC SP 91: 2019, transverse type of mechanical ventilation system is considered for the tunnel section having lengths more than 8000 m, longitudinal type ventilation system is considered for the sections between 500m and 4000m and natural ventilation has been considered for section less than 500m length. Accordingly, ramps shall be naturally ventilated, and the box tunnel shall be provided with longitudinal ventilation.

Suitable air monitoring systems have also been considered. Fire detection, fire alarm and firefighting systems have been provided.

11.2.7 Utility Shifting and Restoration

In the Cost Estimate, provision has been made for rehabilitation of building Structures at GKVK/Veterinary college premises and utility shifting, in addition to direct construction costs. The amounts against these subheads have been adopted as directed by Authority i.e. B-Smile.

11.2.8 Transplantation and Artwork

In the Cost Estimate, no provision has been made for transplantation and tree cutting. However, provision has been made for the Artwork at the entries and exits.

11.3 Unit Rates of Materials:

The cost of materials is referenced from a combination of government-issued data and market rates.

The Government data referenced for rates of items include:

i. Karnataka PWD Common Schedule of Rates (CSR) 2023-24.

ii. MoRTH Standard Data Book, 2019

iii. CPWD Plinth Area Rates 2023 and

iv. CPWD DSR 2023 for rate of diaphragm wall

v. Indian Railway SOR for box pushing under Railway line

vi. Rates of items have also been referenced to similar recent projects.

vii. Rates of some items have also been referenced to market rates.

viii. A transportation lead of 45 km is assumed for muck disposal.

ix. Additional overhead charges for road tunnel works is considered @ 15 % as provided in CSR-2023-24.

x. Contractor’s profit is considered as 10%.

xi. Labour Cess @1% is considered only on the non-CSR items, because Karnataka CSR 2023-24 provides that the rates of the items are derived from subsuming labour cess in the contractor’s overheads.

11.4 Labour Rates:

Labour rates are determined according to the Karnataka Common Schedule of Rates (CSR) 2023-24.

11.5 Centage Charges:

The following centage charges have been considered in the cost estimate:

i. Instrumentation and Monitoring cost @ 1% of civil construction cost

ii. Escalation over the construction cost on the rates of Karnataka CSR 2023-24 (November 2023) to July 2025, has been applied as per WPI.

iii. GST is applied @ 18% of Civil Construction Cost.

iv. Planning & designing Charges are applied @ 1% of Construction Cost.

v. Construction Supervision charges are calculated at 2% of the construction cost.

vi. Tunnel maintenance charges for 10 Years @ 0.25% for the first 5 years, & @ 0.35% for the next 5 Years.

vii. Utility shifting cost at lump sum amount of Rs. 35 Crs. after discussion and deliberation with Authority i.e. B-Smile.

viii. Contingencies charges costs @1% of civil construction cost.

ix. A lump sum cost of Rs. 4.5 Cr. Considered towards deposit for Indian Railways for supervision.

x. Environmental Impact Assessment Charges considered on a lump sum basis i.e., Rs. 75 lacs.

11.6 Assumptions:

The estimate is based on the following assumptions:

1. For working out cost of excavation 70% in ordinary soil and 30% rock has been assumed.

11.7 Summary of Cost

s.no	Description	Length	Amount (A)
1	Entry and Exit open Ramp 3 Lane TCS-1	250.0	37,64,43,542
2	Entry and Exit open Ramp 3 Lane TCS-1A	250.0	31,46,17,487
3	Cut and cover 3-Lane TCS-2	1095.0	3,16,21,96,826
4	Cut and cover 3-Lane TCS-2A	315.0	55,80,99,759
5	Cut and cover (3-Lane+Median wall+3 Lane) TCS-3	2000.0	4,28,04,27,022
6	Open Ramp (3-Lane+Median wall+3 Lane) TCS-4	458.0	60,94,20,698
7	Rail Under Bridge(RUB)	40.0	13,58,22,959
	Sub total (A)	**4408.0**	**9,43,70,28,292**
8	**Other Works**		
a	Instrumentation & Monitoring cost @ 1% of (A)		9,43,70,283
b	Electro- Mechanical Works		54,76,77,102
c	Tunnel Ventilation & Fire Fighting		12,42,81,490

d	Traffic Signs, Markings , Appurtenances etc.		1,00,19,702
e	Restoration of Existing Road, Site Clearence, Junction improvement, Approach Area & Ramps (Road ,Footpath, Lighting etc.)		22,78,57,575
f	Miscellaneous (Landscaping on roads and Art Work in Tunnel etc.)		4,53,25,285
g	Control centre etc		1,32,72,880
	Sub total		**10,49,98,32,609**
	Escalation as per SoR 2023-24		**4,80,07,073**
9	**Estimated Construction Cost Without GST =B**		**10,54,78,39,682**
a	Labour Cess @ 1% (On the Amount of Non SOR items)		1,55,96,307
b	GST @ 18% Payable On Construction Cost Only (On B)		1,89,86,11,143
10	**Construction Cost Including Labour cess & GST**		**12,46,20,47,131**
11	Contingencies charges @1% of (B)		10,54,78,397
12	Planning & designing Charges @ 1% of (B)		10,54,78,397
13	Construction Supervision Charges @ 2% Of (B)		21,09,56,794
14	Tunnel Maintenance For 10 Years i.e., @ 0.25% for the first 5 years, 0.35% for the next five years of (B)		31,64,35,190
15	Land acquisition and rehabilation of building Structures at GKVK/Veterinary college premisses	Lump Sum	25,00,00,000
16	Shifting of utilities Cost	Lump Sum	35,00,00,000
17	Deposit for Indian Railways for supervision	Lump Sum	4,50,00,000
18	Environmental Impact Assessment Charges	Lump Sum	75,00,000
	Total Project Cost (10+11+12+13+14+15+16+17+18)		**13,85,28,95,909**

CHAPTER 12: CONSTRUCTION PROGRAM

The proposed project consists of a twin three-lane urban road tunnel of average 2.204 km length, constructed using the cut-and-cover technique (generally by bottom up approach of construction except along the lake where top-down approach of construction shall be adopted), with approach ramps of 500 m on one end and 458 m on another end. The works include not only the civil construction of the tunnel and ramps but also complete installation of mechanical, electrical, and plumbing (MEP) systems, tunnel ventilation systems (TVS), traffic signage, and associated road safety features. The construction programme has been fully developed to balance technical requirements, safety, environmental considerations, and traffic management in an urban setting.

1. Preliminary and Enabling Works

The programme commences with detailed site surveys, utility identification, and traffic diversion planning to ensure uninterrupted urban mobility during construction. Temporary access roads, barricading, lighting, and safety measures shall be set up. Ground improvement measures and relocation of utilities (water, sewer, power, telecom) shall be completed ahead of excavation to prevent service disruptions.

2. Excavation and Earthworks

Cut-and-cover excavation is proposed to be carried out in a staged manner using secant piles, waler and rock bolt/ soil anchors arrangement to provide stable shoring. Along the lake, diaphragm wall shall be constructed instead of secant piles. Soil excavation shall proceed under strict monitoring of settlement to avoid adverse impacts on surrounding urban infrastructure. Excavated materials shall be transported and disposed of at the locations. Dewatering systems shall be installed to control groundwater ingress.

3. Structural Works

Following excavation, a raft foundation shall be laid with reinforced concrete. The tunnel box structure, consisting of base slab, walls, and roof slab, is constructed using staged casting and formwork systems. Waterproofing membranes shall be applied between structural layers to ensure long-term durability and water tightness. Cross passages and emergency egress points shall be integrated into the structure. Ramps at both ends shall be constructed in parallel and pavement layers developed progressively to match the tunnel structure.

4. Road Works and Pavement Construction

Inside the tunnel and on approach ramps, pavement construction includes 75 mm thick cement concrete wearing course inside tunnel and granular sub-base, wet mix macadam, and bituminous surfacing suitable for high-volume urban traffic for connections. Kerbs, crash barriers, and drainage channels shall be installed. Special attention is given to longitudinal drainage within the tunnel box to prevent water accumulation.

5. Mechanical, Electrical, and Plumbing (MEP) Systems

MEP installation begins once structural works shall be sufficiently advanced. Systems include fire detection and suppression, lighting, power distribution, water supply, sump pumps, and emergency communication lines. Tunnel Ventilation System (TVS) fans shall be installed in coordination with roof slab and duct provisions. Control rooms and SCADA-based monitoring shall be integrated for seamless operations.

6. Tunnel Ventilation System (TVS) and Safety Provisions

Longitudinal jet fans shall be commissioned to meet international fire and smoke control standards. Emergency exits, hydrants, CCTV, and communication systems shall be installed in compliance with safety codes. Traffic signage, lane marking, variable message signboards (VMS), and intelligent transport systems (ITS) shall be also integrated.

7. Testing, Commissioning, and Handover

The final stage involves integrated testing of all systems—MEP, TVS, fire safety, lighting, and signage—followed by trial runs under controlled conditions. Comprehensive safety audits, traffic simulations, and environmental compliance checks shall be conducted before formal handover.

The construction programme is sequenced to allow concurrent progress of civil, structural, and electromechanical works, minimizing overall project duration. Strict quality assurance, safety management, and coordination between civil and MEP teams ensure timely completion of this vital urban infrastructure asset.

The Construction programme is prepared in consultation with the Authority and considers that the Contractor shall mobilise resources on all fronts and at all chainages simultaneously and the Authority shall provide all required ROW parts to the Contractor on day one i.e. on appointed date.

Phase 1: Pre-Construction & Enabling Works (0-8 months)

- Design and planning (M1 to M4)
- Site survey, soil investigations (M1-M2)
- Traffic diversion setup (staging) (M2-M4)
- Utility shifting & protection (M2-M4)
- Mobilization, site office, fencing (M3-M4)

Phase 2:Civil Construction (6-15 months)

- Excavation (by zones) (parallel zones) (M4-M10)
- Retaining walls (diaphragm/RC walls) (staggered by zone) (M5 - M11)
- Base slab (raft + drainage channels) (M6-M12)
- Roof slab construction (M7-M13)
- Box pushing (M 6-M8)
- Backfilling and compaction (M8-M14)
- Above-tunnel road restoration (M9-M13)
- Tunnel architectural finishing (M10-M15)

Phase 3: E&M and Tunnel Systems (8-15 months)

- Ventilation (ducts, fans, shafts) (M8-M15)
- Electrical (lighting, cabling, panels) (M8-M15)
- Fire safety (hydrants, mist, alarms) (M8-M15)
- SCADA, VMS, ITS, CCTV, sensors (M9-M15)
- Tunnel pavement (concrete/asphalt) (M 13—M15)

Phase 4: Testing, Commissioning & Handover (15-18months)

- Integrated system testing (M15-M17)

- Safety clearance & approvals (M15-M17)
- Trial run and handover (M17-M18)

Key Features of Programme

- Parallel sequencing: Excavation overlaps with foundation; ramp works overlap with tunnel roof; MEP overlaps with later civil works.
- Critical path: Excavation → Structure → MEP/TVS → Testing & Commissioning.
- Total Duration: ~18months (1 years + 6 months).